RESTORATION OF DEVASTATED INLAND FORESTS IN SOUTH-VIETNAM

VOLUME I : MAIN REPORT

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Cover:
Aerial view of a bomb crater field in an inland forest in Bien Hoa Province, South Vietnam, taken on 8 August 1971. Picture: Arthur H. Westing (Hampshire College).

WAGENINGEN - 1978

PREFACE

This work is the result of several years study by a "project group". Project groups are made up of advanced students, in this case of the Agricultural University in Wageningen. The participants agree amongst themselves upon a pluridisciplinary research subject, then work together under the supervision of one or more members of the University teaching staff. Very generally, the research subject is chosen according to its usefulness or "social relevance". In the present case, the forester's nightmare of the mistreated Vietnam forests, and the national predicament thus created in this country were sufficient motivations for a thorough study of this subject.

Nothing, I think, is more difficult than the harmonization of the hard facts of our environment with the goals of a human population. The liberty of choosing ways and means to achieve this harmonization may well be the essence of national freedom. Many "development papers" unwittingly try to limit this freedom by prescribing clear-cut solutions for problems occurring in a country abroad. One of the main qualities of the present document is that it limits itself to a very complete inventory of the facts involved in the problem, without presuming upon a decision-making phase which should rightly be Vietnamese.

To a large extent, Vietnam's problems are forest problems. This is not a distorted perspective proceeded from the large number of forestry students among the authors of this report. On the contrary, the very quality of the subject dictated the need for a strong forestry element in this study. Forest wars, a term used in this text, fortunately are scarse and hopefully will remain so. However, these acts of war do present some extreme cases of misuse and mistreatment of forests; the importance of their analysis far exceeds the specific Vietnamese situation.

Hence, reading this book will be rewarding for every planner and decision-maker considering land-use in the tropics. No effort can be lasting in this field if it does not include maintenance and protection against assaults on long-living and stable forest skeletons in the landscape mosaic. Fundamental issues such as sustained yields and ecological and genetical continuity, essential for every form of organized human society cannot be discussed without referring to forests.

Books not only inform their readers, they also form their authors. I believe that the present text is an eloquent witness to the fact that its authors have become competent foresters while creating the book under the very adequate guidance of Dr. Ir. J.H.A. BOERBOOM of our Department of Silviculture. Seeing this remarkable result of " project group teaching" I do hope that it may draw the attention of many university teachers to this system. I also hope that in the future our Department may stimulate many more of such authors and such research.

Dr. Roelof A.A. OLDEMAN
Professor of Silviculture

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The Project Group

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I. INTRODUCTION

Vietnam has been under foreign domination for a long time. At the beginning of our era the Chinese had occupied the country for ten centuries. In 1862 Cochin-China, at that time part of a kingdom with Hué as the capital, became a French colony; the rest of Vietnam followed in 1883.
Through a forced labour-type system, the country was exploited and became one of the richest colonies of France.

In 1940 Vietnam was, with French permission, occupied by the Japanese. In 1941 Ho Chi Minh succeeded in uniting the nationalists and communists into the Viet Minh which, with Chinese support, started to fight the Japanese. After the Japanese capitulation, Ho Chi Minh proclaimed an independent republic which was initially accepted by the French.

However, in 1946 the French reconquered the greater part of Vietnam. A year-long bitter struggle against the French ended in 1954 with the downfall of Dien Bien Phu. At the Conference of Geneva (1954) a provisional division of the country was made at 17°N. The Democratic Republic of Vietnam in the North adopted a socialistic form of government under Ho Chi Minh. In the South, Ngo Diem became president. He got strong American support from 1950 onwards, gradually replacing the French influence.

In 1956 resistance against Diem arose when he refused to have reunion elections. The main objections were, however, the despotic character of his party and government, the privileging of the Catholic minority, his resettlement projects in the Central Highlands, and the sharp and often cruel pursuit of dissidents.
On December 20, 1960 the resistance became organized in the National Liberation Front (F.N.L.) of South Vietnam from which, in 1961, the Viet Cong (the People's Liberation Army) was formed.

President Eisenhower started sending military advisers to South Vietnam in 1955, and when Kennedy became president in 1960 overt American involvement began. However, despite the American support and actions, the influence of the F.N.L. increased and this resulted in a build-up of U.S. involvement which climaxed between 1967 and 1969. When succes held off, the U.S. slowly withdrew its troops until March 19, 1973 when the last departed.

During the American involvement, various methods were employed which aimed at the destruction of large areas of the Vietnam forest; this was considered to have a key function in that war. The consequences of this deforestation for man and environment are not yet fully understood, but they may be disastrous: degradation of vegetation, increased flooding hazard, extermination of a number of plant and animal species, erosion and soil degradation.

The withdrawing American troops were replaced by South Vietnamese soldiers (called "Vietnamization"). After 1973 the war continued as a civil war; but when the Viet Cong offensives resumed it was soon over. On April 30, 1975 the final collapse of the Saigon government occurred and the Provisional Revolutionary Government took over. On July 2, 1976 a reunion took place and Vietnam became one independent country.

Since then a period of building-up has started, including recovery from the war damage, increasing production, improvement of education and health conditions, house building, etc.

During the last ten years many people in Holland have been intensely engaged in the Vietnamese situation, particularly through the Medical Committee Holland-Vietnam (M.C.N.V.), and later through the Committee for Science and Technique (K.W.T.).
In 1972, at the initiative of the K.W.T., Vietnam commissions were set up in various university cities, among which Wageningen was one. Their task was to examine in what ways a university or high school could give assistance to the recovery and rebuilding of science and technology in Vietnam.

The contacts of the K.W.T. and the M.C.N.V. resulted in a list of problems in the field of agriculture. It was hoped that the Wageningen Agricultural University community could give some competent answers to these problems.

One of the problems was which possibilities existed for restoration of the forests which had been damaged by herbicide spraying, bombing, landclearing, etc. In the Department of Silviculture both staff members and students were interested in making a study of this subject. On one hand, the subject contained sufficient scientific aspects to serve as an education-subject for postgraduate study, and on the other hand an attempt could be made to contribute to the rebuilding of Vietnam. In view of the nature and approach of the subject it was chosen for an interdisciplinary team.

The scientific aspects and the social importance of this subject and the procedure desired by the team made the subject suited for study in the form of project education. To limit the extent of the study, only the inland forests of South Vietnam were taken into account.

Because of the nature of the available information, a broad and general framework for this study has been chosen. Thus, as much as possible, justice is done to the educational aspects of the subject and, at the same time, the benefit for Vietnam is considered greatest. Most information is obtained from literature. For general data about Vietnam, much use is made of Vietnamese and French publications. Data about the war - particularly of the period after 1960 - are mostly drawn from American sources. The information about forestry in Vietnam is supplied by literature data of surrounding countries, including Dutch publications of the colonial time.

In view of the scarce information trickling in from Vietnam, particularly with regard to the harmful effects of the war on the forests, this report cannot be seen as a complete reflection of what has happened to the forests.
Various assumptions are based upon available experience and knowledge of tropical forests.

Although the approach of this report does not allow giving concrete recommendations, it does confer an amount of knowledge that can be a valuable contribution to the restoration of inland forest areas.

II. PROCEDURE

In 1975, B. de Jong made a brief "feasibility" study of the subject. This study and the information gathered by him served as a basis for an initial inventory and rubrication of the sub-topics. A division of tasks and a schedule was made; preferably one sub-topic was assigned to two or more members of the group. In the beginning of 1976 the project started.

Information was mainly gathered from libraries: those of the Agricultural University in Wageningen, the Royal Institute for the Tropics in Amsterdam, and the State University and State Herbarium in Leiden.

Furthermore some members visited Paris in mid-1976. An attempt was made to contact the Vietnamese Embassy; several libraries of research institutes were paid a visit including ORSTOM and the "Centre Technique Forestier Tropical" (C.T.F.T.) in Nogent-sur-Marne. Moreover information was obtained via contacts from the Vietnam Committee of the Agricultural University and the K.W.T.
An important base of this study was formed by a report of the National Academy of Science (N.A.S.) in Washington, D.C. entitled: "The Effects of Herbicides in South Vietnam: Part A and B." The English version of our report was also based on a publication by Arthur H. Westing: Ecological Consequences of the Second Indochina War (1976).
In order to obtain more direct information about war damage, opinions about rebuilding, proposed priorities, the method in view and the available means attempts were made to contact Vietnamese experts. Also was requested for a concrete region or field to be studied. It had been decided to start from a broad field of view, in order to give certain techniques, that could be applied to Vietnamese circumstances. This set-up was chosen to guarantee the continuity of the group. When more concrete data from Vietnam about a certain region would come in, then as yet the project would direct to such a region

or field. However, no response came from Vietnam and the broad set-up was continued and further extended.

All the various topics were written in draft, distributed to all members some time before a meeting, and finally discussed with the whole group during the meeting. The started process of thinking along with new information brought about an apposition of the various topics and addition of new ones.
Initially the major part of the report was written in Dutch; later this part was highly condensed and translated into English. Another part, containing the tree species was directly written in English by the various authors.
All copy was corrected by members of the group ; the final text was typed by the Department of Text Processing of the Agricultural University.

The principal viewpoint was that of silviculture, but the following aspects were also dealt with: ecology, soil science, hydrology, agriculture, social/economic, and general forestry.
This was possible because students from different departments, often with varied study-subjects, were participating. The group was composed of the following:

Student	Discipline
C.F.W.M. von Meyenfeldt	Tropical Silviculture
D. Noordam	Tropical Soilscience
H.J.F. Savenije	Tropical Silviculture
E.B. Scheltens	Tropical Silviculture
K. van der Torren	Tropical Agriculture
P.A. Visser	Tropical Silviculture
W.B. de Voogd	General Ecology

Guidance was given by the following mentors:

	Department	Concern
Dr.ir. J.H.A. Boerboom	Silviculture (tropical)	Main mentor
Prof.dr.ir. J.D. Ferwerda	Tropical Agriculture	Intensive, partial
Drs. J. van Alphen	General Ecology	Intensive, partial
Dr.ir. T. de Meester	Soil science and Geology	Incidental, partial

A weekly meeting of a day or half day was convened; all members were chairman by rotation. The main mentor attended nearly all meetings (temporarily filled by ir. N.R. de Graaf) during which he had a constructive, correcting, critical contributive part. The intensive, partial conductors were present when a concept relating to their field was discussed. Little appeal needed to be made to the incidental, partial conductor.

III. THE PHYSICAL ENVIRONMENT AND SOCIO-ECONOMIC SITUATION BEFORE 1961

III.1. PHYSIOGRAPHY

Vietnam occupies the eastern part of the Indochinese peninsula in South East Asia. It lies between the parallels of 8°30' and 23°20' North latitude, and the mean meridian is 107° East longitude. The part under consideration in this report is situated south of the 17° parallel North and was until 1975 known as South Vietnam[x)].
The land area of South Vietnam convers 173 000 km^2, its length from north to south is about 800 km and its width from east to west varies between 70 and 300 km.

[x)] Although no longer existing as such, this name is still extensively used in this report to indicate the area south of the 17th parallel.

The geological building of South Vietnam resulted in four topographically distinct regions (map III 1 and III 2):

- The Mekong Delta
  Consisting of recent, fertile alluvium deposited by the Mekong and Vam Co rivers.
- The Highland of the Mekong (FISHER, 1964)
  Also referred to as Eastern Region, Central Eastern Region (THAI-CONG-TUNG, 1967) or Cambodian Plain (FISHER, 1964).
  This rather flat region is the transition between the Mekong Delta and the Central Highlands. The altitude of this region varies from 100 to 200 m above sea-level. The major part of this area consists of old Mekong terraces with some low basalt plateaus, while along the rivers recent alluvial plains are found. Together with the Mekong Delta it is the former Cochin-China.
- The Central Coastal Plains
  These are a number of small plains lying between the Truong-Son mountain range and the South China Sea from the 11th to the 17th parallel. The plains are sedimentated by short rivers which spring in the Truong-Son mountains, and they generally have a narrow dune strip running along the seashore. Climatic conditions on the different plains vary considerably under influence of the mountains.
- The Central Highlands
  The main element of this region is the Truong-Son or Annam mountain range with altitudes up to 2600 m running from north to south. In the mountains a number of basalt plateaus and some relatively wide plains are found. The east side of the range drops steeply towards the sea, the western flank slopes down gradually to create many highlands. The relief is generally very steep in the mountain range with slopes over 40%. Soils are usually shallow and stony, while parent material is quite variable. The plateaus have an undulating to rolling relief. The parent material, basalt, is generally deeply weathered. Soils have a low to very low fertility but are usually physically good.

In each of these regions there are smaller geographical units formed by differences in geological and topographical conditions. Map III 2 shows these units. For a detailed description cf. THAI-CONG-TUNG (1967).

III.2. CLIMATE

South Vietnam is subject to a tropical monsoon climate. The regular seasonal alternation of wind, viz. a north-east monsoon from October to March and a south-west monsoon from April to September, controls almost every aspect of weather conditions. Important modifications in the general nature of the climate are imposed by the differences in latitude and by the marked variation in relief. The south-west monsoon blowing from the Bay of Bengal brings rain. During the rainy season typhoons may occur from time to time. Around July, there is a temporary period of drought lasting for some weeks. The north-east monsoon does not bring any rain except in the Central Coastal Plains where its path is over the South Chinese Sea. By and large, therefore, South Vietnam has a rainy season beginning in May and ending in October; and a dry season from November to April (except in the Central Coastal Plains where it rains from October to February). The Coastal Plain of Phan Rang is protected by mountains from both monsoons and consequently has a semi-arid climate (700 mm of annual rainfall).
The rainfall total as well as its distribution depends a great deal on the orientation of the mountain ranges in relation to the dominant winds. Annual rainfall is generally 2000 mm, but may be as high as 4000 mm in windward areas,

whereas in protected sites it may be only 1300 mm (Cheo Reo) or even 700 mm (map III 3). The dry season lasts for 4 months in most parts but in some areas it is as short as 2 months while in others it may last 6 months.

The annual average temperature is around 27°C at sea-level and it decreases about 0.6°C per 100 m elevation. The annual range of temperature is small.

Relative humidity is high during all seasons throughout the greater part of South Vietnam.

Some climatic data are given in Table III 1 and Figure III 1.

The most detailed climatic description of South Vietnam is made by SCHMID (1974) for the area between 12° and 16° North latitude. Five climatic types are distinguished based on available data on rainfall and temperature; when available data about relative humidity and the 'Indice Xerothermique' of GAUSSEN (GAUSSEN et al, 1967) was used. (See Table III 2).

In this report with the aid of available climatic figures and topography, an appraisal of the climatic types north of the 16th and south of the 12th parallel is made. The distinction of a 6th climatic type was necessary for the north-eastern part of South Vietnam: "Climats Humide et Chaud" (CHC) (Table III 2 and map III 4). The boundaries of the types of SCHMID are arbitrarily chosen and ill-defined. A major disadvantage of this system is that it is specially made for Southvietnamese conditions. In order to enable comparison with other regions, an attempt is made to link the system of Schmid with the worldwide system of KÖPPEN and two classification systems used in South East Asia, namely the 'Q' system of SCHMIDT and FERGUSON (1951) and the system published by GAUSSEN et al (1967, see Table III 3).

Further information on climate can be found in the work of the above-mentioned authors and in KOTESWARAN (1974) and DOBBY (1961).

III.3 VEGETATION

3.1 Introduction

The description of the vegetation in this section is mainly based on the work of SCHMID (1974). The vegetation types are presented in a highly condensed way and the dynamics of the vegetation are shortly discussed.

SCHMID distinguishes between 12 and 16° North latitude five climatic types (see III.2); within each type the kinds of vegetation on the various substratas are studied.

The definition of his vegetation types is based on physiognomy and floristic composition and refers to the system of Yangambi, that, although based on African vegetation, can be used farily well for the description of vegetation in Tropical Asia.

This system has a physiognomic-ecological basis. For classification with physiognomic criteria structure and life-forms are the determining factors. The ecological criteria concern climate, soil, hydrology and human influence. Some vegetation types according to Yangambi are shown in Figure III 2. For more details on the system of Yangambi cf. TROCHAIN (1957).

In the following, the classification of Yangambi is used as a guide, although the terminology of SCHMID does not always correspond with that of Yangambi.

3.2 The vegetation types

The vegetation types and their distribution under different climatic and edaphic conditions are given in Table III 4.

The areas north of the 16th and south of the 12th parallel are not included in this description. Our map III 5 is extended to these areas with the aid of data from the map of SCHMID and a map of the NATIONAL GEOGRAPHIC SERVICE

(1969) in Da Lat. The legend of this map is linked with the terminology as used in the table (map III 5).
Profiles of some vegetation types of South Vietnam are shown in figures III 3 and III 4.

3.3 Succession

Succession may be defined as sequential changes in floristic composition and structure in vegetation.
Successions are classified into primary succesion or priseres starting on soil not previously occupied by plants, and secondary succession or subseres, starting where previously existing vegetation has been destroyed or damaged (RICHARDS, 1964). This chapter will be confined to the latter.

All climax plant communities are subject to very slow and gradual changes. In addition to changes imposed by secular variations of climate, there are others caused by evolution and spread of species. A dynamic equilibrium exists. Large areas of primary forest have, however, been destroyed and replaced by cultivation or by secondary communities.
Secondary communities derived from tropical forest are as a rule more or less unstable and thus can be considered as stages in secondary successions. The succession may be progressive when a certain stage of establishment is more stable and has a more differentiated structure than a previous stage, or regressive when the reverse development takes place. The first form of succession occurs when vegetation is left to itself and is protected; theoretically the so-called climatic climax will ultimately re-establish itself although probably only after a very long time. The second form often is a result of human or animal impact: repeated interference causes a detoriation in the regrowth vegetation and the climax is deflected to a biotic climax or fire climax.

The word climax is used many times in the above to indicate a situation in which modifications are not expected to occur as long as the climate remains the same.

However, different concepts occur:
VIDAL (1960) uses the word pseudoclimax when, with a given climate, the substrata is the determining factor on the occurrence of a certain formation. If man is the main factor he speaks about peniclimax.
RICHARDS (1964) mentions for the latter case the word biotic climax.

In the next section some factors which play a major part in the dynamics of vegetation are dealt with. It is followed by a section in which ten schemes are presented which give an impression of secondary succession.

For more information about dynamics and succession cf. ODUM (1971), RICHARDS (1964) and WALTER (1964 and 1970). More details about South Vietnam may be obtained from SCHMID (1974) and VIDAL (1960).

3.4 Disturbances in the vegetation

Forest can be disturbed at varying degrees.
Firstly, natural events like the slow death of trees (either naturally or by fungi- or insect-attack, by windfall or lightning, or landslides) may form gaps in the forest. The microclimate becomes less like that of a closed forest when the gap becomes larger. Thus the size of the gap has an important influence on species composition and spatial arrangement in the forest.

Shifting cultivation is considered to be the major cause of the destruction and degradations of climax formations in South Vietnam.
If the fallow period is sufficiently long, a progressive succession takes place during which soil conditions are again improved. In many cases, however, the fallow period has been too short; repeated cultivation and its attendant burning has caused site-deterioration including soil-erosion, and has led to

a regressive succession. This may finally lead to open grasslands. Selective logging resulted in the depletion of certain species. Little attention was given to whether sufficient natural regeneration was available, and no minimum felling diameter was fixed. As a consequence, *Lagerstroemia angustifolia*, a secondary species of little value, has become dominant in the upper storey of many closed forest formations in the lowlands of South Vietnam.

Lastly the major human influence during the last war has to be mentioned and is dealt with in detail in Chapter IV.

3.5 Schematic dynamics and secondary succession of some vegetation types

In the following schemes, mainly based on VIDAL (1960) and SCHMID (1974), general lines of succession following disturbances are given for the most important climax formations considering different climates and substratas (Schemes III 1-10).

III.4 FAUNA

4.1 Introduction

The fauna of South East Asia is considered to be one of the richest in the world. Within this area some species are closely linked to a given type of habitat and even among the most adaptable species the majority shows a distinct preference for a particular biotope.
The specialized interactions existing between animals and plants in a certain biotope are important in this respect.
Different species occupy different niches in an ecosystem, separated from each other in space, time or activity.
Man has had an impact on fauna for a long time, directly by hunting, but especially indirectly by shifting cultivation, exploitation and burning, and has thus changed or destroyed the habitats in which the animals lived.
Disturbance of the habitat leads to the disappearance of some species, while others adapt themselves to the changed environment.

In the following sections the most outstanding species will be mentioned. Information was obtained from comparable areas in South East Asia since no inventory of fauna has taken place in South Vietnam. Most important sources were PFEFFER, 1974 and ANONYMOUS, 1976.

4.2 Mammals

4.2.1 Ungulates

Most ungulates are found in both primary and secondary forest and also in more open formations such as savannah and woodlands. Secondary forest, especially when open, seems to be the most propitious environment for herbivorous ungulates. They are found here in large numbers and fairly large herds, while in primary forest the social unit is usually the family group.

Most characteristic and most important from the economic point of view is the banteng; it is hunted by local people and tourists. The banteng has been domesticated in Bali.
The gaur has vanished from many regions as it is particularly sought after by big-game hunters.
The kouprey, closely related to the banteng and gaur, is the last large mammal to be discovered (in 1937); it thrives in open parklands interspersed with patches of forest along watercourses. The kouprey is confined to a small population in the Lower Mekong Basin, and probably does not occur in Vietnam. It may be of importance for breeding trials as it is resistent to rinderpest and other deadly cattle diseases.

Many deer species occur, of which the sambar and the muntjak or small-deer are the most wide-spread.
In South Vietnam the following other deer are found: Eld's deer, Schomburg's deer, the mouse-deer, pig-deer and some others of which a few are rare. Many deer are domesticated. However, most deer are found in open formations where only water may be a limiting factor, forcing the animals to move over long distances.
Other ungulates are the wild boar, relatively common in primary forest, and the rhinoceros, occurring on grassy and swampy ground, if still present in Vietnam.

4.2.2 Primates

Anthropoid apes like the gibbon show a distinct preference for the primary forest, especially the upper stratum.
Macaques may occur in several biotopes. More bound to a specific habitat are the langurs. The Douc langur is endemic to the evergreen forests of the Annamite Chain; this species has suffered greatly from habitat alteration and is now seriously endangered.

4.2.3 Other mammals

In primary forest are found giant squirrels, big flying squirrels, a number of rodents, and some carnivora such as the clouded leopard and the bear civet. At forest fringes tigers may occur, while the panther is found in both open and closed forest.
One of the bears in Vietnam is the Malaysian Sun-bear.
Wild dogs or Cuon have been seen hunting deer.
Elephants, mainly found in open and secondary formations, have become relatively rare in the wild state. They are domesticated on a large scale.

4.3 Birds

In South Vietnam 600 bird species are known. They are an important part of the ecosystem in all forests.
Swampy and flooded zones are the meeting place of a wide variety of aquatic birds, both sedentary varieties and winter migrants from the northern regions of the continent.
Birds are extensively shot and trapped.

4.4 Fish

Fresh-water fish are found in the many rivers of Vietnam. Zones subject to flooding are important as breeding areas (e.g., mangroves).
Many fishes are caught; fishing is an important source of income for many Vietnamese people.

4.5 Insects

The insect realm of South East Asia is one of the most varied and specialized of the world. A large number of insects are linked with one or another form of vegetation in the tropical forest, or even with a certain plant species. They play an important role in pollination, decomposition of organic material, etc.

III.5 SOILS

5.1 Introduction

The information in this chapter has been drawn from MOORMANN (1961), DUDAL et al (1974), THAI-CONG-TUNG (1967) and FAO/UNESCO (1968).

The soil map + legend of South Vietnam prepared by MOORMANN (1961) is given. For a full description of the soil units, reference is made to the original publications (map III 6). Equivalents of the soil units used by MOORMANN to the system of the United States (USDA, 1975) and to the international legend of the FAO/UNESCO Soil Map of the World are given in table III 5.

The aim of this highly condensed chapter is to give a rough idea of the soils of South Vietnam and their distribution to enable comparisons with other countries.

A brief discussion of the soils by regions is given below.

5.2 The soils by regions

5.2.1 The Mekong Delta

The major part of this vast delta is covered with recent alluvium, which is coarse to medium-textured and well-drained along the rivers, while the backswamps are clayey and often water-logged. These soils are usually fertile.
Saline soils are found along the coast; large areas are covered with acid to very acid sulphate soils.
In the U-Minh area peat soils several meters thick are found.

5.2.2 The Highland of the Mekong

A large area of old alluvial terraces is found here. Texture of these sediments is coarse to medium-coarse. The most important great soil/groups are gray podzolic soils (terres grises) at the elevated positions and low humic gley soils in depressions. These are generally poor and easily eroded, especially the former. Plinthite may occur in the subsoil.
Along the rivers recent alluvium is found in levees of well-drained sandy loam and backswamps with more heavy hydromorphic soils.
Another part of this region consists of flat to undulating basalt plateaus with reddish brown latosols usually of clay texture; they are deep and have good physical properties with fair fertility.

5.2.3 The plains of Central Vietnam

The important upland soils in this area are moderately deep-red and yellow podzolic soils often with plinthite concretions; reddish brown latosols on basalt; non-calcic brown soils which are fairly rich in nutrients of varying depth and usually stony; and sandy regosols on sand dunes.
In the lowland, hydromorphic alluvial soils are found which are locally saline and/or sodic.

5.2.4 The Central Highlands

The most striking landscapes are the basalt plateaus and Truong Son mountain range. The basalt plateaus are relatively old and covered with deeply weathered, friable, sesquioxide-rich clayey soils. The relief may be gently undulating to rolling or even very steep, depending on the age and the degree of geological erosion of the plateaus. Also the physical and chemical properties of the latosols on the various plateaus differ strongly depending on age, degree of destruction of the natural vegetation, accelerated erosion, etc. Indurated plinthite may occur as a concretionary layer or a hardpan. Most soils are deep to very deep, some younger ones are shallow (e.g. in the Binh Tuy Province).

The relief of the mountains is generally very steep; most slopes are over 15%, height differences may be over 1000 m.
Geology differs strongly; in the largest soil group, the red and yellow podzolic soils, great differences occur due mainly to differences in texture. Granite and rhyolite deliver a sandy to loamy texture while with granite the surface may be covered with boulders; dacites mica schists and shales give a clayey

material on which soils are formed transitional to other groups (latosols, regurs, non-calcic brown soils). On weathered sandstone a sandy, weakly-developed red and yellow podzolic soil is formed.
Small basalt areas with latosols (generally shallow) and shallow "regurs" are found. The latter consist of black clay mixed with basalt and are not really regurs since they lack certain characteristics such as slickensides. Most mountain soils are stony and shallow.
At the foot of the slopes colluvium is found; there is very little soil formation because of continuous rejuvenation; soils are commonly deep and well-supplied with water; stony regosols are common.
The mountain valleys are usually narrow with hydromorphic alluvial/colluvial soils. In the Cheo Reo depression large areas of regurs (Vertisols) are found: deep, black clay soils with strong swelling and shrinking.
Finally, on old alluvium (e.g. west of Plei Ku/Dar Lac) large areas of gray podzolic soils occur which are poor, sandy and often contain indurated plinthite.

III.6 LAND USE

6.1 General

In 1960 only 16% of the total surface of South Vietnam was under more or less permanent cultivation. About 30% of the area is potentially suitable for permanent agriculture; the larger part is probably being used for shifting cultivation and is probably covered with shrub or secondary vegetation.
One third of the country is forested, 14% is savannah and natural grasslands.
The remaining land consists of acid swamps, stony and steep slopes, and roads and townships (table III 6).

6.2. Agriculture

Agricultural cultivation is accomplished in either small- or large-scale permanent systems, or in semi-permanent and discontinuous agricultural systems. The first will be discussed below, the second in the paragraph about shifting cultivation.

In table III 7 the area and production/ha of the most important agricultural crops in 1960 are shown.
Rice is by far the most important crop. It is grown as wet rice on lowland soils throughout the country, but the most important areas are the Mekong delta and the Central Coastal Plains. Rice is grown either on smallholdings as subsistence food, or on more or less commercial holdings. In the first case, holdings are usually less than one hectare; in addition to rice, small patches of vegetables, fruits and tuberous plants are grown on the farm.
Commercial cultivation is done either by tenants on 1-5 ha holdings resembling the smallholdings, or by large landowners on estates of 500 ha or more, especially with rubber and cash-crops. The latter also grow other cash crops on a large scale.
For details about rice growing in general reference is made to the large number of publications on this subject.
Rubber is the most important perennial crop. It is grown on large to very large estates by plantation owners and foreign companies mostly in the Highland of the Mekong. In 1958, 20 000 ha were planted mainly, however, in the Central Highlands (Dar Lac, Plei Ku).
Coffee and tea are grown in the Central Highlands, especially in Plei Ku.
Coconut trees and sugarcane are grown as a permanent crop on holdings in the deltas.
Vegetable cultivation is most important in gardens around Da Lat. The most important crops are cabbage, Chinese cabbage, Irish potatoes, onions, garlic, tomatoes and carrots.

A great variety of fruit is found in Vietnam: bananas, mangos, citrus, pineapple and many others.
Tobacco is usually grown in a 2-3 year rotation with rice, corn or peanuts.

Livestock raising is of little importance; meat contributes only a small share to the average diet, and milk is practically unknown. Animals used for draught purposes, such as oxen and buffalo, are the most important livestock.

Pigs are by far the most important source of meat and fat, although most peasants raise a few chickens and ducks.
Fish is more important than meat in the diet of the Vietnames; after rice it is the most important food crop. Some fish culture is found in the Central Coastal Plains.

6.3 Forestry

In table III 8 the production of forest products is given. Most of them are for the national market or for local use. Production is mainly near population centres, with the forest area in the neighbourhood of Saigon the most heavily exploited.
More information about forestry is found in section 7.3.

6.4 Semi-permanent and discontinuous agricultural systems

The most important agricultural system in the Central Highlands is shifting cultivation (called "ray" in Vietnamese), practiced by hill tribes (Montagnards). The basic principle is to clear and burn a patch of ground, cultivate it for a period of one to two years, and then leave it fallow for several years. Provided the fallow period is sufficiently long, shifting cultivation is a stable system. Small patches are concerned, so erosion, if present, is not harmful and the crops protect the land from excessive leaching, and even to some extent mimic the forest in diversity of species and life-forms. The later stages of cultivation gradually merge into a secondary forest succession. It is likely, however, to take centuries to return to primary forest. The increasing pressure on land has in many places resulted in repeated interference with the forest (see also 3.4).

Each of the many hill tribes in South Vietnam has its own cultivation method depending on soil, climate, vegetation and demand. The system may range from a pure ray to a system in which ray is only of minor importance and in which semi-permanent cultivation on alluvial soils plays an important role.

The most common crop in ray is dry-land rice, followed by maize, beans and tuberous plants; if rice is grown in semi-permanent cultivation in the valleys then corn, sorghum and Cucurbitaceae are grown in ray.
According to BARRY et al (1960), in the sub-Montagnard zone (600-1200 m) soils developend on schists on slopes are especially sought after for ray.
In 1960 about 80 000 ha were under cultivation; about 800 000 ha were involved in shifting cultivation (with an average of 2 years cultivation to 20 years fallow).

III.7 SOCIO-ECONOMIC SITUATION

7.1 Population

In 1962 South Vietnam had roughly 14 million inhabitants of which nearly 50% were younger than 16 years. The majority (85%) of the population was Vietnamese, but important communities of Chinese (6%), Khmer (3%) and hill tribes (6%) which consisted of a great many ethnic groups, were found. The population was very unevenly distributed: it was concentrated in delta areas where density might be as high as 1200 persons/km^2, while upland regions are avoided (map III 7). The average density for the whole country was 90 persons/km^2. In 1960 18% of the population lived in towns, of which Saigon had by far the most inhabitants (1,750,000).

Most of the rural population consisted of farmers.
In 1945 80-90% of the people were illiterate, but education was strongly improved: in 1961 46% of the 6-10 years old and 5% of the 11-17 years old children went to school.
Nutrition was poor: the majority of the population did not get the required 2640 cal per day and there was a serious deficiency of vitamins and minerals in the food.
The state of public health was bad around 1960. People were susceptible to diseases because of the poor nutrition. The average life span was 40 years at that time. Many deaths and diseases are caused by unhygienic conditions.
The administrational division of South Vietnam is shown on map III 7. There are 46 provinces subdivided into districts; these are subdivided into communes which consist of many villages.

7.2 Economy

Agriculture occupies first place among the vital sectors of the Southvietnamese economy and is basic to all industrial and commercial activity in the country. Agriculture, principally the growing of rice and rubber, provides a livelihood for about 80% of the population.

Before the division in 1954, Tonkin was the center of the mining industry, while Cochin-China was the rice basket; the parts supplemented each other. After 1954 North Vietnam tried to develop agriculture although highest priority was given to the development of heavy industry. South Vietnam tried to develop its own (light) industry in addition to reorganizing the agriculture. Much progress was made between 1954 and 1960.

7.2.1 Agriculture

In 1960 mostly subsistence crops were grown. Large land ownership was common in the Mekong delta but not as much in the coastal plains and the highlands. The majority of the rural population were tenants or landless agricultural labourers. In 1955 land reform was started but by 1960 only a little area had actually been distributed.
Animal husbandry was of minor importance; fish culture, however, served as a livelihood for 200 000 people.

7.2.2 Industry

From 1954 industry (especially light industry) was stimulated; in 1960 there were a large number of small industries with usually a few labourers. Most important were the food and textile industries. About 2% of the working population was employed in industry.

7.2.3 Trade

In 1960 the value of exports from South Vietnam was about 30% of its imports. Considerable economic help was given by the United States, and also by France, Japan, West Germany and some international organizations. Exports consisted mainly of agricultural products (95%), with a predominance of rubber (c.60%). Mainly non-agricultural products (table III 9) were imported.
Costs of defence took half of the total budget of the country.

7.2.4 Traffic

In 1960 the road system was poorly developed and most roads were in bad condition. Transport over water was important, both by river and sea. Railroads were damaged during the war, but were repared and still at work in 1960.
National airlines were of little importance.
Infrastructure is shown on map III 8.

7.3 Forestry

Before World War II forest exploitation was not very systematic, in spite of the existence of a forest service since 1901.
Annual felling increased gradually until 1945, but then production dropped sharply. From 1954 it was slowly recovering, but in 1960 figures were still below pre-war levels.

7.3.1 Forest types

According to FAO (1955), about one third of the country was covered with forests of economic importance.
Secondary vegetation, however, might deliver fuelwood, while forests also serve important non-economical functions.
Economically the forests may be divided into:

		Surface x 1000 ha
a. Mangrove forest		280
b. Melaleuca woodlands	(Arrière mangrove)	200
c. Dense forest	(Forêt dense)	4275
d. Woodland	(Forêt claire)	
e. Pine forest		120

a. The mangroves deliver fuelwood, timber, charcoal, tannins and dyes. Prior to 1940 this was ecnomically one of the most important types; after that there was a relatively strong decrease in importance because guerilla organizations were operating in Mangrove forest regions.
Mangroves are important for coastal fixation; moreover, they are indispensable for some fish and bird species as a feeding, spawning or breeding place.

b. *Melaleuca leucadendron*, the main species, delivers medium-quality wood. Kajeput oil is distilled from the leaves.

c+d. These forest types deliver 85% of the timber. Besides wood, several minor forest products are extracted (e.g. bamboo and rattan), while important ecological and social functions are performed. In table III 10 the most important timber species are mentioned.

e. Two species are found: *Pinus merkusii* and *P. kesiya*. The first is tapped, the second is used for timber.

7.3.2 Exploitation and forest industry

Extraction of logs from the forest is done by animals or machines.
Sawing is mainly carried out in small local saw mills; transport of logs happens by truck or train.
Large quantities of teak logs are rafted down the Mekong out of Cambodia.
In 1960 small pulp and paper industries existed near Saigon, mostly recycling old paper and making use of bamboo and local wood species.
In 1960 charcoal was mainly produced by 300 kilns at the Ca Mau peninsula.
Most fuelwood was collected by the local population from forests, along roads, edges of fields, etc.
Resin and turpentine are produced from the balsem of *Pinus merkusii* in a factory near Da Lat, since 1938.
Matches are made from *Podocarpus imbricatus* in Saigon.
In 1960 factories for the manufacture of fiber board and particle board were found in Saigon, and a wood-preserving industry was located in Biên Hoa.
At that time South Vietnam imported a considerable amount of forest products (table III 8).

7.3.3 Management

According to FAO in 1955 44% of the total forest area was damaged or depleted; of the remaining 56%, half was almost inaccessible. Thus only 1 400 000 ha of forest was in a good state and economically accessible.
Plantation establishment on a small scale had been started by the French (see IV.3.6.4.5).
Research was directed to the introduction of exotics, natural regeneration, artificial regeneration of local species and reforestation of *Imperata* fields.
The extent of the investigations was reduced, however, by lack of money.
In 1954 forestry training courses were started.

IV. THE WAR ACTIONS AND THEIR CONSEQUENCES

IV.1 INTRODUCTION

With the overt intervention of the Americans in the Vietnamese war in the early sixties, strategy changed drastically. Initially it was a conventional war with anti-personnel and anti-material weapons (WESTING, 1975). U.S. troops maintained on-the-ground control of the various important urban areas of the country, which contained the large majority of its population but covered only a tiny part of the country itself. Over the vast remaining part they attempted to keep control by various means. Since the abovementioned weapons proved ineffective against guerillas, new weapons and techniques were employed to cause destruction of the environment, which provided cover and sanctuary to the Viet-Cong (anti-plant weapons).

Further new methods were applied to force the rural population into so-called strategic villages (hamlets) and refugee camps in which they would be easy to control.
The most frequently used new weapons and techniques were:

- Chemicals (toxic gases, defoliants, and rain-inducing agents)
- High-explosive munitions (bombing and shelling)
- Bulldozing
- Incendiary weapons.

The application of these anti-environment weapons and techniques, often in combination or consecutively, has led to large-scale destruction of natural ecosystems and the contamination and death of millions of people.
Many of the consequences cannot yet be seen. Words like ecocide (WESTING, 1976, after GALSTON, Times 1970), genocide coupled with biocide (NGUYEN KHAC VIEN, 1971), have been mentioned in this context.

During the war South Vietnam was divided into four Military Regions (M.R.) each having "War-zones" and "Free-Fire zones".
Figures IV 1, IV 2, and IV 3 indicate where the principal actions of the war took place.
At this moment a profuse description of the war actions and their environmental consequences is still lacking. On one hand this is due to the very limited information about the war itself; and on the other hand, to the gap in data about the South Vietnamese environment.
It is, for instance, hard to describe in detail the effect of war on the forest, since no forest inventory has been carried out in South Vietnam and no sufficiently-detailed vegetation map exists. In this study only the principal war actions and their effects will be discussed. For more detail please refer to WESTING (1976) who gives a very good treatise about the war and its ecological consequences.

Following a description of the various means of environmental assault (section 2), the effects of these means and methods are discussed on, respectively:

climate (3.1), vegetation (3.2), soil (3.3), land use (3.4), fauna (3.5) and the socio-economic situation (3,6).

IV.2 MEANS AND METHODS

2.1 Chemicals

2.1.1 Anti-personnel toxic gases

Most commonly used was CS (O-chloro-benzalmalononitrile) in the form of an aerosol (therefore not a real gas) and applied in various ways. In addition there was CSI, a finely pulverized form of CS, and CS2, which was used, since 1968, fixed on silicon and therefore more persistent.
These were used for harassment of Viet Cong-minded villages to force the population into strategic villages, and to oust the Viet Cong from their shelters.
CS2 can render an area inhospitable for 30-45 days.
The agents may produce tiredness, abundant tears, nausea, burning feeling on the skin, and a violent cough (NGUYEN KHAC VIEN, 1971).
It was most massively used in the region of Tay Ninh, but was also reported from the provinces of Quang Da and Thua Thien, Quang Nam, Binh Dinh and Quang Ngai.

2.1.2 Soil sterilizing agents

ANONYMUS (1975, after Nguyen Dang Tam*, 1970) mentions the use of the following agents:

- Monuron (CMU): N(chloro-4 phenyl) N-N dimethyl-urea
- Bromacyl: Bromo-5, butyl-3, methyl-6, uracil.

Further information about the use of these agents is lacking, but probably they were used to keep certain areas sterile for a prolonged period (e.g. along roads).

2.1.3 Herbicides**

The first operations of the herbicide program were carried out in 1959, with the participation of the United States. The last herbicide action of the United States dates from October 31, 1971.
Military use started in 1962; it was greatly expanded in 1965 and 1966, with 1967 through 1969 the peak years. From 1970 the application of herbicides was rapidly phased out because of the clear superiority of the land clearing program (see 2.4) the worldwide criticism of the herbicide program, and the general winding down of the U.S. involvement in the war (WESTING, 1972).
The U.S. had used three major herbicides which are generally known simply as agent Orange, White and Blue; until 1964 agent Purple was also used. A description of these agents is given below (after WESTING, 1972).

1. Agent 'Orange'
   a. Composition: A 1:1 mixture of the n-butyl esters of 2,4-dichloro-phenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T).
   b. Active ingredients: 491 and 527 grams per litre, respectively.
   c. Application rate: Undiluted at 28 litres per hectare.
   d. Dosage applied: 14 and 15 kilograms per hectare, respectively.
2. Agent 'White'
   a. Composition: A 4:1 mixutre of the tri-iso-propanolamine salts of 2,4-dichlorophenoxyacetic acid (2,4-D) and 4-amino-3,6,6-trichloropicolinic acid (Picloram) in water.

* Nguyen Dang Tam (1970). Massacres, guerre chimique en Asie du Sud Est. Maspero éd., Paris.

** As herbicides are agents that are merely used against weeds, in this case it would have been better to use the word phytocides, since these agents were applied to destroy all vegetation.

b. Active ingredients: 240 and 65 grams per litre, respectively.
c. Application rate: Undiluted at 28 litres per hectare.
d. Dosage applied: 7 and 2 kilograms per hectare, respectively.

3. Agent 'Blue'
   a. Composition: A 6:1 mixture of sodium dimethylarsenate and dimethylarsinic (cacodylic) acid in water.
   b. Active ingredients: 371 grams per litre.
   c. Application rate: Undiluted at 28 litres per hectare.
   d. Dosage applied: 10 kilograms per hectare.
4. Agent 'Purple'
   a. Composition: 5:3:2 mixture of the n-butyl esters of 2,4-D and the n-butyl and the iso-butyl ester of 2,4,5-T.
   b. Application rate: 28 litres per hectare.

The herbicides used in these formulations are widely utilized in agriculture and forestry for the control of weeds and other unwanted vegetation.
Agents Orange and White consist of herbicides which are structurally analogous to "natural" growth promotors (2,4-D, 2,4,5-T and picloram). They kill by interference with the normal metabolism. Sensitivity to toxic concentrations varies with species; dicotyledons are generally more sensitive than monocotyledons.
Agent Blue consists of arsenical compounds which kill by protein clotting in the tissues; it is relatively more suited against monocotyledons.
Concentrations utilized in South Vietnam were much stronger (ten times or more) than those recommended in agriculture.

The use of agent Orange was stopped in 1970 as it became clear that TCDD (2,3,7,8-tetra chlorodibenzo-para-dioxine), an extremely toxic material possessing teratogenic properties, was present as a contaminant in 2,4,5-T, extensively used in the preparation of Orange.
The great bulk of the herbicides (95%) were sprayed from low flying C-123 transport aircraft planes; most of the remainder was applied from helicopters, with small amounts dispersed via truck- and even boat-mounted spray rigs also.
The MACV[x] distinguishes two main objectives of the herbicide operations:

- Defoliation: the use of herbicides to cause trees and plants to destroy their leaves in order to improve observation.
- Crop destruction: the application of herbicides to plants to destroy their food value (directed at hostile forces).

PFEIFER (1969) indicates what defoliation in fact means:
Major defoliation targets.

1. Nipa palm and mangrove woodlands. The edges of these waterways are sprayed for a distance of 200 to 800 metres back from the water. The objectives include total plant kill and long term vegetation control. Respraying at yearly intervals is generally required.
2. Rain or moist evergreen forests. These targets are sprayed to create bare stretches surrounding Viet Cong strongholds so that movement of men or supplies in and out of the area can be observed from the air. This type of targ requires rapid defoliation.
3. The dense shrubbery and second growth brush along highways and supply roads. These areas are defoliated back into the forest to deprive the Viet Cong of concealment. At points where Viet Cong are known to have set up road blocks for the confiscation of 'taxes' an area 400 metres is cleared to expose such operations for aerial reconnaissance and attack.
4. In the Mekong Delta area, the Viet Cong often secrete caches of ammunition, food and supplies, so well concealed that they are difficult to find on the ground and impossible to detect from the air. Trees, weeds and underbrush are defoliated to disclose the location of these supply dumps.

[x]Military Assistence Command, Vietnam Directive no 525-1, August 12, 1969.

5. In areas that have been cleared for villages, buildings and military posts, heavy grasses and foliage may hide the infiltration of unseen attackers. Long term control is desirable in this application.

Information about herbicide expenditures is derived primarily from a study conducted by the Committee on the Effects of Herbicides in South Vietnam, appointed by the National Academy of Sciences (N.A.S.) by direction of the American Congress. The data are based on about 85% of the total of all herbicides used.
Distribution with respect to vegetation types was evaluated with the help of a vegetation map by ROLLET and a study of aerial photographs. Some of the principal findings of the Committee are shown in the following tables (tables IV 1, IV 2 and IV 3); locations of the defoliation and crop destruction missions are shown in figures IV 4 and IV 5 respectively. From this and other data applied by the Committee, the following can be concluded:

		South-Vietnam		Inland forests		Mangrove		Cultivated land		Others	
A surface in 1000 ha		17,429		10,400		288		3,120		3,626	
B total sprayed area	In ha	1,446		1,078		105		106		157	
	In % of A	8.3		10.4		36.4		3.3		4.3	
Number of sprayings		In 1000 ha	%	In 1000 ha	%	In 1000 ha	%	In 1000 ha	%	In 1000 ha	%
1x		955	66	693	64	58	55	81	76	119	76
2x		324	22	251	24	27	26	17	16	29	18
3x		115	8	90	8	12	11	5	5	8	5
4x or more		56	4	44	4	8	8	3	3	1	1

Subsequent spraying was done to achieve the total defoliation of the lower storeys or to prolong the period of leaflessness.

- Target of missions
  83% Defoliation
  9% Crop destruction
  3% Minor missions (base perimeters, enemy cache sites, along communication lines).
- The percentage of sprayed cultivated land is as high in defoliation missions as in crop destruction missions.
- 75% of the herbicides were sprayed over the inland forest areas
  8% on mangroves
  7% on permanently cultivated areas
  10% on other areas
  Remark: Shifting cultivation fields were considered as forest. Off-target application via drift may have occurred.
- Agent Orange was most often used, representing about two-thirds of the total volume sprayed.
  Orange and White were generally used for forest destruction; and Blue for crop destruction, although Orange was also used for this purpose.
- Defoliation took place all over the country with a concentration north of Saigon, along the borders, especially near the demilitarized zone, and in the mangroves. Missions for crop destruction were flown over the valleys and plateaus in the Central Highlands.

Information other than the N.A.S. report:

BRINDLEY (1973) estimates that 1.96 million ha were sprayed at least once or more in the period 1961-1970.
According to LE CHI THAN (1974) one-third of South Vietnam (5.7 million ha) was soaked in the period 1961-1972.
WESTING (1972) gives for the period 1961-1971 an estimate expenditure of 72.3 million liters (c. 52.3 million kg of active ingredients) sprayed over a cummulative area of 2.576 million ha. In 1976 he mentions a total area of 1.709 million ha involved.

2.2 Cloud-seeding

From March 1967 to July 1972 the Americans seeded cumulus clouds over Indochina with agents including silver iodide and lead iodide. The major reason was to interdict supply routes of the Viet Cong, especially those in southeastern Laos and northeastern Cambodia (fig. IV 6). It was assumed that intensifying and prolonging the south-west monsoon rains would induce landslides and floodings and thereby keep the roads impassable, or nearly so, for a long time.
In table IV 4 the cloud-seeding efforts are shown by year. After March 1968 all sortees above the 19^{o} were stopped.

2.3 Bombs and shells

Between 1961 and 1973 a large number of high-explosive munitions were thrown on Indochina from the air (50%), from weapons on the ground (49%) and from the sea (1%) (WESTING, 1976). They included:

- Carpet bombs (500, 750, 2000 pound)
- Howitzer projectiles (105-mm, 155-mm, 203-mm)
- Gun projectiles (175-mm by the army and 127-mm by the navy)
- High caliber demolition bombs (e.g. the Daisy Cutters of 15,000 lbs.)
- Mines
- Blastbombs
- Anti-personnel fragmentation bombs.

Most commonly used munitions were 500-pounds bombs and 105-mm shells.
The bombings aimed at "harassment and interdiction" of the enemy, and support of the actions of the ground troops. In fact this meant that most bombings were carried out at forests and cultivated land where Viet Cong troops were supposed to be present.
From 1965 to 1973, 14,265 million kg were used, of which 10,176 million kg were exploded within South Vietnam. The major portion was focussed on the following regions: the five northern provinces, particularly in the demilitarized zone, the region around Saigon, and the Ho Chi Minh trail (fig. IV 3). Bombardments were most heavy from 1967-1972. In the period 1965-1973 about 7 million tons of high-explosive crater-producing munitions were used in South Vietnam (WESTING, 1976).

The effect of an exploding bomb is as follows: first there is the initial blast wave (lethal area for a 500-pound bomb is less than 0.01 ha). Than there is flying metal or "shrapnel" which has a much larger lethal zone. A 500-pound bomb scatters "shrapnel" in significant amounts over an area of 0.3 ha.
A 500-pound bomb leads to a crater with an average diameter of 8 (-10) m, a maximum depth of 4 (-4.5) m and soil displacement of 67 (-100) m^3 (WESTING, 1976; ANONYMOUS, 1974).

According to LE CHI THAN (1974) there remain still unexploded in South Vietnam some 2 million bombs and 20 million shells which, it seems, is a rather high estimate considering the 11 million bombs and 217 million shells used in Indochina (WESTING, 1970).
Besides carpet bombing with B-52s, there were also high-calibre demolition bombs

of 1000-15,000 pounds ("Daisy Cutters"), which were dropped to create landing zones especially in MR I and II and south of the Mekong delta. These bombs, of which 160 were used (ANON., 1975) leave no crater but they blow away all trees and other obstacles to leave an average opening of 1.3 ha (WESTING, 1976) while killing all life within 1 km (BRINDLEY, 1973). Some of these special-purpose bombs (the fuel-air explosive bombs) may produce a fire-ball when malfunctioning. In table IV 5 an estimate of the damage of bombs to vegetation is made assuming that a 500-lb bomb clears 730 m^2 (ODUM, 1974).

2.4 Land clearing

In 1965 a new technique emerged in addition to bombing and herbicide spraying, namely systematic forest bulldozing by so-called Rome-ploughs. The basic equipment was the D-7E Caterpillar, a heavy, armoured tractor with a special land clearing blade weighing c. 33 tons.
Initially these were used to clear strips of 100-200 m at each side of important communication lines. In 1970, however, most of the road systems had been cleared (WESTING, 1971b). Sometimes herbicides were applied to keep the strips treeless. By mid-1968 organization into companies of 30 machines for extensive forest clearing started, and it soon became apparent that this means of area denial to guerillas was in some ways superior to herbicide spraying and bombing and shelling (WESTING, 1976). One unit of 30 tractors could daily clear 160 ha of woodland and 40 ha of dense forest (WESTING, 1971b). In total some 325,000 ha of forest - 2% of the total area of South Vietnam - were cleared (WESTING, 1976). Greatest activity occurred in Military Region III especially north and north-west of Saigon in the Iron Triangle. It was, however, also important in M.R. I (Quang Ngai province) and M.R. II (Binh Thua).
In addition to forest areas, thousands of hectares of arable land, rubber plantations and fruit orchards were obliterated.

2.5 Incendiary weapons

These weapons generate very high temperatures when exploding; particles in the bombs are highly adhesive and very toxic when burning. They were especially used against hostile villages and camps as a part of tactical and psychological warfare; the many people heavily wounded by these bombs needed much care from others.
Some attempts were also made to initiate forest fires after defoliation with these weapons. Most of them failed because of the generally humid conditions (WESTING, 1971b); however, succesful attempts were reported from the U-Minh forests (ANON., 1974a).
Most commonly used were napalm bombs and phosphoreous bombs. From 1963 to 1966 about 100,000 tons of napalm were dropped on South Vietnam from the air (NEILANDS et al., 1972).

IV.3 ENVIRONMENTAL CONSEQUENCES

3.1 Climatological effects

3.1.1 General

Through destruction of vegetation, the impact of vegetation on climate (especially on the micro-climate) may locally have changed. Impact of climate on vegetation and soil will be altered by it as well. The magnitude of environmental impact varies with both the absolute and relative size of the treated area, the vegetation, and the location of the area involved. In the following, several micro-climatological factors are quantitively discussed. For a full account of rainforest micro-climate see RICHARDS, 1964.

3.1.2 Wind velocity

The magnitude of a forest's impact on wind speed varies with the structure of the forest (density, structure of forest fringe) and the season. The slow-down of the wind speed by the forest will absolutely and relatively increase with stronger wind speed.
In defoliated forest there will be only a slight increase in wind speed; when the forest has disappeared, however, there will be a considerable increase, depending on the size of the affected site. In gaps smaller than 3x tree height (H) wind speed will slightly increase; in gaps over 3H the difference becomes important. Increase in wind speed may have important consequences: modification of relative humidity (3.1.4), temperature, and evaporation (3.1.6).

3.1.3 Precipitation

3.1.3.1 Spatial distribution

Forest is the best form of vegetation for conservation of both soil and water; the undergrowth plays a vital role in holding and protecting the soil, while larger trees absorb the kinetic energy of raindrops.
Part of the rain is intercepted by the forest crown and evaporates. The remainder, which is called throughfall, reaches the ground; a small part runs down the stem and is called stemflow.
Precipitation in the open = stemflow + throughfall + interception.
Interception depends on structure and species composition of the forest, and duration and intensity of the rains.
For middle Europe the interception within the forest canopy is 20-33% of total precipitation (MITSCHERLICH, 1971).
In South Vietnam, however, most rain falls in heavy storms; on the other hand, most forests are multistoried. Taking this into account, it is estimated that for dense forest the higher value for interception may be taken, while the lower one approaches that for woodland. The disappearance of the forest or leafcover results in an increase of the rainfall reaching the ground; and when the herbs layer is absent, the velocity of the raindrops striking the ground will no longer be slowed down. The total amount of infiltrating water will initially increase, but later on run-off (with or without erosion) may occur when the soil becomes saturated or sealed (section 4.3).
The soil under a grassy vegetation has a lower infiltration capacity thus causing run-off during heavy showers; erosion is, however, not likely to occur.

3.1.3.2 Quantity

Horizontal precipitation or fog-drip as it occurs in mossy forests may greatly contribute to the total amount of water available to vegetation. As this form of precipitation is found on a very small scale in South Vietnam, deforestation will not have had an important influence in this respect.

3.1.4 Relative humidity

Relative humidity will decrease with the disappearance of forest or foliage through an increase in exchange of air and turbulence. In addition soil temperature is raised which results in an increase of convection. A marked decrease in absolute humidity probably occurs only when all vegetation has disappeared (see 3.1.6).

3.1.5 Radiation balance

The net incoming radiation of forest is higher than that of any other vegetation type. This is mainly due to the low albedo of forest (10-20%) compared with grassland and arable land (25-30%) (BAUMGARTNER, 1971b).
Disappearance of the forest may result in a higher albedo and a decreasing amount of absorbed radiation; this has consequences for energy balance (3.1.6).

The amount of light reaching the ground strongly increases resulting in a temperature increase of the soil, intensified evaporation, and oxidation of organic matter.

3.1.6 Energy balance

Most of the incoming radiation of vegetation is transferred into latent heat (evapotranspiration) and sensitive heat.
After destruction of a dense forest, often resulting in another vegetation type, the evapotranspiration will probably not change or it will become slightly lower. The temperature regime, however, will change. The maximum and minimum will reach more extreme values, depending on the size of the affected site. The same holds true for woodland, although its more open structure will easily give rise to increased wind speed, thus influencing evapotranspiration.
If all vegetation has disappeared, no transpiration takes place and only evaporation is left; differences in temperature become more extreme. The soil color is also important with respect to reflection.

3.1.7 Summary

Vegetation has a mitigating effect on the microclimate. Largescale disruption will profoundly alter the microclimate of an affected area, which in turn will seriously hamper the restoration of the original vegetation type. Extremes in insolation, temperature, moisture and wind, near and at the ground are particularly affected.

3.1.8 Macroclimate

3.1.8.1 General

The effect of vegetation on macroclimate is still obscure. If it exists it is difficult to measure due to the erratic nature of climate and the insufficient accuracy of measuring instruments. It is, therefore, not clear whether vegetation disruption as it has occurred in South Vietnam has had an influence on regional weather.

3.1.8.2 Weather manipulation

An increase in rainfall was observed in the affected areas. It is, however, not clear whether the increased rainfall was a result of decreased rainfall in other areas.

3.2 Effects on vegetation

3.2.1 General

In the following the impact of various techniques and means are discussed. It should, however, be kept in mind that they were often employed together or subsequently. Most data are qualitative.

3.2.2 Herbicide spraying

The Committee on the Effects of Herbicides has made an appraisal of the loss of merchantable and non-merchantable timber (4.6) mainly based on aerial photographs, sampling, and a vegetation map (ROLLET). A description of the ecological consequences for different vegetation types was, however, not made. A major problem in both cases was the condition of the forest before the war started. According to ROLLET (1962), at that time most primary forest had disappeared especially in the lowland, and to a lesser extent in the submontagnard zone. Selective logging and shifting cultivation had led to a strong degradation (see III.3.3). In table IV 6, the vegetation types as used by the committee are

"translated" into the types described in III.3 and their area is given. In fig. IV.4 is indicated where herbicide spraying has taken place; with the aid of the vegetation map (Map III 5) the vegetation types concerned are traced.
Most strongly hit were the moist evergreen forests in the northern part of South Vietnam, the moist semi-deciduous forests, and the dry deciduous forests north and north-west of Saigon.
About 1.1 million ha of inland forests were sprayed once or more, about 90% of this area was originally covered with dense forest and 10% with woodland (table IV 2). About 60% of the destroyed inland forest is found in Military Region III.
In the following sections a rough description of the effects on vegetation is given. These effects largely depended on the following factors:

- vegetation type; especially the structure, the sensitivity of the attacked species, and the distribution of these species over the terrain;
- the number of sprayings;
- the interval between sprayings;
- the applied agent;
- the weather conditions and season.

3.2.2.1 Closed forest formations.

a) The moist evergreen forest, the moist semi-deciduous forest, and the montane forest are multi-storied, uneven-aged and often rich in species - on the average there are 100-150 different species per ha.
Relatively few species are found as emergents, only about 10% of the total number. In closed forests these emergents usually have wide spreading crowns (up to 30 m) forming a kind of umbrella which protects the underlying strata against herbicides. In the montane forest these wide-spreading crowns are less common because *Gymnosperms (Podocarpus spp.)* usually form the canopy.
After one spraying all species drop their leaves within 2 or 3 weeks.
Resistent and partly attacked species will sprout again at the beginning of the wet season, which means that they may be bare for a considerable time.
Usually sensitive and non-protected species in the canopy and upper stratum are killed.
Generally, application of herbicides has resulted in relatively large gaps in the canopy and stimulation of growth in non-attacked and resistent species.
The most sensitive species in the canopy and upper stratum are: *Anisoptera spp.*, *Lagerstroemia spp.*, *Pahudia cochinchinensis*, *Parinium sp.* and *Pterocarpus pedatus*.
Less sensitive are: *Dipterocarpus alatus*, *Hopea odorata* and *Shorea cochinchinensis;* while among the most resistent are *Cassia siamea* and *Sandoricum indicum*.
The following figures whow the mortality of trees after one or more sprayings in dense forest:

No of sprayings	% of total sprayed area	% of trees killed outright
one	66	10
two	22	25
three	8	50
four or more	4	85-100

Briefer intervals between sprayings resulted in a higher level of mortality of trees.
Bamboo is more or less abundant in the undergrowth of the closed forest formations of the lowland and the submontagnard zone.
The improved light conditions after herbicide spraying favoured bamboos, such as *Bambusa arundinacea, B. blumeana, Oxythenanthera spp.* and *Schizostachym zollingeri*, and permitted their release.

A factor of importance with respect to this is that monocotyledons are less sensitive than dicotyledons to the commonly used agents Orange and White. Recolonization with bamboo is mainly by vegetative regeneration; seeding of bamboos is infrequent and seed dispersal poor. In addition, herbicides may have resulted in a more or less severe tangling formed by secondary species (*Macaranga spp., Mallotus spp.* and others), climbers and eventually valuable species.
It was assumed that these closed forest formations, after spraying once or twice, would restore themselves if sufficient regeneration was present, even though bamboo was abundant.
Three, four or more sprayings favoured the extension of bamboos and other *Gramineae* (e.g. *Imperata cylindrica*).
Smaller or larger bamboo areas resulted especially where forêt-dense was sprayed.

b) Hallier and thicket.
These sormations, consisting of fast-growing, short-lived (secondary) species, proved to be highly sensitive to herbicide spraying. Spraying of bamboo forests caused the dieback of the above-ground parts but the bamboos usually sprouted quickly again. Regeneration of tree species below the bamboos was to some extent protected against herbicides. Regeneration of tree species above the bamboos was seriously affected by herbicides. Also here the herbicide spraying probably led to an extension of the bamboo area.
Other life forms in the forest were decimated by herbicide attack viz. epiphytes, very abundant in montane forests, stranglers and climbers, especially the tree-crown epiphytes. Also indirectly they were seriously hit because they require specific ecological conditions which may have disappeared. In this respect fauna can also be mentioned, and is discussed in section 3.5.

3.2.2.2 Open forest formations and the dry deciduous forest.

These forests usually have one or two tree storeys and an open structure. After herbicide attack large gaps are formed which will permit light to reach the undergrowth more easily than in closed formations, especially in the dry deciduous forest where *Lagerstroemia angustifolia* is abundant. Restoration is possible if natural regeneration of species in the canopy is sheltered by the undergrowth. Fire will, however, kill most of the regeneration (3.2.3).

3.2.3 Fire

Sometimes forests were succesfully burned after herbicide attack. The effect of these fires was much more serious than herbicide spraying alone. All species in the undergrowth, except those adapted to fire, were killed. Favourable ecological conditions for *Imperata cylindrica* and bamboos were created. Accordingly, it was observed in herbicide-attacked vegetation types that these *Gramineae* were more abundant in the undergrowth when burning had taken place.

3.2.4 Bombing and shelling

Damage to vegetation was done in two ways:
Firstly, at the spot of the blast the vegetation was completely destroyed. WESTING (1976) estimates that 2 million trees over 10 cm d.b.h. were killed outright. In total 1,219,100 ha were completely destroyed (ODUM, 1974).
Secondly, many trees around the blast zone were hit by flying metal. This killed directly by cutting down, or indirectly by causing wounds which served as a site of entry for wood-rotting fungi. *Dipterocarpus spp., Anisoptera spp.* and *Hevea brasiliensis* are quite rapidly vulnerable to destruction of this sort, whereas *Hopea spp.* and *Lagerstroemia sp.* are more resistent (WESTING, 1972b). The value of trees hit by shrapnel is, however, strongly reduced.

The total number of trees over 10 cm d.b.h. killed by bombs and shells is estimated at 45 million (WESTING, 1976). The craters are likely to remain for many years or even decades. Craters in the Mekong Delta that have become ponds, were reported to be surrounded by *Phragmites, Brachiaria* and *Scirpus species* (WESTING & PFEIFFER, 1972). According to WESTING (1976), the sides of craters which do not become ponds are stabilized by vegetation within 4 to 5 years. Craters themselves are only sparsely vegetated or bare.

3.2.5 Land clearing

About 325,000 ha were cleared by "Rome-ploughs"; few data are available on recolonization of these areas.
Recovery of the vegetation - by the development of a pioneer vegetation, gradually followed by natural succession and finally resulting in a more or less primary vegetation - depends among other things on the following factors:

- original vegetation and the character of the pioneer vegetation;
- the total size of the deforestated area and the relative size compared with the remaining vegetation;
- thoroughness of the destruction;
- site factors (soil, slope, rainfall pattern);
- eventual disturbances after land clearing.

It was observed that the invading pioneer community is often dominated by herbaceous or woody *Gramineae* and only rarely by woody dicotyledons such as *Dipterocarpus spp.* (WESTING, 1976).
Succession studies in "mesomorphic evergreen seasonal forest" (BOERBOOM, 1974) showed that regrowth on a mechnically cleared, windrowed and burned terrain was inferior to that of a terrain cleared by manual labour where debris was left. Basal area after 7 years was 40% of the original 24-28 m^3/ha on the first terrain, and 90% of the original 33 m^3/ha on the second one.
Large differences between these sample areas and South Vietnamese conditions exist with respect to the treatment. The equipment used in South Vietnam was heavier and in many cases herbicide spraying or respraying was done after a first land clearing

3.2.6 Other consequences of warfare on vegetation

One indirect effect can be mentioned and that is the concentration of population in certain areas (e.g. Montagnard in Dak To, Kon Tum province). This resulted in an increased demand on vegetation for fuelwood, timber etc.; and also because the shifting cultivation area was considerably extended in these regions. It is possible that parts of the moist evergreen forest and montane forest were clear cut. The high population in this region may have led to expanded cultivation periods or curtailed fallow periods.

3.3 Effects on soil

3.3.1 Herbicides

3.3.1.1 Persistence and disappearance

From investigations of the Committee on the Effects of Herbicides in South Vietnam it was concluded that "the persistence of herbicide residues in the soils of South Vietnam is not a significant factor in subsequent growth of vegetation" (BLACKMAN et al, 1974).
This opinion is, with some reserve, shared by WESTING (1976) after he made an extensive literature review. He states, for instance, that the ecological significance of dioxin (the contaminent in agent Orange) when added to a terrestrial ecosystem, is still obscure.

3.3.1.2 Effect on inland forest soils

Erosion

Although large changes may take place in the hydrology of a forest area after herbicide spraying, erosion is not likely to become serious when slopes are not too steep. Even in the worst cases, when total defoliation had been achieved, the soil was still covered with debris (whether together with remnants of the original vegetation or with regrowth, or not). The litter protected the soil against sealing, favoured infiltration, and reduced the speed of surface run-off water. On steep slopes, however, severe erosion may have occurred after herbicide spraying; surface run-off may have removed both litter and parts of the soil, thus exposing rock. These phenomenons were reported from the provinces of Quang Da, Quang Nam, Quang Ngai, Binh Dinh and Phu Yen on the steep eastern slopes of the Truong-Son Range.

Original vegetation may have been replaced by secondary forest, a bamboo vegetation, or even *Imperata* fields. The first two formations provide a good soil cover. Surface run-off may occur under bamboo vegetation but erosion is not likely to happen as bamboo often has a dense undergrowth and also a dense, superficial root system (COSTER, 1938).

Less favourable is *Imperata cylindrica*; surface run-off may be considerable, although under this vegetation erosion is slight because of the dense superficial root system.

An example of surface run-off and erosion under different vegetation coverage in the Philippines is shown in the table below (after KELLMAN, 1969).

Clayey soil, slope 5% altitude 1000 m, annual rainfall c. 4200 mm.

Vegetation cover	% Run-off	Erosion (g/day)
Primary forest	0.258	0.20
Secondary regrowth	0.264	0.29
Imperata cylindrica	3.017	0.40

The consequences of burning after spraying are discussed elsewhere.

Loss of nutrients

A large amount of the nutrients in a tropical forest ecosystem is found in the biomass. Tropical soils are often poor to very poor (Nitosols, Acrisols and Ferralsols); the fertility greatly depends on the organic matter. This is important as a cat-ion exchange complex, as source of nutrients (N, P and S), and for the physical properties of the soil.

The nutrients of the ecosystem circulate between the biomass and the soil, and nutrients are added to, or disappear from the ecosystem. This is schematically drawn in fig. IV 7.

Herbicide spraying has led to disturbance of the nutrient cycles. Losses of nutrients have taken place through erosion, leaching and volatilization.

The final impact of herbicide spraying on the nutrient status will depend on a number of factors: vegetation type, soil type, temperature, rainfall pattern, slope, degree of destruction and the agent used. Some important effects will be shortly dealt with below.

Spraying once or twice usually resulted in the dieback of a part of the vegetation. The organic debris quickly decomposed, during which some C and N were lost by oxidation.

The loss of minerals depends on the buffering capacity of the soil, the degree of erosion, and the rapidity of vegetation regrowth.

Actively growing vegetation reduces leaching losses by:

- transpiring water and so reducing percolation;
- absorbing an-ions, espcially nitrate, from the soil solution;
- repressing nitrification and so reducing the concentration of an-ions that would otherwise occur (NYE and GREENLAND, 1960).

A part of the vegetation continues growing while regrowth of the other part of the vegetation starts soon after application.

Test applications of defoliants were made on acrisols in closed forest in Thailand. Seven years after herbicide treatment with agent Orange and picloram at a concentration below military application rate, samples were taken at the treated site and on adjacent forest area. Severe losses of nitrogen and available phosphorus were recorded from the defoliated area, and the pH was lower.

Spraying three times or more resulted in sites which were nearly without vegetation for some time due to toxic levels of herbicides in the soil.

Dense forest may be replaced by a succession vegetation e.g. of bamboo, in which much less nutrients can be stored, or even by a succession stage with *Imperata*. Besides disruption of the nutrient cycle, strong modifications in microclimate are also likely to occur (3.1). The effects of this will be discussed under land clearing.

Initially the amount of nutrients in the soil will increase from the debris. Under natural tropical vegetation, mineralization is rather fast, especially for potassium (NYE and GREENLAND, 1960). BARTOLEMEW et al (1953)* state that after 10 weeks 51% of nitrogen, 61% of phosphorus, 93% of potassium, 50% of calcium and 82% of magnesium from the litter had been mineralized.
Through increased temperatures in the topsoil, however, the microbiological activity will increase (optimum temperature of many micro-organisms is about 35°C) resulting in an increased decomposition of litter and humus.
Finally the humus content will decrease and the litter layer will disappear; leaching of nutrients will take place. Especially nitrate is readily leached together with cat-ions of which potassium is the most important.

Induration of plinthite

This will be discussed under land clearing.

3.3.2 Bombing and shelling

Many large and small craters have been created, the size of the crater depends on the munition used, soil characteristics, etc. The average is about 8 m in diameter and 4 m in depth. These craters are more often formed by compaction into the sides than by the soil being thrown out. Also the area around a crater is more or less compacted. The final effect of craters will, among others depend on rainfall pattern, soil type, relief and depth of the water table.

The disappearance of vegetation and the compaction of the topsoil results in strong surface run-off which, especially on sloping parts, causes severe erosion. The soil scattered by explosion or loosened by falling trees will readily be washed away. As bombed terrains remain bare (or nearly so) for a long time, they are subject to severe losses of nutrients (see 3.3.2.2 and 3.3.4), and possible induration of plinthite (3.3.3.5). In addition, the craters can become permanently filled with water when the water table is high.

3.3.3 Land clearing

3.3.3.1 Introduction

For the description of the direct effects of land clearing on soils, data from VAN DER WEERT & LENSELINK (1972), who studied this subject in Surinam, were used. Direct effects are compaction of the top soil and disturbance of the surface soil. This, and the destruction of the vegetation cover, results in erosion, loss of nutrients, possible induration of plinthite, and flooding. These effects will be discussed below.

3.3.3.2 Compaction of the surface soil

The degree of compaction depends on the equipment used, the intensity of the operations, the soil moisture content during operations, and the texture and organic matter content of the soil.
Since the equipment used in South Vietnam was heavier and the operations more thorough, it seems likely that effects will be more serious than those described below for Surinam.
The compaction effect was observed to extend to a considerable depth (70-100 cm). Generally speaking, uniformly textured soils were most susceptible; loamy soils could be compressed to the highest bulk density. Resistence to compaction normally

*Bartolemew, W.V. et al (1953), Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region. I.N.E.A.C., Ser.Sci, no. 57, Brussels.

increased with organic matter content. The volume of large pores, important for both soil moisture and soil aeration, was strongly reduced (fig. IV 8). The effect was worse when operations were carried out during the wet season.
The following possible effects can be assumed: aeration of the top soil was strongly reduced, especially on loamy soils; and possible mechanical hindrance for rooting was increased. Infiltration (table IV 7) and permeability were strongly reduced resulting in waterlogging or surface run-off, often together with erosion. Soil moisture available for plants decreased although available water in the soil increased by compaction. Effective depth of rooting is limited because of the increase of micropores.
Water shortage could occur in the dry season as much water is lost by run-off.

3.3.3.3 Scraping away of the topsoil

Scraping away the topsoil rich in organic matter is very harmful (see 3.3.2.2). Uptake of nutrients, especially immobile ones like phosphorus, will be diminished because depth of rooting is limited and the soil dries out more quickly. Furthermore, the mineralization of organic matter can be decreased through reduced aeration.

3.3.3.4 Erosion

Erosion results from land clearing as the areas concerned become completely bare, probably for a considerable time, with tightly compacted sections with strong surface run-off alternating with parts having turned, loose soil, which is liable to be washed away.
Serious gully-erosion is reported to occur in Surinam at some places after mechanical land clearing, even on gently sloping land.

In South Vietnam, therefore, damage is expected to be massive. Operations were heavy and rough and in many cases soils were loamy (Highland of the Mekong), but fortunately slopes were usually slight.

3.3.3.5 Induration of plinthite

Plinthite, as it occurs in the Highland of the Mekong (in the transition zone towards the basalt plateaus) will irreversibly harden upon prolonged exposure to the elements.
Probably recolonization of bare sites usually has been quite rapid; and induration will have taken place only at spots where plinthite has come to or near the surface through erosion, but this has happened only on a very small scale.

3.3.4. Fire

Contrary to the gradual release of nutrients which follows defoliation, a large amount of minerals are added to the soil following burning (i.e. phosphates, silicates, and carbonates), while the major part of nitrogen, sulphur and carbon are lost.
After burning a large number of cat-ions is found in the soil and the pH is slightly raised.
Losses through leaching are slight as regrowth is usually quick. However, surface run-off and erosion may occur and the forest may be replaced by bamboo or *Imperata*.

3.3.5 Flooding

The partial or complete removal of the forest cover will result in more rainfall reaching the ground in that area (3.3.1). Surface run-off will increase, especially on terrains which have been bulldozed, burned, or bombed; but also to a lesser extent, on herbicide-sprayed areas.
Consequently, much of the rain falling in the area concerned has to be drained

directly by the rivers which gives rise to peak discharges. Together with run-off, erosion occurs to some degree, depending on soil type, slope, rainfall intensity and amount. This leads to an increase of sediment load in the rivers (fig. IV 9). Finally, the waterflow in the wet season will be higher and in the dry season it will be lower (fig. IV 10); downstream this may result in flooding during the wet season and desiccation of crops in the dry season.

3.4 Changes in land use during the war

A direct consequence of warfare is the destruction of arable land and forests in which shifting cultivation or another form of land use (e.g. charcoal burning in the mangrove) is carried out.
There were, however, other important indirect consequences in South Vietnam:
- problems with food distribution;
- food imports from the U.S.A.;
- concentration of the scattered population;
- unsafe fields;
- the great risk of long-term investments; and
- problems in obtaining loans.

In addition, less war-related factors had their impact on land use:
- introduction of new crops and cultivars;
- new agricultural methods (fertilizers, pesticides and implements); and
- changes in the consumption pattern.

There is a general tendency to concentrate production in a smaller area. Data about agriculture are, however, scarce and unreliable because of the state of war.
From the figures of tables IV 8 and IV 9 it becomes clear that the greatest damage to agriculture was done in the period 1965-1970. In the beginning of the seventies agricultural production was increasing strongly. Rice production was recovering since 1969 (fig. IV 11), mainly because of increases in yields (from an average of 2 tons/ha in 1960 to 2.4 tons/ha in the beginning seventies), but also partly because the total area under cultivation increased (from 3 million ha in 1960, 2,4 million ha in 1970, to 3,2 million ha in 1973).
Production of rubber and other perrenials, however, lay behind this increase (fig. IV 12). This was, in the first place, because much of these crops were grown in areas with great war activity, and in the second place because many plantations were neglected and no investments were made. Many trees were killed or seriously damaged by drifting herbicides, particularly Orange which is very volatile. Especially sensitive were jack-fruit, the capok-tree, guave, lychee, coconut tree, and some clones of rubber trees. Little damage seems to have been done to bananas and manioc. Later, agent White which is less volatile was used in the Mekong Delta to avoid commotion with the farmers.
In livestock keeping there was a tendency toward quick production with less risky, small animals (table IV 10).

In forestry the portion of organized trade in fuelwood as well as in charcoal production was strongly reduced. The forest industry steadily decreased. By 1970, however, timber production seemed to recover (table IV 11).

3.5 Effects on fauna

Quantification of the effects of war on fauna is impossible, but it can be determined that the fauna of South Vietnam as a total was seriously reduced, if not decimated. Many of the larger animals were killed directly by bombing, shelling or hunting. The effects of herbicides on animals is not fully known; many ducks, other poultry, pigs and other cattle died or became seriously ill. Some died from eating sprayed food: fish, insects, and birds were observed dying after spraying, and other animals were paralyzed for some time.

A far more important effect of herbicides and other warfare was the destruction of different vegetation types; the habitat of many animals was disturbed or destroyed, thus removing or reducing their source of food and shelter.
Many animals are strongly bound to their habitat. In the tropical forest a large number of animals is restricted to the upper strata. For instance, the gibbon depends on the treetops of the undisturbed closed forest formation. After herbicide spraying it was forced to flee to non-disturbed parts of the forest, if present. However, often the migration of animals is impossible as the potential refuge is already populated to its maximum carrying capacity. Furthermore, gibbons are known to have strong family ties and strong territorial instinct. Langour's behaviour resembles the gibbons; the macaques, however, are more adaptable.
Deer, who are very shy, will take refuge when bombing, shelling, or other military activities take place. The effects of herbicides on their habitat is not clear. The open forest formations in which they usually live were sprayed far less than the closed formations. Also, since deer feed on various plants, their habitat is not very specific and is probably less disturbed than the closed forest. Nothing is known about contamination by herbicides via water and food.
Some of the larger wildlife have been able to flee to relatively quiet regions. For example, in eastern Khmer Republic an increasing number of animals was observed, among others: muntjaks and other deer species, bantengs, gaurs, some koupreys, elephants, a number of monkey species, and wild boars (WESTING, 1972).
Other animals were favoured by war: e.g. mosquitoes (by bomb craters filled with water), rodents (in seriously damaged, herbicide-sprayed forest) and tigers (by the dead bodies of soldiers).
It is clear that the fauna of South Vietnam has been severely disturbed. Possibly some animals which were nearly extinct are now gone forever because of the war: for example, the kouprey (*Bos sauveli*), a tapir (*Tapirus indicus*), a bear (*Ursus tibetanus*), a gibbon (*Hylobates pileatus*), and a pheasant (*Lophura imperialis*).

3.6 Socio-economic situation

3.6.1 Population

3.6.1.1 General

From 1960 to 1970 the population of South Vietnam increased by 2.6% per year to 18.3 millions. Because of hostilities, many people went to the cities where inhabitants increased by 7.5% yearly to 4.8 million persons, of which 3 million were living in Saigon.
Education was improved in 1970: 90% of all 6-10-years-old children and 26% of all 11-17 year-olds went to school.
About 30,000 people were at the university. The health and food situations were poor, however.

3.6.1.2 Socio-economic consequences of the herbicide program

The Committee on the Effects of Herbicides studied 18 settlements from aerial photographs which had been heavily sprayed (table IV 12). In the area covered by this report, 11 spots were studied. Most people were displaced from their settlements following herbicide spraying. In the zone with plantations there were heavy war activities which played a part in the 70% displacement from this area, also.
In the lowland valley settlements near the coastal plains, permanent agriculture was replaced by shifting cultivation. In the upland vallies with permanent agriculture, the settlements were abandoned. Shifting cultivation strongly decreased, although it did not disappear completely.

Other shifting cultivation settlements were almost completely abandoned. It should be stressed that the above cannot be asserted for the whole of Vietnam as only heavily-sprayed areas were studied.
It can, however, be stated that the use of herbicides together with other war-related activities has forced much of the rural population to permanent or temporary relocation, and this has contributed to massive urbanization.
The Montagnards were especially strongly hit since they had no economic alternative.

3.6.1.3 Biological effects of herbicides

Reports of human illness following spraying are so striking that it is difficult to dismiss them as simply the effects of propaganda, or higher than normal death rates, or faulty understanding of cause and effect (ANON., 1974).

Biological effects may be caused by direct exposure, inhalation, or consumption of polluted water and food. Besides illness and death, herbicides may cause chromosomic alterations, birth defects, miscarriages and stillborn children. Also disease-carrying insects and rodents may be favoured by elimination of vegetation.
The very toxic Dioxin (TCDD) contaminant of agent Orange is especially dangerous to pregnant women. Dioxin is highly persistent in the soil, and accumulation may occur in human beings or animals. It was found present in fish in the drainwater of heavily-sprayed areas. Adverse genetic effects and effects on pregnant women have not become clear although there was an indication that herbicide spraying resulted in increased numbers of stillborn births. A direct medical study of any immediate toxic effects of herbicides could not be conducted by the Committee.
However, it is known that many morbid symptoms resulted from herbicide spraying. Deaths caused by herbicides, however, were not apparent eventhough there is an indication that a higher death rate existed for weaker groups of people.
Psychological strain has resulted from herbicide spraying and other war activities and may become long-lasting.

3.6.2 Economy

The strong concentration on agriculture did not diminish after 1960. The drop in rubber production had a great influence on income from exports.
While population was increasing, food production decreased, and imports had to supplement the shortage. In 1965 South Vietnam became a rice-importing country (table IV 13).
Between 1960 and 1975 the economy of South Vietnam was a typical war economy, which could only be maintained by American support. The value of imports was, in 1971, 50 times that of exports ($ 11.5 million). Two-thirds of the public expenditure went to defense in 1970. The average rise in prices for a family household in Saigon from 1960-1970 was 720%. Industrial development was nearly arrested.

3.6.3 Traffic

During the war, portions of the road system were occupied by the Viet Cong while other parts were seized by the South Vietnamese government troops. Many of the roads and railroads were severely damaged; in 1968 only one-third of the total road system was in use. After 1965 the road system was not extended. Transport by water and air increased.

3.6.4 Forestry

3.6.4.1 General

The Vietnamese forests played an important and essential role during the war. Most of the forests were under Viet Cong control and provided them cover and sanctuary. They were considered the territory of a foreign communist power; the people and resources of these areas were the enemy. This shortsighted military view, together with the fact that the forests were considered worthless by many persons (including agriculturists) made the forests logical military targets (FLAMM and CRAVENS, 1971). Consequences of war on forests are briefly presented in table IV 14, which summarizes the effects described in previous chapters. The most severely hit inland forest areas were in War Zones C and D, previously the main log and lumber supply areas for the Saigon market.

3.6.4.2 Economic consequences

WESTING (1971a) estimates that through war-related activities about 71.5 million m^3 of merchantable wood was lost; 47 million m^3 was destroyed by the herbicide program. In later publications (1975) he states more carefully that about 20 million m^3 was lost by herbicides. BETHEL et al (1975) estimated that the herbicide program caused only 0.5-2 million m^3 of merchantable timber and 5.6-11.9 million m^3 non-merchantable timber to be lost. The differences between WESTING and BETHEL et al, are mainly due to differences in the supposed situation of the prewar forests; a forest inventory, however, was never carried out.

Losses in seed supply were not studied by the above-mentioned authors. Economic losses were also sustained by the decrease of minor forest products and by forest industries, etc.

3.6.4.3 Forest industry

The dividing line between Viet Cong and Government was more political than economic (WESTING, 1971a). Outside the heavy battle zones, exploitation of the forests continued during war. The exploited amount of timber and construction wood was:

Year:			
1956	552,000 m^3	1967	205,300 m^3
1960	319,000 m^3	1968	285,000 m^3
1961	342,500 m^3	1969	462,700 m^3
1963	364,500 m^3	1970	405,500 m^3
1965	319,000 m^3		

It should be mentioned that about the same amount might have been cut illegally. Exploitation of minor products strongly decreased, however, and charcoal production was nearly arrested (table IV 14).
Other sources of energy were eventually used instead of charcoal, and it is expected that in the future this will continue (WESTING, 1971a). In the past, however, export of charcoal had been important.
Fuelwood production increased but its portion of organized trade decreased.
Around 1969 forest industry was extensive; there were 317 (mainly small) operating sawmills, one pole-treating plant, one 16,000 ton wood-based pulp and paper plant, one plywood plant, one particle board plant, 403 wood-working shops, and 150 charcoal plants. In total about 80,000 persons were employed in 1968 (FLAMM and CRAVENS, 1971). The total pulp and paper production increased to 43,500 tons in 1971, which was not sufficient to cover the demand (55,000 tons). The potential economic value of the South Vietnamese forests is described as follows (BETHEL et al, 1975, after RALSTON and THO*, 1970):
"While there is an opportunity for the Republic of Vietnam to expand its wood-using industry, it would be a mistake to think that any real competitive advantage exists. True, Vietnam has sizable but unknown amounts of timber resources which can be exploited to a much greater extent than at present. However, on a per-capita basis Vietnam is not in a favoured position compared with many nations of the world and Southeast Asia."

*Ralston, R.A. and Tho, D.C., 1970. The forest sector of the economy of the Republic of Vietnam. Mimeographed Report of the U.S.A.I.D. Mission.

3.6.4.4 Research

After the French retreat, research at the four field stations and laboratories continued at a low level because no capable substitutes were directly at hand, and because of lack of money. Data are only available about the trial station of Lang Hanh. Research was done on the following topics: *Pinus merkusii*: ecology, natural regeneration; *P. kesiya* (above 900 m): soil type; and for both spp.: plant material, spacing, planting in *Imperata* fields, time of planting, and size of planting hole.
A large number of exotics had been introduced and tested (table IV 15); best results with exotic Conifers were obtained from *Pinus caribaea, P. radiata,* and *P. patula*.

3.6.4.5 Plantation establishment

This was started in the twenties. Literature before 1954 deals with the whole of Vietnam. After 1975 the country was united again so plantations in both North and South Vietnam are dealt with in this chapter.
From 1930-1941 13,700 ha were planted in Vietnam, mainly with *Casuarina equisetifolia* ("Filao") which was often used for dune stabilization. Planted at 1000-1400 per ha and in rotations of 10-30 years these species proved sucessful.
About 4000 ha of *Pinus merkusii* at 2000 plants per ha were planted in the thirties for terpentine production.
Other species planted in Tonkin on bare land were: *Pinus sinensis, Cunninghamia sinensis, Liquidambar formosiana, Bischofia javanica, Erythrophleum fordii, Spondias tonkinensis, Talama qioi, Cassia siamea, Manglietia glauca, M. fordiana, Chukrassia tabularis, Eucalyptus spp.* The Montagnards sometimes planted *Melia spp* and *Styrax tonkinensis* before abandoning their fields. In Annam bare slopes were planted with: *Bassia pasquieri, Vatica tonkinensis, Sindora tonkinensis, Aglaia gigantea, Melia spp., Pahudia cochinchinensis, Dalbergia cochinchinensis, Pinus kesiya.*
Regeneration activities were also executed on forested sites, mainly depleted forests. The methods used were complete planting, enrichment planting, or natural regeneration. Successful species in complete planting in Cochinchina were: *Hopea odorata, H. dealbata, Dipterocarpus alatus, Tectona grandis, Dalbergia cochinchinensis.*
Successful planting was carried out with endemic species. A method established at the trial station of Trang-Bôm (former Cambodia) proved successful and was also applied in Cochin China: after clearing and burning, planting was done in alternating rows of an auxiliary species (*Cassia siamea* at a 8-10 years-rotation) and a main species (table IV 15). Between the rows at a distance of 2 m, a leguminous crop (*Indigofera teysmannii*) was planted as a cover and soil improver.
Natural regeneration proved less successful, and enrichment was not found attractive at that time (1940). After 1940 large-scale planting was carried out infrequently. Only in the last years of the war trees were planted on an extensive scale; up to 1200 ha in 1972 and 6000 ha in 1973.
During the war the program "Trees for the People" existed whereby civilians planted trees on an extensive scale. The planting material for reforestation was provided by about 100 small nurseries scattered throughout the country.
Tectona grandis was mainly planted on good soils as stumps but good soil was scarce and the same land was also needed for the resettlement of refugees.
Pinus spp. were planted in their natural habitat. Since natural regeneration is often destroyed by fires, planting was done with large planting material in relatively large plastic bags. *Casuarina equisetifolia* was planted as striplings for dune fixation.
Eucalypts were planted as striplings on bare hill-land below 800 m. In North Vietnam about 60,000 ha were planted from 1940-1972 with both indigenous species and exotic *Pinus spp.* and *Eucalyptus spp.* (WESTING, 1974).

SWANSON (1975) estimates that in South Vietnam about 2 million ha can be considered for planting at this moment (table IV 16).

V LAND USE PLANNING IN DEVASTATED INLAND FOREST AREA

V.1 INTRODUCTION

The need for restoration of the devastated inland forests of Vietnam is recognized. Thus, decisions on land use have to be taken, preferably " in such a way that the resources of the environment are put to the most beneficial use for man, whilst at the same time conserving those resources for the future." (FAO, 1976).
An important part of land use planning is formed by land evaluation. This is defined as follows (FAO, 1976): The process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation.
Schematically the activities in land evaluation are presented in fig. V 1.
From this it can be seen that to connect land use with land, one needs to know the kinds of land use and the land mapping units. The major types of land use for the area concerned are:

1. wet rice cultivation systems;
2. permanent cultivation on rainfed land;
3. grassland systems;
4. perennial cropping systems;
5. shifting cultivation;
6. agrisilviculture;
7. silviculture;
8. protection forest;
9. national parks and reserves.

These types are not described here, but some aspects are dealt with in other sections.
Physical resource surveys will be required to distinguish the landmapping units. These surveys frequently include soil- or land form surveys, ecological surveys, forest inventories, hydrological surveys, road-engineering surveys, etc.
Special attention must be given to war damage. For full details on land evaluation see FAO (1976) and BEEK (1978).

Evaluation must take into consideration the economics of the proposals, the social consequences for the people, and the consequences for the environment. Dynamic aspects of the major kinds of land use are to be considered, viz. changes in the use of land and changes in the land itself. Particularly socio-economic factors are more or less dynamic (e.g. population density, level of know-how, infrastructure, possibilities of investment, productivity), but also physical factors such as irrigation, drainage and soil fertility may change.
Some factors and their relative importance for the listed types of land use are shown in tables V 1 and V 2. It should be born in mind that these tables should purely be seen as a mutual arrangement and weighing of the various criteria for the different kinds of use.

V.2 PLANNING

The objective of this report is to study forestry and only takes agriculture into consideration, when this occurs in combination with forestry.
The local situation in the devastated inland forest areas is described in chapters III and IV. Some relevant data are the following: the areas considered generally are sparsely populated: several Montagnard tribes are found here who practice shifting cultivation.

The vegetation consists of more or less depleted forests on gently undulating to hilly or mountaineous sites.
Permanent agriculture is found in the valleys and near cities.
Perennial crops are grown on relatively fertile soils. During war, which occurred for a great part in the forests, many people left their homes in the forests, while concentration took place in so-called "strategic hamlets". This resulted in a intensifying of shifting cultivation round these hamlets. The forest environment was strongly disrupted by war activities. After 1975 some recovery took place. No clear view about the conomic, soial, and political situation after 1975 could be obtained. Information from several sources indicates that especially in the cities unemployment was high. The government tried to fight this by resettlement in the countryside, and the creation of productive employment there with labour-intensive work. High priority was given to the production of import substitutes and exportable goods.
Policy considerations play an important part in decisions about the designation of inland forest areas: products can be obtained from it, employment is possible, but also national interests like erosion control or conservation arise.
In section VI 5 types of devastated land are broadly identified and the assessment and comparison of a range of kinds of use is made. Recommendations on the kind of land use for each distinct type of damage are made.

VI. RESTORATION OF INLAND FOREST AREAS IN SOUTH VIETNAM

VI.1 FOREST FUNCTIONS

1.1 Introduction

The purposes to be fulfilled by a forest are multiple.
Its many functions often cannot be separated and may be realized at the same time and/or at the same place. Shifts in their relative importance may occur at any moment.
To a certain extent, the forest is a renewable resource. It can, however, only continue to fulfill its functions if it is managed in a durable way. This was, and still is, not always recognized by man: man has caused and still causes a large reduction of the total forested area in a direct or indirect way.
Extensive areas have been deforested for food production and for forest products. It is the responsibility of forestry to judiciously regulate forest use, and to pursue first of all forest conservation and the insurance of an optimum profitability.

Proper forest management not only considers the needs and demands of the moment, but also deals with their evolution in the future. Therefore it is advisable to keep sufficient functional possibilities in reserve in order to be able to react adequately when demands and opinions change.
A forest policy cannot stand on its own but must be an integral part of the development policy of a country.
Its various functions can be reduced to three broad groups:

a) the ecological functions;
b) the economic functions;
c) the social functions.

The ecological function consists of protection (such as regulation of water and soil conservation) since forests have a mitigating effect on climate (see IV-3.1). Furthermore, the forest - particularly the tropical rainforest - lodges an abundance of ecosystems which are unique from ecological and scientific points of view, and which must be conserved.
Forests are also important as a gene reservoir and a source of economically useful plants (and animals).
The primary economic function of a forest is the production of wood to be used for a multitude of purposes (sawn wood, veneer, pulp and paper, fuelwood, destillates, etc.). In addition, many other products are extracted from the forest like resins, turpentines, fruits, seeds, bamboo, rattans, pharmaceutic products, animal products etc.
Finally, by its physical presence forests influence the human environment. In many countries, particularly in developing countries, people live in forest areas and they are directly dependent on it.
People in industrialized countries appreciate it for the possibility of recreation, the rest inspired by forest, and the agreeable appearance of forests as an element of the whole landscape.
In addition, the forest is a source of knowledge, particularly the tropical rainforest, with its large number of ecosystems. Knowledge and understanding together with education can improve the human attitude towards nature.
The various possible functions of a forest cannot all be maximally fulfilled at the same time. For instance, maximalization of wood production will in many forests result in a reduction of the natural wealth and/or increasing erosion hazard. It can, however, be tried by means of certain silvicultural management practices to make the forest fulfill as many functions as possible (multiple use).
The priority of the various functions in a country and in a certain region will depend on both economic and ecological factors.
The various functions may be fulfilled (or improved) by the existing forest (with or without treatments) or by future forests.

1.2 The Vietnamese situation

Originally Vietnam was a country covered with forests. Only in the fertile deltas and river plains the forests were replaced by permanent agriculture. The forests provided the farmers with an important quantity of building materials, energy, food, medicines and other essentials. During the last centuries of technical progress, the relative importance of forests for people decreased, but improved techniques allowed important elements of the forest to be utilized better.

After the French arrived at the end of the 19th century, only a few people (with the exception of the Montagnards) were directly dependent on the forest. Its main function at that time was an economic one - the supply of wood and other products.

Of course the ecological function of the forest was very important too, but this was less obvious and was not observed.

With the increase of human population, the forested areas decreased. The wars of the last 30 years have, of course, had a strong impact on the forests (see chapter III and IV). Locally the forest was badly damaged and the social, economic and ecological functions could no longer be fully accomplished. Therefore, the relative value of those functions has increased.

No concrete data are known about the present situation. The economic functions of the Vietnamese forests are principally: the supply of timber of large sizes, fuelwood, minor forest products, and other products needed for the reconstruction of the country. Forests on better soils will be replaced by a more intensive form of land use which might, for instance, be a plantation of fast-growing trees.

Whether the forests can meet the demands of the people of South Vietnam is not known but in the past, production was probably sufficient to meet the demands (except for pulp and paper). Export of products practically did not occur. The great need for foreign currency might partially be covered by more intensive silvicultural systems, particularly those aimed at more valuable products, such as veneer and sawnwood.

The protection function is considered to be very important. Erosion and all its consequences has become a common feature in South Vietnam. Mechanical land clearing, injudicious felling, and shifting cultivation are the major causes. Great economic losses have resulted from it, but this can be diminished by carrying out re-afforestation projects.

The conservation of a large number and diversity of ecosystems, plant and animal species is an urgent matter in Vietnam (although it might already be too late for some). A number of reserves are known, but they probably suffered from war activity.

Recreative aspects have until now only a little importance around population centres. However, they are likely to become important in the future. Therefore it seems wise at this time to pay attention to these aspects.

VI.2 NATURAL REGENERATION

2.1 Introduction

The tropical rainforest is a complex community; upon and within the framework of trees a range of other plants grows and a large range of animals lives. If part of the forest is destroyed, plants (and attendant animals) recolonize the gap by competing with each other; there is a secondary succession and eventually a community similar to the original is restored (the climax). However, upon repeated interference, restoration becomes difficult or impossible (see also III 3.3).

Distinction has to be made between the process of natural regeneration (spontaneous regeneration) and the silvicultural system of natural regeneration. The first takes place within the dynamic equilibrium of the forest; to avoid disturbances other than natural events, it is necessary to protect the forest area in nature reserves, or strict protection forests. Sometimes a directed exploitation can take place, after which the forest is left without any silvicultural treatment.

The natural regeneration silvicultural system means a range of silvicultural treatments aimed at the displacement of useless and old individual trees in the forest by young merchantable trees. The future stand is formed from dormant regeneration present in the forest, regeneration developed as a result of exploitation or induced regeneration.
Once regeneration is established, periodic silvicultural treatments are required to ensure a maximum rate of growth of the desirable stems. As much as possible use is made of the natural regeneration process.
As soon as planting stock or seed are introduced by man, one speaks of artificial regeneration; if it is done within the forest it is called enrichment (VI.3).
Selective logging has led, and in many countries still leads, to the depletion of merchantable species in certain forest areas; however, no proper management of the rainforest took place. The first attempt to come to a lasting management of the rainforest dates from early 1900 and was made in India and Malaya. The natural regeneration systems developed there have strongly influenced those developed later elsewhere.
As the forests of South Vietnam show some relationship with those of Malaya, the Malayan Uniform System (M.U.S.) will be dealt with in more detail than other existing systems. It should, however, merely be seen as an example of a natural regeneration system which allows better understanding of the function of such a system. It cannot be applied as such in South Vietnam. The large number of factors on which it depends are dealt with in Chapter VI.5.

2.2 Structure of the natural rainforest

Generally the natural rainforest is multistoreyed, often with three or more strata (although sometimes they are not easily distinguished).
The height of the upper stratum varies considerably, but usually does not exceed 60 m.
The rainforest characteristically includes a great wealth of tree species. Sometimes more than 100 species over 25 cm diameter per hectare are found. To give some idea of physiognomy, figures VI.1 and VI.2 show profiles of two forest types in Malaya.
In table VI 1 the number of stems and the basal area per hectare of both forest types are presented, divided into merchantable and non-merchantable spp. The two forest types shown are the "Red Meranti-Keruing" type (a type within the "Lowland Dipterocarp Forest") and the "Seraya-(ridge)" type (a type within the "Hill Diptero carp Forest" of Malaya). Physiognomically -and to a less extent floristically- the first type has some relationship to the moist evergreen forest of South Vietnam; a short description is presented below.
The Lowland Dipterocarp Forest (SYMINGTON, 1943) includes all dry land forests below 300 m, except those on extremely poor soils. The "Hill Dipterocarp Forest" occurs mainly on hills and on isolated mountains between 300 and 750 m. In terms of economics and quantity these two types are the principle vegetation types in Malaya.
Their outstanding feature is the dominance of dipterocarps in most of them, which has a high commercial importance.
In the "Red Meranti-Keruing" type the upper stratum is commonly characterized by a high occurrence (about 50%) of dipterocarps, mainly *Dipterocarpus spp.* and *Shorea spp.* Other valuable species are *Dyera costulata, Gluta spp., Intsia spp., Koompassia sp.,* and *Palaquium spp.* The B-stratum consists of younger trees of the normally upper stratum species, together with members of the families *Burseraceae, Guttiferae, Myristicaceae, Sapotaceae, Myrtaceae*, and others. The C-stratum consists of saplings of the A- and B-stratum, mainly together with members of such families as *Annonaceae, Euphorbiaceae, Rubiaceae, Palmae* and others.
The herb layer consists largely of seedlings of the other layers. Epiphytes are usually poorly represented.
Aspect and site are important factors in the physiognomy of the "Hill Dipterocarp Forest".

The "Seraya-ridge" type is found on ridge tops and is one of the most economically rich forest types in Malaya. The types on hill slopes and valley bottoms are far less important.
The A-stratum is characterized by *Shorea curtisii* which is semi-gregarious; other common valuable species are *Anisoptera curtisii*, *A. laevis*, *Hopea beccariana*, *Heritiera javanica*, and *Tarrietia javanica*. Middle-sized trees and saplings are often poorly represented. The number of trees of higher diameter classes is usually larger than in the "Red Meranti Keruing" type forest; lower diameter classes are poorly represented.
The stemless bertam palm (*Eugeissona triste*) freqently forms a dense thicket 5 to 6 m tall. Ground flora is frequently absent due to the dense shade caused by the bertam palm.

2.3 Important processes with natural regeneration

2.3.1 Flowering and fruiting

In the tropical rainforest some trees are flowering and fruiting all the time, but most species bear flowers and fruits only periodically. Of the continuously flowering species, not all mature individuals are flowering during the whole year; each individual usually has a period without flowering.
Of the species which flower and fruit periodically, many do so annually, some do so a few times per year, and others once every few years. For example, many Dipterocarps fruit heavily every 2-5 years. Periodic flowering is more pronounced in climates with a marked seasonal variation. (Often periods of drought are followed by flowering.) Generally this recurrence is more pronounced for trees of the upper strata than for plants of the C- and lower strata.
Periodic flowering results in sporadic seed supply. However, flowering does not necessarily mean that abundant seedlings are formed; lack of, or incomplete pollination or destruction of seeds can occur (see WHITMORE, 1975).

2.3.2 Seed dispersal

This can be done by many agents. Dispersal by wind and animals are the two principal methods within the tropical rainforest. WHITMORE (1975) states that there is evidence that among rainforest trees, animal dispersal is more effective than wind dispersal (see WHITMORE, 1975 for more details.)
Below each tree which produces heavy seeds, a strong concentration of seedlings can be observed. This holds for e.g. *Anisoptera oblonga* and *Dipterocarpus costatus* in the Khmer Republic (ANON., 1970).

2.3.3 Germination

This usually commences at once or within a few days after dispersal. Germination capacity is usually high, but most seeds quickly loose their viability; for example, this occurs within 3 weeks for many Dipterocarps. Some species show staggered germination over a period of several months.
Some tropical tree seeds have a dormant period before they germinate (e.g. many *Leguminosae*). Others need a special pretreatment (e.g. passage through the stomach of an animal) to hasten germination. Seeds of some species germinate as soon as environmental conditions of a site have been altered by disturbance.
The lack of dormancy of seeds of many rainforest trees has serious implications for silviculture, especially for species which fruit infrequently. Large numbers of seedlings are intermittently present on the forest floor, but natural regeneration depends on the survival of the seedlings at the moment of silvicultural treatment, or the forming of a gap by natural events.

2.3.4 Seedling establishment

When germinating, the food reserves in a seedling are used in a short time; initial establishment is quick. Thereafter growth is much slower. The seedling depends for development on the amount of light, root competition, risk of damage, and other factors.
Within the forest the number of seedlings differs largely from one place to another; this depends, among other things, on the period of time since the last flowering. The natural regeneration of some species shows a clear tendency towards sociability. In Sabah an average of 25,000 seedlings/ha of valuable species is recorded (with a minimum of 10,000 seedlings/ha.) The majority was of the family of Dipterocarpaceae (FOX, 1968). These amounts are rather high compared with other parts of the region.
Despite very low light intensities at the forest floor, a large number of seedlings of undergrowth species, and a fair number of the seedlings of canopy trees, are able to persist for a considerable time. However, their growth is nearly nil.

2.3.5 Establishment of seedlings

In spite of a high mortality rate and growth stagnation in the somewhat closed forest, a number of individuals succeed in reaching the shrub stratum or the lower tree stratum. This can occur through the gradual death of species in the lower strata, or by other causes resulting in a gradual improvement of light conditions. Based on differences in development behaviour, BAUR (1964) distinguishes three groups of species. First there is the group of "truly tolerant species". These are slow-growing, very shade-tolerant species establishing themselves and growing under high forest, finally reaching the upper strata with some benefit from eventual gaps.
The second group are the so-called "gap-opportunists". Seedlings of these species are fairly persistent and able to survive, without developing, under high forest. As soon as the canopy is opened they immediately respond. For example *Shorea spp.* has been known to persist up to 10 years.
The third group of species, the pioneer species, establish themselves mainly or entirely in full light and require full light for growth. Generally these are short-lived species with extremely fast growth in the first years (e.g. *Trema spp.* and *Macaranga spp.*).
The composition of gaps will vary to some extent with their initial size. According to WHITMORE (1975) gaps up to 0.1 ha result in good growth of valuable species. In gaps of 0.2-0.3 ha this regeneration was overgrown by secondary species. In addition to tree species there are also climbers, shrubs, herbs and other undesirable species favoured by improved light conditions. Usually, increased light results in rapid growth of persistent seedlings of which extremely light-demanding species (pioneer species) usually are the fastest growing. Only a proportion of the persistent seedlings survive and they tend to dominate the disturbed area as the short-lived species die. *Shorea leprosula*, for example, is able to keep up in growth with secondary species.
The "gapwise" regeneration of the rainforest results in a mosaic of more or less even-aged groups of trees in different phases of growth.
The natural regeneration system attempts to match the regeneration occurring within the rainforest. It should, however, be noted that the occurrence of certain mature species in the upper strata is no guarantee for effective regeneration within the forest.

2.4 Silvicultural treatment in the tropical rainforest

2.4.1 General

The treatment can aim at improvement by favouring valuable stocking and bettering age structure. This includes cutting all climbers and rattans,and poison

girdling all useless trees above a certain diameter (e.g. 50 cm d.b.h.) and poorly-formed valuable individuals.
This treatment is, among others, advised for areas where exploitation for the present is unlikely (remote areas, economically unexploitable). Exploitation twenty or more years after treatment will give higher results than if no treatment had taken place, and at the same time a better starting-point for subsequent treatments is created. An example of this can be found in the system employed in the former Belgian Congo (Zaîre): "Uniformisation par le haut". This has also been applied locally in Malaysia.

Regeneration establishment is aimed at inducing and then assisting natural regeneration by carrying out a particular management scheme. Regeneration establishment in most cases includes improvement, while improvement also can be carried out without regeneration establishment.

2.4.2 The treatments

Each natural regeneration system consists of a number of silvicultural treatments. The sequence in which, and the point of time at which the various treatments are carried out (and the nature of the treatments) differ from one system to another. Every system is bound to specific conditions (vegetation type, soil, climate, etc.). The most common treatments are discussed below:

a) Soil treatment
Germination can be hindered by a hard, dry soil at the end of the dry season, or by a litter layer.
Soil treatment aims at improvement of the germination conditions for seedlings.
Removal of litter eventually combined with tillage of the soil proved advantageous for germination in Australia and India.
In Venezuela heaping and burning of organic material improved the establishment of *Bombacopsis quinata*, an old-secondary species. A dry season is essential for burning; fire in the rainforest is rather exceptional.

b) Canopy opening
This method attempts to encourage growth of desired species by improving light conditions in the lower strata. It should be done with care; too strong and too sudden admittance of light will enable weed growth to capture the area, and too little light will limit the growth of desired species.
BAUR (1964) distinguishes the following phases of treatment:
- Climber cutting (CC)
- Understorey removal (R): cutting and poisoning of useless trees with heavy crowns in the lower strata. Usually only carried out where regeneration is difficult to induce.
- Felling (F): felling and extraction of merchantable trees above a certain minimum diameter.
- Overstorey removal (Ro): poisoning of useless trees and badly-formed or overmature valuable trees in the upper strata. Elimination of this sort is sometimes also referred to as refinement. Some degree of refining, according to BAUR (1964) includes canopy opening, cleaning, and liberation operations.

c) Undergrowth clearing (C)
This is mainly carried out in forests with a dense undergrowth of shrubs, palms, or bamboos. Its purpose is to promote seedlings on the soil or release dormant seedlings.

d) Liberation (L)
Once regeneration has become well-established (2 to 3 years after canopy opening), it is desirable to make stems free from impedance by unwanted species; thus, the rate of increment of desirable stems will be increased.

e) Thinning (T)
This is done when the useful stocking of a stand is about closed. The best formed and most desirable species are encouraged in their development by

periodic thinning. The time of thinning greatly depends on stocking and the rate of growth of the useful stems.

f) Diagnostic sampling
This is not truly a silvicultural operation but it is discussed here because it plays a very important role in rainforest silviculture. By sampling, data about composition, development, and competing position of the regenerating stock are recorded. This information is used to determine the best type of treatment to be given to the forest.

g) Enrichment planting/sowing (P)
Sometimes this is seen as a part of a natural regeneration system where it is used to enrich forest areas which have insufficient valuable stems (see VI.3.4.2).

2.5 Monocyclic and polycyclic systems

2.5.1 Introduction

BAUR (1964) distinghuishes (although in practice not always correctly) regeneration establishment aimed at obtaining a more or less even-aged stand (monocyclic systems) and regeneration establishment aimed at an uneven-aged stand (polycyclic system). In monocyclic systems all merchantable timber above a certain diameter is removed in a single operation. The felling cycle equals about the rotation age of useful trees.

Advantages of a monocyclic system are:

- obvious economic advantages in having few, but heavy and concentrated logging operations;
- felling damage during a single operation is less than that caused by several exploitations made relatively shortly after each other;
- management of even-aged stands is easier; this is important in areas with a shortage of labour; and
- better establishment of desirable rainforest species which tend to be the light-demanding.

With polycyclic systems exploitation is done in periodic partial harvesting. The felling cycle is shorter than the rotation age of the valuable trees.

Advantages of a polycyclic system are:

- more justice is done, although imperfectly, to the original structure of the forest.
- the continuous protection of the soil against erosion;
- less risk of devastation by cyclones;
- aesthetically more attractive;
- better protection against pests and diseases; and
- smaller-sized stems (and any healthy, larger stems of currently useless but potentially merchantable species) are left to grow until a later felling cycle and only mature and over-mature trees are removed by logging. Any healthy larger stems of currently useless species can be left so that eventual improvements by technological processes can make them merchantable, thus increasing the yield/ha.

2.5.2 Monocyclic systems

2.5.2.1 General

The following systems are noted here:

1) Malayan Uniform System (M.U.S.)
2) The Tropical Shelterwood System (T.S.S.) in Trinidad
3) The Tropical Shelterwood System (T.S.S.) in Nigeria
4) The Extended Shelterwood (E.S.) in the Andamans.

In Table VI.2, time tables for treatment sequences for some systems are presented. In the last three systems the formation of a shelterwood some years before or

during exploitation is considered to be essential.
The objective of a shelterwood is to induce regeneration and/or to avoid weed competition during the first years; furthermore, a shelterwood prevents soil degradation.
In Nigeria, a shelterwood is formed five years before exploitation. Shortly after exploitation it is removed. In Trinidad a shelterwood is formed during exploitation. It is removed five years later. In the Andamans it is formed respectively 2-5 years before exploitation, preferably during a seed year, and three years after exploitation.
In the following discussions, the M.U.S. will be dealt with in more detail (see VI 2.1).

2.5.2.2 Early experiences with natural regeneration in Malaya from 1910 to present.

Essentially the early experiments were improvement operations designed to favour the development of some valuable species. About 1922 the Regeneration Improvement Felling System (R.I.F.) was introduced based on these early operations. Commercial logging was extended to larger areas. Work was carried out according to the Departmental Regeneration Operations and Commercial Regeneration Operations. The difference between these two methods was that operations under the first system were carried out when there was no market for pole and fuelwood. Inferior species were poison-girdled by a 5% sodium arsenite solution; this resulted in the slow death of trees and a gradual canopy opening.
The latter system included cutting of pole and fuelwood before the final felling. Afterwards, depending on the presence of desirable regeneration, one or two so-called seeding fellings were carried out; this included removal of all useless trees over a certain diameter to improve establishment conditions for desirable regeneration.

After World War II the above-described methods were abandoned. Heavy hardwoods (at which the methods were directed) became economically less attractive; instead, fast-growing light hardwoods became the main objective.
During the war and afterwards, up to 1953, silvicultural operations came to a complete halt. Large areas were completely cleared for farms, and there was frequent illegal felling.
After 1953 it was observed that seedlings of *Dipterocarpus spp.*, *Dryobalanops aromatica*, and especially the light-red Merantis *(Shorea spp.)* were capable of good growth in full light conditions, and were able to compete successfully with secondary growth. This meant that the number of clearings could be drastically reduced. Moreover, too much clearing had been advantageous for climbers and secondary species. It also became clear that opening the canopy before felling was not necessary since sufficient natural regeneration was already present.
These observations resulted in the Malayan Uniform System; treatments were only carried out in areas with inadequate seedling stocking. Here canopy opening was done 3-7 years before exploitation, usually during a seed year.
For more detailed information on natural regeneration in Malaya see WYATT-SMITH (1963).

2.5.2.3 The M.U.S. treatments

Year n-5: Understorey removal
In areas where regeneration is difficult to induce, useless trees with heavy crowns in the understorey are poisoned in order to increase the stocking of desirable regeneration.
Year n-3: Undergrowth clearing
Areas with dense *Eugeissona triste* growth and heavy bamboo growth are treated by clearing the undergrowth.

Year n-2: Climber cutting
Trees are sometimes held together by climbers and they can cause considerable damage during logging, especially to desirable trees below felling diameter. Thus poisoning of climbers and ratans is mainly employed in forest types with many valuable stems in small- and medium-diameter classes.

Year n to n-1½: Diagnostic sampling
One of the two samplings is an enumeration of the exploitable trees over 47.5 cm d.b.h. (E.N.).
The other is an assesssment of regeneration under 150 cm in height using a 2% sample. This is called a linear regeneration sampling milliacre (L.S.M.) and it is one of the systematic linear sampling (L.S.) surveys. (These surveys are treated in more detail in Appendix VI A).
The L.S.M. is designed to obtain an impression of whether there are favourable prospects for natural regeneration.
If 40% of the plots (1000 plots/ha) contain desirable seedlings, or 30-40% contain at least 20% of class B or C seedlings, it is considered adquate for the M.U.S. When stocking is lower, felling is delayed if it is clear from E.N. that sufficient seed trees are present.
In practice, however, it is usually impossible to wait for a seed year of the Dipterocarps. Exploitation is often carried out anyway and enrichment planting is employed on poorly-stocked plots.
In table VI 3, the results of a L.S.M. survey in hill Dipterocarp forest are depicted. Other L.S. surveys are used to determine what types of operations are required at what time.

Year n: Exploitation
All trees to be felled are marked by the forestry staff. The minimum felling diameter is 42.5 cm d.b.h. in the more accessible areas; but 57.7 cm d.b.h. is allowed in less accessible areas. If unnecessary damage is done to the remaining stand, the contractor is fined. This damage can be considerable, as is shown in a study by WYATT-SMITH and FOENANDER (1962) in the Kapur forest type of the Lowland Dipterocarp forest. After exploitation, 39% of the area was covered by tracks, tree crowns, etc.; 37% of all species and 33% of all classified species were destroyed. The highest losses occurred in the 3 m high to 5 cm d.b.h. size class, where 56% of all classified species were destroyed. On the average 107 classified species between 10 and 57.5 cm d.b.h. per ha remained.
From table VI 4, it can be seen that logging of 19% of the basal area resulted in destruction of another 13% (which is quite low).
In mountainous areas exploitation damage is a much bigger problem. In Hill Dipterocarp Forest, 55% of the basal area was destroyed during exploitation of only 10% of the basal area (BURGESS, 1971).
At the tops of hills the stocking of desirable species remains adequate; however, on the slopes (which are already poorly in desirable stems) hardly any valuable residue remains after logging. According to BURGESS (1970) the degree of destruction of species varies between 20 and 80%; it increases with increasing slope gradient. Drying out of the soil and erosion may augment the damage. Therefore, the M.U.S. has been modified for Hill Dipterocarp Forest; also treatments given to top and hill slope are different (see 2.5.2.4).

Year n: Overstorey removal
Directly after logging, but at the latest one year afterwards, all useless stems in the upper strata and all climbers are poisoned to improve light conditions and thus favour desirable stems. Trees to be poisoned are cut through to the sapwood; this is done all around the stem, so that no horizontal displacement of the poison through the bark takes place. Sodium arsenite is applied into the frill from a fine-spouted, splash-proof can. The use of 2% 2.4.5-T solution in diesel oil is expensive, but this agent is less poisonous to man; it also gives better results, compared with Na-arsenite, on *Ficus spp.* and other species which contain latex. After girdling, the forest is not entered for one or two years because of the hazard created by large dead trees. Good timing of this treatment is very important. This is closely connected with the rate of mortality of the poisoned

trees which is reported to be 90% after one year in Malaya (WYATT-SMITH, 1963). If, for instance, the seedlings are exposed to full light in the dry season, severe damage to regeneration may be done by desiccation of the topsoil; this reportedly took place in Cambodia (ANON., 1970).
One or two years after canopy opening, thicket-like conditions are created. Regeneration consists of secondary species with many climbers, and also includes desirable species. Of the latter, especially the light-red Merantis *(Shorea spp.)* species is capable of competing with and finally outdistancing the secondary growth to establish itself well.

Seedlings of *Dipterocarpus spp.*, and particularly those of *Dryobalanops aromatica* do not like sudden exposure to full light because they are easily sun-scorched. Moreover, in some areas heavy infestion of a fern called *Gleichenia linearis* smothers the seedlings. Delayed girdling and a higher minimum girdling diameter have been used to avoid these events.
Since it is desirable to destroy relics as soon as possible, girdling down to 15 cm d.b.h. after exploitation is recommended (although the former method appears preferable).
Shorea curtisii, occurring in the Seraya-Ridge type is similarly unable to respond rapidly to complete canopy opening; again, raising the minimum diameter for poisoning from 5 to 15 cm is recommended.
For the Red Meranti Keruing type a minimum poisoning diamter of 5 cm is used.
In table IV 4, the effect of exploitation and poisoning on number of stems and basal area per ha is for the Kapur type given. For profile diagrams illustrating these effects, see BAUR (1964).

Other treatments after exploitation

After poisoning no treatments are carried out for about 5 years. Then a quarter chain sampling of regeneration (L.S. 1/4) is carried out. The principle of this sampling is similar to that of the L.S.M. (see Appendix VI A). The L.S. 1/4 is not of vital importance and is only carried out if regeneration is suspected to be abnormal (e.g. if no poisoning during or shortly after exploitation has taken place). The information obtained is used to determine whether climber cutting, liberation, enrichment planting, undergrowth clearing and/or eventual thinning have to be performed.
Unwanted, heavily-competing species in the canopy, and species which have survived poisoning, can be poisoned again during eventual treatments.
Roughly 10 years after exploitation the half chain square sampling (L.S.½) must be carried out. This sampling can lead to the treatments as mentioned under L.S. 1/4. The principle is the same as L.S.M. (see Appendix VI A).
Roughly 20 years after exploitation the linear sampling in regenerated forest, the L.S.R., is carried out (see Appendix VI A).
This sampling can lead to thinning of the "chosen" and possible "secondary trees", in addition unwanted growth can be poisoned.
Usually this L.S.R. is repeated after 35 and 55 years. Depending on the development of the number of stems and basal area in various diameter classes, thinning may be more or less intensive. Attention is paid to position and form of the crowns, and even to the occurrence of contact between the crowns. Early heavy thinning is dissuaded for the Red Meranti Keruing type. After a light thinning the *Shorea* spp. found in this type were usually of better form and they were able to maintain a high annual increment forming a promising, well-stocked final crop. Generally it is difficult to give the optimum number of trees per ha at a certain age. For *Shorea leprosula* some data are given by WYATT-SMITH (1963, after NOAKES*, 1937).
At 48 years, optimum stocking is 24 stems over 60 cm d.b.h. per ha; at 60 years 45 stems over 72 cm d.b.h. with a basal area of 18.2 m^2/ha is best. A crop of about 75 trees over 60 cm d.b.h./ha is expected at about 70 years.

For a number of natural regeneration systems the expected yield from the original forest and the expected annual increment with total yields from the treated stands is given in table VI 5.

*Noakes, D.S.P. (1937). A yield tabel for meranti. Malayan Forester VI: p. 204-208.

The above-described treatments concern medium and light hardwoods. A special problem arises with the regeneration of heavy hardwoods. If these are the goal of production, the L.S. 1/4 and L.S. 1/2 are not carried out. After poisoning, the seedlings are overgrown by secondary growth and faster-growing valuable species. Liberation every 2 or 3 years is necessary until the tenth year; this is, however, very expensive.
WYATT-SMITH (1963) advises the retention of a light shelterwood on areas with heavy hardwood regeneration. Growth will be slower, but tree form will improve and weed growth will be suppressed to some extent.
After removal of the shelterwood the species are able to develop satisfactory.

2.5.2.4 The M.U.S. in the hill Dipterocarp forest

As was mentioned previously, the M.U.S. has been modified for this type. At least one, but preferably three years before exploitation the E.N. and L.S.M. are carried out and the occurrence of *Eugeissona triste* and bamboo is noted. Under these two types of growth relatively dry conditions are found on the forest floor. The establishment of Dipterocarps here, especially of *Shorea curtisii*, is hardly possible because their seeds will only germinate under moist conditions. Also the competing power of the valuable species is usually insufficient, if more light is admitted.
Control of *Eugeissona triste* and bamboo species is expensive and not always successful. If insufficient stocking is present, is must seriously be considered, whether a treatment is appropriate. The part that A and B class regeneration is in the total stocking, and the presence of seed trees of A and B class regeneration should be taken into account. When stocking is poor and few seed trees are present, enrichment planting can be employed or even complete planting after clear cutting. Fast-growing light hardwoods are preferred here. If sufficient seed trees are present, bamboo species and *Eugeissona triste* are poisoned and exploitation is carried out as soon as a seed year occurs. If there is a sales potential for bamboos, however, these can be exploited instead of being poisoned.
At the top of the hill all useless species are poisoned two years after exploitation of valuable stems over 50 cm d.b.h. Seven years after exploitation the L.S. ½ is carried out, after which all useless species over 10 cm d.b.h. are poisoned. Enrichment planting is prescribed if the L.S. ½ stocking is inadequate; with adquate stocking the regeneration phase is considered to be completed. On the slopes (directly after exploitation) all useless species over 10 cm d.b.h. are poisoned. Five years after exploitation the L.S.½ is carried out provided a good seed year of valuable Dipterocarps has occurred (if not, the sampling is delayed). Depending on the degree of stocking, enrichment may be prescribed.

Because of great felling damages, the L.S.½ in fact provides more important information than the L.S.M. Felling damage can be reduced by poisoning of climbers before exploitation, indicating the felling direction, and raising the minimum felling diameter to 60 cm d.b.h.
If sufficient valuable stems in small and medium diameter classes remain without damage, an intermediate felling can be carried out after 40 years.
Wildlings are often used for enrichment planting. Many Red Merantis, *Anisoptera laevis*, *Dyera costulata*, and *Agathis loranthifolia* are suited to this. Generally speaking, natural regeneration is possible at hill tops, but for hill slope enrichment is prescribed (while at valley bottoms complete planting often is the sole solution).

2.5.3 Polycyclic systems

2.5.3.1 General

These systems are based on the classical "selection" or "groups selection system". In Europe it is known as "selection forest" or "plenterwald". It is particularly employed in mountainous regions, where forests have an important soil conserving and water regulating function. Three important polycyclic systems will be briefly discussed below.

2.5.3.2 The Puerto Rican Improvement Cutting/Selection System

This is carried out in the Luquillo Mountains of Puerto Rico. The vegetation is classified as submontane rainforest (BAUR, 1964 after WADSWORTH[x], 1951). This forest occurs at about 100 to 600 m above sea level. Early cuttings were directed without clear management. Treatments started in 1943; at that time good market conditions for timber existed as well as for less valuable species and smaller sized ones.
It appeared that the valuable species showed good regeneration under permanent shade, suggesting the use of a shelterwood or selection system. The latter was preferred because of:
- the importance of good watershed protection
- the system is more wind resistent
- the important recreative value of the area.

(see also VI 2.5.1).
To achieve durable management under a selection system, initially an improvement is carried out at the same time as exploitation. Trees with crown contact are cut; openings in the canopy should, if possible, not exceed 7.5 m in diameter, and an average freedom of about 2 m on all sides should be provided to the crowns of larger trees.
This can be rather difficult as crown diameters of 15-20 m are fairly common. Felling cycles of 5 to 10 years are kept. It is aimed at the final stand with a basal area of about 18 m^2/ha.
Also WHITMORE (1975, after DAWKINS[xx], 1958) mentions that figure.
According to Dawkins the basal area of natural forest is about 31 m^2/ha and annual increment is nearly nil. To increase this, a reduction of the basal area to 18-24 m^2/ha is proposed.

2.5.3.3 The North-Queensland Improvement/Selection System

This system is employed in North Queensland forests, which are classified as submountain rainforest. In this region a great demand for timber exists. Large differences in value per species and per volume unit are found. There is a tendency to maintain relatively small, economic species and increase their volume so that maximum prices can be obtained. This is one of the reasons for maintaining an uneven-aged forest. After improvement, a selection system with felling cycles of 15 to 20 years is considered optimum. The following silvicultural treatments are carried out:
- climber cutting and cutting of all useless undergrowth not more than 6 months before logging;
- any shrubs, stems, or seedlings of *Laportea moroides*, a troublesome weed, are removed, either by cutting or by poisoning;
- marking of stems for merchantable exploitation: most valuable stems over 76 cm d.b.h. and less valuable stems over 58 cm d.b.h. are felled.In areas with inadequate stocking of regeneration, seed trees are left. Badly formed and any damaged trees are marked. Where necessary, thinning of dense stands outside the felling area should be done;
- exploitation followed by further removal of *Laportea* and other weeds interfering with desirable regeneration;
- removal of useless and less valuable species;

x Wadsworth, F.H. (1951) Forest management in the Luquillo Mountains. Caribean Forester 12(3).

xx Dawkins, H.C. (1958). The management of natural tropical high forest with special reference to Uganda. Commonwealth Forestry Institute.

- soil treatment under seed trees when too little regeneration occurs;
- enrichment planting may be carried out in unregenerated forests; and
- liberation every 3 to 4 years after exploitation.

2.5.3.4 A polycyclic system for the Dipterocarp forests in the Philippines

Conditions are favourable for this system since a good representation in middle-size classes is found here, with few other species present in the upper and middle strata.
Work is based on a felling cycle of 35 years. The minimum exploitation diameter is 80 cm d.b.h. (sometimes 60 d.b.h.). Attempts are made to fell in such a way

that 60% of the valuable stems between 20 and 80 cm d.b.h. are retained. Therefore, groups of trees to be retained are marked, the felling direction is indicated, and "high lead" logging is carried out. After exploitation of the 60% to be retained, about 1/4 dies (REYES, 1968).
In the next 35 years the valuable trees over 35 to 40 cm d.b.h. will reach exploitable diameters. Of the valuable systems between 20 and 80 cm d.b.h. present at the moment of the first logging, about 45% can be felled during the second felling cycle. The production is about the same. About 5 to 10 years later, exploitation is carried out. Climbers are cut and useless stems over 10 cm d.b.h. are removed. This method is possible if the contractor is willing to reduce logging damage; this seems to be successful in the Philippines; in return, a large area is allowed to be cut annually.

VI.3 ARTIFICIAL REGENERATION

VI.3.1 Introduction

Artificial regeneration("Régéneration artificielle" in French) is done when it appears that the standing natural vegetation is economically less valuable, when the forest has been depleted by felling, or when vegetation has disappeared due to other causes (e.g. war actions), when natural regeneration (within the forest of the clear felled area) is no longer sufficient, or when reclamation work should be done artificially.
Aritificial regeneration is the planting of preferred species to ensure profitable exploitation after some time (the rotation time).
Prior stand establishment, nursery practices, seed supply, and site preparation are important. In this report nursery types, nursery practices and seed supply are not treated as they cover an extensive field. (A separate report by other students in forestry on these subjects has been planned, but till now no start has been made.)
The various methods of artificial regeneration which exist differ mainly in the degree to which the original forest or secondary growth is used, and establishment in combination with agricultural crops.
Some of these methods, such as line planting and groups planting, are sometimes grouped under natural regeneration (WYATT-SMITH, 1963, see 3.4.2.1). MAURAND (1943) introduced the term "régéneration mixte" (in addition to "régéneration artificielle" and "régéneration naturelle") indicating a system intermediate to or in combination with natural and artificial regeneration. Here it is dealt with under enrichment planting.
Artificial regeneration is divided into three methods:
- enrichment planting (3.4.2);
- complete planting (3.4.3);
- agrisilviculture (3.4.4).

Site preparation and aspects of maintenance, management and exploitation for all three methods are more or less similar; they are described in chapters 3.4.1 and 3.4.5.

3.2 Nursery types and nursery practices

Because of lack of time expired.

3.3 Seed supply

Because of lack of time expired.

3.4 Planting methods

3.4.1 Site preparation

3.4.1.1 General

This comprises the whole range of technical measures to prepare a site for sowing or planting.
The objective of site preparation is both biological/ecological and economical/ergonomical. On one hand is the improvement of site factors for the species to be planted or the establishment of natural stocking; on the other hand, construction costs should be as low as possible. However, monetary savings in this phase should not cause higher costs at later stages.
In most cases site preparation is the manipulation of the site cover and/or soil conditions. Removal of vegetation is not always necessary; at eroded sites or sand dunes the establishment of a soil cover is the first essential. If the land is stabilized, trees can be introduced. Whether stands are regenerated naturally or artificially, the reasons for and methods of site preparation are basically very similar (CHAVASSE, 1974).
The nature and extent of site preparation depends largely on the following factors:

- weight, type and distribution of vegetation

weight	overground underground	type and distribution	trees shrubs herbs grasses

- site configuration (relief and soil)
- climate (weather patterns for burning, etc.)
- available ways and means (money, machines, and man-power)
- method of establishment, and type and quality of the planting stock.

The methods selected will depend on these factors.
The following operations can be distinguished:

- land clearing
- soil preparation
- chemical weed control.

These aspects will be discussed in the following chapters and also in Appendices VI.C and VI.E.

3.4.1.2 Land clearing

Available methods and implements can be divided into 1) man-power aided by hand tools; 2) (heavy) machinery; 3) chemicals; and 4) fire.

1) Hand tools
   The objective is mainly to sever the vegetation; and when it dries sufficiently to burn it. Manual labour is more appropriate in light vegetation and where there is plentiful labour.
   The most common tools are: machete, reaping-hook, axe, and hand saw. Over the last twenty years many lightweight power tools have been developed like the chainsaw and brushcutters.

Manual labour has limited possibilities and proceeds rather slowly. (For taungya plantations in Surinam it is calculated to take 17 man-day/ha for felling the forest and 1 man-day/ha for burning).
If manual labour becomes too expensive, machines are preferred. On steep slopes (over 30^{o}) and other inaccessible sites, however, manual labour is necessary. In developing countries manual labour will continue to take an important part in site preparation.

2) Machinery
Development of special forest machines has greatly increased over the last ten years (CHAVASSE, 1974).
Most machines can be used on slopes up to about 30^{o}.
The principal purpose of machines is to clear the site before planting (push down the vegetation and windrow debris), or prepare the site for burning.
Some basic types of machines for land clearing are listed in Appendix VI.B.
At sites with a light cover, the operations of removal of vegetation and soil cultivation are often combined (e.g. ploughing, scarifying, scalping, scraping ripping, bedding).
In addition, machines for vegetation removal and cultivation may be operated simultaneously (for instance, brushcutters in combination with ploughs).
Additional problems are raised by heavy vegetation, especially on steep land.
More and more heavy machines are being employed in the clearing of tropical high forests. Trees are uprooted by tree "pushers" or tractors equipped with a so-called KG-blade (shearing-blades). The latter has the advantage that less soil disturbance occurs; the remaining stumps may, however, raise problem in subsequent cultivation (e.g. during plowing).
A description of the procedure of mechanized land clearing done in Surinam is given in Appendix VI C.
After knocking down the vegetation, the debris may be fractioned by choppers, disc-harrows, or slashers; it can be windrowed by tractors equipped with a rake; and/or burned. Troublesome stumps can be removed with "rippers".
Advantages of mechanical land clearing are:
- in short periods a large area can be treated;
- the vegetation is brushed, making burning more effective;
- in light vegetation, debris is sometimes sufficiently chopped, so that burning is not necessary, and this creates a mulch layer on the surface;
- the effect may be superior to that achieved by manual labour;
- the costs can be substantially less than those of manpower.

With respect to costs, in several countries (e.g. Surinam) the possibilities of charcoal production from suitable debris were investigated in order to decrease the costs of clearing.
Disadvantages of mechanical land clearing are:
- severe structural deterioration of the soil may result (see chapter IV.3.3). Especially loamy soils should be handled with care. To avoid harmful effects on soil, the following advices are given (v.d.WEERT & LENSELINK, 1972): With completely mechanized clearing, as many operations as possible should be done in the dry season. It seems that windrowing especially causes the most compaction; thus this operation should not be done under wet conditions. Rowing should preferably take place after burning and the top soil should be disturbed as little as possible. If clearing is continued in the wet season, it is advisable to cut the largest trees by manual labour. Clearing operations shortly after rains and on sandy soils are strongly dissuaded.
- Mechanical land clearing makes high demands upon the operator; good security provisions are very important.

In developing countries it is advisable to work with heavier (stronger) machines than needed, and with machines of one make; this is because there is usually poor supply of spare parts and poor maintenance service.

3) Chemical land clearing
This has already been done for some time in many tropical countries. Chemicals are especially used when other methods are no longer sufficient or are impossible (e.g. on sites with deep-rooted, quickly regenerating shrubs and/or grasses; on steep or stony slopes; and on wet soils).
Costs play a principal part also. Chemicals are used to desiccate, reduce, or kill vegetation in preparation for burning. In moist climates this can be crucial to the effectiveness of the burning.
One must have expert knowledge of the use and effects of herbicides (e.g. the extremely toxic dioxin may be formed when burning debris treated with 2,4,5-T). A method in the high forest is to ring and/or poison large, valueless trees; good results are obtained with tree injectors. Later the undergrowth may be burned.
Over recent years the range of herbicides has increased and more specialized formulations are becoming available. In Appendix VI.E a review on herbicides commonly used in land clearing is presented. Especially killing herbicides are used. In view of environmental considerations, herbicides must be used with finesse and precision. In various countries the use of herbicides and methods of application are strongly controlled by detailed instructions. Usually the herbicides are applied by simple hand tools; in developed countries, however, there is a tendency to use aircraft.

4) Fire
Fire is the oldest and most efficient tool for clearing sites of unwanted vegetation. In some cases it is the only tool needed, but it is more usual for burning to be undertaken after other treatments by machines or herbicides, or both (especially where vegetation is heavy). The advantage of burning is the clean terrain which results from it. There are, however, great adverse effects on soil and soil fauna (see IV.3.3.4).
Burning of standing vegetation is usually not done, because of the great dangers involved. Planning of effective and safe burning requires proper training and skill, and here again there is increasing mechanization (flame-throwers, incendiary "grenades" and "bombs".)

From the preceding it will be clear that single methods are limited to special circumstances. In many cases sites are best prepared for planting by using a combination of methods which give the optimum advantage.
Complete clearing can cause degradation of the site. For soil conservation or preservation of standing vegetation for silvicultural purposes, methods are adopted to keep some portion of the forest cover (e.g. lines are cut through the bush at intervals of several meters.) Most of this work is done by handtools, but there seems to be no great difficulty in adapting available machinery for this operation.

3.4.1.3 Soil preparation including mechanical weed control

The objective of soil preparation is to provide the desired conditions for germination and/or seedling growth. This includes:
- improvement of soil-water relations and aeration;
- counteracting physical obstacles in the soil;
- control of weeds;
- releasing of mineral nutrients to the plants.

In addition, soil cultivation can be applied to avoid other methods like fire and/or herbicides. Depending on the objective, a deep, semi-deep, or superficial treatment may be given.
Superficial cultivation (down to 15-20 cm) is applied to open up the soil for seed and/or planting stock (by improving infiltration, reducing evaporation, controlling weeds). It can be done by hoeing, harrowing, rotocultivation, discing, and ploughing
A semi-deep cultivation (down to 40 cm) aims at structural improvement (e.g. on clay soils). It can be accomplished by digging, spading and ploughing.

Deep cultivation (down to 100 cm) also has the objective of structural improvement. Usually hardpans in the subsoil must be broken. Deep subsoiling and deep ploughing are used, as well as digging or augering of planting holes. Besides depth of cultivation, a division can be made about the extent to which the site is treated. A terrain can be completely treated; or strip, row, or spot cultivation can be employed.
In Appendix VI D a number of machines for soil preparation are presented. Also in soil preparation there is a trend toward increasing mechanization, especially with equipment designed to accomplish specific tasks. In future, manual labour will be reserved for very small areas of difficult terrain.
Deep ploughing used to be a common practice. Nowadays, however, there are reservations against it, not only from the viewpoint of costs, but especially from biological, soil scientific considerations. The exposure of soil to the impact of the weather may result in structural deterioration, decrease of fertility (humus oxidation, leaching of nutrients) and/or erosion, while the soil fauna is also strongly affected. Intensive soil preparation may promote weed growth.
Further knowledge is needed to understand the relationship of diseases and insects to soil treatments. Also, little is known about the effects of soil preparation on nutrient supply (POST, 1974).
Soil preparation is mainly practiced at the beginning or at the end of the dry season. At the beginning it is usually done to control weeds; treatment at the end of the dry season usually aims at increasing water conservation of the soil.
Local conditions will largely determine whether soil preparation is necessary and, if so, which equipment must be used. It is necessary to investigate locally what effect the various techniques will have on soil and the tree stand.

3.4.1.4 Chemical weed control

Chemical weed control prior to planting or sowing is applied in several (mostly developed) countries. In most circumstances no more than 1 m^2 for an individual seedling is treated. This spot treatment is not only done because of monetary savings, but also because of the environmental impact of herbicides. Complete treatment is necessary only with very aggressive and strongly competitive weeds.
The herbicides used for weed control are about the same as those used in mechanical land clearing (see Appendix VI E).

3.4.2 Enrichment planting (Fr. "enrichissement")

3.4.2.1 General

This is the planting of valuable species in an exploited forest; the planting occupies only a certain (usually small) percentage of the forest area, and the remaining forest is disturbed as little as possible.
Although in most cases (in Africa; CATINOT, 1965) in a certain forest only a single species is used for enrichment, usually the regeneration of other valuable species is not done. In Sabah, Malaysia, wildlings of different species were used in one scheme (CHAI, 1975). In other regions, like Africa, the use of nursery-grown stock has been preferred. The objective is to enrich an (exploited) forest in such a way that at the end of the rotation of planted trees, these trees (together with the natural regeneration of valuable species in the remaining part of the forest) again make the forest exploitable. Furthermore, it is hoped that by this extensive operation the natural regeneration of valuable species is so improved that after exploitation the forest can be managed by a natural regeneration system. Based upon the last objective, WYATT-SMITH (1963) groups enrichment planting with natural regeneration. Later authors from Malaysia (like LALL SING GILL, 1970) and from Africa (CATINOT, 1965) arrange it under artificial regeneration because planting is done.

In Vietnam enrichment planting was given a special status by MAURAND (1943) who considered it a third form of regeneration (régéneration mixte) supplementing artificial and natural regeneration (see 3.4.2.4).

3.4.2.2 Line planting (Fr. "plantation en layons")

The principle of this method rests on the introduction of desirable tree species planted on strips (lines) which have been cut into the (exploited) forest at a certain distance from each other running parallel. The natural forest between the lines is disturbed as little as possible. The first experiments with this method were carried out from 1927-1934 in Nigeria by McGREGOR. AUBREVILLE developed and employed it on a large scale in the thirties, mainly in the Ivory Coast (CATINOT, 1965).
Line planting was continued after World War II, and it was also applied in Malaysia in an adapted form. Conditions were quite different in each area. In Africa, mainly light-demanders were, and are used; on the other hand, in Malaysia shade-bearing and semi-light demanders are concerned.
The technique is as follows: lines are demarcated in the forest and cut open to a certain width. The lines run parallel and the distance between them varies from one project to another; within one project, however, they are usually consistent. The lines are always running E-W to catch as much light as possible. The planting stock is sown at regular intervals along the line. This distance varies according to the species, the rate of survival during planting, eventual falling out (in order to have a good selection of the chosen trees during thinning), the size of the crown, and costs of growing and planting.
Further, it depends on the number and distribution of the natural regeneration between the lines of valuable species in the forest.

Africa

CATINOT (1965) investigated the methods of line planting being used until the fifties, in an attempt to find the cause of failure resulting from these plantings. As lack of light proved to be the principal cause, modifications made by CATINOT strongly emphasize adequate light admittance. The data below deal with the modified method.

Technique: Lines 5 m wide are cleared with 10, 15, or 20 m of natural forest between. Within the lines all trees of less than 15-18 cm d.b.h. are cut by manual labour; all thicker trees are poisoned, along with those inside the strips. By this time the height of the forest is reduced to 15 m, thus admitting sufficient lateral light to reach the lines.
The amount of light on the forest floor within the lines is 60-65%, with 25% coming from above and the remaining from the sides.
Planting is done in the middle of the line with a distance of 3 m between the trees. Liberation is annually carried out during the first 6-8 years of establishment. The regeneration of valuable species is encouraged as much as possible in addition to regeneration of shade-bearing species, favouring a good leading up and selfpruning of the plantation. After 6-8 years the trees have reached a height of 8-15 m and are able to establish themselves without further treatments. The number of trees in the above-mentioned spacing is 130-200/ha.

Costs: In 1965 in Ivory Coast the construction of the lines took 28-39 manday/ha including poisoning of all trees over 15-18 cm d.b.h. and nursery work and planting (CATINOT, 1965). Other costs included 130 l diesel-oil with 2% phyto-hormone (see table VI 7). After planting, the annual liberation took 3-4 mandays/ha (mainly climber-cutting). The classical method required maintenance until the 20th year; compared with this, the modified method is a great improvement especially with regard to organization and extent of treatments.

Results: Because of improved light conditions (wider lines and removal of upper forest stratum), a rotation of 60-75 years was possible (compared with 75-100 years before). The desired felling diameter was set at 70-80 cm for which a distance of 8-12 m between the trees was needed. Another method which gave good results, was planting a group of 2-3 trees with 5-6 m between them with a spacing of 15-20 m until the next group was found. The total number of trees was decreased by 1/3 (mainly because of damage caused by falling, poisoned trees). However, sufficient trees remained to make a good choice for the final stocking (20-22 per 100 m, of which 8-9 trees were left after thinning).
The total number of chosen trees was estimated at 25-50/ha, giving a volume yield of 75-200 m^3/ha in 60-75 years (see also tables VI 6 and VI 8).
Some figures about natural regeneration were given by BERGEROO-CAMPAGNE (1958). Observations were made in 550 ha of forest in the Ivory Coast in which lines of 5 m width were cut, with strips of 10 m forest between them.
At the 20th year, before thinning, of the 84 selected trees/ha, 12 were of natural regeneration.

Species: In Africa the following species have been used (after FOURY, 1956; BERGEROO-CAMPAGNE, 1958; CATINOT, 1965):

Scientific name	Trade name	Light demands
Tarrietia utilis *Tarrietia diversifolia*	Niangon	semi-light demanding
Terminalia ivorensis	Framiré	
Khaya ivorensis *Khaya anthotheca*	Acajou	light demanding
Turreanthus africanus	Avodiré	
Lovoa trichiloïdes	Dibétou	semi-light demanding
Guarea cedrata	Bossé	
Triplochiton scleroxylon	Samba, Ayou	light demanding
Entandrophragma angolense	Tiama	
Lophira alata	Azobé	
Terminalia superba	Fraké	
Entandrophragma utile	Sipo	semi-light demanding

Malaysia
A comprehensive review about enrichment planting in Malaysia is given by WYATT-SMITH (1963) and the data below are from his report.
Enrichment is carried out on abandoned fields in the forest, former nurseries, and timber yards after there is an adequate amount of regrowth. The final objective in Malaysia is that all enriched forest areas are to be managed according to the Malayan Uniform System (see VI.2.5.2). Enrichment planting is only done at places where no valuable natural regeneration is found.

Technique: Usually the lines are 1.2 m wide with 6 m of forest between them; planting distance within the line is 1 m. Distances between the lines may, however, be 10 or 20 m, while the distance within the line may be 3.5 to 5 m.
All growth within 15 cm of the planting spot is removed, as well as all root debris down to 22 cm depth. Within a radius of 1 m, all growth below 15 cm d.b.h. is cut. It is important to select a planting spot which is favourable, even if this does not lead to regular spacing.
The canopy is removed by poisoning all dominating trees over 15 cm d.b.h.; after 3 months this procedure is repeated.

Three to four years after poisoning the canopy should have disappeared; otherwise there is still too much shade caused by stem and branches of dead trees. The unwanted vegetation, like climbers, bamboo, *Imperata* and palms has to be removed. If naked-root plants are used, planting should be done before 11 o'clock in the morning; the best method is, however, planting in tubes. For spacing see table VI 6. The surroundings of the planted trees should be cleaned during the first 18 months if necessary.
Liberations within the planted lines are carried out 3, 6, 12, 18 and 24 months after planting. Attention is paid to the removal of climbers and to a good overhead cleaning of the lines in order to allow sufficient light to enter. Clean weeding is considered to be superfluous.
The dominating trees are, if necessary, poisoned again after 12, 18, or 24 months. Further treatment takes place after 3-5 years and 8-10 years, when thinning is carried out. From the data of WYATT-SMITH it becomes clear that in practice every year a treatment is given until 4-5, or even 10 years after planting. Thus, a considerable difference between theory and practice exists.

Costs: In 1963 the maximum acceptable costs over a period of 10 years was estimated at 110 mandays/ha. On the average costs were 75 mandays/ha. Site preparation took 32 mandays per 3000 m with 4 plants per 30 m. Planting the naked-rooted stock took 10.5 mandays/3000 m; planting tubed plants took 10-11 mandays/3000 m. Canopy opening was estimated to take 20 mandays/3000 m (see also table VI 7).
No data about maintenance were available; however, it has been noted that it is cheaper to set the distance between the lines and within the lines at the final spacing.
According to DAWKINS (1958) study in East Africa, 10 trees are necessary to guarantee one; in Malaysia 7-8 trees are considered adequate. Complete stocking is achieved with 40-80 trees/ha from which an average distance of 17.5 - 10 m arises. Maintenance and thinning are recommended as per the Malayan Uniform System. Until 1961 the area under line planting in Malaysia was about 100 ha (WYATT-SMITH, 1963); since that time the area has been extended to at least 7000 ha (TANG HON TAT, 1974; CHAI, 1975).

Production: No data about real or estimated production are available.

Species: In the "Lowland Dipterocarp Forest" good results were obtained with *Balanocarpus heimii* and (slightly less) *Intsia palembanica*. Successful trials with, and large-scale planting of *Dryobalanops aromatica, Shorea acuminata, S. maxwelliana,* and *S. macrophylla* in the lowland rainforest are reported by WYATT-SMITH (1963). For planting on undulating land up to 300 m above sea level the following trees are recommended: *Shorea curtisii, S. leprosula, S. platyclados, S. parviflora, Anisoptera laevis, Dyera costulata* and *Agathis loranthifolia* (LALL SINGH GILL, 1970).
On undulating terrain up to 300 m on Sabah are used: *Dryobalanops lanceolata* and *Parashorea tomentella* (CHAI, 1975).
WYATT-SMITH (1963) recommends the following species for trial plots for both line-planting and group planting in flat lowland, as well as in hilly terrain at higher altitude: *Dipterocarpus baudii, D. costulatus, D. grandiflorus, D. kerrii, D. verrucosus, Shorea pauciflora, S. ovalis, Schima noronhae, Pentaspadon officinalis* and *Tarrietia spp.*
Possible exotics are *Araucaria cunninghamii, A. Hunsteinii, Maesopsis eminii* on well-drained, light soils; and *Shorea gysbertsiana* on alluvial soils.

Laos

According to VIDAL (1960, after LETOURNEUX, 1949*) from 1946-1949 line plantings were carried out in lines 1-1.5 m wide, which were liberated up to 3-4 m in height. Planting was done with stumps and non-stripped seedlings. After planting, the lines were enlarged annually to give the plants greater possibility of development.

*Letourneux, C. (1949): Les Reboisements au Laos.

Species tried were *Pterocarpus pedatus* and *P. macrocarpus*; they did not grow well because of insufficient light and damage by game. *Dalbergia cochinchinensis* - a semi-light demanding species - was planted as stumps and suffered much from termites Direct seeding or planting with stock of at least 1.5 m height and 3 cm d.b.h. was recommended by Letourneux.
Hopea odorata, a shade-bearing species, was planted with plants of at least 1.2-1.3 m height. No yields of these species are known.

Brasil
PITT (1961) gives a review of small-scale trials at several places in Amazonia which had just started at that time.
Technique: lines 20 m apart, 2-3 m wide, plant distance within line 2.5-5 m (200-100 plants/ha).
Overhead opening must be proper, unless a shade-bearing species is concerned. Within the line all growth was cut, except that of valuable species. The larger trees were poisoned; the same was done to shade trees in the upper stratum of the forest strip. No planting was done at places where valuable species were found within the line 2 m from the planting spot, or outside the line 1 m from the planting spot.

Costs: The above method was considered to be too expensive for high forest, and thought to be only significant in secondary growth (PITT, 1961).
The following costs are recorded (in brackets are the normally needed mandays/ha; as plantation establishment was done by inexperienced labour, a faster winding-up of the work was expected by Pitt).
Opening of lines 1-5 (1) mandays/ha; cleaning 1(1); widening 0.8-10 (4); poisoning 0.8-1.4 (1); digging of planting holes 1-3 (1); planting 1.4-4.4 (1); clean weeding 1-1.5 (1-1.5).

Species: Promising tree species were (in brackets: annual height-growth in cm): *Carapa guianensis* (40-50), *Hymenolobium excelsum* (50-130), *Clarisia racemosa* (10-30), *Vochysia maxima* (40-50), *Coumarouna odorata* (20-40), *Eschweilera jarana* (30), *Simaruba amara* (170), *Caryocar villosum* (60), *Bagasa guianensis* (40) and the exotics *Gmelina arborea* and *Albizzia lebbek*.

Production: no information.

Surinam
Between 1948 and 1968, line planting ("stroken cultuur") was carried out. The total area planted by this method was 1030 ha, of which 830 ha were planted with Baboen (*Virola surinamensis)* and 200 ha with Simaroeba (*Simaruba amara)* (BAUER et al, 1975).

Technique: Width of the lines varied from 1-1.5 m; distance between the lines was 2, 3, 5, 7 or 10 m, of which 7 m was the most satisfactory distance. Plant distance within the line was usually 2 m; thus the most common spacing was 7 x 2 m, although 10 x 1.5 often occurred (VINK, 1970). Planting was done soon after the poisoning of all trees over 20 to 25 cm d.b.h. in the forest.
As soon as the plants had started growing well, all trees over 10 cm d.b.h. were poisoned with 2,4,5-T in diesel-oil. After 14 years the forest zones were removed without using the valuable stocking.
In the above it can be seen that there is a principal difference in philosophy between this method and the previous ones; the definition given in 3.4.2.1 does not fully apply. See also table VI 6.

Costs: Establishment took 23 mandays/ha; total costs of establishment, maintenance, and overhead were not available (see also table VI 7).

Production: This varies from 86-285 m^3/ha depending on the length of rotation (22-45 years). (See table VI 8). The data are given for Baboen, but they probably also hold true for Simaroeba (BAUER et al, 1975).

3.4.2.3 Group planting (Fr. "méthode des placeaux")

General

Groups of desired tree species are planted at regular distances from each other. The forest is disturbed as little as possible; and if locally valuable regeneration is found, no enrichment is carried out. This planting method was developed on wind-exposed, grass covered slopes in Ireland and Scotland (ANDERSON, 1953). Belgian foresters adopted this method for application in the tropical rainforest of the former Belgian Congo (Zaïre) (CATINOT, 1965).
Other countries in which the method has been used are Malaysia, Sri Lanka, and Surinam.
In the tropics, the distance between groups of trees can vary from 4-10 m, and between the trees within each group from 0.5-1.5 m. The trees within a group guide each other up. After some time, all except one or two trees are eliminated. The method has been adapted in the several countries to local circumstances. For instance, planting was sometimes done before canopy opening, just afterwards, or some years later.

Africa

CATINOT (1965) gives a description of the method as it was carried out in the former Belgian Congo.

Technique: The nurseries were situated inside the forest to make the plants accustomed to shade. Site preparation included the clearing of plots of 4 x 4 m, with a distance of 10 m between the plots. Only climbers and grasses were removed. Thereafter, as many trees as possible were planted out on these spots (no exact figures given).
Stumps and seeds were used for normal stocking. Small, competitive trees were removed from the surroundings after the new plants started growing. Later, some trees of the canopy were gradually removed.

Costs: Establishment and first liberation took 25-30 mandays/ha. No further information was available.

Production: No information was available.
According to CATINOT, the great advantage of this method is, that it can be applied in every forest formation: dense, open, degraded, or secondary.
The main disadvantage is that the work is spread out over a long period, since light should be admitted very gradually (no objection in our opinion!). Another disadvantage is, in regard to African conditions, that the economically desired species are light-demanding; while the group planting system is restricted to more or less shade-bearing species.

Malaysia

The method is extensively discussed by WYATT-SMITH (1963).

Technique: The distance between the groups and the technique of establishment show great similarity with that of Africa. The groups formed a rectangular pattern in the forest. The distance between the plants within each group was about 1 m; in the end, only one or two plants per group remained. In practice the easiest way was to set the groups at such a distance that in the future no elimination of groups would be needed (table VI 6).
Establishment and planting was done in a similar way to line planting (3.4.2.2). Maintenance was carried out 3-5 and 8-10 years after planting; at the same time thinning to one or two exemplares per group was done.

Costs: Site preparation: The establishment of 100 groups of 4.5 m diameter with a mutual distance of 30 m and with 13 plants per group took 33 mandays. When 7 tubed plants per group were set out, 100 groups took 25 mandays; the planting itself took 16 mandays/100 groups (13 naked-root plants), and light admittance took 8 mandays/100 groups.

Maintenance in the first three years (no maintenance until 3.5 months after planting): 9 mandays/100 groups. In the first six years (no maintenance until six months): 9 mandays/100 groups.
Maintenance during the first ten years for heavy hardwoods: frequent clearings in the first year, then no clearings until the ninth year: 18 mandays/100 groups.
Maintenance during the first eleven years for light hardwoods: 70 mandays/100 groups (too little light was admitted here, and too much undergrowth clearing occurred).
All these data originate from small trial plots of at least 250 groups. The whole scheme was still under investigation in 1963; no later figures are available.

Production: No statements about expected yields were given.

Sri Lanka
Group planting was done with *Berrya cordifolia*. Plots of 7.25 x 7.25 m were cleaned in the forest at a mutual distance of 60 m. At each spot 16 stumps were planted at a spacing of 1.8 x 1.8 m. Around each spot a trench is dug 60 cm deep and 30 cm wide, because of the susceptibility of this species to root-competition. Once the stumps are growing well, the growth of shade-bearing species is neglected. These shade-bearing species have an important function in getting a good stemform of the planted stock (KOELMEYER, 1953; FERNANDO, 1960).

Surinam
Planting in groups was carried out under the name "Bosverrijking" (enrichment). Unlike the method of line planting this method made use of the natural regeneration of the forest to be enriched (see 3.4.2.2).
Group planting was done at two different times, related to the poisoning of the largest trees:

- planting was done directly after poisoning;
- planting was done 2-3 years after poisoning. Losses due to falling debris were avoided by this method (BAUER et al, 1975).

Technique: Every 10 m a very small line (tjip-tjipie) was cut in which at every 5 m a plot of 1.5 x 2 m was cleared. This resulted in about 200 planting spots/ha. If necessary 1-2 months before planting, growth of herbs and grasses was removed by spraying 2,4,5-T in diesel-oil.
Useless trees over 20 cm d.b.h. were poisoned (see table VI 6).
At every spot 3 plants were set out. During the first year a repoisoning in the forest was carried out in order to ensure the killing of all poisoned trees.
After some time one plant per spot remained. Tree species used were: (for veneer) *Virola surinamensis*, *Sterculia spp.* and *Toona ciliata;* (for sawnwood) *Simaruba amara*.

Costs: Total costs during the first years were estimated at 115 mandays/ha (BAUER et al, 1975, see also table VI 7).

Production: For *Virola surinamensis* see table VI 8.
At 22 years the number of stems/ha was 180, plus 20-40 stems/ha of valuable natural regeneration. At a rotation varying from 22-45 years yields from the final cut were from 80-245 m^3; this could sometimes increase with yields from thinnings.
All these data are, however, estimates (see also table VI 8).

3.4.2.4 Régéneration mixte (mixed regeneration)

This method of enrichment was developed at the Research station of Trang-Bom in the former Cochin-China and described by MAURAND (1943). It was developed for forest sites in which areas with pure bamboo growth occur. Natural regeneration of valuable species was impossible at these spots, although sufficient seed trees were available.

Technique: All bamboo culms, except one on each clump are cut. *Cassia siamea* is planted as stumps at a spacing of 2.5 x 2.5 m. At the beginning of the rainy

season the remaining culms are blown down and the *Cassia* quickly grows through the bamboo, thus preventing the regrowth of the bamboo.
After 4 years the *Cassia* has formed a closed forest 8-10 m high with a rich natural regeneration of shade-bearing species below it. Some years later the *Cassia* is removed.

3.4.2.5 Discussion

In this section some problems which arise with enrichment planting, will be discussed.
If wildlings are used problems often occur with the supply of stock. These are caused by the occurrence of alternating seeding years; and because at least in Malaysia, the seeds of economically most interesting tree species have a very short viability. WYATT-SMITH (1963) mentions efforts to use wildlings of *Dryobalanops aromatica* and *D. oblongifolia*. To be usable, the wildlings should not be older than 18 months; the best results were obtained with 6-12 months-old wildlings.
Under natural conditions only a few of these plants are available. Therefore, this method is, according to the author, not useful in large-scale enrichment planting. Later on, however, new experiments were reported from Sabah (CHAI, 1975). Here, in 1954 an exploited forest area of 25 ha was enriched by means of wildlings at a spacing of 5 m (no lines were cut in this case). The best survival occurred with wildlings from 0-15 cm tall; the most successful species were *Dryobalanops lanceolata* and *Parashorea tomentella*.
Another problem in enrichment planting is domination by the surrounding vegetation, which was at least 10 years old in Malaysia at the time of planting.
The greatest technical problem in enrichment is the admittance of light. Too much light quickly results in a tangle of climbers and undesirable secondary species, which compete with the planted stock.
Too little light, on the other hand, gives the plants insufficient possibilities for growth because of too strong shade.
Therefore, sufficient knowledge about light demands of the species to be planted is required. Often, however, little is known about these demands and small-scale trial plantings of desired species should be made to test their suitability.
Bound up with this problem is the problem of costs. When excessive tangling occurs, there is poorer growth of the desired plants, and therefore more clearings are required. Planting will then become more expensive than planned (see also 3.4.2.2 Malaysia). On account of these problems which arise in practice, WYATT-SMITH (1963) formulated the following requirements for the species to be used:

- frequent and regular flowering and fruiting;
- easy maintenance in nursery;
- fast initial growth;
- shade-bearing, and not too susceptible to competition from the side;
- fast volume increment;
- merchantable thinning wood;
- high to very high economic value.

Furthermore, the following characteristics are desirable:

- seed collection should be easy;
- seeds should retain their vitality for at least one week;
- high germination capacity;
- high survival;
- possibility of natural regeneration (also for exotic species),
- good stem form;
- good self-pruning;
- a low crown-diameter-d.b.h. ratio;
- occurrence in groups;
- usually free of pests and diseases.

This is a full list; it is not surprising that Wyatt-Smith had to note that the "ideal" tree had not yet been found.

Another problem is the execution of maintenance work. Planning, as well as the execution of that planning, leaves much to be desired. This aspect is mentioned by CATINOT (1965), as well as by WYATT-SMITH (1963) and TANG HON TAT (1974). The latter authors deal with large-scale planting in the Malaysian Federal State of Perak where, until 1972, 7000 ha were planted. Most of these plantings failed for different reasons, such as: poor planting stock, bad or too-late treatments, poor planning; the greatest problem, however, was the lack of staff members and experienced forest laborers.
The methods of enrichment were developed to create, in an extensive way, a situation in which the (exploited) forest after some time would be exploitable again, and to favour a continuous natural regeneration of valuable tree species (whether introduced or not).
In the past these objectives were not always attained. Extensive treatment implies little disturbance of the forest, and as few operations as possible. In our opinion this can only be achieved when shade-bearing species are used, since the introduced plants should be able to carry on as quickly and independently as possible.
In Malaysia, line planting seems to show good opportunities (silviculturally) in those cases concerning shade-bearing species, which can also be transplanted easily. Data about yield are, however, lacking; many plantings are so recent they can not give reliable results.
In Africa experiments have been carried out for a long time, especially with line planting. The results have been disappointing. CATINOT (1965) realized that the light was of great importance in Africa, because most of the valuable species were light-demanding. Although he adapted the technique to this, in the end the treatments were too drastic and frequent to give satisfying results (GROULEZ, 1976). In addition, the introduced trees, being light-demanding, were not able to regenerate themselves.
Locally, however (as in Gabon) one can be satisfied with the results up till now. On the Ivory Coast, research about more extensive methods of enrichment has started (SYNNOTT, 1976).
Production figures for Africa are only available as prognoses (CATINOT, 1965; table VI 6). Little is known about group planting, but research seems desirable (GROULEZ, 1976).
Summarizing, it can be stated that enrichment, in most cases, has to be limited to shade-bearing and semi-light-demanding species as usually the duration and frequency of the required maintenance operations will be a limiting factor.
If, however, the costs are not grudged (e.g. out of political or social-economic considerations), or if they are not too high - then planning, organization, and execution of the maintenance operations may be a limiting factor, because of the lack of staff members and experienced labour. Training, and creating training courses, is essential.

3.4.3 Complete planting

3.4.3.1 Introduction

This means the planting or sowing of one or more tree species after complete or partial removal of present vegetation, with the objective that the introduced species will finally form a more-or-less closed plantation in which non-valuable species can only occur in the undergrowth. In each area, planting or sowing is usually done simultaneously.
Cutting can be done by plantation or, when mixing is employed, also by species; or under special conditions, by means of a selection system. The latter is of special importance where the forest has a protection function like on slopes and/or when natural regeneration of the planted species occurs and planting has to be carried out only once.
If coppicing species are concerned, one or more rotations can be grown after the first cut.

Complete planting can be done on bare sites after the removal of the original, natural vegetation or after the final cut of a previous plantation. In both of these cases a number of trees can be left to form a shelterwood which is eliminated after some years. Light-demanding species are usually planted without, and shade-bearing species with a shelterwood.
A number of methods have been developed in the tropics to replace the original forest by a more or less uniform stand of valuable species. In Africa the "méthode Limba", "méthode Okomé", and "méthode de Recrû" have been developed. These methods differ in site preparation and the shelterwood used; these differences are caused by the choice of species and by economic considerations (CATINOT, 1965).
A special form of complete planting is the so-called agrisilvicultural system, in which during the first years of the plantation, agricultural crops are grown in between the trees (see VI 3.4.4).
In the following sections a number of aspects of complete planting are discussed to some extent.

3.4.3.2 Direct sowing

This is the oldest method of artificial regeneration of the forest and in some cases remains the best. For many species direct seeding is no longer important, since seedling planting gives much better results.
The best orientation of the seed is usually that which it ordinarily attains in nature (i.e. the long axis is horizontal in most seeds). Sowing on steep slopes may be done rather more deeply than on level land since this will reduce the number of seeds washed down the slope.
Methods of direct sowing include:

a) Broadcast sowing
Seed is sown over the whole plantation area, over selected strips, or over portions of it. The quantity of seed needed is large compared with other methods, but the actual work is easy and cheap. As a rule, the seeds are not covered. This can also be done from an aeroplane. Broadcasting can only be done under favourable conditions (moist, loose soils with little vegetation) or on recently burned *Imperata* grass fields, with species believed to be able to establish themselves.

b) Strip and line sowing
Because of the expense of seeds, the preliminary work of soil preparation is reduced, and in subsequent tending this method is much commoner than broadcasting.
Line sowing implies use of a single line or drill of seed; strips sowing refers to several adjoining lines, or broadcast sowing limited to strips about a metre wide.

c) Patch sowing
In the roughly circular patch of soil at each site several seeds are sown. Generally only one plant is wanted in each, so any extra is used for transplanting to blank sites. A major problem with this method is competing weed growth pressing in from all sides, intensive weeding is necessary.

d) Dibbling
Seed is buried in the soil with the help of a dibbling iron or stake at certain intervals all over the area to be stocked. It is particularly suited to large seeds such as those of many Dipterocarps, but it can be adapted to smaller seeds as well. It is very cheap, and since the seeds are not conspicuous they stand a good chance of escaping vermin. Pregerminated seeds are often used requiring careful handling to avoid injury of the radicle. It is a very general way of supplementing natural regeneration and so is usually done under a shelterwood.

e) Ridge and mound sowing
With this method the seedling is given a greater volume and depth of soil in which to root, and surface drainage is ensured. Another advantage is a

greater freedom for the seedlings from weed competition, as well as better moisture conditions resulting from storage of large volumes of water in the vicinity. There is, however, a risk of soil wash exposing the roots (which may be minimized by not making the ridges too narrow and by firming the soil after sowing). In dry country, it is possible that moisture is condensed in the raised and loosened soil. The high costs of soil preparation make this a rather expensive method.

f) Pit and trench sowing
This is only effective in arid zones for securing young plants as much moisture as possible.

Certain methods can be combined. A trench can be dug and a mound built of the loosened soil: sowing can be done at different levels, thus assuring overall chances of success.
Species to be sown directly should fulfill as much as possible the following requirements:

- they should produce much seed (or at least sufficient seed should be available);
- they should show quick initial growth;
- they should have large seeds with sufficient reserve-food;
- they should form a long tap-root during early stages;
- the seeds should have a high germinative capacity and should store well.

Species which are commonly sown directly are:
Acacia catechu, A. mollissima, A. arabica, Aleuritis moluccana, A. trisperma, Albizzia procera, Anacardium occidentale, Cassia siamea, C. fistula, Gmelina arborea, Intsia byuga, Leucaena leucocephala, Pinus roxburghii, Prosopis juliflora, Pterocarpus pedatus, Shorea robusta.
Some species give good results with both direct sowing and planting, like *Dalbergia sissoo, Terminalia tomentosa* and *Chukrasia tabularis* (FAO, 1957; CHAMPION & SETH, 1968).
Often a pre-sowing treatment of the seed takes place: before sowing the seed may be cut, filed, treated with fire, water or chemicals, etc.

3.4.3.3 Planting

This is an operation which needs time and care. It should be done as much as possible on dull or even wet days; high relative humidity is desirable. The soil should be moist, but not wet and sticky. Planting should be done at the right depth and firmness: the root system must be able to develop freely. Durable potting material should be removed, as this will result in poor root development (spirally growth).
In transporting planting stock to the planting site, care is required to protect them from desiccation or injury. Transport during a few hours on a truck - exposing the stock to the sun - may reduce survival to 10% (FAO, 1957).
Transport of naked-root stock during less than one day requires protecting the delicate roots with peat or wet moss, or dipping the roots in a thin clayey puddle (also other materials can be used). The leaves do not require protection. Stock over one metre tall should be packed in wet jute or wet sacking in addition to the packing material. If transport takes more than one day, protection of the leaves is required (with for instance wet sacking).
The danger of desiccation is less during transport of other planting stock, such as container plants and stumps. Container plants and striplings are disadvantageous because of high transport and planting costs caused by the bigger weight of the plants, container, or clod.
The season of planting: using naked roots, there is practically no option as the season of planting is determined by climate and weather. They are best planted at the beginning of the rainy season when the soil is moist; each day of delay is loss. (In India the planting should be done withint 3 to 4 weeks after the start of the rains).

If heavy rainfall commonly occurs, it is usually better to start planting after the showers have diminished. However, the use of containers permits an earlier start, and work can continue over a long period. Usually irrigation or a little watering is not needed, but it sometimes can be advantageous, e.g. when planting *Casuarina spp.* and *Prosopis spp.* on sanddunes.

The best size of stock for replanting is between 30 and 100 cm. Normally it takes about 6 to 15 months to reach this height in the nursery. As a rule, the smaller the plant, the less it suffers from the actual shock of being uprooted and replanted; but the plants should be of sufficient size to be capable of coping with the surrounding vegetation.

In some cases large plants are required, for example with:

- species which are readily browsed;
- plants which have serious competition from surrounding vegetation;
- plants which obtain their nutrients and/or water from deeper soil layers;
- plants on indurated plinthite banks where young plants with a thin bark may be readily scorched.

In the examples above, use can be made of large plants of at least 3 m high and a root-collar diameter of 6-7 cm. However, setting out these plants is very expensive one man can do only 20 per day. Therefore, this stock should only be used when necessary.

Planting stock can be obtained by collecting wild plants from the forest or by raising them in the nursery:

a) Wildlings

These are sometimes used to supplement nursery stock but are almost invariably inferior to properly raised nursery plants; because of their scattered occurrence, they are usually more costly in the long run. Some species are, however, very difficult to raise in the nursery because of the very short viability of the seed - thus wildlings are the only possible stock. Great care is needed in the choice of wildlings from the forest; they must be vital and well-formed. The following method can be applied: the wildlings are potted in the forest and are kept shaded in a temporary nursery for 3 to 6 months to recover. After that they are planted in the field. Commonly 50% of the stock is lost in the process. (At the time of planting, the stock should not exceed 40 cm; otherwise, mortality will be even higher.)

b) Nursery stock

Even-aged nursery stock is usually more homogeneous than even-aged wildlings, as they are grown under more uniform conditions. Yet differences in quality may occur. The use of poor planting stock can result in open spots in a plantation, or malformed trees. Thus, selection is important; however, one-third of the total stock may drop out in any case. Selection must be based on the following:

- good root/shoot balance;
- good stemform; the stem should not be forked or have long branches; further, it should not be too long, too thin, or have grown too fast because of excessively rich nursery soil; the terminal bud should be in good condition;
- the plant must be healthy.

Below some of the most common methods of planting are discussed according to the different types of planting stock.

a) Planting with naked roots:

The chief points of attention are that the roots are not doubled up, that the collar is at the level of the soil, and that the height of the soil is not below its original level.

Pits are prepared with spades or mattocks and rarely with a cylindrical spade or spiral borer. The hole must be fully as deep as the roots are long; the plant is kept in a central position and a little of the soil is then pushed back into place and pressed gently but firmly against the lowest roots;

the process is repeated until all the soil has been replaced. The roots remain as much as possible in their original, natural position. If the plant can easily be lifted up again, the planting was not done properly. Some rougher and faster methods can be adopted, but only if they prove to be better than those obtained from the standard methods.

With some species on light soils, it suffices to open a notch in the soil with a planting spade, insert the seedling and close the soil by again inserting the spade obliquely some centimetres away from the notch and pushing until the earth covers the roots. It is sometimes helpful to pluck off some of the leaves to reduce transpiration, especially if planting work has to be done on sunny days, or if the soil is not quite wet enough. It should not be done if not necessary, however, since it might retard growth rather than promote it.

Sometimes roots are dipped in a puddled mixture of two-thirds clay and one-third cowdung. This reduces desiccation during transport and delivers some nutrients directly after planting. A disadvantage is that lack of oxygen may occur in the roots; but in many cases a trial of this method is still worthwhile. If not all plants can be set out directly some plants can be heeled in: a shallow, long hole is dug under shade, plants are put obliquely into it, and covered. If ample water is supplied, they can be stored in this way for some time.

Summarizing, it can be said that when using naked-root plants, problems with desiccation can arise, although this is a cheap method; and that survival may be low compared with other methods.

b) Container planting:

This method offers considerable advantages particularly on difficult planting sites and with species which have relatively poor root systems.

The plant is established in a pot under optimum conditions and is planted out with a minimum of disturbance. Depth of the planting hole is usually as long as the length of the container or ball of earth. If roots have grown out of the container or ball, they are trimmed. Large plants require a larger hole as they are more susceptible during transplantation. A large hole with plenty of filling earth favours root development, initial growth and survival.

With compacted soils, a planting put must be prepared at least 10 cm deeper and wider than the size of the container. Containers likely to attract termites should be removed before planting, as well as metal or earthenware containers; other impervious containers such as polythene can be slit open.

The higher costs in nursery and transport are generally more than compensated by reliability of survival. Moreover, one can expect fast development of the planting material.

In addition to the above-mentioned type of container, there are also bamboo, paper, other plastics, asphaltpaper, or netting, which can be used as materials. Sometimes plants are rooted in moss; this material helps to retain moisture around the roots and is helpful whether watering has to be done or not (e.g. on dune sands). In addition, it is very light.

Another method is to make a block of pressed soil with a central cavity which is filled with good soil. The pressed material consists of a mixture of local soil with additions of sand or clay and manure. It should be able to withstand watering and handling. This brick-planting method is applied with success on shifting sands. The main objection is the heavy weight of the material.

Planting with a ball of earth is not essentially different from container planting. The soil should not be too light or too dry because this may result in the ball collapsing. It is important during planting that there is a proper bond between the ball and the surrounding soil, and that the level of planting is correct.

Deep planting has been successful with some pines, especially in dry zones; it involves the burying of a part of the stem. However, most plants cannot stand it since it causes dying of old roots and the development of new ones near the surface. Furthermore, rootrot may occur, resulting in the starvation of many trees (WEIDELT et al, 1976, after TOUMEY & KORSTIAN, 1967*). Many broad leaved species can also be planted considerably below their original level.

c) Stump planting:

This method has been employed in Asia since 1920, and elsewhere as well, with increasing success, especially with species which form a long tap-root. Plants are raised in the nursery, and lifted if the rootcollar-diameter is between 1.0-2.5 cm. The stem is cut obliquely 3-5 cm above the collar and the root is cut off from 15 to 30 cm. Secondary roots are removed entirely. All has to be done with very sharp instruments in order to avoid bruising the tissues. The above dimensions are merely averages, the exact dimensions differ from species to species (see species list).

The shape of the root seems to make no difference, although forked roots give less encouraging results.

Large diameter stump plants can be cut into four sections lengthwise and planted just as they are with a good rate of "take" (e.g. teak).

With planting, the following differences from ordinary plants occur (FAO, 1957).

- a hole made with a dibble suffices;
- planting is possible earlier because of greater drought resistance when compared with leafy seedlings;
- the digging of a trough around the plants is not advisable as stumps do not withstand flooding as well as seedlings.
- the collar should preferably be 1 cm above ground level.

Advantages and disadvantages of this method are:

1) Initial growth is quicker than with seedlings from directly sown seed; but somewhat slower in growing tall when compared to leafy seedlings.

2) Stumps are easy to transport; they tolerate shipments of two to three weeks duration without damage.

3) Stump planting is easy and little manpower is required; establishment is more regular than with other planting material.

4) The cost of plantation establishment is higher than for directly sown seed, but less than for seedlings. Until recently, stump planting was often considered the cause of collarrot which eventually leads to the formation of hollow trees; this proved to be justified in a very limited number of cases only.

Summarizing it seems that the advantages are greater than the drawbacks and that this method is recommended for all species with taproots able to produce adventive shoots at root collar level, (FAO, 1957).

Some species which have thusfar proved successful in tropical Asia:
Acacia arabica, A. catechu, Adina cordifolia, Albizzia procera, A. lebbek, Alstonia scholaris, Bombax malabaricum, Cassia fistula, C. siamea, Chukrasia tabularis, Dalbergia latifolia, D. cochinchinensis, D. sissoo, Eucalyptus rostrata, Gmelina arborea, Lagerstroemia speciosa, Pterocarpus pedatus, Shorea robusta, Spondias mangifera, Sterculia tomentosa, Tectona grandis, Terminalia tomentosa, Toona ciliata, Xylia dolabriformis.

d) Striplings:

This is an "over-grown" seedling or transplant usually about 0.75-2.50 m high which is put into a plantation with the aerial shoot stripped of leaves, and main and side roots pruned.

They are sheltered during transport and planted in large holes. This stock is extensively used in enrichment planting. The method is rather expensive because large planting holes are needed.

*Toumey, J.W. & C.F. Korstian (1967). Seeding and Planting in the Practice of Forestry. 3rd Edition.

3.4.3.4 Sowing or planting

Direct sowing is a fast method; but a large quantity of seed is required (which should be cheap). Conditions must be favourable for germination, and initial growth must be fast in order to be able to withstand competition from weeds. Since frequent weeding is required, agrisilviculture can be a solution.
Advantages of direct sowing are: the quickness of the method, root growth of the plants is not interrupted, and the ease in making mixtures. On the other hand, however, the seedlings are hard to protect against browsing and other pests. Often establishment is slower than that of planting stock on which much care has been spent in the first stage.
Even in areas with good rainfall the risk exists that during dry periods in the wet season and in the first dry season, the surface soil will dry out before the root of the seedling has penetrated deeply enough into the soil. This may result in complete starvation causing a need for resowing.
Another, often insurmountable problem is the lack of sufficient seed, so that ursery growing is needed.
As a rule planting is a much more sure operation. A minimum number of plants is set out, much care can be given to them and this thereby provides them with a good start in the struggle against weeds and browsing by animals.
Many species are difficult to sow directly (like species with slow or irregular germination) while sowing in the nursery is always a success. For a successful plantation, especially on adverse sites, high quality stock is required.
Disadvantages of planting are the higher costs, the higher intensity of labour required, and the higher degree of skill required. In addition nurseries have to be established. With some species poor results have been obtained in the nursery (e.g. *Aphanomirtis spp.* and *Artocarpus spp.* (CHAMPION & SETH, 1968)).

3.4.3.5 Spacing

This depends first of all on a number of factors of a biological-silvicultural nature:

- development in youth;
- stemform; is a straight bole formed in a natural way, or not?
  Fast initial growth is important in suppressing weed growth and for purposes of soil conservation (the degree to which this is required depends on the danger of erosion at the site).
- Rapid closure is advantageous as trees draw one another up with a minimum of branching and forking, and maximum self-clearing of sideshoots.
  Some species have to be forced by close spacing to form a straight bole.
  In addition to the above, economic factors are important. Costs of stock and planting are higher with a close spacing than with wide spacing. Thus, when wide spacing is employed, a beter quality of stock can be used; furthermore the first non-paying thinning can often be avoided.

Also the method of regeneration is important. If agrisilviculture is carried out during the first years of the plantation, wide spacing is needed.
Furthermore, the objective of the plantation is important: resin or tannin production needs different spacing from wood production.
Advantages of close spacing are:

- rapid closure;
- less branching and forking;
- better self-pruning; and
- good opportunities for selection during early thinnings.

Drawbacks are:

- more plants are required than with wide spacing;
- diameter growth may fall behind height growth; which may result in bending and winddamage; and
- root competition with superficially rooting species, resulting in retarded growth.

Advantages of wide spacing are:
- less need for non-paying early thinnings;
- mechanization can be applied;
- less stock required;
- lower planting costs; and
- more space for growing, resulting in better root and crown development and more solid trees.

Drawbacks are:
- likelihood of heavier weed growth since closure is delayed;
- trees grow wider (heavier branching, stronger tapering); and
- formation of wide rings in the central core of the wood, which is generally an objectionable defect in timber.

For balanced development triangle spacing is preferred; and to a somewhat lesser degree, quadratic spacing is favoured.
These are easy to stake out and convenient to arrange. To simplify weed control, the distance between the rows is wider than within the rows. Common spacings are:
3 x 3. 2.5 x 2.5., 2 x 2, 1.8 x 1.8 m or 3 x 2, 3 x 1, 2.5 x 1 and 1 x 1 m.
It can be stated that growth in height is generally not dependent on spacing, although diameter growth is. Wider spacing gives less wood/ha, but more wood/tree. Because of the high costs of early thinnings, there is a tendency towards wider spacings, which make possible agrisilviculture systems.

3.4.3.6 Mixture of species

Natural tropical forests usually contain a mixture of numerous species, and the percentage of valuable spcies is usually low. Stand establishment aims at the best possible utilization of an area by complete planting of valuable species. Plantation can be established with a single species or a mixed crop. The former is usually preferred from economical and silvicultural considerations. Large, united stands of a single species should be avoided because of their greater exposure to damage by pests and diseases, and to reduce fire hazard.
Especially with large-scale pulp and paper production, stands of broadleaved species are best mixed with conifers.
A mixed stand may improve soil conditions or maintain the soil in a good condition for future rotations (e.g. by mixing with leguminous plants; see 3.5).
A better use of the site can be made by mixing deep-rooting and superficial rooting species and/or shade-bearing and light-demanding species. Also, wind resistance by the plantation can be improved by mixing. If soil conditions strongly vary from place to place, it is possible to plant the right species at the right site by mixing them in groups.

Diversification of production can be obtained by mixing.
There are also a number of disadvantages attached to mixtures which are of a technical, silvicultural or economic nature. Monocultures are easier to establish, maintain and harvest. Usually a higher value from the species is obtained from pure plantings compared with possible alternatives. Mixture of species is useless in short rotations with fast-growing species.
Summarizing, the arguments in favour of mixtures are of a biological nature, while those in favour of single species stands are of a more practical and economical nature. The following possibilities for mixing exist (WEIDELT et al, 1975):

a) Individual mixing. Two or more species are mixed alternately. Lack of silvicultural knowledge with this method has usually caused failures.
b) Line mixing. In one stand there are two or more species mixed, by alternate planting in lines of a fixed sequence.
c) Group mixing. Within one stand groups of one species or groups of some other species are mixed in a matrix of a major species. This method is often employed when soil conditions vary notably.
d) Parcel mixing. Parcels of one or more hectares are alternately planted with different species.

e) Mixing by underplanting. Some years after planting the first species, there is underplanted another, shade-bearing species. Examples of this method are plantations of *Pinus kesiya* and *Dipterocarpus sp.*, and of *Albizzia falcataria* and *Swietenia macrophylla* in the Philippines.

f) During the first years of the plantation two or more species are planted after which only one species is allowed to remain to form the final stand. Examples of this are plantations of *Mesua ferrea* and *Cassia siamea* in Vietnam (MAURAND, 1943), and of *Tectona grandis* and *Leucaena leucocephala* in Kenya (GEUS, 1977). In the latter case the *Leucaena* is cut every year before flowering; when the *Tectona* closes, the *Leucaena* dies (see also 3.5).

For mixing tree species with agricultural crops see VI.3.4.4. Usually mixtures of pioneer species should be avoided.

3.4.3.7 Refilling

Even with the most sophisticated planting techniques and optimum planting stock, some plants will die after planting. As soon as possible, beating up or refilling must be done with strong plants to give every opportunity for catching up with the rest of the crop.

In the Philippines beating up is done if mortality is over 20%, or at lower percentages if failures are concentrated at one spot. With a 10-20% sampling, an insight into the mortality can be obtained (WEIDELT et al, 1975). Materials for beating up should already be taken into account when planning the establishment of a stand.

Where sowing is done, surplus plants from well-stocked patches, new sowings, nursery-stock, or wildlings can be used for refilling.

As a rule in the humid tropics no refilling is done after the first year, as plants put out later have little chance of survival. In more arid zones beating up can be done over a longer period. Beating up is commonly done by a single man.

3.4.3.8 Mechanization and costs

Artificial regeneration involves a lot of heavy work, much of it at a busy season for agriculture. Mechanization can take advantage of favourable weather conditions as it is much faster than hand labour.

Labour costs, machine costs, and available manpower are important decisive factors in the choice for mechanization. Due to capital costs of the equipment, the dependence on skilled labour, the difficulty in ensuring efficient maintenance, the required limitations to relatively large-scale projects, and the fact that the equipment may remain idle most of the year: these factors strongly urge care in starting mechanization.

There are three main times for mechanization in planting: viz. the preparation of the planting area (see 3.4.1), the nursery, and the actual planting and tending (3.4.5). Mechanization is much less commonly employed in tropical countries than t is in temperate regions. The most important costs of establishment are planting stock, transport of the stock and planting.

Site preparation can take up a considerable portion of the total costs (20-90%) in the first year (CHAMPION & SETH, 1968).

The costs dealt with here vary strongly, depending on the planted species, type of planting stock, nursery technique, spacing, labour costs, degree of mechanization, and the length of the rotation period.

Establishment by direct sowing is, as a rule, cheaper than with nursery-raised stock. The number of plants produced in the nursery directly influence the costs of planting stock.

Costs of planting may vary greatly from one place to another, caused by differences in physical-biological and socio-economic considerations. Generally speaking, stands raised by the agrisilvicultural system are cheaper than others.

Because yields are obtained much later, establishment should be as efficient and cheap as possible. Yields which can be obtained at an earlier stage are of great importance for profitable commercial production.

3.4.4 Agrisilviculture (taungya system)

3.4.4.1 Introduction and definitions

Since agrisilviculture takes place near the transition between arable farming and forestry, it seems wise to start this section with some definitions:

- Agriculture is the application of labour to nature in cooperation with capital in order to make it produce, for human beings, more useful plants and animals than it would have done had it been left.
  It can be divided into plant production which includes arable farming, and animal production which includes stock-raising and stock-breeding.
- Arable farming includes the growing of crops and the measures bound up with that, such as soil preparation, crop protection, manuring, etc.
- Horticulture is the growing of vegetables, fruits, flowers, avenue-, ornamental-, fruit trees, horticultural seed, and herbs.
  In this section arable farming includes horticulture and perennial crops.
- Forestry is the establishment and/or management of forests in such a way that the objective aimed at is attained as well as possible.

When arable farming and forestry are combined at the same site, one can speak of agrisilviculture when forestry is the principal component; or forest farming when arable farming or grassland farming is the most important.

- Agrisilviculture is a method of forest establishment or forest management, in which silvicultural operations are contracted to arable farmers, who obtain the right to grow crops in between the seedlings during a certain period.
- Forest farming is the planting and maintenance of trees, usually at a wide spacing, at the service of arable farming and/or grassland farming. Usually the primary objective is not wood production, but leaves (cattle food), fruits or protection (DOUGLAS & HART, 1976).

In practice it may be hard to discriminate between both systems, e.g. cocoa is planted under forest trees. In this case agrisilviculture is concerned if the forest consists of valuable species, while forest farming is involved if the trees are merely planted as shade trees for the cocoa plants (HESMER, 1970).
But even on these grounds a distinction cannot always be made as the designation of the area may change "from one day to another", without being directly visible. HESMER (1970) and OLAWOYE (1975) notice the danger of growing (especially perennial) cash crops in areas which are assigned to be forest reserves. The land might be withdrawn from its forest designation if cash crops become more profitable in the long run than the increment of the wood, and if the trees directly or indirectly inflict damage upon these crops.
ENABOR (1974) states that this can occur, but he advises tackling the problem quietly in order to avoid an emotional atmosphere of distrust between "arable farmers" and "foresters". Indeed, it seems wise not to carry out forestry apart from farming; especially not in the case of combined cultivation, since the interests of farmers and foresters can be the same (WESTOBY, 1975; KIO, 1972).
If the farming and forestry values of the land can be properly compared, a justified choice of land use can be made. It is, however, striking that agrisilviculture is extensively reported and investigated only by foresters, while arable farming is also a principal element of the system (ROCHE, 1974).

The agrisilvicultural system as it is mostly carried out nowadays was developed in Burma by Brandis in the second half of the 19th century. The shifting cultivators of the hills were involved in it. They were encouraged to sow *Tectona grandis* at the same time as agricultural crops were sown on the recently-cleared sites.
During the period of arable farming, the young teak plants were attended by the cultivators which received a premium for this; if the area was abandoned, the care for the teak plantation was left to the forestry service.

3.4.4.2 Functions of agrisilviculture

As agrisilviculture is in the first place a system that is applied in forest reserves to afforest or reforest for wood production, trees planted for the sake of agricultural management of soil and crop are not included in this system (see definition of forest farming). Examples of forest farming are on the one hand woody crops like rubber, coconut trees, coffee, tea, fruit trees and fodder crops and on the other hand trees or shrubs planted to protect a crop like shade trees and shelter belts, or to improve the soil during a fallow period.

Wood production such as for firewood and poles can have an important or even essential function in the agrisilvicultural system. But this is not the only purpose of planting; besides the functions served by forestry and arable farming separately, this system has some other specific functions as well.

Although the production of food and industrial raw materials during arable farming plays a minor role in the total land use - economically as well as in time - it still is an essential part of the system.

The specific functions of the combination of forestry and agriculture largely depend on the situation under which the system is applied. Some of these situations will be briefly discussed below.

I. If, for example, in Vietnam, forest reserves are demarcated in areas where, up to that moment, shifting cultivation has been carried out, the cultivators in fact lose their land. They should be compensated for this. In order, moreover, to avoid the possibility that these farmers will settle in densely populated areas or in unused forest areas, the forestry service can offer them the land of the new plantations, and at the same time work as a forest labourer. When non-desirable alternatives exist for the cultivators, they should be motivated by attractive contracts.

II. Another situation in which agrisilviculture can fulfill an important function exists in relatively densely populated forest reserves where there is scarcity of food and arable land. Here, the forest land can be farmed out during a certain period, possibly as long as the forest is in rotation. The farmers use the lower stratum or strata of the forest, especially at the beginning and at the end of the forest rotation. Thus before crown closure and after girdling of the trees before felling, but possible also in between with shade-tolerant crops.

In this situation the importance is not the efficient use of labour, but that of growth factors. In arable farming this form of mixed- and/or intercropping with high tree crops, shrubby crops, and herbaceous crops is called multi-storeyed cropping (NELLIAT et al, 1974).

III. In situations in which the forestry service deals with both afforestation and the cultivation of crops, this combined cultivation can have several functions.

On the one hand it can be financially attractive as the yield from agricultural crops can cover a large share of the establishment costs. On the other hand a number of agricultural crops can serve as a soil cover, while cultivation measures such as clean weeding, fire protection, and manuring can be advantageous to the trees too.

Another point is that more damage might be done to young trees in combined cultivation since many arable crops attract game; but the higher value of the crops can give rise to better protection of the area.

Summarizing the functions of agrisilviculture are:

- Expenditure savings with planting and maintenance;
- labour, food supply and training as forest workers for people who formerly were shifting cultivators;
- surplus production from forest reserves formed by arable crops;
- direct soil cover and soil protection; and
- protection of plantations and arable crops against game.

3.4.4.3 Application of agrisilviculture

Distribution and physical conditions

Being developed in Burma in 1855, the system soon spread to other areas like Java, South Africa, Bengal, Sri Lanka, and later also to Kenya, Nigeria, Sierra Leone, Ghana, Tanzania, Ivory Coast, and Zaire.

HESMER (1970) relates the distribution of the system with two factors:

1) The nationality of the colonizer: the first spread occurred in areas ruled by England, followed by Dutch, Belgian and finally French-governed colonies. In on-colonized independent countries the system was introduced only after World War II, or not at all (Thailand, Liberia). Also in many former French colonies the method is still unknown (Indo-China), while it is of minor importance in South and Middle America.
2) The climate: the method has been limited to areas with pronounced seasons (monsoon regions). In more humid regions the lowland Dipterocarp forest is found, usually with a low population density, and where the vegetation is lush and very dense. Furthermore the regeneration of valuable species in these forests after exploitation is rather satisfying, so that no planting is necessary. In West Africa agrisilviculture is being carried out in the evergreen rainforest near the coast. These forests are less dense and the population pressure is high. The same holds true for the evergreen montane forest of East Africa.

Socio-economic conditions

The first condition is that some area is demarcated as a forest reserve for any reason (protection forest, wood production). One or more of the following conditions should also be fulfilled:

- high population density
- lack of arable land
- sufficient labour supply.

It is noted that these conditions are tightly bound up with each other.

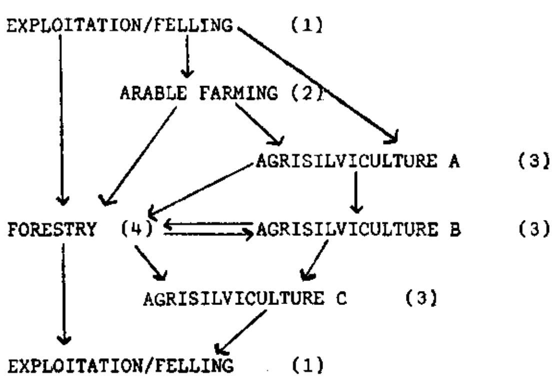
Further conditions for the success of agrisilviculture:

- need for wood (both national and international);
- a well-organized forest management; and
- a stable political situation.

To get the best prospects all three conditions must be fulfilled.

Procedure:

Different alternatives exist in the method of cultivation in the agrisilvicultural system; these are depicted in the following scheme:



Explanation:

(1) Exploitation/Felling:
Often the site is cleared and burned. It can happen, however, that promising valuable regeneration, too small for exploitation, remains. If these trees form a shelterwood, the shade-tolerance or shade-bearing quality and the likelihood of root competition from agricultural crops and trees to be planted must be taken into account.

(2) Arable farming
This can only be carried out on soils not too susceptible to erosion and not too poor. With the choice of an agricultural crop the following factors play a part: quickness of soil covering, degree of soil covering, and fertility demands.
The duration of the period of cropping is mainly determined by the erodibility of the soil and soil fertility; it varies from 1 to 2 years (HESMER, 1970).

(3) Agrisilviculture
The combined cultivation can be divided into three parts, depending on the period during rotation at which it is carried out: the beginning (A), the major part (B) and at the end (C).

A Combined cultivation at the beginning of the rotation:
Agrisilviculture is usually applied for a restricted period with more or less light-demanding agricultural crops until root competition and/or shading by the trees becomes too much (1 to 4 years).
Attention should be paid to an adequate distance between the trees and agricultural crop because of root competition. If arable cropping has started before tree planting, shading must be considered, depending on the light demands of the planted trees.
Furthermore care should be given to clean weeding the young plantation; while the choice of crops is important with respect to nutrient uptake from the soil.

B Combined cultivation, longer lasting
This can be done with shade-bearing crops like ginger, cocoa, and Robusta coffee, and herbs as well as tree crops. In this case root competition and soil requirements of the crops should not be so much that an unacceptable slowdown in the growth of the trees results from it.
Furthermore, the arable crop should not be a host plant for insects which are harmful to the trees nor the reverse. In addition the value of the wood must remain high compared to the arable crops.

C Combined cultivation at the end of the rotation:
This method of combined cultivation is possible only if for some reason or another more light reaches the soil and/or root competition is decreased. The growth of light-demanding annual crops becomes possible again.
For example in Java where teak stands are girdled two years before felling, the trees die outright, so that the amount of light increases and root competition disappears.
To check heavy weed growth, arable crops are grown (HESMER, 1970).

(4) Forestry
Not dealt with in this section.

3.4.4.4 Species and crops for combined cultivation of forestry and arable crops

In the agrisilvicultural system, arable crops are grown during different stages of development of a forest plantation (although until now it has mainly been done in the beginning). In fact this is a form of intercropping or mixed cropping which can be called "multi-storeyed cropping". The basic principle is that the various strata existing in the forest are filled in with arable crops, as was done, for instance, with a combination of coconut trees, cocoa, cinnamon, and pine-apple (NELLIAT et al, 1974).
Within a combination, one species will hinder another in growth, if both apply at the same moment for scarce growth factors such as light, water or nutrients.

The species or cultivars which will be best compatible in a combination, have to differ as strongly as possible at all times, both phenotypically as physiologically (v.d. LEE, 1976).
Differences between species or cultivars concern the habitat above as well as below the ground, the light requirements, or the uptake capacity of the roots. However, some competition for space or growth factors cannot be avoided; thus the species must adapt themselves.
Some tree species, for instance, which normally rooted very superficially, proved to be able to lower their root system upon frequent soil working, without a marked influence on their capacity. It seems that very little research has been carried out in this field.
The components of the combination must also differ as much as possible with respect to their status as a host for parasitic and damaging animals or plants.

A. Tree species
As trees form the most important component within an agrisilvicultural system, first a tree species should be chosen. Many species are suitable for this, but until now teak (*Tectona grandis*) has been used in the majority of cases, especially in Asia (KING, 1968). For Asia one can also mention *Dalbergia latifolia*, *D. sissoo*, *Shorea robusta* and *Swietenia macrophylla*. These species generally have a long rotation (60-80 years), consequently human population density should be low: two years cropping at a rotation of 80 years implies a density of about 15 persons per square kilometre of arable land.

Low population density makes agrisilviculture unattractive as it becomes difficult to construct adequate infrastructural provisions. The situation can be improved by using a longer cropping period and by shortening the rotation of the trees.

A second group of trees suited to this system is the fastgrowing species usually planted for pulp and paper production, e.g. *Eucalyptus spp.* and *Pinus spp*. These trees do not have the disadvantage of long rotations, but because of the cost of transporting much bulk with a low value per unit, they need to be planted near a factory and are usually therefore concentrated so that little space is left for arable crops.

A third group consists of woody and often wood producing agricultural crops which are planted in mixtures with arable crops. This group includes rubber (*Hevea braziliensis*), cashew (*Anacardium occidentale*), black wattle (*Acacia mearnsii*), capok (*Ceiba pentandra*, *Bombax malabaricum*), and many other species delivering fruits, nuts, seeds, or resins which can be eaten or sold. Combinations fo these species with arable crops or fodder crops are also referred to as forest farming (DOUGLAS & HART, 1976).

Although wood production is the most important function of the forest in the agrisilvicultural system, some attention must be paid to the aspect of soil improvement as the forest also has a function as fallow vegetation for the cropping period. Monocultures of teak do not have a positive effect on the soil; on slopes erosion may occur below a plantation (HESMER, 1970). The same can be said of a number of other trees, which makes the establishment of a cover crop necessary during the period when no crops are grown (see VI 3.5).

A considerable amount of nutrients is carried away from a site with the logged stems, especially when the bark and thin branches are taken. To depict the magnitude of the amount of nutrients, see table VI 9, which includes some figures about minerals in the tropical rainforest. To be able to grow arable crops in the years after exploitation, the amount of nutrients in the soil must be at an adequate level.

B. Arable crops
The choice of a crop in a agrisilvicultural system is usually not linked with the biological requirements of the tree species to be combined with it. Mainly socio-economic considerations play a part, based on the nutritional and agricultural traditions of the farmers (FAO/SIDA, 1974).

Certain arable crops are permitted in forest plantations in certain countries but not in others, e.g. bananas, plantains, manioc, maize, rice, sugar cane, tobacco and yam. Perennial cash crops are usually excluded so that the agrisilvicultural system can be considered a "quasi-multiple use of forest land" (KING, 1968).

Some experiments seem to indicate that the combined cultivation of arable crops and forest trees results in a lower yield and a decrease in soil fertility, but in the majority of cases both cultures show an increase in production without adverse consequences for the soil (FAO/SIDA, 1974).

As long as only annual and bi-annual crops are permitted, the farmers in agrisilviculture areas will stay on a subsistence level, as the yields are hardly sufficient to give a marketable residue (EDUN, 1966 in FAO/SIDA, 1974).

After stating that in principle all arable crops can be grown combined with forest (although often under certain conditions only) the question remains which crops can be used at which stage of forest development. The arable crops can therefore be grouped under light and nutrient requirements (see also HESMER, 1970). Cereals require a fairly large amount of light and have at the same time a high nutrient demand, especially during flowering-initiation and fruiting. Thus they are suitable to be combined with the young plantation in the first or second year if adequate nutrients are still available in the soil and little or no shade is cast by the trees. The principal cereals of Southeast Asia are dryland rice (*Oryza sativa*, morphologically and anatomically strongly different from wet rice) and maize (*Zea mays*); sorghum and several millet species are of minor importance. Pulses and oil-containing annual seed crops generally make the same demands as cereals. Within these groups are beans and peas *(Phaseolus spp.* and *Vigna spp.)* chick-peas *(Cicer arietinum)*, soya *(Glycine max)*, groundnuts *(Arachis hypogea)*, sunflower *(Helianthus annuus)*, Simsim *(Sesamum indicum)*, castor *(Ricinus communis)*, and *Guizotia abyssinica*.

Annual crops grown for their seeds die after flowering and fruiting. In their only flowering and fruiting period they make high demands on the growth factors. Root crops, however, are different. The yield depends on the total amount of light received in a certain period, and although the nutrient uptake is rather high, they make less strong demands on soil fertility. A number of root crops are somewhat shade-tolerating and therefore suited to combined cultivation in a latter stage of forest development.

The most common root crops are: manioc *(Manihot esculenta)*, sweet potatoes *(Ipomoea batatas)*, potatoes *(Solanum tuberosum)* and *Araceae* like *Colocasia spp.* and *Xanthosoma spp.* Root crops are well-suited to be combined with fast-growing trees like *Eucalyptus spp.*

Shade-bearing crops which can be planted under a closed forest includes *Dioscorea* species (of which some deliver edible roots and others a raw material for the pharmaceutical industry) and *Zingiberaceae*, of which ginger (*Zingiber officinale*) and turmerie (*Curcuma longa*) deliver root-stocks, and cardamon *(Elettaria cardumomum)* seed.

Somewhat shade-tolerating shrubs which deliver stimulants are coffee, tea and cocoa. With a fairly wide spacing of the forest, these shrubs can form the lower stratum, which can deliver a valuable crop without making high demands on soil fertility (although of course the maximum yield cannot be obtained).

The same can be said about the large and multiform groups of fruit trees including *Citrus spp.*, *Carica papaya*, *Psidium guajava*, *Durio zebethinus*, and *Arthocarpus integrifolia*. These fruit trees can be planted simultaneously with forest trees and annual crops and they will deliver fruits until they are completely shaded by the forest trees. The same holds for bananas, these were successfully planted in Zaire in a "système sylvobananier" together with Limba (*Terminalia superba*). Pineapple (*Ananas comosus*, *Bromeliaceae)* is somewhat special because this plant delivers fruits even under rather heavy shade. Although they have a lower sugar content than when grown in full light, they are still very suitable for tinning.

Usually vegetables and herbs including cabbage (*Brassica spp.*), various leaf vegetables and tobacco, and fruit delivering crops like eggfruit, tomatoes, ocras, peppers, pumpkins and cucumber, make rather high demands on both nutrient supply and light. These crops are often grown on small holdings in between cereals, possibly on somewhat more fertile spots.

The birds-eye view presented here about crops to be grown in between forest trees is not complete, and moreover hardly any attention has been paid to possible combinations as data about certain interactions between crops and trees are lacking. Little research has been published about the effect of interaction (both competition and mutual stimulation) on the yield of the various components apart, compared with the yield of the combinations as a whole.

3.4.4.5 Organization and planning of agrisilviculture

One of the first matters which arises when planning agrisilviculture in a certain region, is the form or organization. Of particular importance is who (or which service) is responsible for what.

Different organization forms can be distinguished in the regions where agrisilviculture is already employed. The most common form is a governmental forestry service, owner, or manager of the land, which carries out planting of the trees and harvesting, or which puts out a contract to a third party.

The forestry service issues parcels of land to farmers, just large enough to supply food for one family. The farmers grow their subsistence crops on this patch of land and they carry out work for the forestry service, or they pay rent for the land and are paid as forest labourers. In both cases the work for the forestry service can be cutting and clearing of the existing vegetation, site preparation, and cleaning of the young plantation. Often farming activities of the peasants are not sufficiently backed up with supplementary measures by the government. Some times only prohibition orders concerning crop choice are given; then the farmers hardly have a chance to obtain any prosperity by farming activities. In addition, it is usually forbidden to grow arable crops in the forest reserves where agrisilviculture is carried out, so that usually farming activities are legally limited to the growth and harvesting of minor forest products.

Consequently this organization form is mainly suited to transforming shifting cultivators into forest labourers, and keeping forest labour cheap.

A second organization form is when the forestry service undertakes the growing of arable crops under its own control, or issues this to contractors who construct the forest. The functions of the arable crop plus attendant cultivation measures are usually to keep the young plantation free of weeds or to cover a part of the establishment costs by revenues from agriculture. Forestry as well as agricultural activities are often carried out mechanically. Examples of this form of organization can be found in India in the federal states of Kerala and Madras (HESMER, 1970).

In a third organization form, forestry and agricultural extension for the farmers is involved, most ideally by a cooperative organization which also provides for marketing of agricultural as well as forestry products. In Sri Lanka this system is called the Cooperative Afforestation System (HESMER, 1970). The cooperative obtains a licence for a certain area from the governmental forestry service, it fells all valuable trees of the forest and sells this to the government for a fixed price. The remaining wood is sold to those interested. Afterwards, teak is planted at a fairly wide spacing (3 x 3m) so that arable crops can be grown in between for about 3 years.

Within this organization form the agrisilviculture can easily be evolved to a real multiple land use system. An example of the latter is the "système sylvo bananier" in Zaire carried out by the Société Agrifor and developed by the INEAC. Here bananas (4 x 4m) were planted simultaneously or later interplanted by limba (*Terminalia superba*) at spacing of 12 x 8 or 16 x 46 m. When the bananas became overshaded and went out of production, cocoa or coffee was interplanted (HESMER, 1970).

When the organization form and laws are created a precise planning of the course of the agrisilvicultural rotation has to be made. Within this planning a large number of strongly connected factors play a part.
Some of these are:

- Production of forest as well as agricultural products. Planning of the desired production, quantitatively as well as qualitatively, is the basis for all further organization.
- The rotation in which the trees play the important part, and the succession of phases of intercropping (see also procedure).
- Manuring; type of manure and quantity per crop must be established.
- Crop choice. The choice of the trees comes first, and the choice and sequence of arable crops is as much as possible adapted to this.
- Spacing and plant densities. The possibilities of the system can be enlarged by varying the spacing of trees and crops. For instance, teak is planted in spacings varying from 1.8 x 1.8 m to 3.6 x 4.5 m (HESMER, 1970).
- Parcelling and succession of phases in forest establishment. The rotation of the forest, and the availability and mobility of labour are two of the determinants which influence what area can be forested annually, and what size the arable fields will be.

To be successful in all aspects, planning of the form of settlement and its attendant infrastructure is needed.
If population, not production, is the first priority in an agrisilvicultural system, then the planning of re(af)forestation of a certain area must be done around a village where at least the following provisions are available: a dispensary, a school, and a trade centre (shop or market). If the minimum number of families is set at 100 (implying 700-800 inhabitants per village) and if the arable land needed for one family is assumed to be one hectare, this means that, based on two years of agricultural use within the young plantation, every year 50 ha must be cleared and forested. At a forest rotation of 60 years, the village requires 3000 ha of arable land, assuming that the forest is not (or only slightly growing. If the village has more than about one hundred families it means, under the given assumptions, that mobility of the village plus social provisions should be taken into account. At a certain point in the rotation the distance from a village to the field (estimated at a top limit of 5 km by FAO, 1974) may become too large.
Social institutions may be needed if the settlement pattern, composition, or the size of the village strongly differs from what the people were used to previously.

Besides the public services sector, the specific forest and agriculture service sector should be included in planning. For this an extension service and eventually a credit organization should be organized. It is assumed that the farmers themselves do not wish to remain on a subsistence level, and therefore the government and in particular the forest service must be concerned for their desires.

3.4.5 Maintenance, harvest and management

3.4.5.1 Weed control

This is very important for the maintenance of tropical forest plantations. In the tropics weeds are considered to be all plants which hinder the optimum development of desired species. This hindrance can be competition for light, nutrients, and/or water, but it can also be of a mechanical nature. Weed control is especially important in the first years after planting. After crown closure it is limited to deformation-causing climbers and stranglers.

Weeds can be divided into four groups:
1) grasses;
2) herbs, shrubs, and small trees;
3) climbers and stranglers;
4) larger trees (WEIDELT et al, 1975).

It should be borne in mind that weeding is not always advisable since weeds cover the soil; on exposed sites weeding may be more harmful than competition (see also nursery crops VI 3.5). Therefore, weeds should be controlled only as needed. After removal of weeds, new weed growth springs up which may be different from the former one. A light lateral shading by weeds may improve stemform and check development of heavy branches on (planted) trees. Under dry conditions weed control may be necessary to reduce fire hazard.
The frequency and need for weed control depends on the planted species and local conditions. In warm, humid climates three to four times weeding in the first year is not uncommon; in arid climates nil to two times per year is normal.
Weeding has to be carried out more often when use has been made of small and/or poor planting stock. Consequently frequent weedings are required when direct sowing is applied; during weed elimination the plants can also be set at the right distance. The number of years during which weed control is required largely depends on the rapidity of crown closure. Widely spaced plantings require a longer period of weeding than narrow spaced ones.
Control of grasses, herbs, and small trees can be effected in the following ways:

a) Cutting down by machete or reaping-hook (most common in the tropices): all weeds are cut down, or only those around the trees.
b) Crushing down the weeds: in the Philippines, experiments have been reported in which special shoe-broadening constructions are worn by heavy persons in order to crush down the weeds, thus weakening them.
c) Mechanized weed control: use is made of a tractor with a rotary-cutter or other implements. Wide spacing should be chosen to permit the use of machines for maintenance. Hand-operated machines can be used also.
d) Chemical weed control: often applied in developed countries. Use is made of selective herbicides; they should not damage the trees (nor be dangerous for man or animals); usually it is either a monocotyledon- or a dicotyledon-killer.
e) Cattle: in certain stages of development of the plantation, especially with agrisilviculture, cattle can be used to eat and trample weeds in the plantation provided the trees are not damaged.

Climbers and stranglers are controlled by frequent cutting and removal. Climbers sprout very rapid after cutting, therefore spraying with herbicides may be a good supplement to control. After crown closure, the nuisance caused by climbers will rapidly decrease.
Larger trees can be eliminated by cutting, girdling or the use of chemical agents like 2.4-D or 2.4.5-T and arsenical compounds. Cutting of larger trees is seldom done because of the damage they can cause when falling.
In line plantings complete weeding is done in the lines only; however, between the lines weeding is only carried out if necessary and this is usually limited to larger trees and climbers.
In group planting, maintenance is often difficult because of the inconvenient arrangement of the cultures. With agrisilviculture plantations, as a rule the practicing cultivator carries out the weeding of the stands. Weed control is very expensive; therefore possibilities for reducing its frequency by silvicultural measures must be thoroughly investigated.

3.4.5.2 Pruning

Practically every tree forms branches; the length of the period of exposure to light determines to a certain extent the diameter of the branch.

The degree to which lower branches die depends on genetic factors and the density of the stand. The best natural pruning can be observed in closed, even-aged stands (WEIDELT et al, 1975, after SMITH, 1962*)
The activity of fungi is very important for self-pruning. After planting, shoots at the base of the tree, forkes, and lower branches of young trees should be pruned in order to obtain a clear, straight bole.
Dead and living branches are not beneficial for the quality of the wood for certain applications.Ingrown living branches are less harmful than dead ones, which cause defects and holes in the wood.
Pruning of branches is usually beneficial for obtaining knotless, more highly appreciated timber. It is especially important when natural pruning is insufficient Pruning must be started at an early stage. It is mostly limited to dead and moribund branches such as forks, heavy side branches, etc.
When green branches are pruned resin may flow out of conifer trees and formation of water sprouts may occur on broad-leaved species. When green branches are pruned, the crown/root system ratio is modified and this influences growth. Pruning of heavily damaged and/or shaded branches, however, does not affect the crown/root ration since they contribute very little to net production. The removal of green branches usually has more influence on diameter growth than on height growth: diameter growth of the lower portion of the stem is slowed down compared to that of the upper part. This may have a favourable effect on form.
Usually natural pruning of broad-leaved species is better than of conifers (WEIDELT et al, 1975). Cutting off is done as near the bole as possible leaving only a small scar which is readily occluded by the growing cambium around it. Some species are liable to infection and therefore the wound has to be covered.
Use is made of a pruning saw with accessories (e.g. of bamboo) and pruning-shears. Also, various types of small circular saws or drills operating at the end of a telescopic pole are available (CHAMPION & SETH, 1968). Costs of pruning must be balanced by the surplus value obtained from the wood. Therefore pruning is often restricted to the so-called elite systems, which are those trees thought to belong to the final yield crop. However, these are difficult to distinguish in an early stage, so more trees are pruned than necessary.

3.4.5.3 Thinning

Trees need room for the crown as well as the roots. The diameter and volume increment depend upon the amount of room each individual tree has.
Root competition starts quickly after planting, first with grasses and herbs and later with adjoining trees.
Diameter increment of the trees is stimulated by heavier thinnings. With a fair thinning regime, height growth is not influenced by spacing. The volume increment of valuable timber and the total volume per surface unit is, with wider spacing and heavier thinnings, not less than obtained with narrow spacing and light thinning regimes, provided there are no gaps in the canopy (WEIDELT et al, 1975).
Thus thinning (or "liberation") is carried out to improve form and growth of the trees that remain in order to have the final yield in the most profitable form, concentrated on the best available stems. Removal of undesirable, dead, diseased or moribund trees is another reason for thinning because this minimizes the risk of loss from pests and diseases. This second type of thinning is also called "refinement". The elite trees need to be evenly spaced over the site. With thinning attention should be paid to the position of the crown in the canopy, the appearance of the crown, health of the trees and stemform. Inferior trees which compete very little can be retained as a soil cover.
Thinning is done in a number of subsequent operations. It should be done regularly, frequently, and not too intensely. If thinning is delayed too long, many species are unable to respond to the improved conditions. In the tropics it is a practice to thin every 3 years during the early stage of the plantation, and every 5 years later on (DE HULSTER, 1970).

*Smith, D.M. (1962). The practice of Silviculture. New York.

The first thinning is carried out at 6-8 years of age. This first non-paying thinning is often done mechanically;on uniform stands alternate lines are systematically removed. A number of thinning methods exists. In many countries precise instructions are given - sometimes as a part of yield tables - about the number of trees to be removed and retained for different ages. The instructions are based on one of the following methods:

a) Basal area method: the basal area is a good indicator of density; it must be kept sufficiently below the potential maximum; this method is especially important in uneven-aged, non-uniform stands.
b) Numerical thinnings: instructions are limited to the number of stems to be retained per hectare at different ages and for different site qualities. This method is especially important in uniform stands.
c) Distance method: the number of trees to be retained per hectare is calculated by using the formula $S = \frac{a}{Oh} \times 100$, where S = grade of thinning in %, a = average spacement and Oh = top height; this method, strongly corresponding with b), is mainly suited to light-demanding species.
d) Tree thinning: healthy, well-formed stems are given sufficient development; poor-growing, badly formed competing trees are removed; this method deals with changing circumstances within the stand.

The number of trees planted at the beginning (for instance 2500/ha at a spacing of 2 x 2 m) is considerably reduced by thinnings leaving a final crop of 250-500 stems. The yield of thinnings is particularly important for the return of the plantation. By timely thinnings, possible damage from physical agents (e.g. wind) can be avoided, while the incidence of pests and disease is also reduced.

3.4.5.4 Protection of plantations (and naturally regenerated forests)

Every plantation is subject to outside influences, especially when immature. These include threats from the climate, flora, fauna, and man. Strong winds, heavy driving rain, fierce sun, deficiency of rainfall, hail, snow and frost are among the climatological attacks against which protection is difficult to obtain. In this respect the best that can be done is to chose the species, which are best adapted to local conditions.

Some cultural and technical measures can diminish the incidence of calamities. For instance shelter belts or mixed planting can reduce wind danger; adequate soil cover can provide a shelter against heavy rain; a shelterwood can shade a young plantation; and the right date for planting and/or irrigation can prevent water deficiencies. (Hail and frost are very uncommon in South Vietnam, and snow is unknown).

For protection against flora elements see 3.4.5.1 and Appendix II.

Protection against fauna consists of prevention from or combating pests and diseases, and the exclusion of harmful mammals. The disastrous occurrence of pests and diseases may be prevented by not establishing large-scale plantations of a single species. It is also necessary to maintain good forest hygiene, and to undertake correct silvicultural methods. Biological control is preferable; mechanical and chemical control are generally too expensive or not possible. Nowadays much use is made of so-called integrated control which consists of combinations of different methods.

Large earth-bound animals can be excluded by weirs or ditches, but this is usually very expensive. Hunting may be an alternative. Generally speaking, young plantations are very attractive to many animals.

Damage done by man consists of illegal felling, grazing by their animals, and fire - although the latter may be caused by natural events as well. Fire must be prevented; in drier climates, better protection is needed. Protection measures can include fire lines, mixed plantations, easy accessability, necessary materials and extension.

3.4.5.5 Harvest

Harvesting can be done simultaneously by area, or through intermediate selective felling of a part of a stand.
The first method is most commonly used in artificial plantations. It offers many economical, silvicultural, and technical advantages. The disadvantages mainly concern biological conditions and the soil; and the method has a number of limitations on sloping areas. The size of the area to be harvested can strongly vary; however, small areas are preferred. The use of machines and the transport of product require a good infrastructure. Selective cutting is especially undertaken in those stands which have an important soil conservation function, or where only a part of the stand consists of valuable species, or in less uniform stands.
Periodic cutting gives periodic revenues, which may be advantageous. The harvest is, however, as a rule technically more difficult to execute and quite some damage can be caused to the remaining stand during felling and extraction. As harvest is mostly a technical matter, it will not be further discussed here.

3.4.5.6 Planning

Every plantation requires a detailed plan which forms the basis of all work to be done. Every large-scale forest plantation should be based upon planting research, planting plans, clear planting data, and a simple and effective reporting system.
The planting survey, being the basis of the planting plan, is the first action to be undertaken when preparing a new plantation. This survey is carried out by crossing the area and collecting detailed data about topography, infrastructure natural vegetation and historical events, location and boundaries of the area, soil conditions, actual land use, and judicial status.
If sufficient data have been gained, the area is divided into compartments and sub-compartments which should be as homogenous as possible.
The data from the planting survey together with data about the climate, the objective of planting, and the species considered, are embodied in the planting plan. At the same time, data about the needed infrastructural improvements, nursery establishment, quantity of seed, equipment, labour, finance, etc. are all dealt with.
A time schedule is set with a sequence for planting, and at the same time an estimate of annual expenditures is made. The number of years covered by the planting plan should be at least five, and it should be made sufficiently early to enable the obtaining of seed and the growing of planting stock.
Planning of the work is required for an effective and efficient management. The whole planning and execution should be recorded in a plantation register.

3.4.5.7 Control and administration

Correct and complete administration and regular control are the conditions for a well-executed management.
A proper administration of all relevant information for every plantation is essential for the success of afforestation. All data about every planting should be kept, starting with a description of the former vegetation.
According to WEIDELT et al (1975) (after FAO*) all data about the area, the surface, the objective of planting, the species, and the seed source; everything about the stock, planting method, spacing, season of planting, infilling, weed control, pruning, and thinning should be recorded.
All further relevant data should be mentioned as well, with associated costs, yields, manhours, materials, and time. A separate administration should be kept for the nursery.
Regular control is essential for a well-run project. Work must be checked, and the silvicultural development of the stands must be examined.

* F.A.O. (without year). Reforestation administration. Planting instructions for some forest trees [illegible]

This is of great importance for further planning of the work. Good accessibility improves the possibilities for control.
Maps with scale of at least 1 : 10,000 are necessary for good management.

3.5 The use of auxiliary crops

3.5.1 Introduction

Cover crops during first establishment or maintenance of tree plantations serve, on the one hand, to conserve good soil characteristics; on the other hand, they improve deteriorated, eroded, or exhausted soils.
Soil improvers can be divided into those which are worked into the soil by soil cultivation (also known as green manuring crops) and soil-improvers which improve by fixing nitrogen from the air and by the production of litter.
Most soil-improvers belong to the sub-families of *Mimosoidae* and *Papilionoidae* of the family of *Leguminosae* (PURSEGLOVE, 1974). Soil improvers often provide soil cover as well, although not always (shrubs like *Leucaena leucocephala* are good soil improvers, but they have only moderate soil cover qualities - WHYTE et al, 1953).
Cut leaves can be used as a mulch, and thus provide a good soil cover.

3.5.2. Cover crops

Any crop providing a good soil cover, whether planted for this purpose or not, is a cover crop (PARRY, 1956). Within this description it should be noted what is meant by a "good" soil cover: conditions to be fulfilled by a cover crop:

- It should protect the soil and reduce or prevent erosion.
- It should at least maintain the soil structure and its infiltration capacity.
- It must keep the soil temperature as low as possible, thus reducing humus decomposition.
- It should be perennial, easily to be propagated, and readily spread, preferably by seed.
- Rapid and luxurious growth is desired in order to cover the soil and to suppress unwanted vegetation as quickly as possible.
- It should not compete with the planted trees.
- It should not require much tending and must be able to stand pruning and/or mowing.
- It should be able to grow in full light conditions during the early stages of plantation establishment, but it should also be shade-bearing and be able to maintain itself after canopy closure.
- It should be drought-resistant especially in areas with a pronounced dry season.
- It should not be a host plant for the same pests or diseases that affect the planted trees.
- It should not produce chemicals toxic to the planted trees.
- It should be fairly easy to remove if necessary.

Judging by this list, it will be difficult to find a suitable cover crop in a particular situation, so that often mixtures of various species are used.
A soil cover can include legumes, grasses, or the natural vegetation. If natural vegetation is adequate or maintenance can make it so, it is advisable to use this form of cover. Of the grasses only the cespitose species is suitable as a soil cover e.g. *Axonopus compressus* (carpet grass), *Paspalum notatum* (Bahia grass), *Pennisetum clandestinum* (Kikuya grass), and *Cynodon plectostachyus* (giant star grass).
Bahia grass especially seems to be matchless for soil conservation (MCILROY, 1972).
However, grasses are often competing.
In general it can be stated that dense turf in good condition is not inferior to a forest cover from the point of view of soil conservation (WEBSTER & WILSON, 1971).

Legumes have, in addition to their soil covering function, a soil improving capacity. Whether this possibility finds expression depends on the circumstances regarding the presence of attendant Rhizobium strains and mineral nutrition. A fairly good cover and conservation can be provided by a number of creeping legumes, but shrubby legumes may show some gaps on the surface through which more surface run-off may occur than is desired (WEBSTER & WILSON, 1971).

3.5.3. Soil-improvers

When soil needs improvement, a soil cover alone is not sufficient. This situation arises when trees make higher demands on the soil than can be fulfilled by it; or when the forest has a function as fallow vegetation in addition to wood production as happens in agrisilviculture. A monoculture such as teak cannot be expected to give soil improvement (HESMER, 1970).
The following conditions should be fulfilled when considering a soil improver:

- It should deliver a lot of organic matter which readily decomposes into humus. The humus will improve the structure and infiltration capacity.
- It should bring up minerals from the surface soil.
- It should fix nitrogen, which in due time will become available to trees and crops that are cultivated.
- It should be able to establish on poor soils.

If the third condition, nitrogen fixation, cannot be fulfilled (or when prices of nitrogen fertilizers are high) cespitose grasses will be suitable soil improvers, as they make less of a demand on the mineral reserves of the soil than legumes (PURSEGLOVE, 1974). But as the C/N ratio is usually high in the organic matter of grasses, mineral nitrogen should be applied.
Although other species, especially in the tropical rainforest, are able to live symbiotically and fix nitrogen, the *Leguminosae*, particularly those of the subfamilies of the *Mimosoidae* and *Papilionoideae* are known to be the best N-fixers, when they fix nitrogen by root nodules. These root nodules come into being, because Rhizobium bacteria, normally living free in the soil are attracted by the legume roots, penetrate the root hairs and permeate the cortex.
Here they cause all division, from which the tetraploid cells result which form the nodules.
A particular Rhizobium species or strain cannot produce root nodules on every *Leguminosae*; there exist specific Rhizobia for the different groups of *Leguminosae*. Therefore, when introducing a legume, it should be known whether the related Rhizobium is present. When it is not, it should be introduced as well.
The existence of nodules on legume roots does not have to mean that N-fixation is really taking place. The growth and effectiveness of the nodules is influenced by the C/N ratio of the host plant, the quantity of available moisture and the presence in the soil of adequate phosphate, calcium, magnesium, molybdeen and boron. In most cases it is therefore advisable to apply phosphate and microelements when sowing a leguminous crop.
Effective root nodules contain red leghaemoglobin which is visible when it is sliced longitudinally. Ineffective root nodules are small, hard, spherical, and have a green spot inside. In this case the Rhizobium bacteria parasite on their host and the legume concerned will probably make higher demands on the N-reserves of the soil than some other cover crops (PURSEGLOVE, 1974).
The total gain received from nutrients of a creeping leguminous cover crop in the first five years is 225-350 kg N/ha, 18-27 kg P/ha, 85-131 kg K/ha and 15-27 kg Mg/ha (Anon., 1972). Nye & Greenland give data of the net annual N-fixation for forest and savannah which are in the order of respectively 105 and 40 kg N/ha (NYE & GREENLAND, 1960).
Creeping legumes are often sown in a mixture in between cash crops such as rubber. An example of the ratio of such a mixture of *Pueraria phaseoloides*, *Centrosoma pubescens*, and *Calopogonium mucunoides* is 5 : 4 : 1 (weight percentages) when at least 5.7 kg/ha is sown (ANON., 1972).

The seeds of many legumes require pre-sowing treatment because of their hard seed coat. This can be done by means of hot water or with sulphuric acid.

3.5.4 Legumes used for cover and improvement

In South Vietnam the following legumes are reported to be used (WHYTE et al, 1953):

Acacia dealbata	*Dolichos lablab*
Cajanus cajan	*Erythrina lithosperma*
Calopogonium mucunoides	*Indigofera endecaphylla*
Centrosema pubescens	*Indigofera hirsuta*
Centrosema plumieri	*Mimosa invisa*
Crotalaria anagyroides	*Phaseolus semi-erectus*
Crotalaria alata	*Pueraria phaseoloides*
Crotalaria usaramoensis	*Tephrosia candida*
Crotalaria striata	*Tephrosia vogelii*
Desmodium ovalifolium	*Vigna hosei*

In Java, teak plantations, established in an agricultural system are underplanted with *Leucaena leucocephala* and acacias like *Acacia villosa* of which the wood is used as fuel. *Acacia villosa* has the advantage that it is less often grazed by cattle (HESMER, 1970).
In table VI 10, some characteristics of shrubby and herbaceous *Leguminosae* used in the tropics and subtropics as soil cover, green manure, or for erosion control are given.

3.6 Choice of a tree species

See Appendix IV.

VI 4 NATURE CONSERVATION

4.1 Introduction

The originally rich ecosystems of South Vietnam (see III.3 and III.4) have been seriously disturbed by shifting cultivation, extraction of forest products, hunting, and particularly by war and war-related activities (see chapter IV).
To meet their primary demands, men unavoidably interfer with various vegetation types. But this must be done in a way that can be spoken of as repsonsible land use and this must be based on ecological principles.
At the same time, from the ethical, bio-cultural and socio-economical point of view, the natural resources of a forest should be managed in such a way that the coming generations have the same possibilities of use as the present-day one.
Motives for establishment and maintenance of reserves are:

- indirect economical use, for example for tourism or water regulation;
- direct economical use for "wildlife utilization": that is the utilization of the natural fauna to obtain protein, fat, skins and organs;
- unforeseen future value: at this moment little is known about tropical plants and animals, particularly about the potential utilization of many species.
- scientific value: the tropical forest is considered an enormous gene source with many species which may be important for the breeding of crops and animals. Furthermore little is known about the functioning of the tropical forest ecosystem so that insufficient knowledge exists about the possibilities of durable production in an ecosystem derived from the tropical forest and influenced by man. Once a tropical forest has degenerated, it is very difficult and time-consuming to restore it (if this is possible at all).
- Value as natural beauty.

To meet these objectives it is essential that certain areas are left in their natural state or are given the possibility of restoring themselves in order that as many natural elements as possible are conserved or developed. This can be achieved by the designation of certain areas as reserves, national parks, etc. Below are some criteria which play a part in the selection of areas to be conserved, followed by a discussion of measures which should guarantee the durable conservation of natural elements.

4.2 Criteria in the selection of an area for a reserve or national park

The most important criteria are:

a) The area should offer sufficient possibilities of natural life or development of natural communities.

b) The area should be large enough to accommodate the elements considered for protection. Therefore, the area should be as large as the living area required by the species to be protected; it is even better to reserve at least three times this surface.

c) The life communities to be protected should be conserved in their mutual relationships and the transition areas between one type of vegetation and another (i.e. forest to savannah) must especially be preserved. Transects of gradients should be aimed at: for example from the bottom of a lake (or sea) up to the top of a mountain. A good knowledge of geographical and ecologic-topographic differentiation of the various areas is necessary. Therefore a good conservation program includes an inventory of the natural elements of the country. With this knowledge a responsible choice can be made about which area should be protected.

e) Adequate management of the reserve must be possible. For this purpose planological, mechanical control and financial measures should be taken.

f) There must be possibilities for scientific research.

Besides the above factors, practical possibilities play a part. In selecting a suitable area mostly other forms of land use must be weighed against it. Commonly national parks and reserves are situated in areas unsuited to permanent agriculture.

4.3 Management

Management of flora and fauna occupies an important place in the management of natural resources. For an adequate management within the reserves one must be able to exclude all undesirable influences from outside (poachers, pollution, water extraction, disturbances, etc.) and to realize all desirable measures. For plants this may concern control of the groundwater level, grazing, burning, etc. For animals it may be necessary either to limit their number by catching or shooting them, or to protect them (strict reserves), or to introduce them. On account of man, the manager must be able to close the whole reserve or a part of it; and if the area is accessible, to impose those restrictions needed for the reserve (e.g. hunting interdiction, fire preventive measures). Also adequate guarantees should be created for good development and protection of flora and fauna outside the reserves.
The following factors are important for a proper management of the natural resources both inside and outside a reserve:

- A national conservation policy must exist. To be durable and feasible, a legal basis and a conservation institution are essential. The institution can be a part of the Ministery of Agriculture or Deparment of Forestry.
- Sufficient educated labourers should be available, as well as education courses.

- One should be able to raise sufficient funds.
- Carrying out investigations is very important. In the first place inventories are important. Further research should be carried out in regard to the occurrence, distribution and life conditions of the principal ecosystems in their specific habitat, and to the flora and fauna elements which require special management. Research should indicate the carrying capacity of an area, and data about the population of a species. This is not only important for proper management within the reserve, but also augments knowledge about how to utilize natural resources in a more responsible way.
- Education and extension in schools and by various newsmedia are of outstanding importance for effective nature conservation.
- Contacts with international organizations such as the FAO, I.U.C.N., W.W.F., etc. play an important role in getting advise for the development and management of reserves.
- To realize a proper and diversified nature conservation policy, contacts with neighbouring countries are important.

4.4 Nature conservation in South Vietnam

In spite of the war, some efforts were made to do something in the field of nature conservation. In 1959 some laws concerning protection of the fauna and national parks became effective. Hunting licences, hunting zones, and hunting prohibitions were established. Furthermore, five areas totaling 676,640 ha were designated to become a zoological reserve. The Krong-Poko reserve near the boundary with the Khmer Republic and Laos is the largest (533,670 ha).

However, according to PHAM HOANG HO (1965), the existing laws were not sufficiently effective to protect rare animals like rhinoceros, tapir, kouprey, gaur and others. Apparently the regulations were not enforced during the war. The above author also emphazises that a large number of endemic plant species should be protected, including the tree species *Pinus krempfii, P. dalatensis, Libocedrus macrolepis, Dacrydium pierii, Podocarpus imbricatus,* and *P. neriifolius.* Particularly the regions of Bach-Ma, Vong-Phy, Hon-Ba, Da Lat and Chau-Doc are considered of outstanding importance.
To conserve the greatest possible diversity of life communities and interesting flora and fauna elements in South Vietnam, PHAM HOANG HO (1965) and PHUNG TRUN NGAN (1965) propose a number of areas to be designated as national parks or reserves in addition to the already existing reserves (see Appendix VI F).

It is, however, still unknown how far the existing and the proposed conservation areas are able to fulfill the conservation function.
Two aspects, which require special attention concerning nature conservation in South Vietnam are periodic burning and shifting cultivation.
Periodic burning is mostly caused by man. Particularly in lowland woodlands (*Dipterocarpaceae*), highlands (*Pinus merkusii, P. kesiya*), and in the savannahs it is a problem. Effective fire control is essential from the viewpoint of nature conservation. The measures to be taken may include:
- Establishment of fire breaks in fire-sensitive areas.
- Adequate fire control brigades, as for instance those which have been set up in the regions of Dran-Da, Lat-Finnom.
- Education campaigns and no-burning bonus systems for communities as was formerly done with some success in Laos and Khmer Republic.

Shifting cultivation carried out by the Montagnards is, in South Vietnam considered as the principal cause of erosion and deforestation. It can, however, be observed that cultivated areas in an environment of natural life communities bring about diversity, particularly when the disturbance is relatively slight. The acitivities of the Montagnards offer certain plants and animals a change in development. In many cases this can be spoken of as enrichment. For instance, the

activities of Montagnards in Malaysia have created a niche for the gaur (KNOX DENTAN, 1965).
Thus, shifting cultivation may be advantageous for nature conservation. Whether it is destructive or not, largely depends on the length of the fallow period. Brief rotation periods have resulted in impoverishment in some areas in South Vietnam (e.g. Plei Ku and Quang Duc). In other areas measures should be taken to insure that these areas do not proceed in the same way.
To solve these problems all kinds of complications must be overcome; especially the differences between the lowland people and the Montagnards (including religious and ritual aspects) play a part in this complexity. The agrisilvicultural system can offer an useful alternative to shifting cultivators (see VI.3.4.4).

VI 5 CONSIDERATIONS ON THE RESTORATION OF DEVASTATED INLAND FORESTS

5.1 Introduction

After determination of the physical potentials existing for various kinds of land use, a socio-economic analysis of the needs of the land is carried out; this results in a designation of the desirable land use (see Chapter V). When weighing a choice between an agricultural or forestry classification, socio-economic, political and cultivation factors play an important part. Since this project group mainly deals with forestry, it is assumed that a forestry destination has been chosen.
Forests can have several functions which often go together (see VI.1.1). When the economic function is the most important, then the question arises which products will be needed, and for what market will they be produced. Furthermore, it must be decided whether they will be produced in an artificial or a natural regeneration system (see VI.2 and VI.3.4).
In the following sections, various aspects of both natural and artificial regeneration systems will be discussed and some considerations on restoration of various types of devastated sites are presented.

5.2 Natural versus artificial regeneration

5.2.1 Introduction

Often a number of silvicultural systems are available for recovery or improvement of the silvicultural production of a certain vegetation. These systems differ in a great number of aspects; every system has its advantages and disadvantages. Of importance are the existing vegetation, the available quantity and quality of labour, the knowledge of the systems, and the production aim. Besides silvicultural aspects, socio-economic and political aspects are important (for example in areas with a high population density or high demand for pulp, generally the artificial regeneration system will be preferred). The final choice of a system should be made after a deliberated analysis.

5.2.2. Principal differences between artificial and natural regeneration

In the following section, the principal differences between the three systems (artificial regeneration, natural regeneration, and spontaneous regeneration) will be placed next to each other and compared. Natural regeneration is more or less considered to take place in mixed broad-leaved forests, while artificial planting is done mainly in open areas. The characterizing aspects of spontaneous regeneration, such as great diversity and strong buffering capacity, emerge (generally somewhat less strongly) in natural regeneration. Artificial regeneration deals with a far less varied ecosystem with low diversity and a weak buffering capacity. Production is, however, greatest in the last system.

actor	Spontaneous regeneration	Natural regeneration systems	Artificial regeneration
. Importance of the forest in view of:			
water regulation and soil conservation	great	great	little to less great
biotope for various plants and animals	great	less great	little
education and research of natural ecosystems	great	less great	little
. Number of valuable species	small to large	usually large	usually one or some
. Exploitation	difficult to harvest; high costs per unit of harvested product	difficult to harvest	easily harvested
. Standing volume of valuable wood	small	medium to small	high
. Wood production	very low; annual increment ± ¼-1m^3/ha	low; annual increment from 1-2 to 3-6 m^3/ha	high; possible annual increment 15-20 m^3/ha; in extreme cases 30-40 m^3/ha
. Felling cycle	very long	long	moderately long to short
. Structure of stand	heterogeneous; usually diameter class distribution according to Liacourt	uneven aged and heterogeneous	even aged and homogeneous
Resistance to pests and diseases	high	high	low
Control of pests and diseases	less relevant	less relevant	fairly good
. Sensitivity to risk of extreme climatological conditions	slightly sensitive	slightly sensitive	sensitive
. Silvicultural research	not relevant	techniques of these systems are not everywhere known and applicable; long term research required; results uncertain	techniques more known and readily applicable; after a few years of research, tangible results can be obtained
. Skill of labour	not relevant	high demands because of difficulty of silvicultural measures	low to no demands for level of skill; silvicultural measures usually simple

Factor		Spontaneous regeneration	Natural regeneration systems	Artificial regeneration
13.	Control of silvicultural treatments	not relevant	as a rule, difficult	as a rule, easy
14.	Flexibility of adaptation of various silvicultural measures to changing circumstances	not relevant	quite possible	hardly or not possible
15.	Initial costs	not relevant	low	high
16.	Possibility of temporary growing of agricultural crops	not relevant	impossible	quite possible
17.	Labour intensity	not relevant	extensive	intensive
18.	Mechanisation of establishment and maintenance	not relevant	impossible	quite possible
19.	Economic risks in view of calamities	less relevant	small	great
20.	Minor forest products	present in low quantities but in great diversity	to a somewhat smaller degree as under spont. regeneration	may be present in large quantities but in small diversity
21.	Social aspects	by local population often not recognized as an estate	as under spontaneous regeneration	often recognized as a culture by local population

5.2.3 Natural regeneration in Vietnam

From here, it is difficult to say whether a natural regeneration system has possibilities in Vietnam. When it is considered, it will probably concern the following vegetation types:

a) The moist evergreen forest with valuable species such as *Dipterocarpus spp.*, *Hopea odorata, Dalbergia bariensis, D. cochinchinensis*, and others is fairly well represented on the strongly segmented plateaus. Natural regeneration may be possible here, unless the area is insufficiently accessible, or if the protection function of the forest is neglected.

b) The moist semi-deciduous forest with valuable species such as *Amoora spp., Anisoptera cochinchinensis, Hopea odorata, Dipterocarpus obtusifolius*, and *Lagerstroemia angustifolia*.

c) The dry deciduous forest with valuable species such as *Pterocarpus pedatus, Pahudia cochinchinensis, Terminalia spp., Hopea odorata, Dipterocarpus spp.*, and *Lagerstroemia angustifolia*.

d) The "halliers" belonging to a succession series, of which the climax is formed by one of the vegetation types mentioned above.

e) The "forêt semi-dense" with valuable species such as *Xylia dolabriformis, Sindora spp., Parinarium spp., Irvingia spp., Pterocarpus spp.*, and possibly with an undergrowth of valuable bamboo species like *Bambusa spp., Schizostachym zollingeri*.

The gaps created by herbicide sprayings in the canopy of closed forest formations (IV.4.2.2) can be compared (very roughly) with the overstorey removal which is done in various natural regeneration systems. These "treatments" were, however, carried out with much higher concentrations of herbicide, and were far less selective. Observations made in a closed forest formation (moist semi-deciduous forest or dry deciduous forest may be the most appropriate formations) during the French colonial time indicated that two years after soil treatment and a certain admittance of light, an adequate stocking of valuable regeneration was present mainly consisting of *Shorea hypochra* and *Dipterocarpus dyeri* (ANONYMUS, 1935, 1936). Few data are present to establish whether this has been happening after the recent herbicide spraying of closed forests. It was observed that understories of upland forests which had been defoliated but not burned, had a species composition including heavy components of desirable *Dipterocarpaceae* and a little bamboo, even when defoliated three times (except on places where it had been logged heavily). Most of the defoliated and burned areas showed very little successful regeneration by *Dipterocarpaceae*. It should be mentioned that the information regarding the extent of these problems is grossly inaccurate (NEWTON, 1977, personal communication). Data about this regeneration are, however, required in order to be able to assess whether a natural regeneration system has possibilities or not.

If the mentioned vegetation types are accessible, a linear sampling can be carried out in order to determine whether an adequate stocking of useful regeneration is present and whether it is able to establish itself amidst the tangle. It should be determined whether liberation has to be carried out or if it is better to wait for some years. Competing bamboo may be poisoned, but it seems more appropriate to cut and use it, especially when a market for the bamboo species is present. It is known that bamboo can be very abundant, in particular on slopes. Possibly, a rational exploitation of bamboo can be started, followed by a natural regeneration system, eventually with enrichment planting. This has been done in the "Hill Dipterocarp Forest" in Malaysia.

Before application of a natural regeneration system, the following factors must be considered:

- Understanding of the dynamics of the forest (VI.2.2) is required. Research is needed to gain this understanding.
- It may take 15-20 years of research before the system really starts.
- Educated labour and training should be available for the initial research as well as for the subsequent treatments.
- Research should include determination of the amount of light needed for optimum growth of valuable species and minimum development of non-desirable species, the number of treatments required, an analysis of the costs needed to form a valuable stand compared with the yields, and a reduction of logging damage.

5.2.4 Artificial regeneration in Vietnam

In the past, experience has been gained with this system, particularly with planting in an open area, and "régénération mixte". No evidence about other forms of enrichment planting nor agrisilviculture in Vietnam could be obtained from literature.

If line planting is to be considered, research will be required to deal with the following problems:

- Site preparation: width of lines, intervals between lines, poisoning of thick trees, degree of treatments in the vegetation between lines.
- Planting: species, planting stock, method of planting, distances along the lines, light requirement, natural seedlings, growth.
- Maintenance: tending within and between the lines, thinnings.

An economical and silvicultural analysis of the potential of the system should be made. Research will occupy a large number of years (at least 10) before large-scale plantings can be put into practice.
Similar considerations hold for group planting.

Vegetation types which might be considered for enrichment planting are:

- The moist evergreen forest, the moist semi-deciduous forest, the dry deciduous forest and the "hallier". Particularly when spontaneous or natural regeneration has given unsatisfactory results, enrichment planting can offer a good addition or improvement. The appropriate light admittance is often the greatest problem. Usually these vegetation types are to be found on slopes where more intensive forms of planting are undesirable from the point of view of soil conservation.

- Bamboo vegetation types. Possibilities of enrichment planting depend on the relative size of the bamboo area as compared with the surrounding vegetation. Bamboo as well as tree species may be introduced; these will form the stand together with spontaneous regeneration of valuable bamboo and/or tree species.
- Thicket. Line or group plantings can reduce the costs of site preparation when compared with complete planting. Spontaneous regeneration or a natural regeneration system are not possible here. In this vegetation type only light-demanding species can be planted.

In the past, quite a number of species has been planted in open areas in South Vietnam, particularly in the coastal zone and also inland. To apply large-scale planting in the future, short-term investigations usually will be sufficient. They should be focussed especially on species for planting on different sites. Terrains with highest priority in planting are eroded sites or sites subject to erosion, with emphasis on soil conservation and soil improvement. Other sites suited to complete planting are the economically less productive vegetation types such as *Imperata* fields, savannahs and prairie-steppes.

In principle, open field planting (or complete planting) can be done everywhere; however, in heavily varied vegetation the costs of site preparation are very high, while ecologically more justifiable alternatives are present.

Agrisilviculture, as far as we know, is seldom applied. In the first place this system might be of special importance for those areas where sifting cultivation is practised. These areas are often covered with a heavy vegetation so that they are not attractive for complete planting as yet. In these areas, there should be a changing over in the system from shifting cultivation to agrisilviculture. Also on terrains where in the past complete planting was applied, the possibilities for agrisilviculture should be investigated; it should be employed as much as possible.

5.3 Considerations on the recovery of various devastated sites

5.3.1 Introduction

Although the various war actions and their impact often cannot be separated from each other, in the following section five types of sites have been distinguished for the devastated inland forest:

a) sites sprayed with herbicides (5.3.2);
b) bombed and shelled sites (5.3.3);
c) sites cleared by "Rome ploughs" (5.3.4);
d) eroded sites (Appendix III);
e) Imperata fields (Appendix II).

For each of the first three types of sites, a key plus explanation has been made in which some considerations of potential importance are dealt with. A number of important socio-economical and political considerations have not been taken into account, simply because they are very hard to fit in. However, these considerations play an important role in deciding on a forestry designation and further conclusions about the silvicultural use of a certain area. It should, therefore, be stressed that the keys are only to be used as an approach. The final decision about a certain site will depend on a complex of factors. The mentioned considerations should be closely examined, and eventually fitted into the Vietnamese destination plans.

5.3.2 Terrains sprayed with herbicides

5.3.2.1 Key

1.	**Accessibility of the terrain**		
a)	not accessible		
a_1	explosives still present	removal of explosives	1.b
a_2	risk of falling wood or presence of tangle	some years waiting	1.b
a_3	position of the terrain		
a_{3a}	sufficient financial means	$7b_1$	
a_{3b}	insufficient financial means	7a	
b)	Accessible	further inventory	2.
2.	**Vegetation type**		
a)	Closed forest formations		
a_1	moist evergreen and moist semi-deciduous rainforest, dry deciduous forest	3	
a_2	"hallier"	4	
a_3	bamboo vegetation	5	
a_4	thicket	6	
b)	open forest formations-savannah		
b_1	large complex	14 — 14a. 15.a 14b. 17.a_1	
b_2	scattered small areas	7.a, eventually too 17.a or 15.a	
3.	**Closed forest formations**		
a)	locally intensive pure bamboo stands	forest, 7.b	
b)	mixed with bamboo in scattered small areas	during some years 7.a,-7.b_1-7.b_2 16.b 14.b-17.a_2	
c)	without bamboo	7	
4.	**Hallier**		
a)	mixed with bamboo	14.b-17.c 16.b	
b)	pure	7-7.a or 7.b_2 14.a-15.a 14.b-17.a_2 14.c	
5.	**Bamboo vegetation**		
a)	pure stands	16.b	
b)	"forêt semi-dense"	16.a	
6.	**Thicket**		
a)	bamboo with potentials	14.a-15.b-16.b 7.a	
b)	bamboo with no potentials	14-14.a-15.a 14.b-17.a_1	

7.	Natural regeneration	
a)	spontaneous regeneration	protection forest, reserve
b)	natural regeneration system	
b_1)	improvement	e.g. "Uniformisation par le haut" system
b_2)	regeneration establishment	8.
8.	Medium diameter classes	
a)	well established	9.b
b)	poorly established	9.a
9.	Monocyclic or Polycyclic system	
a)	Monocyclic	10
b)	Polycyclic	
b_1)	strong canopy opening harmful	e.g. Selection System (N.S. Wales)
b_2)	strong canopy opening not harmful	e.g. Group Selection System (N. Queensland)
10.	Valuable stocking	
a)	adequate	11
b)	inadequate	12
11.	Reaction on light admittance	
a)	favoured by strong light admittance	e.g. Malayan Uniform System
b)	favoured by moderate light admittance	shelterwood needed during some years e.g. Post-exploitation System (T.S.S., Trinidad)
12.	Inducation of valuable regeneration by canopy opening and cleaning	
a)	possible	13
b)	impossible	14.b-17.b
13.	Reaction of induced valuable regen.	
a)	adequate	e.g. Pre-exploitation Shelterwood system (T.S.S. Nigeria)
b)	shelter still necessary	e.g. Extended Shelterwood System (Andamans, India)
14.	Artificial regeneration	
a)	complete (open field) planting	15
b)	enrichment	17
c)	agrisilviculture	taungya system (usually not on slopes
15.	Complete planting aimed at	
a)	trees	planting of valuable tree species
b)	bamboo	16

16. Bamboo culture

a)	with a thin shelterwood of valuable tree species	management system aimed at bamboo as well as at trees
b)	pure bamboo stands	managed by selective felling system

17. Enrichment

a)	line planting	
a_1	light-demanding species	
a_2	shade-bearing species	
b)	group planting	
c)	régénération mixte	especially with useless bamboo and potentials of valuable regeneration of tree species (seed sources present)

5.3.2.2 Explanation to the key

1.a_1) - Explosives may form a danger for more than a century. They can be traced, however, by means of detectors; and then eliminated.

1.a_3) - In Vietnam this holds for many forest areas in the montagnard and sub-montagnard zone, although it should be kept in mind that these forests have an important protective function.

7.a) - With spontaneous regeneration, the natural succession has been left alone to follow its course and the area is protected against outside influences. This can be done if the area is inaccessible or if the forest has an important protective and/or social function (e.g. soil conservation, hydrology, nature conservation, or recreation).

7.b) - First it should be questioned, of course, whether the desired wood products can be obtained by a natural regeneration system, and if so, whether they can be obtained in sufficiently large quantities.

8, 9, 10, 11, 12, 13. - According to VANNIERE (1974), a high number of stems in the low and medium diameter classes per hectare are an indication of a polycyclic system. Which monocyclic or polycyclic system is most suitable depends on the economic circumstances and forest policy, and on the most suitable silvicultural treatment for a certain vegetation type.

5.3.3 Bombed and shelled terrains

5.3.3.1 Introduction

When dealing with this type of terrain, it should be kept in mind that only a part of it is covered with craters. To make an area such as this productive agai a solution for the problem of the craters must be found. If, however, adverse affect of craters on the site is relatively small (no erosion, few craters per surface-unit) than efforts may be limited to the non-affected parts of the site. Before a large-scale undertaking, local investigations into the best possible biological and/or mechanical procedures must be carried out. If this is neglected, recovery may not happen at all, or it may take a long time.

5.3.3.2 Key

1.	a)	Terrain accessible	3
	b)	Terrain inaccessible because of:	
	b_1)	unexploded munitions	2

	b_2)	dense vegetation or falling wood	to be left alone for some years and then 2
	b_3)	position of the terrain	
	b_{3a}	financial means available for opening up	2
	b_{3b}	financial means unavailable	protection forest (reserve)
2.	a)	Financial and technical means to eliminate explosives available	3
	b)	Financial and technical means available	protection forest (entrance prohibited)
3.	a)	Sloping terrains with occurrence of erosion	Appendix III
	b)	sloping or flat terrains with little or no erosion	4
4.	a)	Few craters per surface-unit	5
	b)	many craters per surface-unit	11
5.	a)	Terrain between the craters	6
	b)	Terrain directly around craters	7
	c)	Inside the craters proper	9
6.	a)	Moist evergreen and moist semi-deciduous forest, dry deciduous forest, hallier	Enrichment planting; eventually complete planting or agricilviculture (eventually natural regeneration)
	b)	Less high and/or more open vegetation. Thicket, woodland, savannah, prairie-steppe	Line planting (except in the two latter types); agrisilviculture (not on prairie-steppe); complete planting; eventually nat. regen.
	c)	Bamboo vegetation, at least partially economically valuable	Rational management of bamboo stands
7.	a)	Soil covered	8
	b)	Soil scarcely covered or bare	soil cultivation and planting of suitable species
8.	a)	Vegetation economically and/or ecologically valuable	spontaneous regeneration
	b)	Vegetation not valuable	soil cultivation and planting of suitable species
9.	a)	Craters dry	soil cultivation and planting of suitable species
	b)	Craters filled with water	10.
10.	a)	Craters to be reclaimed by biological methods	soil cultivation and planting of suitable species
	b)	Craters cannot be reclaimed	spontaneous regeneration

11.	a)	Sufficient financial and technical means, labour; flat terrains	12
	b)	Insufficient means and man-power; sloping areas	natural regeneration; protection forest
12.	a)	Terrain between craters	line planting; complete planting
	b)	Around craters	soil cultivation and planting of suitable species
	c)	Craters themselves	9

5.3.3.3. Explanation to the key

1.b_2) - Some years after disturbance, the impenetrability will diminish (is "moved upwards") and all dead wood will have dropped.

2. - The presence of non-exploded munitions in the forest will prevent every activity. Whether it will be eliminated or not depends on the technical possibilities and the priority given to it.
How highly the economical potential of the forest is estimated cannot be judged from here, but in our considerations it is assumed that the terrains must be made productive again. Therefore, unexploded munitions have to be removed.

3. - The need for erosion control is evident; however, priority cannot be judged from here.

4. - This division is subjective and no concrete form can be given to it directly.

6.a) - With complete planting, the whole standing vegetation must be removed. Since yields, except fuelwood and charcoal, probably cannot be obtained from the removed vegetation, agrisilviculture may be preferred, because of the lower initial costs. However, enrichment planting (in particular, line planting with shade-bearing species) seems to be the best method. With every method of artificial regeneration attention should be paid to grouped mixing of species because mixed planting increases the likelihood of getting the right species on the right spot under varying soil conditions.
The disadvantage of a natural regeneration system is that valuable regeneration mostly has to be obtained from the smaller diameter classes, since the medium diameter classes are usually useless because of implantation of shrapnel.

6.b) - Compared with the vegetation types under 6.a), costs of site preparation are lower so more intensive forms of planting seem attractive. For natural regeneration the same disadvantages hold as under 6.a).

6.c) - See 5.3.2. and Appendix I.

7. - Soil-improving species will be advantageous for soil fertility and may reduce soil compaction. Soil cultivation is rather simple.
Investigations about suitable species have to be carried out. The soil improving and soil conserving properties of a species will usually be more important than the direct economical value.

10. - Filling the craters, as has been done on behalf of agricultural use, is not practical for forested areas for the following reasons:
1) it is too labour-intensive; 2) the relatively fertile topsoil of non-hit terrain might be removed; 3) drainage on the spot of the crater remains poor.

Therefore, it is better to break the compact, impermeable layer; this is only feasible when the crater is dry. The introduction of strongly transpirating species at the crater's fringe (e.g. *Eucalyptus spp.*) or in the crater, might favour reclamation; further soil cultivation may result in permanently better drainage.

5.3.4 Cleared terrains

5.3.4.1 Key

1.	a)	Terrains subject to erosion (surface runoff)	erosion control measures; protection forest; see Appendix III
	b)	Terrains not subjected to erosion (or hardly)	2
1.	a)	Sloping terrains (gradients over 30%)	to be left for some years; then, eventual natural regeneration or enrichment planting
	b)	Flat or gently sloping terrains (gradients below 30%)	3
3.		Original vegetation	
	a)	Moist evergreen and moist semi-deciduous forest, dry deciduous forest, hallier, forêt semi-dense, woodland	4
	b)	Thicket, savannah, prairie-steppe	7
4.	a)	Favourable development of secondary growth	5
	b)	Poor development of secondary growth	complete planting
5.	a)	Terrain inaccessible because of dense growth	to be left for some years, then 6.
	b)	Terrain accessible	6
6.	a)	Secondary vegetation includes considerable number of valuable species	spontaneous regeneration; liberation of regeneration; eventually enrichment planting
	b)	Little or no valuable regeneration	line planting, complete planting; agrisilviculture
7.	a)	Imperata fields	Appendix II
	b)	Others	complete planting; eventually agrisilviculture or line planting

5.3.4.2 Explanation to the key

2.a) - The erosion hazard on sloping terrains always exist. Recovery of vegetation will reduce the hazard, but it may take several years before proper protection is achieved.

4.a) - It is considered to be favourable when a varied and ascending vegetation develops so that the soil will be permanently protected.

4.b) - Special attention should be paid to mixing with soil improving species and other auxiliary crops.

6.b) - Soil deterioration has not happened to such an extent that a varied secondary growth has been made impossible. On soils which have become too poor, agrisilviculture is dissuaded.

VII CONCLUSIONS

A. PRE-WAR SITUATION

1. Before 1960 the South Vietnamese economy was weakly developed in general, and it was unilaterally directed at agriculture with little industry. The forestry sector was underdeveloped; it was mainly concerned with the extraction of valuable species out of what was left of the primary forest, in order to supply some manufacturing industries. Means and manpower were scarce, and research and training were done on a very modest scale. A proper forest inventory has never been carried out.
2. Already before the war actions in forest areas, there was a strong human impact on the inland forests especially in the lowland and the sub-montagnard zone. The originally rich ecosystems had been disturbed seriously, or had been degraded to less rich ecosystems by over-exploitation, shifting cultivation, periodic burning, uncontrolled hunting, etc.
   The moist evergreen forest had disappeared because of this; it could only be found on steep slopes and on strongly dissected plateaus.

B. CONSEQUENCES OF THE WAR

3. To give a clear picture about the effects of the various war actions has been difficult because of lack of adequate information from the field, and also because a complete picture of the pre-war situation is lacking.
4. About 1.4 million hectares of South Vietnamese forest have been sprayed with herbicides one or more times. Of the forest thus affected, 80% belong to the inland forest which are 90% closed, and 10% open forest formations. In particular, the moist semi-deciduous forest, the dry deciduous forest and the "forêt semi-dense" have been most seriously hit. *Lagerstroemia angustifolia* and *Leguminosae* occurring in these forest types proved to be very sensitive. As a rule it can be stated that gaps in the canopy originated from the herbicide sprayings, and that, depending on the species composition and the number of sprayings, a more or less homogeneous light admittance resulted from it. Especially hallier- and bamboo species have been favoured by this. Locally a heavy tangle of secondary species including climbers have developed. Also locally, pure bamboo stands may have developed, particularly where bamboo was present in the undergrowth before spraying. Bamboo proved to be less sensitive to herbicides since the most commonly used agents were dicotyledon killers. The establishment of bamboo and *Imperata* was strongly favoured by burning after spraying.
   Herbicide residues probably did not hinder the regrowth of vegetation anywhere.
5. About 104,000 ha of forest in South Vietnam were completely destroyed by bombing and shelling. About 5 million ha were damaged by high-explosive munition. Many craters were made with an average diameter of 10 m and a depth of 4 m. In and immediately around each crater the soil is very compacted. Colonization by vegetation is very difficult; surface runoff and erosion may occur. Many of the craters became filled with water, creating a breeding place for *Anopheles spp.*, increasing the danger of malaria.
   At a distance of some meters around the craters all vegetation was knocked down; at a much larger distance trees have been struck by shrapnel, often leading to death. Economically, the hit wood is worthless and the forest is rendered inaccessible by the presence of much non-exploded munitions.
6. About 325,000 ha of South Vietnamese forests were completely destroyed by mechanical land clearing. Locally, the soil became very compacted, in particular where the operations were carried out in the wet season and on loamy soils. The debris from the clearing was sometimes left on the spot and burned, but in most cases it was pushed aside.

On many such areas soil fertility dropped because of leaching of nutrients, local removal of the top soil, and accelerated oxidation of humus. Compaction of the top soil, surface runoff, and erosion increased; this had implications for downstream areas where extremes in river discharge became more pronounced and the sediment load increased.
Induration of plinthite probably occurred at a very small scale only, mainly after erosion in areas with (soft) plinthite. Whether secondary vegetation develops after land clearing depends on a number of factors. If it does develop, it probably will be of little economic value. It seems likely that *Imperata spp.* will become more extensive.

7. As a result of the war, on one hand the de-population of the countryside accelerated and the population of towns strongly increased; on the other hand, in forested areas local concentrations of Montagnards took place (especially into strategic hamlets and because of fleeing from insecure areas). As population density becomes too high, shifting cultivation becomes ecologically unjustified and is rendered impossible; locally the vegetation is seriously degraded, which results in soil degradation and/or erosion.
8. Disturbance and degradation of the vegetation already taking place before the war was reinforced by the war actions. As a result, flora and fauna were seriously depleted. Some animals have even been threatened with extinction, particularly because of the intensive damage inflicted on their habitat.

C. LAND-USE PLANNING

9. An inventory of the physical potentials for various forms of land-use should be made. In order to obtain a good view of ecological conditions, the mutual relations between climatological, edaphic, and biotic factors should be investigated.
It is advisable to adhere as much as possible to international acknowledged systems for typification and classification of climate, vegetation, and soil. The system for climate is that of SCHMIDT and FERGUSON, as well as the bioclimate type-system of GAUSSEN; for vegetation the UNESCO system is best; for soil the FAO/UNESCO Soil Map of the World or the American System (Soil Taxonomy, 1975) is useful.
A fauna inventory should be carried out. Aerial photographs are a useful means, together with terrestrial surveys, to obtain most of these inventories.
Subsequently, a land-use plan should be made, based upon a socio-economic analysis of the needs of the country.
10. The development of the forestry sector may have important advantages for Vietnam as a diversification of the economy. It can also contribute to satisfying wood demand, spreading the population, creating employment, and saving of currency. To come to a directed development of the forestry sector, information about the position, extent and wood quantity of the various forest types must be obtained. For this purpose, a forest inventory is necessary.

D. POSSIBILITIES FOR RESTORATION

11. The considerable amount of non-exploded munitions present in the forests prevents every activity during a large number of years. To make the terrains accessible and productive again, the explosives must be eliminated. This could be achieved by detectors.
12. If the principal function is the production of raw materials (like wood and minor forest products), the following methods can be employed:
    a) Spontaneous regeneration;
    b) Natural regeneration as a system;
    c) Artificial regeneration by means of enrichment planting, complete planting or agrisilviculture.

13. Considerations about which production method to be applied in the various areas will depend on cultivation, socio-economic, and political factors. The choice is based on local conditions; for example, mainly natural regeneration can be applied in areas with vast forest reserves and low population density, while artificial regeneration is preferred in areas with a great pressure on land.
14. In hilly and mountainous areas, the protection function of vegetation is of primary importance. If the cover is effective in performing this function, incidental exploitation of valuable products can take place, after which the vegetation is left alone (spontaneous regeneration).
15. Natural regeneration
For application of a natural regeneration system the following factors are important:
    a) Adequate valuable stocking must be present, or easily induceable; this is a prerequisite.
    b) Knowledge about the ecology of the species is required.
    c) Experience is necessary with treatments to be considered such as light admittance, liberation.
    d) Reduction of logging damage.
    e) Presence of sufficient skilled labour.

    If research on a natural regeneration system is being considered, it should concern the moist evergreen forest, the moist semi-deciduous forest, the dry deciduous forest, the "halliers", and the "forêt semi-dense".
16. Artificial regeneration
In the past, artificial regeneration has proved to be successful in Vietnam, especially with complete planting and the "régénération mixte". As far as it is known, other forms of enrichment planting (like line-planting and group-planting) have never been employed in Vietnam. Agrisilviculture is also little known.
If one wants to introduce less-known endemic species and exotics, they must be tested first on their suitability in trial plots. During a period of several years, growth and development of the various species have to be observed. By elimination and tests it is finally decided which species can be planted.
17. Large-scale complete planting requires relatively short-term research because experience with this way of production has been gained in Vietnam. Terrains which should first be considered for complete planting are those which are eroded or being eroded; savannahs, *Imperata* fields, and the prairie-steppes.
18. Research on the spot is necessary to examine the possibilities and prospects for line-planting and group-planting. Vegetation types to be concerned in this research are the moist evergreen forest, the dry-deciduous forest, the "halliers", the bamboo formations and the thickets.
19. As far as we know, agrisilviculture is little or not applied in Vietnam. this system forms an alternative to shifting cultivation and is, among other systems, to be considered for areas where the Montagnards are living. The Montagnards are traditionally seen as a special problem in Vietnam because of their shifting cultivation, and the contrast they form with the lowland population.
Organization and support play an important part. With every forest establishment by means of complete planting, the possibilities of combinatior with temporary arable farming should be considered.
20. Natural regeneration as a means of recovery of inland forest areas in South Vietnam seems best considered for herbicide-sprayed terrains. Investigations have to show whether an adequate stocking of valuable regeneration has appeared, and whether this regeneration will be able to develop well. If so, good possibilities for a natural regeneration system seems to be present. Liberation may be required to favour further development of valuable regener tion. This will require research also. When bamboo is present this may consi

of valuable or useless species. Rational management of valuable bamboo, eventually combined with valuable tree species, will produce sustained production in a rather simple and inexpensive way.

21. Presently inaccessible terrains in the montagnard and sub-montagnard zone may be considered for improvement. When after some decades the terrains become accessible and can be exploited (for instance by an improved infrastructure) a greater yield/ha may be possible and a good starting point for more intensive silvicultural management is created.

22. The bombed terrains will be economically useless for a long time unless man undertakes action. If it is decided to make such terrain productive again, distinction should be made between:
    a) the craters themselves;
    b) the area directly around the crater;
    c) the remaining area.

    Each of the distinguished terrain types has its own distinctive approach and treatment. Filling of the craters, as was frequently done in agricultural areas, is not feasible in forested areas. Combined biological and mechanical methods might be a solution for making the terrains cited under a) and b) productive again. The terrain directly around the crater may be improved by soil cultivation and the introduction of suitable species. The craters themselves, if water-filled, first have to be reclaimed. This might be achieved by the introduction of strongly transpirating species at the edge of the crater of in the crater itself, or of species able to break up compacted layers.

    Once dry, cultivation may (further) break the compacted soil and provide permanently good drainage.

23. Possibilities for the recovery of Rome-ploughed terrains include spontaneous regeneration, complete planting and, possibly, enrichment planting. Agrisilviculture is to be dissuaded because of severe soil impoverishment and compaction. Because of the erosion hazard, a quick soil cover is necessary, especially on sloping sites. The use of soil-protecting and soil-improving auxiliary crops is advised.

24. Bamboo, locally occurring over vast areas, has many uses. Large, united areas offer good prospects for pulp and paper production. Until now, however, little has been known about the suitability of the various endemic species for this purpose. Large-scale planting might play an important role in the future, but until now this role has been limited because of the lack of suitable propagation techniques. Therefore, research will be required, involving a proper management technique for the existing natural areas and the areas to be established.

25. *Imperata* fields occur in South Vietnam over more or less extensive areas. Although the herb has a very low value, some uses exist: roofing, isolation. Control of *Imperata spp.* can be realized by biological, mechanical, or chemical means.

26. Auxiliary crops may offer important support during planting or maintenance of tree plantations, in conserving favourable soil characteristics, and in restoring deteriorated, eroded, or impoverished soils. Especially *Leguminosae* are useful as auxiliary crops.

27. It is necessary to take measures which will lead to conservation of the still existing valuable ecosystems, as well as measures which possibly recover, but at least counteract degradation of already seriously-affected ecosystems. For this, certain areas have to be designated as reserves, national or regional; these areas should meet a number of criteria.

28. For proper management of natural resources inside as well as outside the reserve, the following conditions hold:
    a) A national forest policy must be laid down which has a legal basis, and in which there is a place for nature conservation.
    b) A well-formed institution for the execution and control of the various measures.

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