Technical Guidelines for Reforestation

at Ex-Coal-Mining Areas

– Based on the outcomes of experimental reforestation activities at ex-coal-mining areas in South Kalimantan, Indonesia -

Japan International Forestry Promotion and Cooperation Center
(JIFPRO)

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

Fakhrur Razie, Hamdani Fauzi and Mahrus Aryadi
Lambung Mangkurat University, Indonesia

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Foreword

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. Deforestation by mining is a big issue these years. Problem soils such as strong acid soils and/or too much heavy metal soils appear at the ex-mining areas. In some cases it is too difficult to reforestate. In Indonesia, among other developing countries, coal mining is rapidly increasing due to the increase of demand in recent years. Acid sulfate soil (ASS) occurs after mining development which leads to acid mine drainage and increase of devastated land. As a result, biodiversity is lost and the risk of disaster such as frequent flood is rapidly increasing.

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 ex-coal-mining areas in South Kalimantan, Indonesia, 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 Barito Watershed Management Center as our counterpart, the coal mining companies (PT. Antang Gunung Meratus and PT. Tanjung Alam Jaya), Laambung Mangkurat University and the Forestry Research and Development Agency of Ministry of Forestry in Banjarbaru.

March 2015

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

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Chapter 1. Background and Objectives

1-1. The current status of coal mining in Indonesia

Coal production has been increasing rapidly in Indonesia after opening up the investment on coal sector from overseas in the early 1990s. Indonesia's coal production in 2012 reached 440 million tons, 43 times more compared to 1990 and it ranked 4th in the world. About 380 million tons (86%) of those are exported to Japan and Korea and emerging countries such as China and India for mainly power generation (82 times more compared to 1990). Meanwhile, domestic consumption stands low at 60 million tons (14%) in 2012. However, in order to secure the volume of the domestic coal demand for fire power generation which is expected to increase rapidly in the coming years, the Ministry of Energy and Mineral Resources of Indonesia issued Minister Regulation No. 34/2009 "Domestic Market Obligation for Mineral and Coal" and started to adopt protectionist policies to limit the export volumes and allotted the amount of domestic use to coal companies.

Indonesia's coal reserves ranks 13th in the world. They are located in 3 provinces, East Kalimantan, South Kalimantan and South Sumatra. Coal production and exports in 2012 in East Kalimantan and South Kalimantan accounts for 90% of Indonesia. The Indonesian Ministry of Energy and Mineral Resources issued a law on Mineral and Coal Mining in January 2009 (Law No. 4 of 2009 on Mineral and Coal Mining, hereinafter, the 2009 New Mining Law). In line with the new law, Contract of Work (COW) which was applied to foreign mining companies was banned and mining concession was unified to licensing scheme (a mining business permit). Top-10 coal companies with coal business area of tens of thousands ha account for 60 % of total coal production and exportation. Small and medium-sized companies (more than a thousand) account for the remaining 40 %.

1-2. Policy on Reclamation of coal mined land

Open-pit coal mining is common in Indonesia. It gives big impacts on the environment and landscape because of the deforestation, devegetation and deformation of land (Figure 1).

Figure 1 Ex-mining land in East Kalimantan

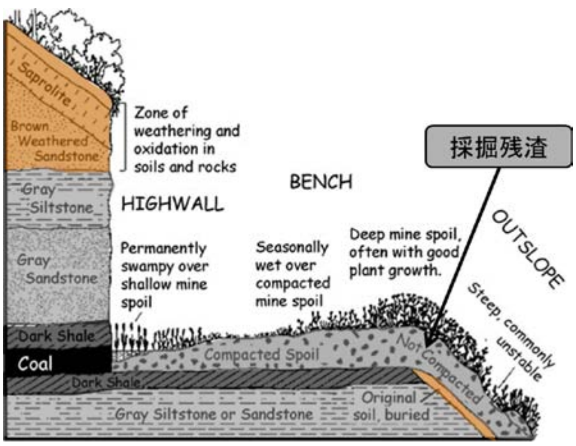

Figure 2 Topography generated by open-pit mining (Diagram)
Source) W. Lee Daniels and C. E. Zipper. 2010.

Thus the handling procedure of ex-mining areas is stipulated in the Government Regulation No. 78/2010 Regarding Reclamation and Post Mining as a by-law of New Mining Law. Mineral and Coal Enterprises need to submit to the government the reclamation and utilization plan of ex-mining areas and get approval of it in advance. They are obliged to reclaim and utilize the land based on the plan or restore the land to the same usage as before the project. Especially in case if the expected mining land is the forest site, they need to gain the borrowing permit from the Indonesian Ministry of Forestry. Among the forest sites in Indonesia, mining is permitted only in the "Production forest" (tunneling and/or open pit mining is allowed) and the "Protection forest" (tunneling mining is allowed but open pit mining is not). It is banned in the "Conservation forest". If borrowing forest site, the pit needs to be filled in after mining and forest reclamation should be done before returning. ("the Use of the Forest Estate" (Government Regulation No.24/2010), "Reclamation and Restoration of the Forest" (Government Regulation No.76/2008)) Indonesian Ministry of Forestry regards the reforestation of ex-mining areas which is rapidly increasing these years as one of the most important challenges to be handled. The Ministry issued "the Guideline for Reforestation" (Forestry Minister Regulation No.4/2011) and "the Guideline for the Evaluation of Reforestation" (Forestry Minister Regulation No.60/2009) and started to promote the reforestation in the ex-mining area.

1-3. Obstacles to the reforestation at the ex-mining land

However, so many obstacles exist to the reclamation of forest in the ex-mining lands. The main factor of making the reforestation difficult is often due to the specific soil properties. Generally, the original strata before mining contain surface soil and subsoil with brown / yellowish materials which are weathered and oxidized by iron. Below the soil stands bed rock layer with grayish materials in initial weathering stage and not being oxidized. Further below it reside sedimentary rock layer with dark- grayish materials and black coal layer (Figure 2). Open-pit mining is conducted by removing bed rock and surface soil. These sediment removed from the mining land (known as Overburden) is dumped to the dump site as waste or is used when refilling the hole (Figure 3). Most of the overburden are unweathered grayish materials in gravel. Grained one is infertile. In addition to that, land leveling and setting is conducted by frequent loading of very heavy vehicles in order to prevent landsliding. The hardening and compaction of the refilled materials disturb the fixing of plants. The compacted surface soils become less able to absorb rainfall. Thus most rain run off with surface soil. As a result, the fixing of plants becomes further difficult.

If overburden contains potential acid material, Pyrite, it causes the emergence of Acid Sulfate Soil (ASS) over time, which makes it difficult for every vegetation to survive (Figure 4).

Figure 3 Leveling at ex-mining land

Figure 4 Dead plants due to Acid Sulfate Soil

To handle these problems the following procedure is stipulated in "the Guideline for Reforestation" of Indonesian Ministry of Forestry as mentioned above .

a) In case of open pit mining, overburden should be stored separately by weathered brown-yellowish materials and unweathered grayish materials.
b) When dumping overburden or using it to refill the hole, put the grayish materials first and then overlay the brown-yellowish materials for fully dressing.

The field, however, is shallow in brown-yellowish layer thus it is difficult to store or procure the materials for surface refilling. There may be no choice but to use the grayish overburden for land leveling in some regions. If those overburden contains Pyrite, the soil becomes highly acidic, which disturb the reforestation. For these reasons several open-pit mined lands remain abandoned and the number of devastated land is increasing in East Kalimantan and South Kalimantan. Coal business association composing of local environmental NGOs warns the situation is bound to get worse, pointing out the loss of biological diversity and the possibility of natural disaster such as flood.

So this research aims to verify empirically appropriate procedures for reforestation (land leveling, dressing, fertilizing, selecting tree species) by conducting the tree planting tests in the post-mining lands.

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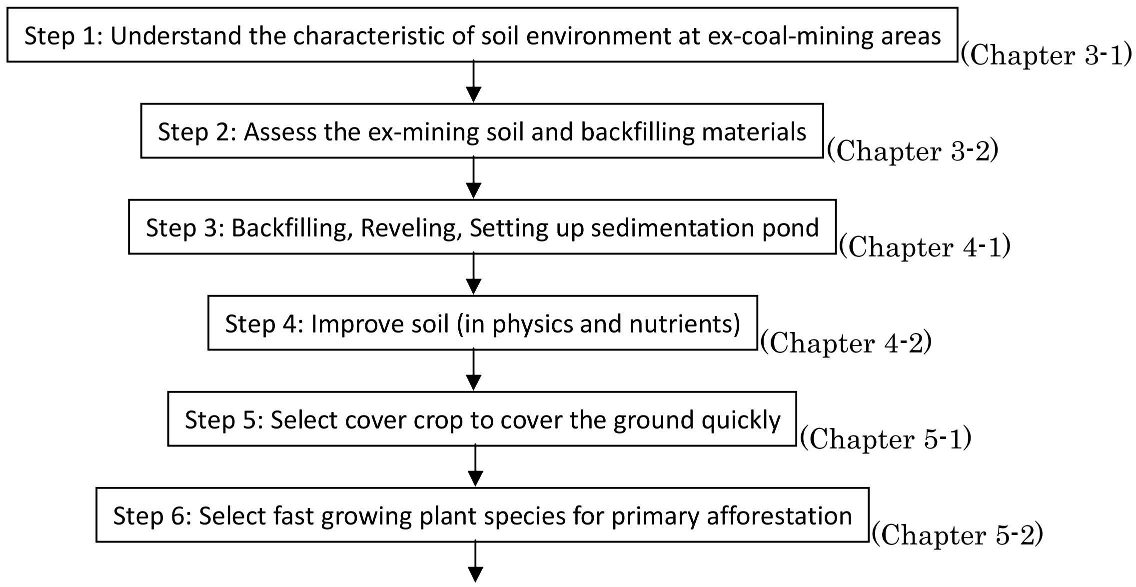
Chapter 2. Technical Requirement for Forest Rehabilitation at Ex-mining Areas and Implementing Procedure

2-1. Technical Requirement for Forest Rehabilitation at Ex-mining Areas

It is difficult to rehabilitate the forest at the back filling sites or dumping sites after mining because problem soils occur due to the bed rock appearing on the surface as overdue. The problems mean soil runoff and erosion due to the bare ground in addition to the oligotrophic and low organic soil and poor soil physical properties such as high bulk density and low porosity. If the soil contains the potential acid material, Pyrite, it is further difficult to reforest because the soil becomes acid sulfate by the oxidation of pyrite and heavy metals will be released under the condition of strong acidity.

The following conditions are needed as basic techniques for forest rehabilitation at the ex-coal mining areas.

1) Understand the characteristic of soil environment (backfilling materials and waste soil) at the ex-coal-mining areas
2) Assess the potential acidity (Chapter 3- 1, 2)
3) Revel in order to prevent the soil runoff and erosion (Chapter 4-1)
4) Improve soil (in physics and nutrients) (Chapter 4-2)
5) Select cover crop to cover the ground quickly (Chapter 5-1)
6) Select fast growing plant species for primary afforestation (Chapter 5-2)
7) Select long life plant species for secondary afforestation leading to desired forest (Chapter 5-3)
8) Nursery of planted trees (Supplemental planting, top-dressing, weeding and cutting) and maintenance (counter measure against wild fire), which are very important.



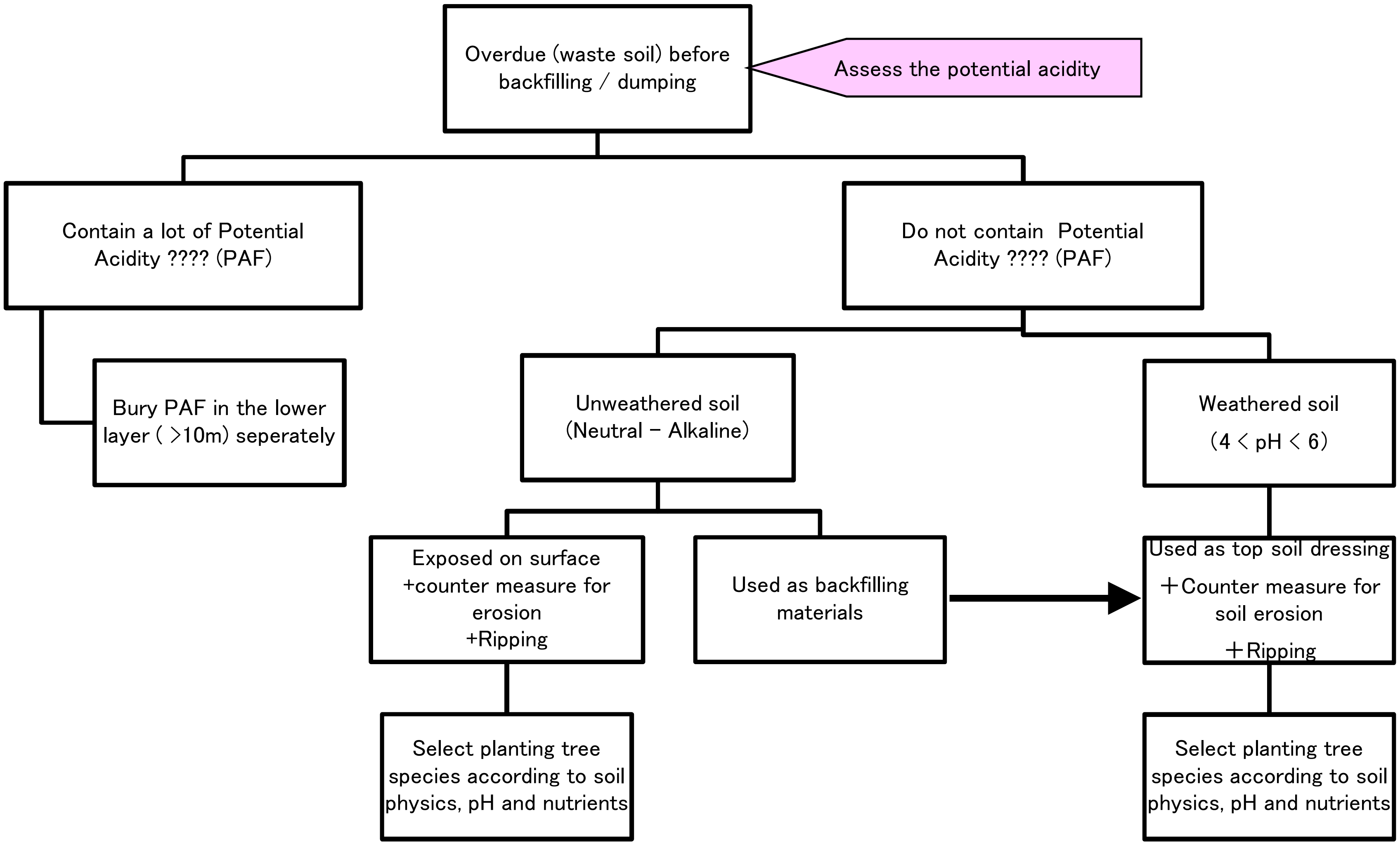
Step 7: Select long life plant species for secondary afforestation leading to desired forest

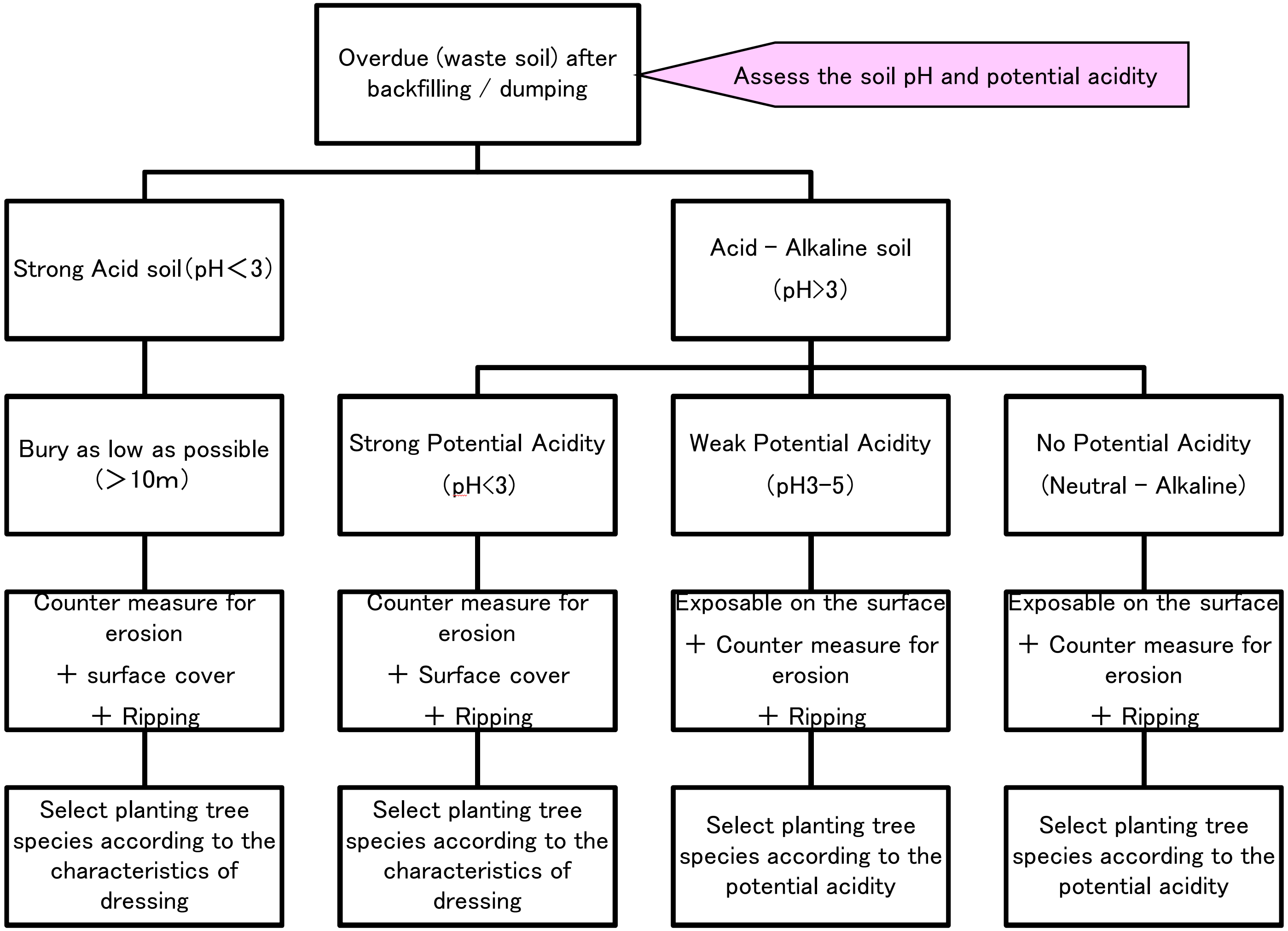
↓ (Chapter 5-3)

Step 8: Nursery and maintenance of planted trees (Chapter 6)

Figure 2－1. Technical Requirement for Forest Rehabilitation at Ex-mining Areas and Implementing Procedure

2-2 Implementation procedure for forest rehabilitation at ex-coal-mining areas (Decision Tree)





Overdue (waste soil) after backfilling / dumping
Assess the soil pH and potential acidity
Strong Acid soil(pH＜3)
Acid – Alkaline soil (pH>3)
Bury as low as possible (＞10m)
Strong Potential Acidity (pH<3)
Weak Potential Acidity (pH3–5)
No Potential Acidity (Neutral – Alkaline)
Counter measure for erosion ＋ surface cover ＋ Ripping
Counter measure for erosion ＋ Surface cover ＋ Ripping
Exposable on the surface ＋ Counter measure for erosion ＋ Ripping
Exposable on the surface ＋ Counter measure for erosion ＋ Ripping
Select planting tree species according to the characteristics of dressing
Select planting tree species according to the characteristics of dressing
Select planting tree species according to the potential acidity
Select planting tree species according to the potential acidity

Chapter 3. Characteristics of soil after coal mining and its assessment

It is a standard method to refill a pit after open-pit coal mining with overdue and dress with surface soil which has been stored aside on digging. If dressed with the surface soil stored aside in sufficient depth (at least 1m), the soil environment, especially chemical environment, does not change dramatically as before the digging, which is best for the forest rehabilitation. But if the dressing is not conducted with surface soil or its depth is not sufficient, the soil environment of the surface will vary depending on the characteristics of the overdue, resulting in forming extremely unnatural environment. In addition to that, the soil is compacted by heavy machines such as the big dump trucks and bulldozers moving to refill the land in the case of open-pit coal mining.

The soil after coal mining may become unnatural chemically and physically, thus the forest rehabilitation may be limited. For this reason, this project aims to develop a basic manual to rehabilitate and reforest degraded lands after coal mining and we developed a model forest at a land after coal mining in South Kalimantan (Indonesia). We monitored the soil characteristics (especially soil acidity and physics) and its change as well as the survival and growth of the planted trees.

A summary of soil environment after coal mining and the method to assess is described in this chapter.

3-1. Soil environment after coal mining

3-1-1. Characteristics of soil chemicals (pH level)

a) When refilled with the sediment not containing Pyrite

If the overdue does not contain Pyrite and is not weathered relatively soon after the digging, it contains a lot of basic elements such as Ca, Mg, K, Na, etc. Pits are generally refilled soon after the mining thus the unweathered sediment is mainly used as refill. In that case basic ion is released continuously due to the weathering and erosion of primary minerals (rock forming minerals) in the overdue, making the soil alkaline with around pH 8. But then, basic elements are leached gradually by rainwater, returning to the pH level of the vicinity. pH of the natural tropical rainforest soil which contains Acrisol (WRB)/ Ultisols (U.S. Soil Taxonomy) widely found in South East Asia humid tropical zone is 4-5. pH increases to 5-6 with the erosion of basic elements in the biomass into the soil.

The duration of keeping the soil alkaline will depend on the balance between the total amount of basic elements in the overdue and the speed of weathering and erosion. The result of this project shows that there is no possibility of the rapid shift from alkaline to acidic within 4 years if the overdue does not contain pyrite. The soil keeps alkaline environment for longer period than 4 years thus it means the planted trees are to be put under the environment for the period. (See BOX 1)

BOX1 Soil pH change with time at ex-coal mining site – a case of South Kalimantan

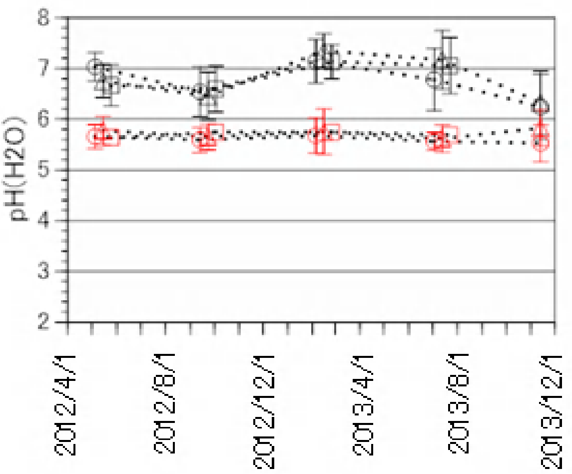


Figure Soil pH (H_2O) change with time at ex–coal mining site

Black: refilled with fresh mining residue

Red: refilled with fresh mining residue and top dressing with forest surface soil.

○:0–10cm in depth, △:10–20cm, □:20–30cm (n=10)

Soil pH of most spots (in black) refilled with fresh mining residue was 6.5 - 7.0 at first, increased to above 7.0 due to leaching of basic cations with weathering after 9-14 months and then decreased to 6.2 after 18 months. Compared to the natural forest soil of pH4.0-5.0 which is mainly Acrisols in the surrounding area and to the secondary forest and waste cogon grass of pH5.0-6.0 (pH of wasteland is higher than that of natural forest because cations existed in forest biomass permeate soil with the devastation of forest), pH of spots refilled with fresh residue was consistently higher and the acidification process was slow as a whole. pH value did not change much by depth of the samples. As shown by the length of error bar, pH values varied significantly by spots measured. It was found that soil materials with different properties are unevenly distributed and a part of it contained pyrite. pH of topsoil dressing is stable at 5.7-5.8 during the measurement period and it reflected the property of the surrounding soil used as top dressing. It was assumed that top dressing material was homogeneous judging by relatively small standard error.

b) When refilled with sediments containing pyrite for top dressing

In many cases, a formation containing pyrite (see BOX 2) exists above or below coal. When a formation with pyrite exists above target coal, pyrite gets mixed in with the overdue. As explained in BOX 1, when exposed to air pyrite generates acid sulfate. If the surface is dressed with the sediments containing pyrite the soil condition becomes strongly acidic on the surface and thus it can be very difficult for every plant to survive and grow. For this reason, it is really important to bury the sediments with pyrite in deep soil to segregate it from surface with the aim of avoiding acidification when refilling the mining pit.

BOX2 Generation and Oxidation of pyrite

Pyrite will be generated under the condition in which the simultaneous supply of both SO_4^{2-} and organic matter in the seawater or brackish water. For example, mangrove, which grows in seawater and brackish water, is under the condition. Under the anaerobic environment formed by the decomposition of organic matters, a lot of SO_4^{2-} ($2.65 gL^{-1}$) existing in seawater generate H_2S of sulfur (S (-II)) compound reduced by heterotrophic bacterium which is obligate anaerobes.

$$2CH_2O+SO_4^{2-}=H_2S+2HCO^{3-}$$

Generated S (-II) react with Fe^{2-} which is already generated under the higher oxidation- reduction potential than sulfate reduction, which result in the precipitation of metastable blackish iron sulfide (FeS) at normal temperature.

$$Fe^{2+}+ S^{2-}=FeS$$

FeS react with atomic sulfur (S(0)) which is generated by the oxidation of S (-II) and exists in seafloor sediment, which generate pyrite (FeS_2).

$$FeS+S(O)=FeS_2$$

When pyrite in the seafloor sediment is dehydrated due to uplift, the following reaction will proceed with the presence of oxygen.

$$FeS_2+1/2O_2+2H^+=Fe^{2+}+2S(0)+H_2O$$

$$2S(0)+3O_2+2H_2O=2SO_4^{2-}+4H^+$$

These reactions are very slow in purely chemical condition. However, the reaction is proceeded rapidly if involved in microbial groups such as iron and sulfur bacteria. Rapid acidification progresses due to the sulfate generated by this process. Oxidation of pyrite is enhanced further by Fe3+ as an oxidant which is dissolved in solution if pH is below 3.

$$FeS_2+14Fe^{3+}+ 8H2o=15Fe^{2+} +2SO_4^{2-}+16H^+$$

Half-life period of this reaction is 20-1000 minutes. The oxidation of pyrite generates Fe^{2+}, which produces Fe^{3+} with the help of iron bacteria, which results in the further oxidation of pyrite.

But when the sediment containing pyrite get mixed with the refill for the surface dressing, the soil remains neutral or alkaline until sulfate is produced due to oxidation. Soil acidification proceeds gradually by leaching of sulfate and the soil pH becomes below 2 in an extreme case. The speed of acidification will vary depending on soil hydrothermal environment and the activity of microorganism to react with. It may take several years to show strong acidity when the speed is slow. (See BOX 3)

Some sulfates generated by oxidation are runoff by rainwater or neutralized by basic cations in the sediments thus rapid acidification will not occur when the soil has less pyrite and much basic materials because most of sulfates are neutralized. However, if the soil is relatively high in pyrite and does not contain enough basic materials to neutralize sulfates, it becomes strongly acidic.

As described above, the speed of acidification and its acidity in soils containing sediment with pyrite are determined by multiple related factors and its balances such as the amount of pyrite in the sediments, the speed of oxidation, the sulfate neutralizing capacity of the sediments, the speed of removing sulfate by permeate and surface runoff.

Soil pH environment varies largely depending on the variation of the refilling materials and with or without top soil dressing. And it changes with time. For this reason, it is imperative to know in advance the soil environment (pH), with or without pyrite and the acidity (potential acidity) developed by the oxidation of pyrite with time.

There is no doubt that it is fundamental not to use sediment with pyrite as a refill for top soil dressing and to bury it in deep underground. We will need a simple method to assess a formation with such risk.

BOX 3 The difference of oxidation depending on the refilling materials

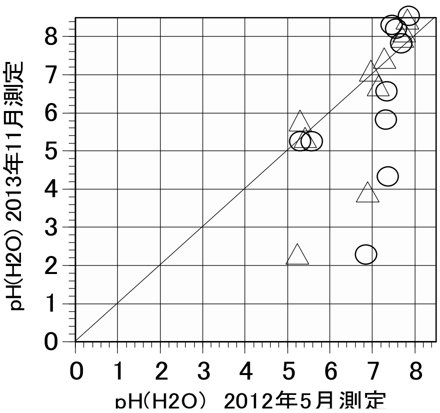


Figure: pH (H_2O) Change one and half year after refilling
○:0-10cm in depth, △:10-20cm

As shown in the left figure plotting pH (H2O) of samples at the time of refill and one year later, most samples distributed along the 1:1 line. At most points without pyrite pH did not decrease by the leaching of basic cations after such a short time as one and half year, however, acidification at 4 samples is clearly indicated. In extreme case pH dropped to around 2.

This figure shows that sediments used as a refill gradually leaches basic cations with weathering and pH decreases accordingly but the speed is slow and soil acidification progress relatively immediately if the soil contain pyrite and a condition is matched.

3-1-2. Physical property of soil – Bulk density, Porosity

1) Generation of compacted soil

Refilling and leveling process is conducted by big dump truck and big bulldozer thus surface soil is strongly compacted and shows extremely high bulk densities and low porosities (see Box). It is widely known that water retention ability and permeability of soil decreases due to the compaction and less porosities. This kind of soil has a serious drawback in that the soil tends to be excessively moist, and at the same time, dry. Therefore growth and development of plant root is physically inhibited and survival and growth of planted tree is limited due to excessive moisture damage or dry damage if tree is planted in the compacted soil at the ex-coal mining land.

Compacted soil is not good at permeability thus rainwater permeation into the soil is limited so a lot of rainwater becomes runoff, which results in heavy runoff of surface soil. In addition, refilled land is bare and has no cover to protect the surface at first thus severe surface soil runoff is inevitable due to the hard raindrop hit of typical humid tropical region. Soil dissipation limits the growth of planted tree in addition to the restriction factors attributable to physical property described above.

Therefore, it is ideal to improve the soil physical property (to increase porosity and permeability) before the rehabilitation of forest. Cultivating and ripping method is recommended. It is also necessary to prevent and alleviate soil runoff. Some constructions are needed such as backfilling to make the slope gentle, making terrace, setting up drain. Protective measures for surface soil such as cover crop and mulching are also needed.

BOX 4　Severe soil runoff at ex-coal mining land

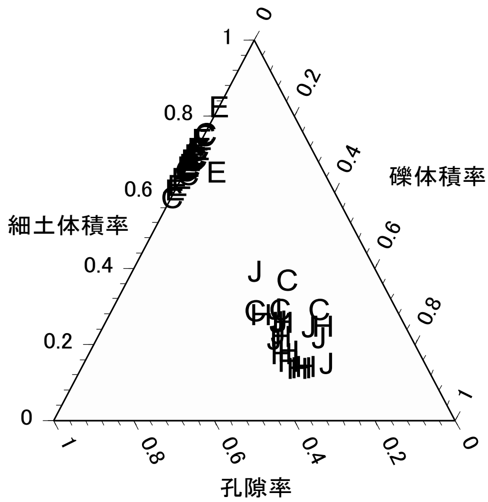


Figure: Change for a year in the ratio of fine soil, gravel and porosity－A case of South Kalimantan-
(Outline character: test result right after refilling
Black character: test result after a year
△:Refilled area, ○:Dressed area

Left figure shows how volume percent of fine soil (<2mm), gravel (>2mm) and pore space contained in a certain volume of soil sample collected by using a cylinder changed in a year after refilling. As shown here, most of soil samples contain little or no gravel, fine soil 60-80% and pore space 20-40% at the first measurement. However fine soil decreased to 15-40%, porosity remains almost the same 20-40% and gravel increased significantly 30-70% a year later at the second measurement.
It is expected that soil materials such as fine grain materials and gravels in this experimental site is heavily compacted by big dump truck carrying refill material and ground leveling by heavy machine thus soil become less pore spaces. Under these poor soil physics, it is thought that severe erosion on surface soil occurred because rainwater permeation into the soil was limited so a lot of rainwater became runoff and also due to bare land and hard raindrop hit of typical humid tropical region. As a result, fine particle material in surface soil run off over time, which led to larger percentage of gravel in the soil. This hypothesis is supported by the morphological property of soil profile at first and second measurements.

3-2. Assessment method of ex-coal mining land soil and refill materials

3-2-1. Soil pH and potential acidity

pH(H_2O) is widely used as the most simple parameter to indicate the chemical environment of soil. Soil pH is the basic information when selecting tree species and managing soil thus it is ideal to measure it before planting trees at ex-coal mining land. The number of sample points necessary to grasp the current soil situation depends on the uniformity of refill materials at the ex-coal mining land. If different materials are clearly found across a wide area by judging the color (especially the intensity of black) and particle density (sand or clay) of refill materials, it is desirable that pH should be assessed at several tens of sample points for each materials to get a representative value. The depth to measure pH should be about 0-10cm, the most surface layer where plants root grow or lower layer- 50cm if possible.

As described above, if refill materials contain pyrite, it creates strong acidity over time and its acidity depends on the amount of pyrite. It is possible to know in advance how much acidity it will show in the future by measuring the potential acidity by forcibly oxidizing it beforehand. Forced oxidation is conducted by adding hydrogen peroxide water (H_2O_2) to the sample. Potential acidity is measured by using a pH glass electrode or simply pH-test paper after transforming all sulfur in pyrite into sulfuric acid (H_2SO_4). Samples (especially fresh sediment soon after mining), however, contain a lot of basic elements which neutralizes some of sulfuric acid generated thus the potential acidity assessed in this method does not necessarily indicate the accurate amount of acid. Because in the actual time course some of sulfuric acid generated are runoff with rainwater and neutralized by basic elements released due to weathering of minerals. Therefore, pH value assessed as potential acidity does not always appear in fact and the test result should be regarded as just a potential value.

BOX 5 Simple method to measure pH (H_2O) and potential acidity of soil / sediments

1) To obtain the accurate pH (H2O) of soil; add 2.5 times of distillated water to 1 moist soil in weight (ex, 10g of moist soil : 25ml of distillated water). Stir the mixture until all soil mass are dispersed to the muddy suspension and then measure the pH by using a glass pH electrode (pH meter).
To obtain the rough pH in the field; it can easily measure a suspension of soil: water = 1: 2.5 using pH test paper. For more detailed method, see below.

SSSA 1996; *In* Method of Soil Analysis, Part 3 – Chemical Methods, Soil pH and Soil Acidity, 475–490

2) To measure the potential acidity simply in the field, place approximately 1/2 teaspoon of the soil sample (about 5 g) into glass test tube (wide-mouth and tall, 20mm in diameter and 200mm in length) and add 1-2 millilitres of 30% H2O2 (adjusted to pH 4.5–5.5 by adding a few drops of dilute NaOH) to the soil and stir the mixture. DO NOT add more than several milliliters of H2O2 in order not to overflow the reactant of the soil:peroxide mix. Allow approximately 15 minutes for any reactions to occur. It may not be necessary to stir the mixture if substantial sulfides exist and the reaction will be vigorous and may occur almost instantly. If the reaction is violent and the soil:peroxide mix is escaping from the test tube, a small amount of distillated water can be added (using a wash bottle or pipette) to cool and calm the reaction. The above mentioned steps may be repeated until the soil:peroxide mixture reaction has slowed. Usually one or two extra additions of a few millilitres of peroxide are sufficient. This will ensure that most of the sulfides have reacted. Wait for the soil:peroxide mixture to cool and then measure the pH by using a glass pH electrode or simply pH-test paper. For more detailed method, see below.

Queensland Acid Sulfate Soils Investigation Team et al. 2004: *In* Acid Sulfate Soils, Laboratory Methods Guidelines, Version 2.1, Acid Sulfate Soil Field pH Test, H1-1 – H1-4

The soil pH or potential acidity assessed is used as a standard to select tree species for forest rehabilitation.

The result of this model forest project shows that it is difficult for any tree species to survive in the soil below pH 3.0 (See BOX??). The pH of the soil in tropical rainforest and tropical seasonal forest is generally 4.0-5.0 and 5.0-7.0, respectively. Thus, we suggest the following pH segments as a criteria for deciding planting tree species.

Acidity segment

i) Acidity Class I : below pH 3.0 (Very strongly acid)
ii) Acidity Class II : pH 3.0-4.0 (Strongly acid)
iii) Acidity Class III : pH 4.0-5.0 (Acid)
iv) Acidity Class IV : pH 5.0-7.0 (Moderately acid)
v) Acidity Class V : above pH 7 (Alkaline)

The above segment can be used for potential acidity as it is thought that a pH close to it will occur in the near future.

Potential acidity segment

i) Potential Acidity Class I : below pH 3.0 (Very strongly acid : Strongly suspected the presence of sulfide)
ii) Potential Acidity Class II : pH 3.0-4.0 (Strongly acid : Slightly low possibility of sulfide presence)
iii) Potential Acidity Class III : pH 4.0-5.0 (Acid : Sulfide presence unknown)
iv) Potential Acidity Class IV : pH 5.0-7.0 (Moderately acid : Almost no presence of sulfide)
v) Potential Acidity Class V : above pH 7 (Alkaline : Almost no presence of sulfide)

3-2-2. Soil physics

It is important to understand the physics of surface soil in which plant root grow when forest rehabilitation is conducted at ex-coal-mining land. Among parameters to refer are soil hardness to be measured by intrusive hardness scale, bulk density which is the weight of dry soil divided by the total soil volume and porosity itself, etc. It is highly convenient to measure the soil hardness because it can be assessed on the spot. But it has a flaw that the value can be changed significantly depending on the volume of soil moisture and measured value can vary enormously even at the same soil stratum. Thus the credibility as an indicator is not high. The credibility of porosity is high in showing directly the airspace of soil but it is not convenient to measure porosity because a precise measurement such as true specific gravity is needed at a laboratory. On the other hand, the drying, screening and weighing samples are needed to measure bulk density but it can be assessed by relatively simple equipment, thus it is widely used as a parameter to indicate the soil physics.

As shown in BOX6, bulk density of natural soil in tropical forest is generally fell in the range of 0.9 - 1.6 Mg Kg^{-1}. The surface layer contains a lot of humus where soil animal is active and a lot of rootlet develops. Surface layer with developed soil structure shows low bulk density and lower layer shows higher. Bulk density of surface soil is 0.9 - 1.3 Mg Kg^{-1} depending on the content of humus and clay. Plant root will grow in the surface soil. Then, it is adequate to classify the surface soil of ex-coal mining land into the following 3 classes.

In the case of Compacted soil class I, the soil property environment does not exist naturally. Some kind of measures such as cultivating will be needed because the growth and development of root is severely limited and the following circumstances will occur such as an excessive moisture damage caused by drainage defect, a dry damage due to less porosity, a severe surface soil runoff stemming from less permeability.

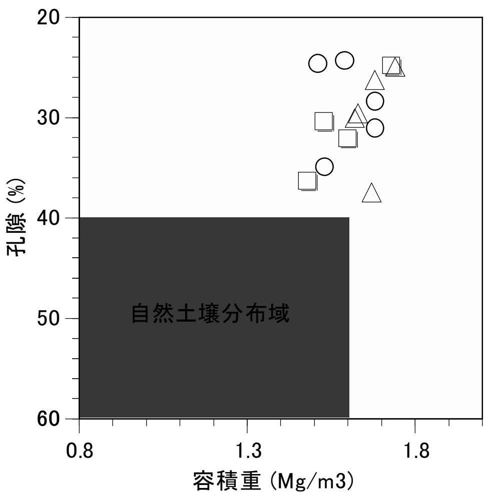
Soil physics class by bulk density

i) Compacted class I : Strongly compacted (bulk density: above 1.6 Mg Kg^{-1})

ii) Compacted class II: Compacted (bulk density: 1.3-1.6 Mg Kg^{-1})

iii) Compacted class III: Soft and Loosened (bulk density: less than 1.3 Mg Kg^{-1})

BOX6 Property comparison of natural soil and ex-coal mining soil – a case of South Kalimantan



The left figure shows the bulk density and porosity of sample soils collected just after refilling of ex-coal mining pit in South Kalimantan. The bulk density (defined as the dry weight of soil per unit volume of soil) of these sample soils is very high (1.5-1.8 Mg Kg-1), porosity is less than 40%, which does not overlap with the distribution area of natural soil (native forest soil in East Kalimantan). It indicates that compaction developed to the extent which does not exist naturally due to the refilling process.

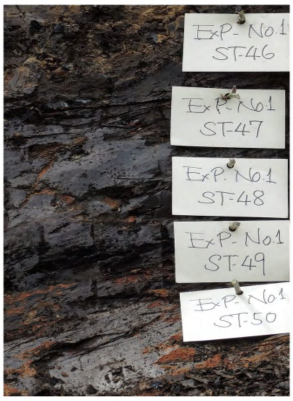
Figure Soil physics of refilled site at ex-coal mining
○: 0-10cm, △:10–20cm, □:20–30cm

3-2-3. Simple method to assess the potential acidity of refilling materials

It is most important to select the sediments without pyrite and potential acidity as refilling materials for forest rehabilitation at the ex-coal mining pit. Thus it is needed to assess the potential acidity of the sediments. There are mainly two methods to estimate the potential acidity. One is to assume the potential acidity by extracting fractionally sulfur in pyrite and directly determining quantity of sulfur related to the development of acidity. The other is to assume the potential acidity by chemically oxidizing sample soils with hydrogen peroxide water and measuring the volume of hydrogen ion generated by a titration method. However, these two methods are based on the premise of the analysis at a laboratory and requires highly specialized knowledge. Therefore it is not practical to test a vast kind of sediments produced from the mining pit by using these methods considering the time and cost. For this reason, this time we tried to develop a simple method to estimate the potential acidity in the field.

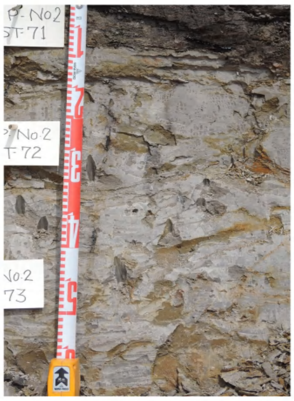
Among sediments with a lot of pyrite, what contains less dark color displays light-colored, on the other hand, oxidized materials shows yellow- brown- red colors depending on ferrioxide and hydroxide. We measured the color of sediments in each formation in the field by using digital soil color meter and made a review whether there is a relationship between the color and the potential acidity.

BOX 7　Different forms of sediments

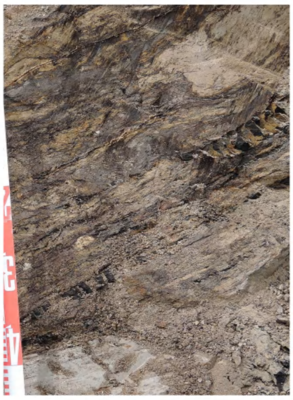


1

2



3



4

5

6

Photo 1: Clay, blackish brown, partly lamellas

Photo 2: Clay, dark-gray, no lamellas

Photo 3: Clay, slightly gray, no lamellas

Photo 4: Clay, dark brown, lamellas

Photo 5: Sandy, slightly gray, no lamellas

Photo 6: Sandy, slightly gray-brown, lamellas

As a result, it revealed that among elements forming the potential acidity and soil color, a parameter displaying black/white (L* in the L*a*b* color space) will be a valid index for potential acidity (BOX 8). The surface of sediment is mostly covered by the coat of oxidized iron with time and is generally dry. So, to measure the color, we scraped off the surface of sediment with a knife, etc to expose unoxidized fresh sediment and made flat, smooth and moist (white will be overestimated if dried) part and then measured the color placing the soil color meter on it. To measure the color of sediment, we scraped off the surface of formation and made it flat, smooth and moist (white will be overestimated if dried) part and then measured the color placing the digital soil color meter (KONICAMINOLTA-SPAD503) with L*a*b* mode on it. Color of each formation is not necessarily even and in most cases there is a certain variation in color. Thus, we measured the color 10 times for each formation and regarded the average as the representative color of the measured sediment.

We designed a draft plan to assess the potential acidity using L* as a reference, based on the result of this experiment (see BOX 8). We made a classification assuming that using sediment with pH <3 as a refill led to a huge risk to strong acidification of soil.

BOX 8 Relationship between potential acidity and soil color (L* ; an index of black/white)

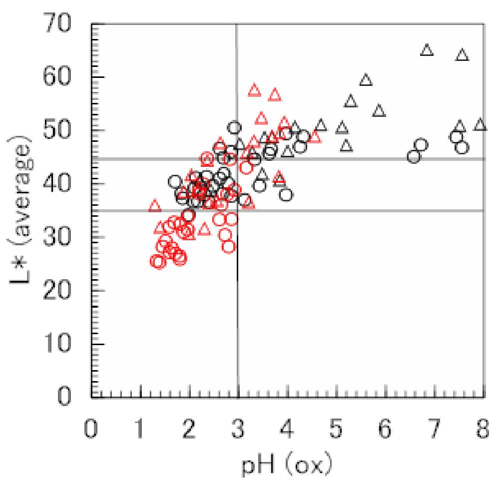


Figure: Relationship between potential acidity (pH(ox)) (See BOX 5) assessed by hydrogen peroxide oxidation and L* (Smaller in value, blacker in color) measured by digital soil color meter.
(○:Clay without lamellas
○:Clay with lamellas
△:Sandy without lamellas
△:Sandy with lamellas)

We measured the color in addition to particle size, with or without lamellas structure in roughly 100 different formations passing obliquely the ex-coal mining pit wall and also measured the potential acidity (pH (ox)) of sample soils in the same formation. As shown left, pH(ox) distributed widely, pyrite content varied largely, distribution of L* was big, different samples had largely different color value, there existed clear correlation between pH(ox) and L*. L* decreased (increase of black) as pH (ox) decreased. Especially, all darkish samples with L* <35 fell in the range of pH(ox) <3. Many samples with L* =35-45 showed pH(ox) <3. On the other hand, samples with L* >45 showed pH(ox) >3. pH(ox) tended to increase further as L* increased.

Focused on particle size and lamellas structure, almost all samples with L* <35 and pH(ox) <3 were clay and derived from sediments with lamellas structure. Samples with L* >45 and pH(ox) >3 were mostly sand and partly materials containing lamellas structure. All clay samples distributed in the same area were the one without lamellas structure. Clear correlation between a* and b* in the L*a*b* color space and pH(ox) was not found.

Risk class of sediment based on soil color (L*)

i) **Risk class** I：Sediment with L*<35 has extremely high risk of acidification. Do not use it as a refill for forest rehabilitation. It is needed to set apart and bury it deep under the ground (more than 10 m in depth) to prevent oxidation.

ii) **Risk class II**: Most sediment with L*=35－45 is classified into high risk. Same handling as above sediment with L*<35 is needed for this class. However, some sediments in this class contains relatively low risk. If you select low risk sediments and use it as base material for forest rehabilitation, you need to assess the potential acidity in advance by using hydrogen peroxide to make it oxidized.

iii) **Risk class III**: Sediment with L*>45, especially sandy and without lamellas structure, has low risk. But some sediments with clay and lamellas structure will show potential acidity of pH(ox) around 3, so the potential acidity for sediments with these properties should be assessed in advance by using hydrogen peroxide to make it oxidized.

Note 1) Positional relationship between sedimentary layer showing potential acidity and coal layer: Sediment showing potential acidity does not necessarily show strong potential acidity near the coal layer. It may be difficult to estimate the presence or no presence of pyrite or its amount from the positional relationship of layers.

Note 2) The correlation between L* and pH(ox) explained above was obtained by samples collected from only 2 mining pits in South Kalimantan. Thus it is unclear that the same criterion is applicable to the other sites. However, it is thought that a similar relationship exists between potential acidity and the color (especially L*) of sediments even in a different region. We think it is better to make the same kind of review on different sediments and regions and verify the relationship between the parameters and set an original criterion.

Chapter 4. Backfilling, Leveling/Site preparation, Setting up Sediment Pond and Soil Improvement

4-1. Backfilling, Leveling/Site preparation, Setting up Sedimentation Pond

4-1-1. Backfilling, Leveling/Site preparation, Setting up Sedimentation Pond

Leveling is needed for the mining pits to be backfilled after the coal mining and for mounds and steep slopes made by overdue (waste soil). Also certain constructions are needed to prevent soil runoff, soil erosion and landslide. At the same time it is important to prevent acid mine wastewater from leaking into public water area.

Only wall part and the surrounding areas will be reinforced for too big mining pit and pits left behind without backfilling due to expiration of mining permission in order not to create hazards such as landslides to the people in the vicinity.

<Work procedure>

1. Identify whether the overdue (waste soil) contains potentially acid forming (PAF) material or not.
2. Bury the PAF separately in the bottom of a pocket 10 m below the surface. Cement the hole with clayish materials in order to prevent oxygen and/or water from infiltrating into the hole. If oxygen and/or water infiltrate, PAF will react with it and generate acid mine wastewater.
3. Place non acid forming (NAF) material on the surface as backfilling material.
4. Conduct a research on the geology to determine the maximum slope angle and length for a factor of safety and to prevent landslide and large-scale erosion from occurring.
5. Cover (dress) the area (already leveled with PAF) at least 30cm with topsoil or as much as you can get.

4-1-2. Control of erosion and sediment

Erosion and sediment should be controlled before, on and after the mining activity to prevent soil runoff from developed land and also to prevent pollution and sediment (shallow river and lake) in public water areas such as river and lake. The soil at ex-mining area may possibly contain harmful heavy metal thus it needs to be appropriately handled in order not to leak outside of mining area.

Soil control is the key to the success of reforestation at ex-mining areas. The soil used for leveling and site preparation and topsoil used for dressing are susceptible to erosion due to the unstableness of soil particle. Thus it is vital to control soil runoff / erosion and sediment.

As for general method to control erosion, please see a brochure “Konservasi Tanah dan Air (Conservation of soil and water)” published by Directorate General of Forest and Land Rehabilitation of Watershed Management and Social Forestry Development, Ministry of Forestry or General Handbook (2011). This handbook focuses on the method to control the erosion and sediment biologically by planting cover crop and by constructing sediment pond.

<Construction of sediment pond and maintenance procedure>

1. Calculate the volume of surface water to flow in the business area and its flow direction and the speed of erosion.
2. Direct the surface water to the sediment pond by digging ditch. The size and number of the sediment pond is decided based on the calculation result of the volume of surface water and the speed of erosion.
3. Construct sediment ponds with level structure. The first pond is placed on top to receive runoff water which contain most solid materials of sediment. Then, water flows from the first pond to the second. At this point the solid content is already decreased. Water flows from the second to the third, these water flows continue until the content of the solid dissolved into the water falls below the acceptable value regulated by law/rule.
4. Plant cover crops on the slope of the ponds to prevent the erosion of pond’s slope and landslides.
5. Monitor the acid level (pH) of water every day. If the pH is below 6, additional procedure using lime is needed. It is acceptable to run the water into the public water area after the pH of water and volume of impurities fall below the value regulated by law/rule.
6. Maintain the pond regularly to reinforce the slope of the pond. Scoop out the sediment from the pond once the pond contains full of sediments.

4-2. Soil Improvement (Soil physics and nutrients, etc)

The waste soil which is disposed by mining is whether dumped to the dump site as waste or used to backfill the mining pit. Unweathered grayish overdue which accounts for most of the overdue is generally rudaceous and refined materials are oligotrophic. In addition, for the purpose of preventing landslide, the soil is compacted by the heavy machine which is used to dispose the waste soil and/or to level the backfilled pit. Heavy compaction of soil inhibits the fixing of vegetation. Compacted surface soil is low in permeability thus most of rainwater runs off as surface runoff water. On this occasion, heavy surface soil runoff occurs which results in the further inhibition of vegetation fixing.

4-2-1. Improvement of soil physics by ripping

To improve the soil physics, attach a ripper to the rear of bulldozer and rip the surface ground. Or place the blade of bulldozer on a skew and rip the surface then make ridges.

Photo 1 Ripping by using the blade

Photo 2 Ridges after the ripping

4-2-2. Dressing over planting pit and Application of compost

Ex-coal-mining area is compacted and scarce of organic matter so the soil tends to be low in water-holding capacity. After ripping the ground deep and over a wide area, it is effective to increase the water-holding capacity of the bottom of the hole by placing the forest surface soil which has a big water-holding capacity and/or organic materials such as compost. This will induce the growth of the root in the deeper ground.

4-2-3. Application of phosphate fertilizer and/or chemical fertilizer

Tropical soil is generally scarce of Phosphorus. The soil nutrients should be improved by applying phosphate fertilizer as base fertilizer. Nutrients are extremely scarce so it is ideal to regularly apply chemical fertilizer (NPK, etc) for additional fertilization.

Chapter 5. Selection of cover crop and planting species

5-1. Selection of cover crop to quickly cover the surface

1. After leveling the ground to prevent soil runoff and erosion, select cover crop to cover the surface. Examples are Pueraria javanica(PJ), Centrosema pubescens(CP), Clopogonium mucunoides(CM), Mucuna spp, Sorghum bicolor, etc. The speed of germination and growth varies depending on the species of cover crops. It is better to select PJ, CP, CM, Mucuna with the ratio of 1:1:1:1.
2. Soon after the completion of land leveling, plant cover crop.
3. When the land is relatively flat and below 5% slope, it is acceptable to plant the cover crop at a spacing of 1x1 m. In case of more than 5% slope, plant the crop in line along the contour and the interval between lines should be 1-1.5 m. Cover crop can be planted over the entire surface (Blowing method)
4. To improve fertility of the soil, apply organic fertilizer of 0.5-1 kg to the hole (spot) of each plant and to each meter/line in case of line system. Apply organic fertilizer of 5-10 ton to each hectare for overall area. In addition, enough lime should be applied.
5. The interval of spot or line in which cover crop will be planted should be narrowed or widened depending on the soil condition (fertility, etc) of the targeted area.
6. Vines such as PJ, CP, CM, Mucuna sp. have habits to creep, spread, cling and squeeze, etc. Perform nursery activity to the vines to prevent the damage to the planted trees.

5-2. Selection of pioneer tree and fast-growing tree of short-life species for the purpose of quick initial greening

To prevent the soil runoff and erosion plant pioneer and fast-growing trees which grow under direct sunlight at bare land as a first step for the rehabilitation of forest at ex-coal mining area. However, pioneer and fast-growing trees are short-lived so they will be dead before too long. Therefore, after the success of initial greening, as a second step, plant shade-tolerant trees which are long-lived and need shade in order to achieve the targeted ideal forest in the end.

<Work procedure for initial greening>

It is acceptable to plant pioneer and fast-growing trees as the initial greening soon after or at the same time planting the cover crop. Work procedures for initial greening are as follows.

1. Pile a stake (marking bar) at the point to plant to create a layout for planting.
2. Plant trees in line with Indonesian success criterion for forest rehabilitation (plant 625 trees/ha at a spacing of 4x4m).
3. Make a hole for planting (at minimum 40×40×40cm) by hand or machine.
4. Analyze the fertility of the soil to be planted to find out the appropriate volume of organic fertilizer, inorganic fertilizer and lime needed to each hole of planting. Generally, each hole will need organic fertilizer 2-5kg, NPK 100-200g and lime 200-400g.
5. Planting work should be done at 8:00-11:00am and 14:00-16:00pm during the monsoon season to avoid the strong sunlight.
6. It is all right to plant pioneer and sun trees at the open area without shade of ex-coal-mining land.

<Examples of fast-growing sun trees>

・Indonesian local species

Jabon putih（Anthocephalus cadamba）、Jabon merah（Anthocephalus macrophyllus）、Melaleuca（）、Duabanga（Duabanga mouccana）、Benuang（Octomeles sumatrana）、Kemiri（Aleurites moluccana）、Eucalyptus sp.、Melaleuca（Melaleuca leucadendron）、Kayu merah（Pterocarpus indicus）、Waru（Hibiscustiliaceus）、Kapuk（Ceiba pentandra）、Sengon laut（Falcataria moluccana）、Johar（Cassia siamea）, etc.

・ Foreign species

Akasia（Acacia Mangium）、Sengon Buto（Enterolubium Cyclocarpum）、Mindi（Melia azedarach）, etc.

5-3. Selection of long-life planting species for second greening to achieve the ideal forest

As stipulated in the Regulation of The Minister of Forestry No. 60/2009 (P.60/Menhut-II/2009), long-life trees should comprise 40% of the total trees at the ex-mining land in the end.

<Examples of slow-growing sun trees>

・Indonesian local species

Jati（Tectona grandis）、Sungkai（Peronema canescens）、Pericopsis mooniana 、Matoa（Pometia pinata）、Sonokeling（Dalbergia latifolia）、Leban（Vitex cofassus）、Reban（Vitex pubescens）、Elmerellia celebica 、Pinus merkusii（Pinus merkusii）etc.

・Foreign species (Not Indonesian origin)

Mahoni（Swietenia macrophylla）、Khaya（Khaya anthotheca）etc.

<Examples of long-life shade trees>

Various Meranti（shorea spp）、Ulin（eusideroxylon zwageri）、Makassar Ebony（Diospyros celebica）、Ipil（Intsia bijuga）、Kapur bukit（Dryobalanop aromatica）、Malacca-jinkoh（Aquilaria malaccensis）、Apitong（Dipterocarpus spp）、Agathis lorantifolia 、Nyatoh（Palaquium spp）、Kegaki（Diospyros blancoi）, etc.

<Work procedure for second greening>

One or two years after planting trees for initial greening, plant long-life trees after the improvement of micro weather such as sufficient shade. The work procedures are as follows.

1. If planning to plant long-life trees later as the second greening, plant the pioneer and fast-growing trees at a spacing of 4x4m.
2. Plant the trees for second greening in between of initial greening trees and 2m ahead of the line. By doing so, a tree for second greening will be planted in the center of the surrounding 4 trees of initial greening.

Refer to "Appendix A-3. Characteristics of the planting tree species in Indonesia" at the end of the book to select pioneer tree and fast-growing tree of short-life species for initial greening and long-life planting species for second greening.

Chapter 6. Maintenance and protection for planted trees

6-1. Maintenance for planted trees (supplemental planting, top-dressing, weeding and cutting)

The purpose of Maintenance activities for planted trees is to secure the survival and good growth of the trees. Maintenance activities are supplemental planting, additional top-dressing, grass and cover crop control and insect and mammalian pest control. If some trees are dead after the planting, it is needed to plant supplemental trees. The soil at ex-coal-mining areas is generally deficient of nutrients so additional top-dressing is needed for the healthy growth of planted trees. Regular cutting of legume (ground cover) is especially important because those vines tend to coil around and squeeze planted trees resulting in the death of the trees (photo 1). If it is sought to achieve an ideal forest, Acacia Mangium planted as initial greening which grow naturally and easily are needed to cut down (photo 2). Monitor insect and mammalian pest constantly and work for the prevention of them.

<Work procedure>

1. Keep monitoring at least 3 months after tree planting activity to find out if some trees are dead.
2. Plant supplemental trees immediately if you find some trees are dead. It is ideal to plant seedling a little higher (bigger) than the one already planted not to be left behind the growth of trees already planted.
3. Apply additional fertilizer to the surviving trees after the supplemental planting.
4. Make a furrow around the root of planted tree and apply fertilizer around the root. Apply 100g of NPK fertilizer per seedling along the furrow and cover it with soil again.
5. Apply additional fertilizer at the beginning of rainy season in which the soil is getting wet and at the end of rainy season in which the soil is still wet.
6. Keep applying fertilizer until the height of the planted trees exceeds the one of the shrub/grass. Also, apply additional fertilizer if the sign of malnutrition such as the color or shape of the leaf or delay of growth is observed.
7. Cut/weed the shrub/grass and vine growing in the area 0.5-1 m in diameter around the root in order to avoid competition in nutrition, water and/or light with shrub/grass and to avoid wrapping and squeezing of planted tree by vine.
8. Control insect and mammalian pest as needed.
9. Keep Maintenance activities until the planted trees grow bigger than the shrub/grass around. Cut/weed vines regularly afterward to avoid the damage of

wrapping and squeezing by vines.

Photo 1 Damage of wrapping by vine

Photo 2 Cut down native Acacia mangium

6-2. Counter measure against wildfire

In tropical areas the temperature is always high and the amount of evapotranspiration is large. So no rain for a week may dry out the land and increase the risk of wildfire. If a wildfire occurs after the tree planting all the efforts for forest rehabilitation so far will come to nothing (photo 3, 4).

Photo 3 Wildfire damage at planting site

Photo 4 Wildfire damage at planting site

Wildfire may occur by lightning or leaves rubbed each other in the dry forest area in America and Australia. But it is not remarkable in the tropical areas. Wildfire is in many cases caused by human. Man-caused wildfire will be usually as follows; Fire spreading during swidden burning, 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 fire-belt outside the tree planted area (photo 5)

ii) Separate the tree planted area into some parts and set up fire-belt between the parts.

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

iv) Prescribed burning/Controlled burning in the fire-belt

Photo 5 Fire-belt 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.

AppendixA-1. Suitability of the planting tree species which were used for the demonstration study for the rehabilitation after the open-pit coal mining

No.	Planting tree species	Suitability					
		2011/ 2012		2012/ 2013	2013/ 2014		2014/ 2015
		AGM	TAJ	AGM	AGM (A)	AGM (B)	AGM
		alcaline /acid	alcaline /acid	alcaline /acid	alcaline /acid	alcaline /acid	N.A.
1	*Eucalyptus pellita*	○	○				N.A.
2	*Melaleuca cajuputi*	○	○				N.A.
3	*Melaleuca leucadendron*			○			
4	*Terminalia catappa*			○			N.A.
5	*Aleurites moluccana*			◎		◎	N.A.
6	*Hevea brasiliensis*	△	△				
7	*Acacia auriculiformis*						N.A.
8	*Acacia mangium*	◎	◎	◎	◎	◎	N.A.
9	*Enterolobium cyclocarpum*	◎	◎		◎	◎	N.A.
10	*Paraserianthes falcataria*			◎			N.A.
11	*Samanea saman*			◎	◎	◎	N.A.
12	*Ficus variegata*				△		
13	*Anisoptera marginata*				△		N.A.
14	*Shorea balangeran*			△	△	△	N.A.
15	*Shorea leprosula*						N.A.
16	*Shorea roxburghii*						N.A.
17	*Mangifera kasturi*			△			
18	*Azadirachta indica*			△			
19	*Swietenia macrophylla*	○	△		◎	◎	N.A.
20	*Mimusops elengi*						N.A.
21	*Schima wallichii*						N.A.
22	*Antocephalus cadamba*	○	○			△	
23	*Antocephalus machropyllus*			◎			
24	*Alstonia scholaris*				◎	◎	N.A.
25	*Dyera polyphylla*			△			
26	*Fagraea fragrans*	△	△				
27	*Gmelina arborea*				◎	◎	N.A.
28	*Peronema canescens*			○			N.A.
29	*Tectona grandis*	△	△				
30	*Vitex pinnata*						N.A.
	Number of the species	9	9	12	9	9	20

< Suitability >

◎ : Excellent

○ : Good

△ : Fair / Poor

N.A. : No data is available

Appendix 2. Characteristics of trees examined in the experimental plots of coal mining areas, Kalimantan Selatan

28 tree species were examined on survival and growth at the areas after mining coal in Kalimantan Selatan (South Kalimantan Province). Origin and natural habitats, preferable site conditions, propagation, utilization and other noteworthy topics of these tree species were investigated. Indonesian names were cited from PROSEA and local names were advised by Mr. Rusmana, Forestry Research Institute, Banjarmasin. Books 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
Eucalyptus pellita (Eukali)	Myrtaceae. Large tree－H;47m. Origin - Tropics & Sub-tropics, Australia, 12° ～ 18° S。Tropical seasonal forest with slight dry spell. 800m>. Tree is distributed in Queensland and N.S Wales. Northern type is suitable for tropics. Precipitation-900～2,400mm.	Adapted to wide range of site conditions. Mininum temperature – over 12℃. Propagation by seed – easy.	Wood use－Heavy hard wood－S.G.:0.99。 Plantations are good & popular in Brazil. Planting of the tree has just started in South East Asia. Northern type is used for plantation.
Melaleuca cajuputi (Kayu Putih)	Myrtaceae. Small tree -DBH: 50cm, H:25~40m. Origin: detail unknown –Thailand~Australia? Naturally growing on hills of Moluccas of Indonesia. Coastal area and lower montane areas – 30~400m. Min. temp. - 17~22℃. Precipitation -1,300~1,750mm.	Fresh water peat swamp. Tolerant to acid sulphate soil. It grows on steep crests in Moluccas, too. Resistant to acid condition and strong light condition. Tolerant to salty wind. Resistant to seasonal water logging up to 1m.	Essential oil - Cajupti Oil. Anti-microbes, anti- inflammation, relaxation and others. Wood use for structure and poles – Medium weight - S.G. 0.72~0.82. Good fuel wood. Only the species distributed to westwards over Wallace line.

		Propagation: by seed - easy.	Domestic species.
Melaleuca leucadendron (Galam)	Myrtaceae. Small tree -H:15～30m、DBH:30～50cm. Origin: Tropical Asia. Communities with *M. cajuputi* on coastal fresh water swamps where are behind areas of mangrove forests.	Fresh water swamps. Resistant to acidic soil condition and strong sun light. Tolerant to slight dryness. Adapted to acid sulphate soils.	Wood use – suitable for construction and pole – medium to heavy hard wood – S.G.:0.7～0.9. Substitutes of Cajuputi oil. Domestic species
Terminaria catappa (Ketapang)	Combretaceae. Medium size tree - DBH:150cm、H:25m. Origin – very wide from India to Polynesia islands. Tropical rain ~ tropical seasonal forest. Sandy and rocky areas of coastal plain and on river banks. Up to 2,000m. Precipitation - 480mm~4,290mm。	Good on riparian soils. Suitable on moist soil. Tolerant to seasonal water logging. Slightly resistant to salty water. Suitable pH ranges 4.5~8+. Resistant to strong wind. Fruiting is frequent. Propagation is by seed.	Wood use – light structural wood – light to medium weight hard wood – S.G.:0.45～0.72. Roadside tree and fruit tree. Roast nuts is edible. Oil of nuts is very good – Indian almond. Domestic species.
Aleurites moluccana (Kemiri)	Euphorbiaceae. Small to medium tree -DBH:150cm,H:10~40m. Origin: not clear, but maybe India to Polynesia islands. Slightly dry tropical seasonal forest. Possibly, the tree would be able to grows in sub-tropical areas. Up to 1,200m. Temp. - 18.7~27.4 ℃. Precipitation - 640~4,290mm.	Natural habitats – well drained sandy areas & rocky limestone hill. Resistant to dry to wet conditions. It would be able to grow on poor soil on steep crest. Optimum pH range is 5~8.0. Propagation： by seed.	Nut use – Candle nuts. Extraction of slightly poisonous oil which contains some cyanides. Very good oil for industrial works, candle, medical purpose, material for paints, & other many purpose. Wood is sometimes used.

			Domestic species?
Hevea braziliensis (Karet)	Euphorbiaceae. Brazil Amazon basin to Guianas. Small to medium size tree (Deciduous) - H:30~40m, DBH: 50 cm. Tropical rain to tropical seasonal forest (6° N~6° S). Wet lowland forest. Maximum - 500m> Precipitation: 2000~3000mm。	Seasonal submergence is not suitable. Friable soil is very suitable because of root system. Soil fertility would not affect growth, largely. Suitable in the areas of 2000~4000mm in rain fall. Not suitable under 1500 mm in precipitation. Seed propagation – grafting good tree to the seedling stumps.	Latex use – Para-rubber. Latex harvested 5 to 35 years in Malaysia. 20 to 30 year rotation in Indonesia. Wood use – medium weight – S.G. 0.56 ～ 0.64. Sometimes damaged by blue stain fungi. Furniture, various boards. Oil from seeds. Char coal.
Acacia auriculiformis (Local name - Akor)	Leguminosae. Medium size tree - H:30,DBH:50cm. New Guinea Island & Australia. Wet tropical seasonal forest. Edges of fresh-water peat swamp, riparian areas, coastal sand dunes & flood plain. About 90m> in PNG. Lower temperature – up to 12℃。	Suitable on deep, moist alluvial soil. It can grow on lowland and fairly poor soil. Tolerant to dryness. Very good seed production. Tree can be planted to hill up to 1,000m. Vigorous initial growth would be expected in plantation.	Wood use – medium~heavy hardwood – S.G.0.49~0.84. As bole is usually twisted and branched, useful parts are limited. Dark, beautiful heart wood – good material for decoration. Good fire wood.
Acacia mangium (Tongke hutan、Local name -Akasia)	Leguminosae. Medium～large tree H: 35m、DBH:90cm. Molucca, New Guinea & Australia. Wet tropical seasonal forest. Up to 500m (Australia),	Tolerant to poor soil & acidic soil. Tree can survive on poor drainage site & grow on higher & drier sites than that of *A.*	Wood use ─ medium weight hardwood – S.G.:0.53~0.69. As bole is straight compared with former species, wood would be

	Commonly, within *Acacia-melaleuca* association. Areas around fresh water swamp.	*auriculiformis*. Reproduction of seeds is very good.	easily used for construction & furniture purpose. Good fuel wood. Fodder for cattle.
Enterolobium cyclocarpum (Sengon Buto)	Leguminmosae. Large tree - H30m、DBH:300cm. Origin-Central America. Evergreen and deciduous tropical seasonal forest. Not many information.	(From our experience) Resistant to strong sunlight and dry condition. Vigorous growth under poor soil conditions. Seed reproduction: very easy.	Wood use – very light hardwood- S.G.0.47. Little durability.. Suitable tree for rehabilitation of devastated land.
Paraserianthes falcataria (Sengon Laut)	Leguminosae. Medium & large tree - DBH:100cm、H:40m. Moluccas~Solomon Islands. Tropical seasonal forest. Lowland riparian forest and coastal forest, mainly. Some grow at high elevation up to 3,300m. Precipitation - 2,000～2,700mm. Temperature -20゜C<	Poor fertility – possible. Poor drainage – not good. Low resistance to submergence. High P requirement. Resistant to strong sunlight & dryness. Propagation: by seed - easy. Land exposure would stimulate germination.	Wood use – very light wood – S.G.0.3～0.5. Fuel wood and fodder. Plantations are widely spread in South East Asia. Notice to insect pest. Guiness Book Record: Miracle Tree - H25.5-DBH17cm/6y.
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 conditions. Adequate pH ranges in 5.5~8.5. Resistant to strong sunlight & dryness around 700mm. Tolerant to seasonal water logging. Propagation-seed	Shade tree – wide tree crown. Wood use – medium weight – S.G.:0.55. Dark stripes in wood: good for wood carving and handicraft. Fuel wood.
Ficus variegate	Moraceae. Medium size tree - H:40m、	Resistant to strong sunlight.	Not special use. Planting is not

(Local name-Nyawai)	DBH:70cm. Very wide distribution: India ~ Solomon Islands. Tropical rain forest. Lowland dipterocarp forest. Dense in Kalimantan.	Soil requirement is not severe. It may be resistant to dryness. Fig tree without rooting from branches.	popular. Tree may be good for feeds for wild animals. Domestic species.
Anisoptera marginata (Mersawa Tenam)	Dipterocarpaceae. Large tree - DBH:135 cm, H : 45m. Borneo, Peninsular Malaysia & Sumatra. Tropical rain forest. Mixed dipterocarp forest. The tree distributes individually. Up to 1,200m.	Fresh water peat swamp. Rich in coastal swamp. Few in inland. Tree can grow on sandy soil such as Kerangas. Propagation: direct sowing and cutting.	Wood use – medium weight – S.G.0.52～0.80。 An endangered species in Borneo. Domestic species
Shorea balangeran (Local name – Balangeran Kahui)	Dipterocarpaceae. Gigantic tree – H.: 60 m、DBH: 180cm. Philippines & Borneo. Tropical rain forest. Lowland dipterocarp forest up to 1,000m. Selangan Batu group.	Cleyey soils are suitable. Sites with wet and well drainage conditions are favorable. Excess water would not be suitable? Propagation: direct seeding or cutting.	Wood use – heavy hard wood –S.G.0.84 ～ 0.95. Very high durability. Domestic species. Synonym :*Shorea falciferoides*
Shorea leprosula (Meranti Tunbaga)	Dipterocarpaceae. Large tree - DBH:150 cm、H:60m. Wide distribution in lowland dipterocarp forest. Fast growing species among dipterocarps. Up to 600m. Light red meranti group.	Good on soils from shale・igneous rocks. Tolerant to temporal water logging. Unsuitable to sandy soils with low drainage such as Kerangas. Light demander. Propagation: direct seeding or cutting.	Wood use - light ~ medium weight hard wood – S.G. - 0.47~0.64. Frequency of fruiting would be high among genus *Shorea*. Domestic species.

Shorea roxburghii (Local name - Talura)	Dipterocarpaceae. Small to large tree. India to northern parts of peninsular Malaysia. Lowland species in Thailand and Malaysia. A member of white meranti.	Tolerant to reductive soils such as surface gleyed soil. Resistant to acidic and poor nutrient condition. Tolerant to seasonal submergence. Resistant to strong sunlight.. Propagation: seeding or cutting.	Wood use – medium weight – S.G.:0.5～0.74. In Indonesia and Peninsular Malaysia, many successful cases are observed.
Mangifera kasturi (Kasturi)	Anacardiaceae. No information in books on plant taxonomy such as PROSEA. (from observation): This species would grow around H:30m, DBH:100cm+. Limited in tropical rain forest and lowland forest, probably.	(from observation) Suitable on riparian area. Goop on fertile & moist soil. Not so strong to dryness.	Fruit use. Small mango (5~10cm). Very sweet & strong flavor. Domestic species Endemic species in Kalimantan?
Azadirachta indica (Mimba、Imba) (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	In Peru, not so good on acidic soil (Acrisol), but very good on calcareous soil (calcic	Wood use – medium weight – S.G. 0.5～0.6. Wood is very high in quality.

	parts of South America. Tropical rain forest ~ wetter type of tropical seasonal forest. Lowland forest.	Cambisol). Suitable on convex and well drained areas. Resistant to strong sunlight.	Insect - *Hypsipyla robusta* gives Severe damage in some part of Kalimantan.
Mimusops elengi (Tanjung)	Sapotaceae. Small ~ medium size - DBH:100cm、H:30m. India~Myanmar. Variety of the species would originate Asia- Pacific Areas. Tropical rain forest ～ tropical seasonal forest with short dry spell. Rich in coastal areas. It would grow on rocky areas up to 600m.	Good growth is expected on rich Soils. Resistant to wet condition (excess wet should be less than 2months). Propagation: by seed. Vegetative propagation would be possible. Seeds can be stored in 9months. Cutting would be possible.	Wood use – heavy hardwood – S.G.0.78 ～ 1.12. Dark red ~ dark reddish brown – very beautiful. Medicinal use – leaf & bark Fragrance - flower Garden tree Domestic species
Anthocephlus cadamba (Jabon, Local name – Jabon Putieh)	Rubiaceae. Medium to large tree - DBH:90cm、H:45m. Originated from Nepal to PNG. Tropical rain forest ~ tropical seasonal forest. Riparian and alluvial deposits of coastal areas up to 1,000m. Precipitation - 1,500 ～ 5,000mm.	Good on natural banks & alluvial plain with well drainage. Tolerant to water logging by flooding in short period. Resistant to strong light. Not so good on soil with poor nutrient condition. Propagation: seed - easy.	Wood use – very light wood – S.G.0.29 ～ 0.56. Processing is very easy. Use in wide variety of purpose. Very rapid growth - H:11m/2y. 30 year rotation – Indonesia. Domestic species
Anthocephalus macrophyllus (Jabon, Local name – Jabon Merah)	Rubiaceae. Large tree. No detail data on actual size. Tropical seasonal forest with short dry spell. Slawesi & Moluccas Islands. Lowland to lower montane	No detail description on site conditions. Unsuitable to dry climate. Min. temperature - 15 °C。	Wood use –same as previous species, *A. cadamba.* Locally, medicinal use. Domestic species.

	areas.		
Alstonia scholaris (Pulai) *A. macrophylla* (Pulai Daun Besar)	Apocynaceae. Medium ~ large tree - DBH: 20~80cm、H:10~60m. India ~ Australia. Tropical rain forest. Lowland ~ montane forest up to 1,230m. Adapted to various parts. *A. macrophylla* grows up to ca. 500m.	Good on moist & well drained riparian areas. Possible on other sites. Tolerant to conditions from ultra basic or calcareous rocks. Tolerant to acidic condition, too. The latter grows on Kerangas. Unsuitable on excess water..	Wood use – light wood – S.G.0.35～0.45. Medicinal use – stomach-ache, easing snake poison (*Alstonia scholaris*)- tree bark. Domestic species
Dyera costulata (Pantung, Local name – Jelutong Gunung) *Dyera polyphylla* (Local name – Jelutong Rawa)	Apocynaceae. Giant tree - DBH:300cm, H:80m. Thailand ~ Borneo. Tropical rain forest. Lowland to montane forest up to 1,220m. This species is distributed on drier sites. *D. polyphylla* is distributed on wet land.	D. costata growth on well drained soil. Suitable on red yellow soil (Acrisol). *D. polyphylla* is possibly grow on acid sulphate soil (thionic Fluvisol). It produces knee root for respiration.	Wood use – light wood – S.G. 0.45. Sap use – chewing gum. One of the biggest tree in south East Asia with *Koompassia excelsa.* Domestic tree
Fagrea fragrans (Tembusu)	Loginiaceae. Medium ~ large tree - DBH:120cm、H:35m. Bengal ~ Borneo ~ Mindro. Tropical rain forest. Lowland forest up to 800m. Coastal area and Kerangas area.	Possible on poor nutrient soil. Poor drainage would be possible. Tolerant to periodical water logging. Sometimes, tree is associated with Melaleuca in swamp. Resistant to low O_2.	Wood use – medium to heavy wood – S.G.0.68 ～ 0.89. In Indonesia, so-called [Iron Wood]. Good use for heavy construction. Domestic species.

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.
Peronema canescens (Sungkai)	Verbenaceae. Small to medium size - DBH:70cm、H:20-30m. Borneo, Sumatra & peninsular Malaysia. Tropical rain forest. Lowland & hill dipterocarp forest. No report in natural stand. Up to 900m.	Good on deep soil. Possible on other soil. Light demander. Resistant to acidic soils. Seeds loose activities, soon. Direct seeding is preferable. Cutting is possible.	Wood use – light wood – S.G.0.36～0.73。 Mono culture is recommended. A report of good performance in seasonal flooding areas, up to 600m in planting. Domestic species.
Tectona grandis (Jati)	Verbanaceae. Medium to large tree - H:50m、DBH:150～25cm. India to Laos. Tropical ~ sub-tropical seasonal 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.	Good on deep soils. Suitable pH ranges pH6.5～8.0. Suitable soil for growth: Ca & P rich soil. Wet soil & acidic soils are not suitable. Seed reproduction is good. Grafting of good tree on stumps of seedling is popular. Stump planting is usually conducted.	Wood use – medium weight – S.G.0.8～0.75. Wax is contained in wood which introduces smooth taste of wood. High quality wood - good for furniture & construction, Small trees are used as poles..

[Book list for species investigation]

Main information:

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Supporting information:

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Malaysia Red List (2010): Chua, Suhaida, Hamidah & Saw, Research Pamphlet No. 129, FRIM

Dipterocarps of Sabah (north Borneo) (1964) : Wood & Meijer, Sabah forest Record No.5, Forest Department

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

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

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℃[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℃[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 4.5[6]			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[1] [6]
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]

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