Technical guidelines for reforestation in degraded limestone areas under semi-arid climate

- Based on the outcomes of experimental reforestation activities in degraded limestone areas under semi-arid climate in East Nusa Tenggara Province of Indonesia -

Japan International Forestry Promotion and Cooperation Center (JIFPRO)

March 2015

Technical guidelines for reforestation in degraded limestone areas under semi-arid climate

- Based on the outcomes of experimental reforestation activities in degraded limestone areas under semi-arid climate in East Nusa Tenggara Province of Indonesia -

Eiichiro Nakama, Seiichi Ohta, Tokunori Mori, Yasuo Ohsumi and Satohiko Sasaki
Japan International Forestry Promotion and Cooperation Center

Japan International Forestry Promotion and Cooperation Center
(JIFPRO)

March 2015

Forward

During the past decades, deforestation and forest degradation continues especially in developing countries. According to the report of the Food and Agriculture Organization of the United Nation (FAO), approximately 13 million hectors of global forests have been lost annually due to forest land conversion to other land uses, forest fires and natural disasters, while reforestation and natural regeneration account for an increase of approx. 7.8 million hectors of forest cover. This means the net loss of global forest is estimated at 5.2 million hectors.

Adverse impacts of forest conversion to farmland can be minimized as far as the land is properly used and managed in a sustainable manner. However, in some cases, problem soils are exposed and abandoned as degraded land. In Indonesia, among other developing countries, when forest covers are lost under the semi-arid climate conditions, agriculture and animal grazing activities will lead to decline of soil productivity. As a result such land is left and become wasteland.

How to recover degraded forest land in semi-arid areas is not only an issue in developing countries, but also have become a global concern which need to be addressed urgently. In order to tackle such an issue, the Forestry Agency of Japan, under its program to support reforestation in developing countries, has started a four-year project of “Model Forest Development in Degraded Lands” starting from the Japanese Fiscal Year of 2011.

This project is aimed at developing appropriate methodologies for land preparation, tree species selection, planting techniques for degraded land recovery, taking into consideration the scientific data such as environmental and soil conditions of the plantation sites in semi-arid limestone areas of East Nusa Tenggara Province, through on-site surveys and establishment of pilot reforestation sites. These technical guidelines are the result of the model pilot reforestation activities.

We would like to express our sincere appreciation to the International Forestry Cooperation Division of the Forestry Agency, Ministry of Agriculture, Forestry and Fisheries in Japan for their financial support and advises for the implementation of this project. Our special thanks also to the project advisory committee members chaired by Dr. Katsuhiko Kojima, the University of Tokyo for their guidance on the planning and implementation of the surveys. Last but not least, we owe our deepest gratitude to the

Directorate General of Watershed Management and Social Forestry Development of the Ministry of Forestry in Indonesia and the Benain Noelmina Watershed Management Center as our counterpart, the Forestry Research and Development Agency of Ministry of Forestry in Kupang and the Forestry Services of the Soe District Government in East Nusa Tenggara Province, Indonesia.

March 2015

Dr. Satohiko Sasaki, President
Japan International Forestry Promotion and Cooperation Center (JIFPRO)

Table of Contents

Chapter 1. Background and purpose of the project

1-1. Present status of forest vegetation and degradations in East Nusa Tenggara Province of Indonesia

These technical guidelines have been compiled based on the results obtained from the sub-project: "Development of reforestation techniques on wastelands after human activities" under the "Project of forestation in developing countries" of Forestry Agency of Japan. The sub-project was implemented by Japan International Forestry Promotion and Cooperation Center (hereinafter referred to as "JIFPRO") from April 2011 to March 2015.

The main activity of the sub-project was to establish reforestation techniques through experimental planting on the following two model reforestation sites:

1) Acid soil areas of backfilling land by coal mining activities in South Kalimantan Province under tropical rainforest climate;

2) Degraded lands by extensive farming activities in limestone areas in West Timor of East Nusa Tenggara Province under tropical savanna climate.

While the present reforestation guidelines are prepared for the latter model site, namely the degraded farming land under dry climate of West Timor, they could also be applied to limestone based tropical monsoon forest areas of South East Asia in general, such as eastern islands of Indonesia, inlands of Indochina and Myanmar, western parts of the Philippines, southern parts of Papua New Guinea and northern parts of Australia.

Figure 1 shows monthly rainfall patterns at Banjarmasin and Kupang, the nearest weather stations of the two experimental sites in South Kalimantan and West Timor respectively. According to the precipitation data from 2012 to 2014, the annual rainfall in Kupang city ranges from 1,500 to 2,000mm. The rain is mainly distributed in wet season from November to April while average rainfall during dry season is only 80mm.

The climate in West Timor is categorizes as tropical savanna by Köppen climate classification or dry sub-humid land by the UNEP dryland classification (with annual rainfall exceeding 800mm in the tropics). In East Nusa Tenggara Islands in general, rainfall is less in northwestern parts (including Kupang city) than in southeastern parts. However, the annual rainfall in the model areas in southern part of West Timor would not fall under 1,000mm. Thus, West Timor can be categorized as severe seasonal dry area or a relatively humid semi-arid area.

As discussed in detail in Chapter 2, the soils of West Timor are originated from lifted limestone with savanna climate, where tall forest tree species, such as broad-leaved and/or deciduous trees, could potentially grow. These trees can tolerate weak alkaline soils and dry period for several months.

However, relatively humid savanna vegetation (grassland with scattered shrubs) currently predominates in substantial areas of West Timor. As discussed below, this is the result of retreat of natural vegetation succession by reckless farming activities and repeated burning for grazing.

Indonesian Forest authority and local people wish to recover the natural forests on these degraded lands, and to increase production of fruit and other forest products in order to improve local livelihood.

According to "Ecology of Nusa Tenggara and Maluku" (K.A. Monk et al. 1997), average annual rainfalls and lengths of dry season in Kupang City in 1980 was same as the present conditions, but total rainfall during the dry season had exceeded 300mm. It may have turned somewhat drier recently.

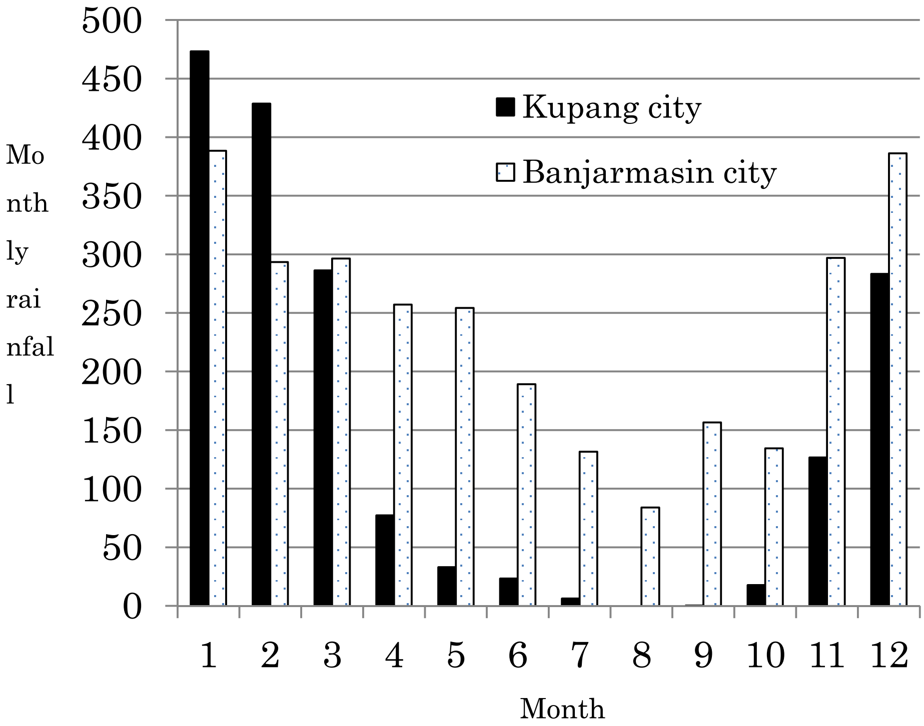


Fig. 1　Monthly rainfall at Banjarmasin city (average year) and Kupang city (average 2012 to 2014)
Annual rainfall and ranges of monthly average temperature are 2,870mm and 26.1～28.0℃ in Banjarmasin and 1,755mm and 24.9～28.8℃ in Kupang.

While the potential vegetation of Nusa Tenggara Province belongs to dry forest zone with deciduous trees, about 30% of the provincial territory is currently covered by dry shrub forest (so called Belukar in Indonesian) (K.A. Monk et al. 1997). In Timor Island, annual slush and burning of forest lands has repeatedly been practiced for more than a century, in order to claim the land for shifting cultivation, grazing and hunting. Such exploitive human activities have reportedly led to disappearance of dense forests and invasion of savanna vegetation consisting of pioneer shrubs and alang-alang (Imperata cylindrical) grass.

In the degraded grassland of Nusa Tenggara region, in addition to pioneer shrub species, the following tree species have been said to be a indictor; ①*Albizia chinensis,* ②*Eucalyptus alba,* ③*Melaleuca cajuputi,* ④*Acacia* sp., ⑤*Causarina junghuhniana,* ⑥*Ziziphus mauritiana,* ⑦*Tamarindus indica,*⑧Plam（*Borassus flabellife, Corypha utan*）(A.K. Monk *et al.*, 1997).

In addition to these species, *Acacia farnesiana, Bauhinia malabarica, Cassia fistula, Schleichera oleosa, Ziziphus mauritana etc.* are also said to be found in the grasslands of East Nusa Tenggara (Adisoemarto 1982). According to van Steenis (unpublished, in A.K. Monk *et al.*), if such grasslands in Timor are protected from human activities, many pioneer tree species in surrounding natural forests would invade into the grasslands by through seed dispersal. These include *Dillenia pentagyna, Pandanus* sp., *Nauclea orientalis, Aegle marmelos, Causarina junghuhniana, Acacia leucophloea, Melaleuca cajuputi, Sesbania grandifolia, Eucalyptus alba, Tamarindus indica, Timonius sericeus, Borassus flabellifer, Corypha utan* etc. These species would make small and mosaic colonies. These species will provide valuable information in the selection of planting species for degraded drylands.

Production and accumulation of plant biomass per a unit area will decrease as the vegetation cover changes from closed forest to open forest, to savanna and to wilderness. This means that absorption and accumulation of atmospheric carbon dioxide would also be reduced accordingly. Thus, reforestation of devastated grassland in East Nusa Tenggara Province will not only help improving local environments, but also contribute to the conservation of global environment.

1-2. Basic concept of reforestation in degraded dryland

From the ecological perspective, the final goal point of reforestation in degraded land is to recover the original climax vegetation in the given area. However, on the land which is currently used or has been used by local people, the first measure to be taken is to stop the degradation at present stage. It is believed that, while 13% of vegetative degradation or desertification in semi-arid land are caused by natural factors, 87% are the consequences of anthropogenic factors such as overgrazing, over-cultivation, annual slash and burning (Yoshikawa et al., 2004). Degraded grasslands scattered around Kupan city are also not an exception. Therefore, in the first stage of reforestation, prohibition or restriction of human activities could, in many cases, support natural vegetation transition, namely from grassland to shrub woodland to closed shrub forest and to closed tree forest. However, as described before, it would to take several hundreds of years, for a grassland and pioneer shrub land to recover to the original state of tropical high forest (van Steenis in K.A. Monk et al., 1997). It is considered that human reforestation activities could shorten this period.

The present technical guidelines describe the reforestation technologies recommendable for raised coral limestone areas under tropical savanna climate, which are degraded by above-mentioned causes. In addition to potted seedling planting method widely practiced in tropical zones, basic technologies and know-how provided in these guidelines are summed up in the following four points except the soil perspective described in Chapter 2. These are 1) selection of tree species in situ, 2) selection of planting time 3) production of seedling with strong drought resistance, and 4) preserving soil moisture.

In addition to those, other techniques often used in semi-arid area (where annual rainfall ranges from 300 to 800mm) are also introduced in Chapter 3, because dry ecosystem may be progressing in West Timor.

Chapter 2. Technical Requirement and Implementing Procedure for Reforestation in Semi-arid Limestone areas

2-1. Technical Requirement for Reforestation in Semi-arid Limestone areas

While primary obstacle of forest restoration in semi-arid limestone areas is the absolute shortage of rainfall, other disadvantages in soil properties, such as effective soil depth, soil particle composition, clay mineral composition and chemical property, may make tree growing more difficult.

Basic techniques needed for reforestation in semi-arid limestone areas are as follows;

1) To understand the characteristic of soil environment in the target area (Chapter 3)

2) To select planting tree species and enhance drought resistance of seedlings (Chapter 4-1)

3) To improve soil to avoid desiccation of planted trees and site preparation (Chapter 4-2)

4) Selection of planting time and watering (Chapter 4-3)

5) Nursery (measures to prevent damages by animals) and maintenance (measures against wild fire) after planting

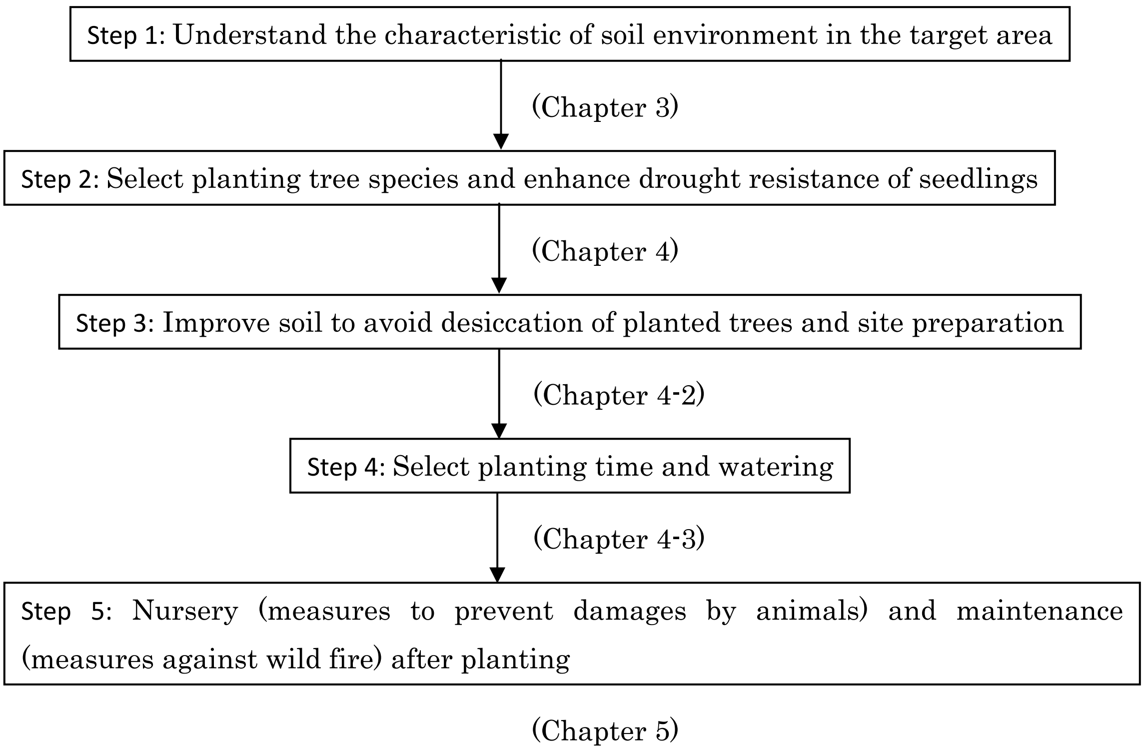
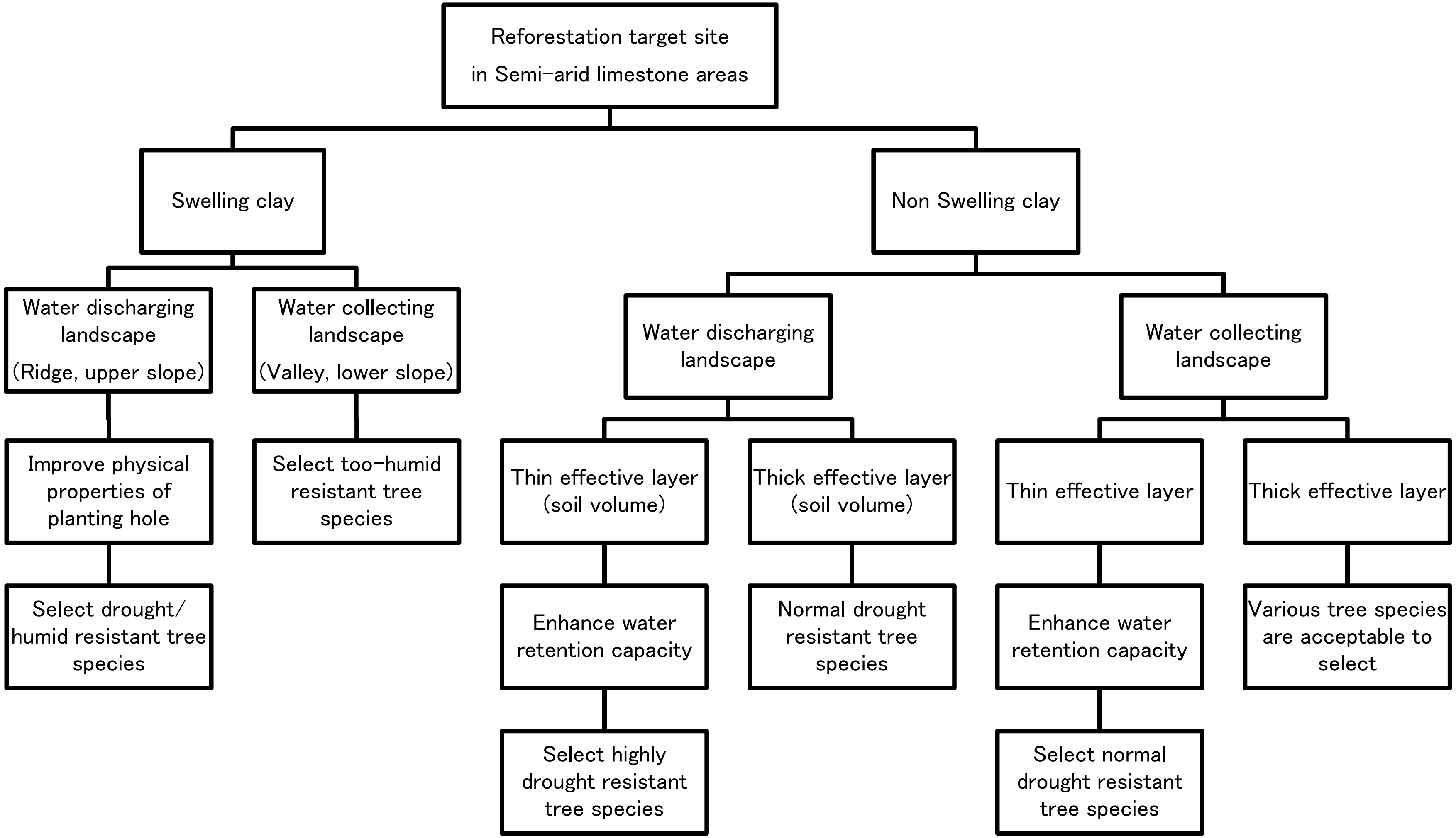


Figure 2-1. Technical Requirement and Implementing Procedure for Reforestation in Semi-arid Limestone areas

2-2. Implementing Procedure for Reforestation in Semi-arid Limestone areas (Decision Tree)



Chapter 3. Classification of soils and their characteristics (property) found in lifted (raised) coral-rags under semi-arid climatic conditions

Central part of semi-arid tropical zone is categorized as tropical savanna (Aw) by Köppen climate classification. Soil Moisture Regime (SMR) under U.S. Soil Taxonomy is categorized as "ustic moisture regime", where a part of soil profile is dry in more than 90 cumulative days per annum and wet in more than 180 cumulative days as well as at least 90 consecutive days.

Soil Temperature Regime (STR) is categorized as "isohyperthermic", where mean annual soil temperature is 22 ℃ or more, and the difference between mean summer and winter soil temperature is less than 6 ℃.

While primary obstacle of forest restoration in such areas is the absolute shortage of rainfall, other disadvantages in soil properties, such as effective soil depth, soil particle composition, clay mineral composition and chemical property, may make tree growing more difficult.

Even in the same semi-arid condition, soil types vary in relation to parent materials, topography and land use history. Thus, for the success of reforestation in semi-arid zone, it is crucial to understand soil characteristics of the target sites in order to select plant species and planting method accordingly.

The pilot project was implemented with an aim of developing a simple manual for forest restoration on problem soil areas in semi-arid zone. Pilot plantation plots were established on degraded lands due to agro-pastoral use which are widely found in West Nusa Tenggara Region (West Timor) of Republic of Indonesia. Plant survival and growth rates are monitored.

Unlike other volcanic islands of Sunda, Timor Island is formed by uplifting of crust. Geologically, majority of the island consists of uplifted coral reef limestones, while marine sedimentary rocks are found in some areas. Central part of the island is mountainous surrounded by low-to-middle altitude mild hills and plateaus. On these hills and plateaus, exploitive agriculture and pasturage have been practiced for long period of time.

This chapter describes main soil types found under semi-arid climate conditions, especially on uplifted coral reef limestone areas of West Nusa Tenggara Region (West Timor). It also explains general characteristics of each soil type and how to determine such soils.

3-1. Soil environment of coral-rag areas in semi-arid land

Several different soils covers (types) are distributed in the target areas according to the soil map of Kupang Region of West Timor.

According to the soil classification of WRB (World Reference Base for Soil Resources), most widely distributed soils are Leptosols (equivalent of Entisols under U.S. Soil Taxonomy) in association with Kastanozems (Mollisols, *ibid.*). Second largest soil types are Luvisols (Alfisols, *ibid.*) mixed with Inceptisols (Cambisols, *ibid.*) where Cambisols and Leptosols are also found in relatively large areas. Vertisols together with other soil orders are also found in some areas.

Characteristics of these soil types in accordance with WRB, and corresponding names used in FAO Soil Map of the World and U.S. Soil Taxonomy are described in Box 1.

Box 1: Major soil types (under WRB: World Reference Base for Soil Resources) found in uplifted coral-rags under semi-arid climate conditions
— Example of West Timor —

Followings are the five major soil types which may be found in Kupang Region of West Timor. Characteristics of each soil and their corresponding names defined in FAO Soil Map of the World and U.S. Soil Taxonomy are described below.

✓ Leptosols:

Leptosols are so-called immature soils which comprise very thin soils over continuous rock (partially weathered or highly calcareous hard rock) and soils that are extremely rich in coarse mineral fragments.

Leptosols strongly reflect characteristics of parent materials. Calcareous soils are more fertile in chemical property than non-calcareous types, have good drainage but their low water retention capacity limits effective soil volume for supporting root systems.

Leptosols include Lithosols of the FAO Soil Map of the World (FAO–UNESCO, 1971–1981), Lithic subgroups of the Entisol Order or Rendoll (subgroups of Mollisols) of the US Soil Taxonomy.

✓Kastanozems :

Kastanozems, which are found in dry zones, have dark brown surface soils with rich organic matter and calcareous or gypsum subsoils. Their dark surface horizon (Mollic horizon) is thinner and not as dark as that of Chernozems. Biological production is low under dry climate. The soil have high base saturation and the pH (H_2O) is neutral to week alkaline. Because of limited infiltration due to thin Mollic horizon with low porosity (40-55%), cultivation on this soil type is susceptible to water erosion of topsoils. The name 'Kastanozems' is used in the legend of FAO and Ustolls (related to Mollisols) in the U.S. Soil Taxonomy.

✓Luvisols :

Luvisols have subsurface horizons with high concentration of high activity clays. They are high in cation exchange capacity (CEC) and base saturation, with low aluminum saturation. Luvisols have rich chemical property. This is because that the soil nutrients are kept under dry climatic environment, where leaching process is restricted. The pH (H_2O) is neutral to moderately alkaline. Drainage is generally good, but infiltration is limited when fine clays are accumulated in lower horizons. The name 'Luvisols' is used in the legend of FAO and equivalent of Alfisols in U.S. Soil Taxonomy.

✓Cambisols :

Cambisols are characterized by slight to moderate weathering of parent material and found in various environmental conditions. The soil properties widely vary in mineral composition, chemical and physical properties. Most Cambisols have medium texture, stable soil structure, high porosity and good internal drainage. Cambisols are mildly acidic to neutral in pH (H_2O) and generally fertile. The name 'Cambisols' is used in FAO legend and include Dystrochepts and Eutrochepts (both are types of Inceptisols) in U.S. Soil Taxonomy.

✓Vertisols :

Vertisols are dark, clayey deep soils dominated by swelling clay minerals such as smectite, that expand upon wetting and shrink upon drying. They form wide cracks from the soil surface down to at least 50 cm depth when drying out. The upper part of the soil commonly consists of strong and columnar soil structure. In the subsoil a typical vertic horizon slickenside develops. Vertisols are relatively rich in chemical property but have shortcomings derived from their physical characteristics: low hydraulic conductivity when wet and a rapid water loss through the cracks when dry. Both FAO Soil Map of the World and U.S. Soil Taxonomy use the name 'Vertisols'

Above mentioned soil distribution in Timor Island shows the coexistence of relatively mature soils with thick soil layers (such as Kastanozems and Luvisols) and immature thin soils with gravelly layers (such as Leptosols) and weakly developed soils such as Cambisols. Such mixed distribution "mature" and "immature" soils may have been formed in association with geomorphological changes overtime and agro-pastoral land use practices in the area.

3-2. Inter-relationship among soil types, topography and land use

Lifted coral reef land in semi-arid zones generally forms wavy/undulating topography. Only shallow and gravelly AC soils (Leptosols) often develop over silicon-deficit limestone, where formation of crystalline silicate clay mineral is limited. Rendzina is typically found in topsoil (A horizon) which lay immediately over the parent material (limestone) without development of subsoil (B horizon). On undulating landscapes, soil denudation usually dominates on convex slopes while sedimentation occurs on concave slopes.

A survey conducted in the target area of West Timor revealed the fact that such land has long been used for agro-pastoral activities. Severe erosive effects on convex land surface have led to loss of fine-textured topsoil (fine earth materials). As a result, land with shallow soil with rich coarse fragments (Leptosols) is left abandoned as degraded land or used only for extensive agriculture or pasture land.

On the other hand, soil materials washed down from upper slopes by erosion are accumulated on depositional landforms such as mildly concave slopes and depressions edging convex slopes. In such areas, relatively thick and fertile soils such as Kastanozems are formed in accordance with the types of local parent materials and soil formation process. Such soils are being cultivated selectively due to their fertileness.

On relatively flat plateaus and mildly raised slopes, soil materials are not eroded and stay on the land surface. Such soils are rich in iron oxide minerals that are formed by weathering of limestones. Relatively well-developed red to dark-reddish Cambisols with good drainage occur on such terrain. Some of such soils with thick effective layer and high water retention capacity, are actively used for agro-pastoral activities. Concave slopes, where soils with thick effective layers occur, are also water catchment where soils are kept relatively moist. Thus, such land is typically used for crop cultivation despite semi-arid climatic condition characterized by long dry season and limited rainfall during wet season.

Convex slopes with thin and gravelly soils are also water discharging landscape simultaneously, where soils are dryer due to low water retention capacity and excessive drainage due to high porosity. Such soils are either abandoned as degraded land or used for pasture and extensive crop cultivation. Soil conservation and development measures need to be taken on such land by increasing vegetation cover and organic matter supply by afforestation activities.

Where there is supply of silicon from upper slopes, which have been produced by weathering of silicicolous rocks, clayey and vertic Luvisols and Vertisols occur.

3-3. Soil type classification where afforestation and reforestation can be planned.

Based on the above observation, the following four soil types are identified as main soil types occur on raised coral-rag areas.

i) Gravelly and immature soils (Leptosols / Entisols)

Leptosols cover largest areas of plateaus in West Timor and are one of the main target soils for forest restoration degraded area in East Nusa Tenggara. Mixture of Red to dark-red Cambisols and Kastanozems with dark brown topsoils are also found in this area. In general, soils of this type are widely distributed on convex slopes, where fine soil materials are lost by erosion resulting from long intensive agriculture and livestock production. As a result, the soils have extremely thin effective sola and rich in stones and gravels with frequent limestone outcrops. Parent materials of raised coral reef have alkaline pH (pH 7 to 8 by field measurement). Water retention capacity as well as nutrient supply of soils with such characteristics are expected to be low.

ii) Relatively deep soils with red to dark reddish color (Cambisols/Inceptisols)

Red to dark reddish Cambisols occur on the plateaus or mild slopes on uplifted coral-reef areas together with Leptosols described above. Cambisols have alkaline soil reaction of pH 7 to 8. Because of their distribution on mostly flat or gently sloping terrain, soil loss and erosion rate are relatively small (10 cm to 80 cm) and soil layers are relatively thick. Since calcareous parent materials release little silicone by weathering, normal formation of silicate clay mineral is restricted. Most part of fine-textured soil materials consists of secondary mineral represented by iron oxides.

With relatively large effective soil volumes, Cambisols in the target area are considered as soils with fewer disadvantages in chemical property, except for deficiency of nitrogen and phosphate.

On the other hand, pseudo sand-like fine aggregates are formed in this type of soils. Extremely fine pores within such fine aggregates hold water with very high retention, and holding capacity of available water that is used by plants is restricted. Water deprivation could stunt vegetation growth.

iii) Dark brown soils with high organic concentration in topsoil (Kastanozems / Mollisols)

Kastanozems with dark brown topsoils occur on gently sloping concave terrain alongside with Cambisols. Soil materials washed down from upper convex terrain are deposited and stabilized in such concave area, forming relatively thick effective soil layers (approx 50-100 cm). In addition, humic substance formed by continuous supply of plant organic matter are accumulated as persistent calcium salt of humus.

As a result, topsoils exhibit dark color and contain relatively large amount of organic matter and possess better physical and chemical properties accordingly.

Kastabizems, as well as above mentioned Cambisols, are considered as less problematic soils in the target areas since topsoils rich in organic matters are considered to be fertile. But since mineral soil components mainly consist of iron oxide minerals, water retention capacity of this soils may be limited like Cambisols.

iv) Clayey soils with vertic characteristic (vertic Cambisols -Vertisols / vertic Inceptisols - Vertisols

Clayey soils with vertic characteristics, that well upon wetting and shrink upon drying are found in part of relatively steep hills and mountainous areas. Main parent material of such soils is considered to be limestones, since they are partly exposed to soil surface. It is considered that mixture of silicone produced by weathering of silicate rocks and silicate clay minerals, especially 2:1 type clay minerals such as smectite and vermiculite with swelling-shrinking characteristics, generated from limestones under high concentration of Ca and Mg in soil systems.

The pH is alkaline from 7.6 to 7.9. Soils become extremely hard in dry season due to existence of 2:1 type clay minerals. Many surface cracks (mostly from 2-4 cm in width) are formed by drying of shrinking clays. Due to excessive drainage through these surface cracks, soils may be kept dry even during scarce rains. Cutting of seedlings roots may also restrict regeneration of vegetations in some cases.

During wet season, on the other hand, soil porosity decreases considerably by swelling of clay minerals and result in extremely poor internal drainage. Excessive moisture in coils could cause restricted growth and damage of root systems.

Since throughout the sola, soils are clayey and crack formation prevail, if development of slikensides are observed in lower layers, the soil is classified as Vertisols. When slikensides are not observed, the clay eluvi-illuviation is nor normally observed. In such case, the soil can be classified as vertic Cambisols.

BOX 2: Profiles Major Soil Types found in Coral-Rag Areas in Semi-Arid Land

1 2 3 4

Figure: Profiles of four major soil types typically found in West Timor

No 1: Stony immature soil (Leptosols / Entisols), No 2: Reddish to dark reddish relatively thin soils (Cambisols/Inceptisols), No 3: Dark brown soils with high organic concentration on surface layers (Kastanozems / Mollisols), No 4: Clayey soils with vertic characteristic (vertic Cambisols -Vertisols / vertic Inceptisols - Vertisols)

Chapter 4. Reforestation technologies in degraded dryland originated from limestone

Major impediments to vegetation growth in degraded dryland in general are (1) lack of moisture and (2)movements of topsoils. However, it is considered that the adverse impacts of soil movements are insignificant in tropical savanna climates, except in coastal sand areas. Thus, this chapter focuses on the countermeasures to be taken against lack of moisture during reforestation activities in semi-arid and dry sub-humid areas (annual rainfall about 1,000mm, more than 6 months of dry season with monthly rainfall below 50-60mm,under UNEP classification). Considering the current situation that the climate in East Nusa Tenggara became a little drier due to the deforestation and degradation, this chapter also mentions other reforestation technologies used in the semi-arid areas (annual rainfall 300-800mm, UNEP)

Related guidelines are also found in two JIFPRO reports; "Re-vegetation manuals for yellow sand measures" (2008, JIFPRO) regarding vegetation recovery technologies in semi-arid deserts of continental Central Asia and "Guidelines for afforestation to improve forest vegetation and water supply" (2014, JIFPRO) which describes significance and necessity of afforestation at semi-arid area of Kenya.

4-1. Drought resistance of planting tree species

1) Selection of planting tree species

When selecting planting species in an afforestation project, firstly, the purposes of the project and then the environmental conditions of the sites need to be taken into consideration. The purposes of this sub-project is to develop afforestation technologies on the land degraded by human activities and to contribute to the improvement of local livelihoods. From the ecological standpoint, in order to recover the vegetation on degraded land, the first candidate species should be the ones that are currently regenerating and the climax forest tree species that used to grow in the area. However, these species alone cannot meet the needs of local residents and also immediate re-planting of climax tree species on degraded bare land is too risky. Thus, it is recommendable that domestic and exotic tropical tree species that have already been planted in Indonesia be included as candidate species. In order to identify these species, the ecological and distributional characteristics of approximately 90 candidate species are studied. The results are shown in Attachment 2, Table of Characteristics of Afforestation Tree Species of this report.

As the next step, the tree species suitable for environmental conditions of the planting land were chosen. The annual rainfall of the planting site ranges from 1,500mm to 2,000mm. 95% of which concentrates in 6 months of rainy season, leaving remaining 6-months dry season extremely drought condition. Given the condition and since pioneer trees or light demanding trees have high adaptability against dry bare land, such trees as pioneer and drought tolerant species (for example, deep-rooting and/or deciduous trees) were selected from the above mentioned table as the candidate trees.

Regarding further information about planting tree species that are tolerant to tropical dry climate are described by Asakawa (1999). He classified dry conditions by length of rainy season and amount of annual rainfall, and the tolerant trees species to them are listed in Table 4 and 5 in his book "Afforestation Technology in the Tropics". Chapter 1 of this book also describes the indicator tree species of savanna grassland and the pioneer tree species invading into the grassland in Timor are as candidate tree species.

The planting sites of this sub-project is covered by soils derived from limestone. In dry climate conditions, the surface soils tend to accumulates salts and prone to alkaline conditions. For this reasons, it is necessary to select tree species that are not only tolerant to drought but also to salinization and alkalization. Relationship between tree species and soil conditions in West Timor are described in Chapter 2. Tree species that are resistant to high salt and alkaline soils can be selected from the "Table of Afforestation Tree Species Characteristics" in Attachment 2. Worldwide tree species of high salt tolerance and alkali-resistant tree species are listed up in the books by Asakawa (1999) and Tumbull (1986).

From the groups of the tree species mentioned above, it is desirable to select the planting tree species in accordance with requirement of local residents (refer to Attachment A-1 PlantedTreeSpecies_Adequateness). Timber and multi-purpose tree species such as *Swietenia macrophylla, Pterocarpus indica, Mangifera indica, Annona muricata, and Syzygium* sp. could be selected for a test planting from the view point of resident's request. By using a healthy and well harden seedling stocks and by promoting a rapid root development after planting (these described below), these species can probably survive and grow slowly, even if they have poor drought tolerance. One of the methods is to plant these species at base of slope where the soil moisture conditions appear to be relatively good.

Finally there is a problem of seed and seedling supply. When the preparation term is limited, the supplying of seedling stocks become sometimes the limiting factors for species selection. The species used in this project (Attachment A-1) is also no exception.

2) **Enhancing drought resistance of seedlings**

Relatively young seedlings with small capacity pot are generally used in case of industrial plantation in tropics. On the other hand, larger planting stocks (over 50cm seedling in height) are used in the semi-arid area, because this method often supports higher survival and growth rate of planted trees.

Regardless of the size of the seedlings, the most important thing is to enhance plant resistance to strong sunlight and drying when raising seedlings. In the tropics, seed germination and seedling are often carried out in a mild environment under the shade net. Therefore, in order to enhance drought resistance of the seedlings, hardening operation should be done before shipment. Such a practice is necessary for the seedings to withstand intense heat and dryness of the planting sites. Details of hardening works are explained in Table 1. Duration and strength of the hardening process need to be modified in according with the species characteristics and seedlings production processes. It is desirable to carry out the hardening process while observing the growth of the seedlings.

Seedlings produced without hardening process have some characteristics unsuitable for planting on degraded bare land with long dry season. For example, the seedlings grew up with full irrigation and mild light nurseries have generally tall but slim stem, thin and broad leaves, and poorly developed root systems (Photo 1).

Table 1. Hardening of the seedlings

Purpose	By enhancing seedlings' resistance capacity to dry conditions under strong light in order to improve their survival rate.
duration and timing	One to a few months after reaching the required seedling height (The faster growth of seedling is, the shorter treatment term is). This will be done just before shipment of the seedling.
Major treatments	1) Gradual reduction of watering up to and 1/2 to 1/3 of normal watering. 2) Expose to sunlight fully. In the case of seedlings raised under dark shade, gradually shift from full shade to open light toward the final stage. 3) Generally reduction of fertilizers. When fertilizers are necessary, reduce N and enrich the supply of P, K, and Ca. 4) Wide spacing between seedlings for stimulating growth of stems and roots.
Major change of	1) Thick and hard stem. Suppression of height growth.

seedling form	2) Formation of hard, thick and small leaves. Reduction of transpiration rates and increase of resistance to strong sunlight 3) Well development of root systems. Shoot/Root ratio is small.

Photo. 1 Seedlings with poor roots grown under dark shade.

Photo. 2 Seedling grown at open bed. The soil caught firmly by the roots when plastic pot was broken, but thick root emerged outside of the pot. This root should be timely cut off at nursery practices.

When potted seedlings are raised on ground surface, it is important to cut off the roots growing below the pot by periodically moving them (Photo 2). In case of net shelves, root trimming is unnecessary because the roots grow out from the pot dry up naturally. In any case of nursery practices, seedlings should not be kept in a pot too long until the roots are coiling at the bottom, nor too short (or in dark condition) when roots can only poorly develop. In the latter case, soils fall off when removing from the pot, leaving bare roots at the time of planting.

In summary, the species with weaker drought resistance or with slow root development must be nurtured to enhance their strength and drought tolerance.

4-2. Operations for avoiding desiccation of planted trees

Of the following measures against moisture shortage of planting sites, 1)-i) and 2)-i) are suitable for use in West Timor, and the others are generally used in more drier regions (e.g. semi-arid area by UNEP classification).

i) Micro catchment of rainwater, the promotion of a water penetration and a water holding capacity of soils

Micro catchment is a method of inducing rainwater to the planted trees by building a low embankment around the trees (Fig. 2, Photo 3). In addition to this, low soil bank (Photo. 4) or stone bank and groove or terrace in mountain slope (Photo. 5, Fig. 3) are made in order to prevent the runoff of rainwater and to stimulate the water penetration into planting holes.

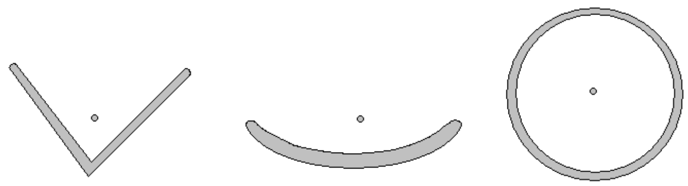


Fig. 2 Typical water catchment banks. From the left hand; open type, fish scale type, closed type

Photo 3 Water catchment banks and planting holes (Asakawa, 1999)

Photo 4　Long type water catchment bank in Burkina-Faso

Photo 5　Planting in terrace on mountain slope (Kourai, 2004)

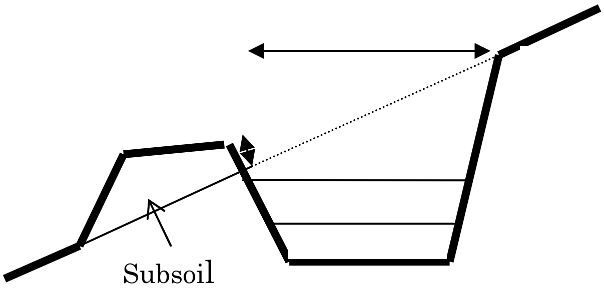


Fig. 3　Vertical section of terrace in Loess Plateau of China (Fujimori, 2007)

In a case of terraces under drier conditions, there are various methods such as wider spacing between terraces, lower planting density and so on. Lowering the planting density is effective to reduce water consumption by leaf transpiration per land area. These water-collecting methods have been widely adopted throughout the world in afforestation works in severe dry land in order to combat desertification.

ii)　Increase water holding capacity of soils:

Degraded dry lands by human activities often have low water holding capacity due to shallow top soils, hard soil particles and less organic materials. Digging as large and deep hole as possible and then putting organic matters or topsoils into the bottom of the hole will improve the water holding capacity of deep soil layers. This operation is effective to allow the tree roots to grow deeply. In addition to organic matters, charcoal is also effective for a holding capacity of water and minerals. Water retention agents (polymeric absorbents, hydrogel) are used by some industrial plantation companies in Indonesia. Water holding capacity of soil will be improved by putting water retention agents with plenty of water into the planting hole at the time of planting or attaching the agents around the root. The agents generally release and supply water to the root for about a week after the planting. In tropics, there is sometimes a period of no rain for a week to 10 days (dry spell) at the beginning or the end of rainy season. If the dry spell come just after the planting, it is highly possible to dry out and kill the seedlings because the roots is not fixing yet. With the application of water retention agents at the time of planting, the survival of planted seedling will increase.

Water retention agent in dried solid form used in this experimental site in East Nusa Tenggara absorbed water 100-150 times its weight for 5 hours. Place 5 litter of the agent to a planting hole (30cmX30cm and 40cm in depth) and mix it with the bottom half soil of the hole. In this experiment, water retention agent was applied at the end of dry season, in other words, before the rainy season. There were no rain for 2 weeks after planting but all the planted 16 trees survived thanks to the agent and all fixed because of the rain falling 2 weeks later (photo 6).

However, if the water retention agents have larger water absorbing capacities than the roots, they could deprive water from the tree roots in reverse. That point should be taken into account when selecting the sort of water retention agents.

(a)Put water retention agent into hole

(b) Planting

(c) Planted seedling 3 months after plantation　(d) 100% survived (all 16 planted trees)

Photo 6　Planting with the application of water retention agent at experimental site in East Nusa Tenggara

iii) Size of planting hole

In relation to i) and ii) of the section 1 above, let's introduce an example of land preparation in semi-arid zone in central part of Myanmar. In that area, annual rainfall is about 800mm and continuous 7 months have rainfall less than 100mm. They dig planting holes of 30cm width, 90cm length and 60cm depth during the dry season (Photo 7). Then they put back topsoils and humus in the center bottom of the hole. Excess subsoils are used for making small embankment which is built at the side of the hole in order to collect rainwater. This planting hole can be sufficiently effective in the water catchment, penetration and holding as described above. Hundred percent of survival of planted trees have been achieved at the place where watering could done at the same time of planting. The tropical monsoon zone in Southeast Asia, including the savanna zone of West Timor, where drying is weaker than that in Myanmar, these planting method would not be necessary.

Photo 7　a deep planting hole and its vertical section (right). Wideness of hole is 30cm. Left hand side of the hole is topsoil and the right is subsoil. A part of subsoil is used for water catchment bank at the side of the hole. Big seedlings of nearly 1 meter in heights is planted.

2) Prevention measures of moisture evapotranspiration from soil and planted trees

i) Prevention of moisture evaporation from soil:

Prevention of moisture evaporation from soil is usually done by mulching which prevents direct exposure of soil surface to sunlight. Mowed grass, sometimes small stone or sand are laid around planted trees as mulching materials (Photo 8). The surface of sand dunes is very dry but the sand at 10cm depth is often wet. Inspired by this idea, farmers practice 'sand cover agriculture', a method to cover farmland with a thin sand layer, in dry areas of northwest China (Koizumi et al., 2000). In heavily degraded land in Bolivia, as described the next section, a method of direct seed sowing and stone mulching was applied in afforestation projects (Photo 9). These methods may not be use in tropical areas because temperature of sand or stone may rise too high and damage stems of planted trees. Another method to prevent evaporation of ground water from the soil surface is shallow tilling of soil surface in order to cut the capillaries of soil water (Fig. 4). In the case of West Timor, mulching with organic matters such as mowed grass is recommendable if such materials are available.

Photo 8 Grass mulching (Asakawa, 1999)

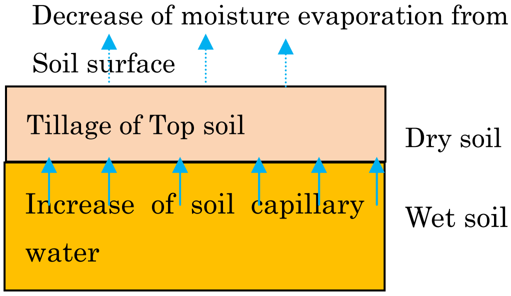


Fig. 4 Cutting of soil capillary water surface by tillage

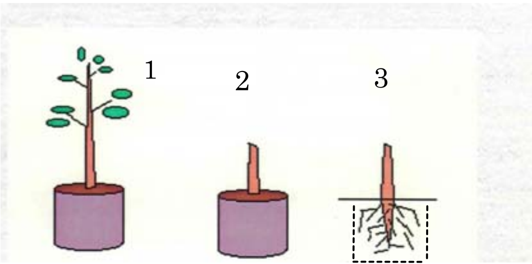
ii) Restraining of transpiration from transplanted seedlings

It is important to maintain good water balance of seedlings immediately after planting in order to support their survival and subsequent growth. Transplanted seedlings have limited water absorption capacity for some days until their roots are expanded into soil. During this time, moisture evaporation from their twigs and leaves need to be minimized. Best time for transplanting deciduous trees is, thus, when they defoliate. As for the species with high coppice ability, stump seedlings whose shoots and roots are partially removed, are used for transplanting because water loss from the seedlings can be minimized. Use of stamp seedlings is famous for teak planting in Thailand. Generally deciduous hardwood trees have strong sprouting force and also hold sufficient amounts of storage materials in their bodies during dry season. They can expand buds and roots even at a term of no photosynthesis activities. For the species with such physiological ability, stamp seedlings can also be used in afforestation in dry area. For example, it may be possible to cut the upper part of the shoot before shipping of potted seedling stocks, and then plant them after removing pot at the plantation sites (Fig. 5).

Asakawa (1999) listed the tree species which have high possibility of stamp planting (Table 2). It should be noted that levels of adaptability for stump seedling transplantation vary even among species listed in the table. For example, Verbenaceae species belongs to the groups with high adaptability of stump planting while Dipterocarpacaea belongs to weaker group. In any case, use of properly hardened seedlings is important in transplanting.

Table 2 Tree species that are available to planting by stump seedling

Family name	Species name
Anacardiaceae	*Spondias mangifera*
Apocynaceae	*Alstonia* sp.
Bombacaceae	*Bombax malabaricum*, *Ceiba pentandra*
Boraginaceae	*Cordia alliodora*
Combretaceae	*Terminalia* sp.
Dipterocarpaceae	*Shorea roxbrugii*, *Hopea orodata*, *Vatica odorata*
Euphorbiaceae	*Bischofia javanica*
Leguminosae	*Acacia* sp., *Cassia* sp., *Dalbergia* sp., *Erythrina* sp., *Gliricidia sepium*, *Leucaena luecocephala*, *Pterocarpus* sp., *Xylia* sp.
Lythraceae	*Lagerstroemia speciosa*
Meliaceae	*Azadirachta indica*, *Cedrela* sp., *Khaya* sp., *Lovoa* sp.
Moraceae	*Chlorophora excelas*
Rubiaceae	*Adina cordifolia*
Sterculiaceae	T*riplochiton scleroxylon*
Verbenaceae	*Gmerlia arborea*, *Tectona grandis*



1: Ordinary potted seedling,
2: Cut off upper stem of the seedling and transport to field,
3: Planted stump seedling after removing the plastic pot.

Fig. 5 Example of planting by stamp seedlings

Planting density is not so much important factor in the case of young tree plantations. However, after 10 years or more of plantations, plantation with high tree density may have a die back of tree top or sometimes death of a whole tree due to water constraint. There is a possibility that water supply from highly closed forests in water reserve area may decrease during dry season, too. Therefore, it is desirable to select a planting density under consideration of annual rainfall. If annual rainfall is less than 800mm, it would be difficult to make high density forests (e.g. >1,000/ha) in the tropics. In the area of annual rainfall is less than 300mm, planting of trees other than special shrubs are usually difficult.

The climatic condition of West Timor is savanna climate with around 1,500mm or more of annual rainfall as described above. High forests with deciduous trees can be established there. In savanna area with annual rainfall less than 1,000mm (e.g. southeast area of Sumba and Uetaru Island or central part of Myanmar), planting density would be safe below several hundred per hectare. Indeed, the standard planting density in semi-arid area of Myanmar is 750 seedlings/ha.

Underplanting method is also effective for protecting planted seedlings from the strong sunlight (Photo 9). Sometimes, methods to cover planted trees by artificial shades (netting or bamboo baskets) are tried in limited areas such as street trees and garden trees. Coffee, cocoa or some agroforestry crops are usually grown under shade trees.

Photo 9 Planting between trees (Asakawa, 1999)

3) Direct sowing and direct cutting-planting

Direct seed-sowing can sometimes be used in dry land and/or degraded land. Because devastated drylands have less weed, germinated seedlings do not need to compete with weeds. Furthermore, the seedlings rarely die from little dryness because their roots grow naturally into deep soil layer (Noda, 2000). It is important to combine the direct sowing and other planting measures. For example, there is a successful example of direct sowing at degraded land by using terraces or groove construction and stone mulching (Photo. 9, Fig. 6 by Shiozuru 2003). Candidate species for direct sowing are the species of large seed and pioneer species because these species can grow promptly and vigorously even in degraded land. In other cases, the seeds of a grass (*Agriophyllum squarrosum*) of semi-desert that can germinate as soon as they have some rain are sprayed to prevent the shifting sand in devastated semi-desert. In greening of wide areas, the aerial dissemination of tree seeds from an airplane is carried out in China, Australia, etc. (Yoshikawa et al., 2004) .

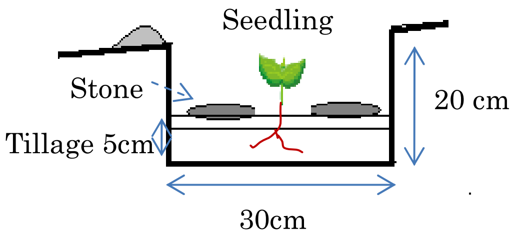


Photo. 9 Direct sowing of *Acacia* sp. in the trench and stone mulching (Bolivia, Shiozuru, 2003)

Fig. 6 Longitudinal schematic view of photo. 9

Tree planting by direct cuttings to the bare ground are widely carried out in the semi-arid areas of north China. Poplar and willow are suitable species for direct cuttings, and their thick and long scions are inserted deeply into the soil before their spring growth. Even in tropical areas, *Gliricidia sepium, Caliandra calothyrsus, Gmelina aborea, Pterocarpus indicus, Peronema canescens* are easy to do cuttings, and they are widely used such as hedges and boundary fences.

4-3. Selection of planting time and Increase of water supply to planted seedlings

i) Selection of planting time

Although this is a matter of common-sense, planting during early stage of rainy season is the most important point under tropical savanna and tropical monsoon climates. In the case of West Timor, the rainy season lasts from the middle of November to the middle of April. The best planting time is therefore December to January, because planting site gets fully moist and planted trees can develop their roots deeply until the end of rainy season. Development of roots into deep soils are important for a plant to survive during severe dry season for 6 months. In central dry zone in Myanmar, for example, tree planting starts after the second rain of the rainy season. This is to firmly confirm the start of rainy season, because in some years, rain may not start some time after the first rain of the season. Considering the plant physiology, dormant trees is most suitable for planting as they are ready for budding at the end of dry season (plant dormant period). Thus, it is recommendable to prepare the planting at early as possible toward the end of dry season. By tilling of planting holes during the dry season, rain water will penetrate into soils and water holding capacity will be enhanced. This will help planted trees to tolerate temporal water deficiency before the roots develop and stimulate resuming of smooth regrowth.

ii) Watering

Continuous Irrigation: Under the tropical savanna climate such as West Timor where annual rainfall is more than 1,000mm with 5-month rainy season, continuous irrigation is not necessary. In the semi-arid and semi-desert areas, the water conduits from irrigation dam and/or sub ground water are set up for farmlands, but these systems are generally uncommon for tree plantation. Continuous supply of large amount of water in semi-arid area often leads to accumulation of salt on the ground surface. To prevent this, dripping irrigation method is adopted for fruit and agricultural crops (Yoshikawa et al. 2004), while this method is still at the experimental stage in tree plantation.

Temporal watering: When the water supply is needed at the tree planting site in semi-arid area, this would be done once at the same time of planting, or a few times when rainfall is scarce. Planted trees are generally left under natural condition in many cases.

4-4. Summary of recommendations

Afforestation technologies at the lands where dry season are more than six months in tropical savanna zones have been described in Chapter 3. Application places of these technologies are mainly divided into two climatic areas from the view point of economy and efficiency. Namely, in Southeast Asia, the first is the region where annual rainfall exceeds 1,000mm (i.e. dry and semi-wet area)and the second is the regions where annual rainfall is a range between 300 to 800mm (i.e. semi-arid area). The first places are, for example, inland of Indochina Peninsula, East Java, the most parts of Nusa Tenggara Islands and the second places are central area of Myanmar and southeast area of Sumba Island etc.

In dry and semi-wet areas, for example where the annual rainfall is one thousand and hundreds mm like West Timor, it is recommended that the following afforestation technologies are adopted.

1) To select high resistant species for drought. In other words, to select from the following species groups; pioneer species, light demanding species, deciduous species, deep-rooting species, species with hard and small leave, etc.
2) To plant the seedlings at moist soil conditions after start of rainy season, and then to finish the last planting three months before rainy season ends. In order to keep proper plant timing, it is desirable to finish land preparation such as digging holes within dry season.
3) To raise strong seedlings for degraded dry lands. This can be done, for example, by hardening practices and root trimming in the nursery.
4) To reduce moisture evaporation from ground during dry season by the mowed-grass mulching around planted trees. It is recommended to mow the grasses at the planted site between the end of rainy season and the early dry season in order to prevent the wildfire and livestock entering. The mowed grasses can also be used as mulching.
5) To input the top soil or composts at the bottom of planting hole in order to stimulate the root growth rapidly and deeply. This practice is important in all cases of tree planting.

In addition to the above recommendations, in semi-arid areas where annual rainfall is less than 1,000mm, the following treatments have been done in central arid zone in Myanmar and Sahel area in Africa will be effective; 1) Setting up the micro-catchment of rainwater, 2) digging the large planting hole in order to increase the water holding capacity of soil, 3) watering at the time of planting, and 4) using the shade trees or underplanting. In addition to these, it is safe to keep a low planting density of hundreds per ha, because maintenance of high and dense forests is generally difficult in dryland.

Chapter 5. Maintenance and protection after tree planting (measures to prevent damages by animals and wildfires)

In general it is important to make Maintenance activities and protect the planted trees after the plantation. Especially in semi-arid areas, there are many cases in which planted trees are damaged by grazing cattle and they are lost by wildfires during the long dry season. Protective measures for the planted site are described below.

5-1. Protective measure against animal damage

In the semi-arid areas it is impossible to cultivate crops during the long dry season. So extensive grazing is popular in many areas. During the dry season when the vicinity of planted site is burnt by wildfire, grass (food for cattle) becomes so scarce that cattle may invade in the plantation to bite. Thus it is necessary to build a guard fence around the planted site as below.

1) Set up a hedge (bio fence) around the planted site

Iron bar may be used as a pole of guard fence for planted site but it is expensive. Wood logs go bad in a few years. So the tree species which can grow from stem cutting such as *Gliricidia sepium* (Gamal) and/or *Lannea coromandelica* (Kedondong Pagar) are used as the pole of bio fence. Bamboo or wire is tied around the pole to set up the fence. Such fence is widely used in the semi-arid limestone areas because it can be set up easily and at relatively low cost.

Photo 1 Grazing cattle invading into the plantation

Photo 2 Bio fence

5-2. Protective measure against wildfire damage

If a wildfire occurs after the plantation, all the efforts for forest rehabilitation so far will come to nothing. Two experimental sites among 4 of this project in East Nusa Tenggara Province were damaged by wildfires (Photo 3, 4).

Photo 3 Wildfire damage at the plantation

Photo 4 Number tape melted by wildfire

Wildfire may occur by lightning or leaves rubbed each other in the dry forest area in America and Australia. But it is rare in the grassland in East Nusa Tenggara Province. It is reasonable to assume that fires are caused by human because they occurred in the dry season and there were no trees hit by lightning. Man-caused wildfire will be usually as follows; Fire spreading during slash-and-burn, firing to renew grass plant for grazing cattle, mishandling of tobacco or bonfire and arson out of curiosity.

There are mainly two countermeasures against wildfire; technical countermeasure and social countermeasure.

1) Technical countermeasure to prevent wildfire damage

i) Set up firebelt outside the tree planted area (photo 5)

ii) Separate the tree planted area into some parts and set up firebelt between the parts.

iii) Remove completely the flammables such as dried grass within the planted area

iv) Prescribed burning/Controlled burning in the firebelt

Photo 5 Firebelt outside planted area (12m wide)

Photo 6 Prescribed burning/controlled burning Source) The Nature Conservancy

2) Social countermeasure to prevent wildfire damage

i) Regular patrol to the planted area

ii) Set up a rule for the prevention of wildfire in the surrounding villages

iii) Introduce responsibility sharing system to manage the planted area and pay cash reward to the effort to prevent a wildfire.

iv) Plant trees which will give benefit to the residents within or without the tree planted area.

References (order of the Japanese syllabary)

Asakawa Sumihiko (1999) Afforestation Technology in the Tropics Japan International Forestry Promotion and Cooperation Center 137pp.

Koizumi Hiroshi, Ohguro Toshiya, Mariko Shigeru (2000) Ecology of grassland and desert, Invitation to Ecology (in serial) Kyoritsu Shuppan Co., Ltd. 250pp.

Japan International Forestry Promotion and Cooperation Center (2009) Technical Manual for Reforestation in yellow sand areas (Measures against desertification and greenery at arid land) JIFPRO 203pp.

Korai Yasuyuki (2004) Introduction of afforestation case in Sichuan Province, China Tropical Forestry N.S.61 : 53-60

Noda Naoto (2000) Afforestation by direct seeding of Senna siamea (*Cassia siamea)* (Follow-up report) -Appropriate technology to reduce risk in semi-arid land- Tropical Forestry N.S.48 : 53-58

Fujimori Suehiko (2007) Afforestation technology in Loess Plateau in China Tropical Forestry N.S.69 : 48-56

Shiozuru Takamichi (2003) Afforestation by direct seeding – project of afforestation and erosion prevention by local residents in Tarija valley in Bolivia, Tropical Forestry N.S.58 : 31-40

Yoshikawa Ken, Yamanaka Norikazu, Ohte Nobuhito (2004) Nature and Greenery of arid land – for the restoration of ecosystem in the desertified land- Kyoritsu Shuppan Co., Ltd. 233pp.

(available only in Japanese)

Adisoemarto、S. (1982) Sumber daya alam di Camplong dan Sekitarnya、Kecamatan Futule'u-Kabupaten Kupang Timor、 NTT. Lembaga Biologi National、 Indonesia

Kathryn A. Monk、 Yance De Fretes、 Gyatri Reksodiharjo-Lilley (1997) The Ecology of Nusa Tenggara and Maliku、 Periplus Editions (HK) Ltd. 966pp.

Turnbull、 John W. (1986) Multipurpose Australian Trees and Shrubs. Australian Center for International Agriculture Research. 316pp.

van Steenis (1997) not published, referred to former book (K.A. Monk *et al.* 1997)

Appendix 1. Suitability of the planting tree species which were used for the rehabilitation in degraded drylands based on the result of the demonstration study

No.	Planting tree species	Suitability				
		Nekban		Penfui	Silu	Soe
		Vertic / clay soil		Deep soil	Shallow rocky soil	Shallow rocky soil
		2012/ 2013	2013/ 2014 (replant)	2012/ 2013	2013/ 2014	2014/ 2015
1	*Annona muricata*				△	
2	*Persea americana*					◎
3	*Santalum album*					◎
4	*Eucalyptus urophylla*		○		○	○
5	*Syzygium cumini*		△	△		
6	*Syzygium samarangense*					○
7	*Aleurites moluccana*	○	○		△	
8	*Acacia* sp.		◎			◎
9	*Cassia siamea*				○	
10	*Dalbergia latifolia*				△	
11	*Enterolobium cyclocarpum*	◎				
12	*Pterocarpus indicus*	○	◎	○	○	◎
13	*Samanea saman*				○	◎
14	*Tamarindus indica*				○	
15	*Artocarpus heterophyllus*			△		
16	*Casuarina junghuhniana*		◎	◎	○	○
17	*Sterculia foetida*	◎	◎		◎	○
18	*Schleichera oleosa*				◎	
19	*Anacardium occidentale*				◎	◎
20	*Azadirachta indica*	△				
21	*Swietenia macrophylla*	△	△	○	△	◎
22	*Toona sureni*	○		○		
23	*Citrus* sp.					◎
24	*Manilkara zapota*				△	
25	*Planchonia valida*					◎
26	*Gmelina arborea*	◎	◎	◎	○	◎
27	*Tectona grandis*		○	△		
	Number of the species	8	10	8	15	14

< Suitability >

◎ : Excellent

○ : Good

△ : Fair / Poor

N.A. : No data is available

Appendix 2. Characteristics of trees examined in the experimental plots of exploited semi-arid areas, Nusatenggara Timor.

27 trees are examined on survival and growth at the experimental plots set on the over exploited areas in Nusatenggara Tomor (East Nusatenggara Province). Origin and natural habitats, preferable site conditions, propagation, utilization and other noteworthy topics of these tree species were investigated. As among 27 species, 2 species are unknown in suitable scientific name – Acacia and Citrus. 25 species are investigated on the characteristics above. Indonesian names are cited by PROSEA and local names are advised by Ms. Desitarani in Ministry and field staffs of Forestry Research Institute, Kupang. Books used for investigation of these characteristics of trees were also listed up.

Scientific name (Indonesian name)	Distribution and general feature	Site conditions, physiology, propagation	Use and other topics
Annona muricata (Sirsak)	Annonaceae. Shrub ~ small tree - H:3~10m. Origin: Tropical Ameica. Tropical rain forest ~ tropical seasonal forest wit short dry spell. High temperature and high humidity. Up to 1,000m. Latitudinal limit: 25° S	Tree would be able to grow on common soils. Unsuitable under water logging. Good on well drained soils. As roots are shallow, unsuitable under dry conditions. No resistant to cool temperature. Propagation: by seed. Grafting good strain to stocks from seed.	Fruit use. Fragrant fresh fruit. Use for juice and ice cream. Good fragrance and taste.
Persia Americana (Avokad)	Lauraceae. Small tree - H:20m. Origin: Mexico to Peru. Tropical and sub-tropical rain forest and seasonal	Resistant to low temperature (1～2℃). Suitable temperature: 25～33℃, daily deviation: 8～10℃. Very	Fruit use. Fresh eating. Oil extraction from seed. Oil used for cosmetics snd

	forest with short dry spell.	weak to windy condition. Therefore, mixed planting with other trees is good. Good on moist soil. Not good on sea water and Cl^-. Precipitation: ～2,500mm. Propagation: by seed. Seed loses activity in a week.	medicines. Wood use – medium weight – S.G.0.66。 At planting time, supporting tree or shelter trees are very important.
Santalum album (Cendana)	Santalaceae. Small tree - H:10m、DBH:30cm. India, Indonesia ~ PNG. Tropical seasonal forest. Precipitation: 600 ～ 1,500mm. Elevation: 600 ～ 1,200m. Minimum temperature: over 10℃. Cooler site in tropical areas.	Good on deep & moist soil. Good in well drainage sites. Need well sunlight. Although tree does not grow fast on sandy soil, intensity of fragrance would be more. Host plants are needed in juvenile stage.	Essential oil, sandal wood and incense production. Wood use – heavy wood – S.G.0.9。 Domestic species
Eucalyptus urophylla (Ampupu)	Myrtaceae. Large tree - H:55m、DBH: 200cm. Lesser Sunda Islands and Moluccas Islands (8～10°S). Growing in National Park of East Timor where located in high elevation. Member of tropical seasonal forest. Minimum temperature: 8~12℃. Elevation: Up to 3,000m. Suitable elevation in planting : 500～1,400m (Bali).	Best on deep, moist, well drained soil. Resistant to dryness. Resistant to dryness & strong sunlight. Planting & natural regeneration are very easy. Propagation: by seed. Management after planting is also easy because of rapid growth after planting.	Wood use – medium ～ heavy wood – S.G. about 0.7. Plantations in Bali & other places are good in Indonesia. As initial growth is good and wood quality is good, planting is recommended in Indonesia. Hybrid with *E. alba* is observed. Domestic species.
Syzygium cumini (Jamblang, Local	Myrtaceae. Small tree - H:10～15m. Himalaya to Australia. Tropical	Tolerant to various types of soil. Resistant to dryness.	Fruit use. Fresh fruit & juice. Fodder use. Medicinal use of

name – Jambu Air)	seasonal forest with distinct dry season. Up to 600m.	Propagation: by seed. Grafting is conducted for getting good quality.	seeds, locally. Fire wood. Domestic species.
Syzygium samarangense (Jambu Semarang, Local name - Jawa)	Myrtaceae. Small tree - H10～18m、DBH:25 ～ 50cm. Malaya, Andaman Islands. Tropical rain forest with slight dry spell. Lowland up to 1,200m。	Suitable on moist clayey soils. Suitable on sandy soils with high sub-water level. Fertilization is effective for good growth.	Fruit use. Fresh fruit is edible. Fruit has fragrance. The fragrant extraction is used for other food.
Aleurites moluccana (Kemiri)	Euphorbiaceae. Small to medium size -DBH:150cm、H:10~40m. Detail origin is not clear. India to Polynesian Islands? Mainly dry tropical seasonal forest to sub- tropical seasonal forest. Up to 1,200m. Temperature: -18.7~27.4℃. Precipitation: 640~4,290mm. Member of Lowland forest.	Natural habitats are well drained sandy soil and limestone hills. Resistant to dryness. It can survive on wide range of sites. Suitable pH ranges pH5~8.0. Propagation: by seeds.	Nut use – Candle Nuts. Nuts include some toxic substances. Industrial oil, candle, medicinal use, material of paints, so on. No information on wood use. Domestic species?
Acacia spp. (auraria?) (Local name – Akasia) Similar to *Acacia auricuriformis* × *mangium*	Leguminosae, Medium size tree. Endemic? in Timor. Hybrid of *Acacia auricuriformis* ×*mangium* ?. Tropical seasonal forest. Montane species..	Should be examined.	Should be preserved in Timor. Domestic species. Endemic in Timor?.
Cassia (=*Senna*) *siamea* (Johar)	Leguminosae. Small to medium size -DBH:50cm、H:20-30m. India to Sumatra. Dry dipterocarp forest and	Good on moist sites in dry areas. Good on deep soil. Resistant to dryness and strong sunlight.	Wood use - (iron wood) –heavy wood S.G.0.8 ～ 1.0. Blackish base with pale stripes – very

	tropical seasonal forest. Up to 1,100m.	Propagation: by seed.	beautiful. Good for furniture and wood carvings.
Dalbergia lathifolia (Sonokeling)	Leguminosae. Medium to large tree - H:43m 、 DBH:180cm. Nepal to Indonesia. Tropical evergreen seasonal forest to tropical deciduous seasonal forest. Less than 6 months of 40mm> of precipitation. Up to 600m in Java. Plantation: up to 1,000m.	Good on deep and moist soil. Good on well drained soils. Soil with poor nutrient and rocky soil are not suitable. Resistant to dryness and strong sunlight. Min. temperature: 6° C. As fruiting is not good, cutting of branches and roots is possible.	Wood use (rose wood) – medium to heavy wood S.G. 0.80~0.86. Wood shows very beautiful dark purplish color. Young tree are very good for fuel wood. Leaves: fodder. Domestic species.
Enterolobium cyclocarpum (Sengon Buto)	Leguminosae. Large tree - H15~30m、DBH:300cm. Originated from Central America. Evergreen & dry topical seasonal forest.	Resistant to dryness and strong sunlight. Adapted to poor nutrient soil. Propagation: by seed – easy.	Wood use – light wood - 0.47. Low durability. Shade tree: coffee plantation. One of the suitable tree for land rehabilitation in South East Asian countries.
Pterocarpus indicus (Sonjokembang, Local name – Kayu Merah)	Leguminosae. Medium to large tree - DBH:350cm 、 H:40m. Myanmar to pacific islands. Very wide distribution. Tropical rain forest~deciduous tropical seasonal forest. Rich in riparian areas. Elevation: up to 100m in PNG, but it can be planted up to 600m.	Better growth is expected on deep soil in riparian areas. The tree grows various types of soil. Light demander. Resistant to dryness. Propagation: by seed. Stump planting is introduced. Plantation record: DBH:49cm/60y. (Malaysia)。	Wood use – medium to heavy hardwood – S.G.0.55~0.90. Reddish brown wood with beautiful dark yellow stripes. One of the most useful wood for furniture and wood works. Wood: yellow fluorescence. Domestic species. Listed on red

			list in original areas.
Samanea saman (Trembesi)	Leguminosae. Large tree - H:25~40m、DBH:200cm<. Northern parts of South America. Tropical rain forest～tropical seasonal forest (dry month - 2~4month>). Elevation: up to 1,000m. Precipitation: 1,000~2,500mm. Min. temp.:18~22℃.	Suitable on wide range of soil condition. Adequate pH ranges in 5.5~8.5. Resistant to strong sunlight & dryness around 700mm. Tolerant to seasonal water logging. Propagation: by seed	Shade tree – wide tree crown. Wood use – medium weight – S.G.:0.55. Dark stripes in wood: wood carving and handicraft. Fuel wood.
Tamaridus indica (Asam)	Leguminosae. Large tree - H:30m、DBH:200cm. Origin: not clear, maybe from tropical Africa. Tropical savanna & dry tropical seasonal forest. Plantation would be below 2,000m. Many varieties.	Tree can grow in many types of soil, from sandy soil to clayey soil. Nutrient demand is not so strong. Unsuitable to acidic soil. Resistant to dryness, strong wind & cool climate. Propagation: by seed. Fruiting is decreased in rainy sites.	Fruit use. Matured fruit is eaten in fresh and used for material of cakes. When fruit is sour, people make jam. Young fruit is used for cooking as sour material. Fruiting starts 4~5 after planting.
Artocarpus heterophyllus (Nangka) Similar to *Artocarpus kemando*	Moraceae. Medium size tree - H:30m、DBH:50cm. India ～ Myanmar. Sub-tropical ~tropical seasonal forest. Mixed dipterocarp forest. It grows on swampy lowland.. About 1,000m in Indonesia. Precipitation: 700~4,200 mm.	Not so resistant to dryness. Good on moist soil. Suitable pH: pH4.3~8.0. Growth on soils from limestone is not so good. Propagation: by seed.	Fruit use – so-called Jack fruit. Fresh eating and material for cooking. Nuts are also edible. Sap is used for glue. Wood - material of painting. Wood use – light to medium weight – S.G.0.60
Casuarina	Casuarinaceae. Medium～large tree -	No special demand to sites.	Wood use – heavy wood –

junghuhniana (Cemara Gunung, Local name - Kasuari)	H:35～60m、DBH:100～150cm. East Java to Lessor Sunda Islands (endemic species of Indonesia). Tropical seasonal forest. Montane forest. Up to 3,000m in Sunda.	Propagation: by seed. Root has nodules of Frankia. Inoculation of Frankia in nursery would be important in planting time.	S.G.0.79～1.3. Wood has good durability to water.. Usage: very easy processing. Synonym: *C. montana.* Domestic species.
Sterculia foetida (Kepuk, Local name - Nitas)	Stericuliaceae. Medium to large tree - H:40m、DBH:90～120cm. Very wide distribution – from east Africa to Hawaii. Tropical seasonal forest with distinct dry season. Lowland & coastal forest. Elevation: 1,500m>	Very good performance in dry conditions. Very clear light demander. Not much special demand to soil. Propagation: by seed – easy.	Nuts use. Roasted nuts are eaten. Oil for light from nuts. Medicine and material of batik painting are from bark. Wood use: very light to medium weight - S.G.0.25～0.60. Domesticspecies?
Scleichera oleosa (Koosambi, Local; name Kesambi)	Spindaceae. Small tree - H:15m. India, to Indonesia. Tropical rain forest to dry tropical seasonal forest. Up to 1,000m (naturally --600m). Minimum temperature: 24 ℃ . Precipitation - 900~3,000mm.	Good on slight acidic soil. Good on well drained soils. Propagation: by seed. Sprouting from root is used. Seeds lose activity in short period.	Roasted nuts are eaten. Oil from nuts (Makassar Oil – high quality). Used for cooking, light & so on. Fruit is edible. High quality lac and charcoal. Wood use – S.G.0.90~1.08. Domestic species.
Anacardium occidentale (Jambu Mede, Local name – Jambu	Anacardiaceae. Small tree – H.:12m. Northern part of Brazil to Guiana. Tropical seasonal forest with short dry spell – 2~5months). Precipitation:	Good on deep and well drained soil. Unsuitable to water logging. Suitable pH range: pH4.5~7.0. Resistant to dryness. Minimum	Nuts use. Fresh fruit is eaten and used for juice. Oil from crust of nuts. Painting material from bark.

Mente)	800~1,000mm. Lowland forest & coastal forest. Not many in higher elevation.	temperature: 17℃. Condition of good fruiting: small rain in flowering and very dry in maturing time of fruits. Propagation: by seed.	Wood use – medium weight –S.G.0.63. Not so high in quality.
Azadirachta indica (Mimba) (or Mindi)	Meliaceae. Small~medium size - DBH 90cm、H:25m. Pakistan to Myanmar. Savanna ~ tropical seasonal forest. Up to 700m (in case of plantation – up to 1,500m).	Suitable soil pH ranges in 6.2 - 7.0. Suitable precipitation is around 1,000mm, but tree would grow in areas around 400mm and over 2,000mm. Resistant to strong sun light and dryness.	Medicinal use. Some of pesticide. Wood use – medium~heavy hardwood – S.G.:0.72-0.92. Good wood quality – a member of mahogany.
Swietenia macrophylla (Mahoni)	Meliacease. Medium ~ large tree (in Peru, tree is giant size) - DBH :150cm、H: 40m. Central America to northern parts of South America. Tropical rain forest ~ wetter type of tropical seasonal forest. Lowland forest.	In Peru, not so good on acidic soil (Acrisol), but very good on calcareous soil (calcic Cambisol). Suitable on convex and well drained areas. Resistant to strong sunlight.	Wood use – medium weight – S.G. 0.5～0.6. Wood is very high in quality. Insect - *Hypsipyla robusta* gives Severe damage in some part of Kalimantan.
Toona sureni (Suren)	Meliaceae. Medium to large tree - H:40～60m、DBH:100～300cm. Nepal ～ New Guinea. Tropical seasonal forest. Precipitation: 800～1,800mm. Up to 2,000m.	Very good on deep fertile soil. Good on moist loamy soil with suitable drainage. Favorable growth would be expected on Ca rich, alkaline soil. Resistant to dryness. Propagation: by seed.	Wood use – medium weight wood – S.G.0.53. Wood has ceder flavor. Wood processing is very easy. Domestic species.
Citrus sp.	Citrus family. Shrub ~ small tree.	Need dry spell. This cultivar is	Fruit use. Fresh fruiot and

Citrus reticulate c.v. soe? (Jeruk Keprok?)	Origin – India ~ China. Same species of Unshu orange of Japan. 45° N~35° S. Tropical ~ sub-tropical seasonal forest. Suitable elevation in Indonesia: 600~1,300m.	developed in Soe. Resistant to dryness. No specific demands on soil. Good in moist sites. Tolerant to cool climate. Propagation: budding on stump.	juice – same as Unshu Orange of Japan. Cultivar of *Citrus reticulate* for adapting to highland climate of Timor Island.
Manilkara zapota (Sawo)	Sapotaceae. Small ~ medium tree - H:25m, 100cm. Various varieties in the genus are distributed in Asia, but this species originated in tropical America. Tropical rain forest. Lowland species such as coastal plain. Up to 500m.	Good on sandy soil such as Regosol which is almost sand. Unsuitable to dry condition. Remarkable effect of fertilization. Propagation: by seed. At planting time, shading is effective. Grafting is usually introduced for keeping good strain.	Fruit use. "Sapodilla" fruit. Fresh fruit has good taste. Lac is produced – low quality. Wood use – heavy wood – S.G.0.9 ~1.15. Good for wood carving. Similar species, *M. kauki*, is used as seedling stock for grafting.
Gmelina arborea (Jati Putih, Local name - Gmelina)	Verbenaceae. Small to medium size - DBH:100cm、H:30m. Pakistan ~ Sri Lanka. Tropical rain forest to tropical seasonal forest (wide distribution). Up to 1,500m (India).	High nutrient demand such as Ca. Good on fertile moist soil. Poor on bleached soils. Light demander - Mixed planting with other trees is not suited because of competition. Resistant to dryness. Propagation: by seed.	Wood use- light wood – S.G.ca. 0.50. Easy processing. Use for furniture, construction & so on. Planting for devastated areas. Good tree for rehabilitation.
Tectona grandis (Jati)	Verbanaceae. Medium to large tree - H:50m、DBH:150～25cm. India to Laos. Tropical ~ sub-tropical seasonal	Good on deep soils. Suitable pH ranges pH6.5～8.0. Suitable soil for growth: Ca & P rich soil. Wet	Wood use – medium weight – S.G.0.8 ～ 0.75. Wax is contained in wood which

	forest (deciduous type). May have distinct dry season. Up to 1,000m. Precipitation: 1,200 ~ 2,000mm (Indonesia). The tree introduced to Indonesia 400～600 years ago.	soil & acidic soils are unsuitable. Seed reproduction is good. Grafting of good tree on stumps is popular. Stump planting is usually conducted.	introduces smooth taste of wood. High quality wood - good for furniture & construction, Small trees are used as poles.
Planchonia valida (Putat, Local name - Fafi Nakaf – Timor, Langaha - Sunda)	Lecythidaceae. Large tree: H:50m, DBH:150cm. Origin – Malesia, Sumatra, to Lesser Sunda Islands. Tropical seasonal forest. Elevation; 300~1,300m.	Good on swampy alluvial soil. Relatively moist sites. Resistant to damage by fire. Requirement of strong light. Resistant to strong sunlight. Propagation by seed.	Wood use – medium to heavy wood: S.G. 0.61~1.01. Good for fuel wood. Young leaves: vegetable. Domestic species. Endangered species in original sites.

[Book list for specie investigation]

Man information;

Plant Resources of South-East Asia (PROSEA) (1992-continued): vol.1 to vol. 12, Remens, Soeranegara, Wong, and others (ed.): ITTO, Commission of EU, FORDA

Supporting information;

Tree Flora of Sabah and Sarawak(1995~2012-continued):vol.1 to vol. 7 Soepadomo, Wong, Saw and Chung, (ed.) ITTO, FRIM, Sabah Forestry Department & Sarawak Forestry Department

Eucalypts for Planting(1979): Maxwell Ralph Jacob(ed.)、FAO Forestry Series No.11, Rome

Field Guide book of Plants for Restoration (2014): Desitarani, Miyakawa, Ismail & Rugayah, Ministry of Forestry, JICA & LIPI, Jakarta, Indonesia

Handbook of Nuts (1989): James Duke, CRC Press, United States

Plant list on useful tropical plants(1984) : Research group on tropical plants(Iwasa, Kikata, Kitana, Sasaki, Suzuki, & Hara) – in Japanese

Useful Timber Tree in Tropics(1978):Tropical Agriculture Research Center(Kaburagi, Kikata, Kitano, Hara & Yamada)、Tropical Agriculture Research Series No. 16 – in Japanese

Fruit of Brazil(1978): Goro Hashimoto, Tropical Agriculture research Series, No. 15

Appendix 3. Characteristics of the planting tree species in Indonesia

Order name	Family name	Botanical name	Indonesian name	Use	drought	flood	swamp	sandy	rocky	acid	alcaline	salinity	low temp.	frost	wind	fire	grass	Climate, Habitats	Rainfall	Dry period	Altitude	Bacteria	Mycorrhiza	Growth
Celastrales	Celastraceae	*Lophopetalum javanicum*	Perupok djawa	furniture, plywood, etc.3		T[0]	T[0]			T[0]								lowland rainforest or often inundated and/or peat swanp forest[0]			<1400m[0]			
Malpighiales	Euphorbiaceae	*Aleurites moluccana*	Kemiri	seed oil, timber, etc.3	T[1]		W[7]				<8[7]		8°C[7]		T[7]			arid to humid climate in subtropics and tropics[1]	650-4300mm[7]	3-5 months [7]	<1200m[7]			intolerant[7]
Malpighiales	Euphorbiaceae	*Hevea brasiliensis*	Karet	rubber solution, timber, etc.3		T[1]												tropical evergreen rainforest[1]		2-3 months [1]	< 400-500 m[1]			intolerant[E]
Malpighiales	Euphorbiaceae	*Jatropha curcas*	Jarak	seed oil, hedge3	T[1]						6-9[11]							arid to semi-arid, relatively dry tropical zone[1]	750-3000mm[8]	<4-6 months [8]	<1800m[8]			intolerant[E]
Malpighiales	Hypericaceae	*Cratoxylum arborescens*	Geronggang[0]	furniture, plywood, etc.3			T[0]											humid tropics, often dominant species in coastal swanp forest[0]			<900-(1800)m[0]			
Malpighiales	Rhizophoraceae	*Combretocarpus rotundatus*	Prepat darat	interior wood, furniture, etc.3			T[0]											humid tropics, peat swamp and Kerangas forest[0]			<100(300)m[0]			secondary[0]
Fabales	Fabaceae	*Acacia auriculiformis*	Akasia	timber, firewood, pulp, etc.3	T[1]	T[2]	T[6]			T[2] >3.0[15]	T[2]	T[2]		? T[1], non-frost[2]	W[1]		T[1]	tropical lowland with dry season, savanna climate[0]	700-2000 mm[1]	< 7 months [1]	< 80(400) m [1,0]		N fix[15]	fast0
Fabales	Fabaceae	*Acacia crassicarpa*		pulp, etc.E		T[1]	T[1]	T[1]		T[1]		T[1, 2, 6]		non-frost[10]		T[6]	T[6]	temperate to high-temperature humid and semi-humid tropics, savanna climate[0]	1000-3500 mm1,500-3500mm6	<3-6 months [10]	<200(700)m[0,6]		N fix[15]	fast6
Fabales	Fabaceae	*Acacia decurrens*	Akasia	various matrials, etc.3	T[17]						W[17]		T[E] -5°C[17]	root-T[E]	T[17]	root-T[E]		cool and temperate semi-humid zone[17]	(350)600-1000mm[17]		<2000m[E]		N fix[15]	fast, intolerant17
Fabales	Fabaceae	*Acacia mangium*	Akasia	timber, firewood, pulp, etc.3	W[E]	W[1]		T[2]		T[1,2,6] 4.5-6.5				non-frost[10]			T[1]	moist to humid[2], tropical lowland[1]	1500-3000 mm[2]	<3-4 months [6]	<200(800)m[0]		N fix[15]	fast, pioneer, 2
Fabales	Fabaceae	*Cassia siamea*	Johar	timber, firewood, etc.3	T[6]									w-T[6]	T[6]			tropical monsoon climate[6]	650-1500mm[6]	4-6 months [6]	<1000m[6]		Non N fix[15]	intolerant[6]
Fabales	Fabaceae	*Delonix regia*		gargen & roadside trees, etc.3	T[18]							T[18]						tropical savanna climate[6]	700-1800mm[6]	6 months [6]	<2000m[6]			intolerant[E]
Fabales	Fabaceae	*Dalbergia latifolia*	Sonokeling	timber, etc.3	T[E]											T[E]		tropical dry deciduous forest[1]		<6 months[0]	<600(1000)m[0]		N fix[15]	slow[E]
Fabales	Fabaceae	*Enterolobium cyclocarpum*	Sengon buto	timber, etc.3	T[1]		W[6]			T[15]	T[6]			w-T[6]				broad habitat in tropical and sub-tropical zone[1]	750-2000mm[6]	1-6 months [1]	<900(1100)m[6]		N fix[15]	fast, intolerant6
Fabales	Fabaceae	*Gliricidia sepium*	Gamal	hedge, fodder, apiculture, etc.1	T[E]		W[6]	T[1]		w-T, adapt			15 <[1]	root-T[6]				broad habitat in tropical and sub-tropical zone[1]	(400)900-1500(3500)mm[6]	5(8) months [6]	<600[E]		N fix[15]	intolerant[6]
Fabales	Fabaceae	*Koompassia excelsa*		timber, furniture, etc.3			T[0]											tropical lowland forest[0]			<650m[0]			
Fabales	Fabaceae	*Leucaena leucocephala*	Lamtoro	greening, fodder, firewood, etc.3	T[5]	T[5]			T[5]	W[5]	T[5] 5.5-7.7	T[5]	W[1] 15-25	root-T[1,5]	T[5]	root-T[1,5]		tropical humid or semi-humid zone[1]	1200 mm <[1] 1000-3000 mm[5]	6-7 months [1] 8-10 months [5]	< 500 m[5] <1500m[6]		N fix[15]	fast6
Fabales	Fabaceae	*Paraserianthes falcataria*	Sengon laut	timber, plywood, pulp, etc.3			W[6]			＞3.8[15]					W[1]	W[1]	T[1]	perenial humid and monsoon climate[1]	2000-2700mm[6]	2-4 months [1] 0 month[6]	<1600 (3300)m[6]		N fix[15]	fast6
Fabales	Fabaceae	*Parkia speciosa*	Petai	shell, seeds, etc.3		T[1]	T[1]	T[1]							T salt			tropical lowland rainforest[1]			<1000(1400)m[0]		N fix[15]	
Fabales	Fabaceae	*Pterocarpus indicus*	Angsana, Kayu merah	timber, etc.3		T[1]						T[0]						coastal to middle-altitute forest and seasonal moisture forest[1], humid tropics[9]			<600m[0](1300 m[6])		N fix[15]	intolerant[6]
Fabales	Fabaceae	*Samanea saman*	Trembesi	timber, fodder, etc.3		T[6]	T[6]											tropical lowland[6]	760-3000mm[6]	2-4 months [6]	<700m[6]			intolerant[6]
Fabales	Fabaceae	*Sesbania grandiflora*	Turi	firewood, fodder, medicine, etc.3	T[1,6]	T[1,6]							W[1] 10		W[1]		T[6]	tropical humid and semi-arid land[6], often manglobe hinterland forest[0]	suitable 適 1000mm<[6]	9 months [1]	<800(1200)m[0]		N fix[15]	fast1, pioneer0
Fabales	Fabaceae	*Tamarindus indica*	Asam	fruit meat, medicine, etc.3	T[1]						4.5-8.7[6]	T[6]		T[1] (grown)[0]	T[1]		T[1]	lowland forest with broad soils and climatic conditions, savanna and open forest[0]	510-4300[6]		<1500m[6]		Non N fix[15]	intolerant[6]
Rosales	Moraceae	*Artocarpus altilis*	Sukun	fruit, timber, etc.3		T[0]	W[1]						W[1]					high-temperature and humid lowland tropical forest, river-side and/or swamp forest edge in PNG[0]	2000-3000[0]. 1200-2500m[6]	short dry season[1]	<600(1000)m[0,6]			fast, intolerant1
Rosales	Moraceae	*Artocarpus heterophyllus*	Nangka	fruit meat, seeds, timber, etc.3	W[1]	W[1]	W[1]				6-7.5[0]		T[1] W[0]	T[1] W[0]				(humid) tropis and sub-tropics[1]	1500mm<[9]		<400(1200)m[0]			

Cucurbitales	Datiscaceae	*Octomeles sumatrana*	Benuang	timber, plywood, pulp, etc.3	W[6]												W[6]	humid tropics 湿潤熱帯[0]	1500mm<[0]	<1 month[6]	<1000m[0]			intolerant6
Fagales	Casuarinaceae	*Casuarina equisetifolia*	Cemara laut	sand dune stablization, timber,	T[1]	T[1,6]		T[1,6]			T[6]	T[1,6]						semi -arid to semi-moist zone[1]	700-2000 mm[6] 200-5000 mm[6]	4-6 months [1] 6-8 months [6]	< 1500 m[6]	Actinomycetes Frankia	N fix[15]	intolerantE
Fagales	Casuarinaceae	*Casuarina junghuhniana*	Cemara gunung? Kasuari?	timber, firewood, etc.3	T[1,6]	T[1]			T[1]	>2.8[15]			T[E]			root-T[1]		tropical monsoon zone[1,6]	700-1500mm[6] 750-2500mm[9]	4-6 months [9]	<3000m[6]		N fix[15]	fast1
Myrtiflorae	Combretadeae	*Terminalia catappa*	Ketapang	shade tree																				
Myrtiflorae	Lythraceae	*Duabanga moluccana*	Benuang laki	timber, plywood, etc.3			T[E]											humid tropics[1]			<1200m[0]			pioneer[0]
Myrtiflorae	Myrtaceae	*Eucalyptus camaldulensis*		timber, pulp, etc.3	T[E, 6]	T[1, 6]	T[1, 6]	T[E]		T[E, 6]	T[6]	T[E, 6]				root-T[6]		humid to arid tropics[1]	250-1250mm[6]	0(4[6])-8 months [1]	<600m[0]			fastE
Myrtiflorae	Myrtaceae	*Eucalyptus deglupta*		timber, pulp, etc.3	W[1,0]	W[1,0]					6-7.5[14]			W[1,0]		W[1,0]		humid tropics[1,0]	2000-5000mm[0,9]	no dry season	<1800m[0,9]			intolerant6
Myrtiflorae	Myrtaceae	*Eucalyptus pellita*		timber, pulp, etc.3										? T[1] non-		T[10]		humid and semi-moist tropical lowland[1]	1000-4000mm[10]	2-4 months [9]	<800m[10]			secondary[E]
Myrtiflorae	Myrtaceae	*Eucalyptus urophylla*	Ampupu	timber, etc.3							W[1]					T[10]		secoundary open mountain forest in monsoon climate[0]	800-2200mm[10]	3-8 months [10]	90-2000m[10]			secondary[0]
Myrtiflorae	Myrtaceae	*Melaleuca alternifolia*		essential oil, piles, wind-break, etc.19	T[19]	T[19]	T[19]							non-frost[19]	T salt air[19]	T[19]		river outlet zone in sub-tropics and lowland forest along swamps[19]			<300m[19]			intolerant19
Myrtiflorae	Myrtaceae	*Melaleuca cajuputi*		medicine, piles, fuelwood, etc.2	T[2]	T[2]	T[2]		T[2]	T[E]								tropical humid to semi-moist zone[2]	1300-1750 mm[2]	<2-3 months [2]	<200m[2]			intolerantE
Myrtiflorae	Myrtaceae	*Melaleuca leucadendron*		medicine, spice, fuelwood, etc.3	T[2]	T[2]	T[2]	T[2]	T[2]	T[E]		T[2]						tropical semi-moist to semi-arid zone[2]	650-1500 mm[2]	<4-8 months [2]	<500m[2]			intolerantE
Myrtiflorae	Myrtaceae	*Syzygium aromaticum*	Chengkeh	medicine, spice, etc.3	W[E]									W[E]				middle to small forest and rainforest, tropical and sub-tropical zone6	1500-3500mm[6]	<1-2 months [6]	<1000m[1]			young-tolerant[6] middle-understory
Myrtiflorae	Myrtaceae	*Syzygium cumini*	Jambu hutan	colorant, timber																				
Myrtiflorae	Myrtaceae	*Syzygium Samarangense*	Jamby semarang	fruit																				
Sapindales	Anacardiaceae	*Anacardium occidentale*	Jambu mente	fruit, timber, etc.3	T[1]									W[1]				tropical and sub-tropical monsoon forest[6]	800-1000 mm[1]	4-6 months [9]	300(800)m[6]			intolerantE
Sapindales	Anacardiaceae	*Lannea coromandelica*	Banten	hedge, etc.E	T[E]													Distributed in India to Southeast Asia, deciduous open forest in monsoon zone in Thailand[24]						secondary[E]
Sapindales	Anacardiaceae	*Mangifera casturi*	Kasturi		W[E]													cultivated in Mataram, South Kalimantan, threatened species	1200 mm<[E]	<1-2 months [E]	flat land[E]			intolerantE
Sapindales	Anacardiaceae	*Mangifera indica*	Mangga	fruit, timber, etc.3	T[1,0]	T[1]								W[1]				tropical to sub-tropical[1], monsoon climate[6]	750-2500mm[0]	3 months [1] <[9]	< 600(1200) m[1,0]			intolerantE
Sapindales	Anacardiaceae	*Mangifera odorata*	Kuwini	fruit, etc.3	W[E]													humic tropics[0]	1200 mm[1]<[0]	short period[1, 0]	< 1000 m[1]			intolerantE
Sapindales	Meliaceae	*Azadirachta indica*	Mimba	timber, medicine3	T[1,6]	W[1,0]					6.2-7.0			T[1,0]				most areas of tropical plain[1], originated from tropical and sub-tropical dryland[6]	650-1150mm[6]		<700m[0] (1500m[6])			intolerant0
Sapindales	Meliaceae	*Khaya senegalensis*		timber, plywood, etc.3	T[1]	T[1]	T[1]											scattered in riverside forest and savanna forest with relatively high precipitation[1]	700-1500mm[9]		<1800m[9]			weak shade tolerant[6]
Sapindales	Meliaceae	*Melia azedarach*	Mindi	timber, firewood, etc.3										T[1]				sub-tropics[1], tropical monsoon[6]	600-1000mm<[6]		<2000m[6]			
Sapindales	Meliaceae	*Sandoricum koetjape*	Kecapi	fruit, medicine, shade tree, etc.1														tropical humid and monsoon climate[1]			<600[0](1200)[13]m			young-Fast[13]
Sapindales	Meliaceae	*Swietenia macrophylla*	Mahoni	timber, plywood, etc.3		W[0]					6.5-7.5[0]				T[1,0]			savanna pine forest to edge of climax rainforest[1]	400-2500mm[0]	0-4 months [0]	<1500m[0]			intolerantE
Sapindales	Meliaceae	*Toona sureni*	Suren wangi	timber, plywood, etc.3							T[0]			T[0]				floristic regions of tropical india to malaysia[0]			<1700(2100)m[0]			
Sapindales	Sapindaceae	*Nephelium lappaceum*	Rambutan	fruit, seeds, etc.3	T[1]	T[1]	T[1]			4.5-6.5[0]				W[1]	W[1]			tropical humid lowland[1]	2500mm<[0]		<600m[0]			middle-understory[0]
Sapindales	Sapindaceae	*Schleichera oleosa*	Kesambi	seed oil, timber, medicine, etc.3	T[E]						T[E,12]							tropical semi-arid to humid forest[12]	900-1500(3000)mm[12]		<600(1000)m[12]			
Malvales	Dipterocarpaceae	*Anisoptera marginata*	Mersawa tenam	timber, plywood, etc.3			T[0]			T[0]								grows in humid tropics, peat swamp and Podsol heath[0]			<1200m[0]		ectomycorrhiza[16]	

Malvales	Dipterocarpaceae	*Dipterocarpus alatus*	Keruing	timber, plywood, etc.3	T[1]					T[E]								evergreen and arid deciduous forest[1], tropical monsoon climate[6]		6 months [1]	< 500 m[1]		ectomycorrhiza[16]	border regeneration[16]
Malvales	Dipterocarpaceae	*Dryobalanops aromatica*	Kapur bukit	timber, plywood, medicine, etc.3			W[E]											tropical lowland, along mountain ridge[6]			< 300 m[6], <400m[0]		ectomycorrhiza[16]	young shade tolerant[0]
Malvales	Dipterocarpaceae	*Dryobalanops lanceolata*	Kapur paji	timber, plywood, etc.3							T[0]							tropical lowland, middle slopes[6], basic volcanic soils[0]			<800m[0]		ectomycorrhiza[16]	border regeneration[0]
Malvales	Dipterocarpaceae	*Hopea odorata*	Merawan	timber, resin, etc.3						T[E]								tropical humd evergreen forest[1], common in riparian forest[0]			< 600 m[1],		ectomycorrhiza[16]	border regeneration[6]
Malvales	Dipterocarpaceae	*Shorea balangeran*	balangeran	timber, plywood, etc.E		T[E]	T[E,0]											tropical peat swamp forest[0]			<100(1000)m[0]		ectomycorrhiza[16]	secondary
Malvales	Dipterocarpaceae	*Shorea javanica*	Damar kaca	timber, plywood, etc.3	T[1]	T[1]				T[E]								tropical lowland rainforest[1]	1600 mm <[1]	< 6 months [1]	< 300(500) m[1,0]		ectomycorrhiza[16]	border regeneration
Malvales	Dipterocarpaceae	*Shorea leprosula*		timber, plywood, etc.3		W[6]	W[6]											tropical lowland rainforest[6]		<0 month [6]	< 700 m[1,0]		ectomycorrhiza[16]	border regeneration[0]
Malvales	Dipterocarpaceae	*Shorea roxburghii*		timber, plywood, etc.E	T[E]					T[E]						root-T[E, 6]		tropical monsoon climate, often arid deciduous, evergreen and bamboo forest[0]			<1200m[0]		ectomycorrhiza[16]	border regeneration[6]
Malvales	Malvaceae	*Hibiscus cannabinus*		fiber[E]			W[22]					T[22]		W[22]				grows in tropics, sub-tropics1, from 45°N to 30°S[22]	Growing peirod : >100mm/month,> 20℃[22]					intolerant 2 2
Malvales	Malvaceae	*Hibiscus macrophyllus*	Waru gunung	timber, firewood, fiber, etc.4														tropica Asia[0]			<1500(2400)m[0]			secondary[0]
Malvales	Malvaceae	*Sterculia foetida*	Nitas	timber					T[E]			T[E]						tropics: often river-side and coastal stony area[0]			<1000m[0]			intolerantE
Malvales	Malvaceae	*Ceiba pentandra*	Kapuk	floff (綿毛), plywood, seed oil, etc.3						4.7-6.9[6]					W[6]	W[6]		humid evergreen and deciduous forest[1], tropics and sub-tropics[6]	1000-5700mm[6]	< 6 months [6]	<600(1200)m[6]			intolerant6
Malvales	Malvaceae	*Durio kutejensis*	Lai	fruit meat, etc.3														humid tropics[0]			<Foothills[0]			
Malvales	Malvaceae	*Durio zibethinus*	Durian	fruit meat, seeds, etc.3														humid and semi-humid tropics[2]	1500mm<[0]		<800(1800)m[0]			
Malvales	Malvaceae	*Hibiscus tiliaceus*	Waru	timber, fiber, etc.																				
Malvales	Malvaceae	*Ochroma lagopus*	Balsa	materials for floater and varios craft, tc.3		W[6]	W[6]					W[6]		W[6]				humid tropics[6]	1500mm<[6]	<4 months [6]	<1000(1800)m[6]			Fast, pioneer[6]
Malvales	Malvaceae	*Theobroma cacao*	Koko	seed butter, etc.3	W[21]	T[21]												humid tropics[1], lowland rainforest[21]	1000-3000mm[21]		<300m[21]			understory[21]
Malvales	Thymelaeaceae	*Aquilaria spp.*	Gaharu	spice, timber, fiber, etc.3	W[0]													tropical forest in Southeast Asia			100-1300m[0]			middle-understory[0]
Ericales	Theaceae	*Schima wallichii*	Puspa	timber, etc.3		T[1]	W[6]					T[1]	>-3℃[6]			T[E, 6]		broad habitat in tropical and sub-tropical zone[1] in asia[6]	1100-1400mm in China[6]		<3300m[6]			intolerant6, young slow
Ericales	Ebenaceae	*Diospyros ebenum*	Kayu hitam	furniture, ornament26, timber, etc.3	T[26]													relatively arid areas from India to Sulawesi[0]			<900m[0]			
Gentianales	*Apocynaceae*	*Alstonia angustiloba*	Pulai hitam	timber, etc.																				
Gentianales	*Apocynaceae*	*Alstonia scholaris*	Pulai	timber, plywood, etc.	W[22]	T[25]					T[E]							humid and monsoon[0]	>1300mm[23]		<500(-1000)m[0]			secondary[0]
Gentianales	*Apocynaceae*	*Dyera costulata*	Jelutung	timber																				
Gentianales	Gentianaceae	*Fagraea fragrans*	Tembusu	timber, plywood, etc.		T[E]	T[0]							T[E]				tropic humid to monsoon climate[0]			<1500(2800)m[0]			secondary[0]
Gentianales	Rubiaceae	*Anthocephalus cadamba*	Jabon putih	timber, plywood, etc.3	W[6]	T[1]	T[1,6]											humid tropics[0]	1500-5000mm[0]	< 1-2 months [6]	<1000m[0]			pioneer[0]
Gentianales	Rubiaceae	*Anthocephallus macrophyllus*	Jabon merah	timber, plywood, etc.0		T[0]	T[0]											humid tropics, more torelant in dry climate rather than Jabon putih[0]	(200)-5000[0]		<1000m[0]			pioneer[0]
Gentianales	Rubiaceae	*Coffea arabica*	Kopi	seed drink3	W[20]			W[1]		T[1]				W[20]				tropical dry and monsoon area, high altitude rainforest[20]	1500-2000 mm[1]		1500-2000 m[1]			weak shade tolerant[E]
Tubiflorae	Verbenaceae	*Gmelina arborea*	Jati putih	timber, plywood, etc.3	T[1]	W[1]		T[1]			T[E]			T[1]		T[E]	W[6]	monsoon forest[0]	750-5000mm[0,6]	3-5 months [0]	<1200m[0]		Non N fix[15]	Fast, intolerant0
Tubiflorae	Verbenaceae	*Peronema canescens*	Sungkai	timber, etc.3	W[6]	T[6]										root-T[E]		humid tropics[0]	1500-5000mm[E]		<600(-900)m[0,6]			Fast, intolerant0
Tubiflorae	Verbenaceae	*Tectona grandis*	Jati	timber, etc.3	T[E]					W[E]	W[E] 6.5-7.5[6]			root-T[6]		root-T[1]		temperate, humid tropics with dry season[1]	600-4000 mm[1]	3-6 months [6]	<1000m[0]			pioneer[0]

Reference

0 PROSEA Vol. 2, 5(1), 5(2), 5(3), & 12(3)
1 Agroforestree Database, World Agroforestry Centre. http://www.worldagroforestry.org/resources/databases/agroforestree
2 John W. Turnbull Edit (1986) Multipurpose Australian Trees and Shrubs. Australian Centre for International Agricultural Research
3 熱帯植物研究会編（1984）熱帯植物要覧. 養賢堂
4 Wikipedia (2011閲覧) http://id.wikipedia.org/wiki/
5 Office of International Affairs U.S. (1984) Leucaena: Promising Forage and Tree Crop fo te Tropics. National Academy Press U.S.
6 森徳典ら（1996-97）熱帯樹種の造林特性第1-3巻. 国際緑化推進センター
7 森 徳典（2013） 熱帯のAlueritas. 海外の森林と林業 NS.No. 85
8 Jones, L & Miller, J.H. (1991) Jatropha curcas. Astag Technical paper, Land Resources Series No.1, The Worl Bank Asia Tehcnical Department Agriculture Division, 12pp.
9 浅川澄彦 (1992) 熱帯の造林技術. 国際緑化推進センター
10 John C. Doran and John W. Turnbull Edit.(1997) Austrarian Trees and Shrubs: Species for land rhabilitaion and farm planting in the tropics. Australian Centre for International Agricultural Research1
11 Jatropha curcus plantations (2013閲覧) . www.jatrophacurcasplantaions.com/
12 Jomes A. Duke (2001) Handbook of nats. CRC Press
13 E. Soepadano, L.G. Saw and R.C.K. Chung (2004) Tree flora of Saba and Sarawak. Vol.5 & 6. Malaysian Government
14 FAO (1979) Eucalyptus for planting
15 Dale O. Evans and Lawrence T Szott Edit. (1955) Nitrogen Fixing Trees for Acid Soils. NAFTA & CATIE
16 Simmathiri Appanah & J. M. Turnbull Edit. (1998) A Review of Dipterocarps, Taxonomy, ecology and silviculture. CIFOR
17 Acacia decurrens (2013閲覧) http://www.pfaf.org/user/Plant.aspx?LatinName=Acacia+decurrens
18 Wikipedia(2013閲覧) Delonix regia. http://en.wikipedia.org/wiki/Delonix_regia
19 Kew Royal Botanical Garden, Melaleuca alternifolia. (2013閲覧) http://www.kew.org/plants-fungi/Melaleuca-alternifolia.htm
20 Wikipedia (2013閲覧) コーヒーノキ http://ja.wikipedia.org/wiki/%E3%82%B3%E3%83%BC%E3%83%92%E3%83%BC%E3%83%8E%E3%82%AD
21 Kew Royal Botanical Garden, Theobroma cacao (2013閲覧) http://www.kew.org/plants-fungi/Theobroma-cacao.htm
22 GlobinMed (2013閲覧) Hibiscus cannabinus. http://www.globinmed.com/index.php?option=com_content&view=article&id=80300:hibiscus-cannabinus-l
23 R.S. Troup (1986) The Silviculture of Indian Trees. Vol.2.
24 S. Gardner, P. Sidisunthorn, and V. Anusarnsunthron (2000) A Field Guide to Forest Trees of Northern Thailand
25 Forest Inventry and Planning Institute (1996) Vietnam Forest Trees
26 熱帯農業研究センター（1978） 熱帯の有用樹種
E Experience & Estimation, 経験上の知見及び記述からの推定（赤字）