Faculty of Resource Science and Technology

Assessing Selected Soil Morphological Properties of Different Tree Planting Distance Plots at Secondary Forest of Takasago UNIMAS Educational Forest

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Bachelor of Science with Honours

(Plant Resource Science and Management)

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Assessing Selected Soil Morphological Properties of Different Tree Planting Distance Plots at Secondary Forest of Takasago UNIMAS Educational Forest

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This Final Year Project thesis is submitted

In partial fulfilment of the requirement for the degree of the Bachelor of Science with Honours

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Supervisor: Dr Hafsah binti Nahrawi

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Final Year Project Report ☑

Masters ☐

PhD ☐

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Assessing Soil Morphological Properties at Secondary Forest of Takasago UNIMAS Educational Forest: Different Tree Planting Distance Plot

Jacklin Anak Mathew

Plant Resource Science and Management Programme

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ABSTRACT

Deforestation has decreased the forest cover in Sarawak and led to land degradation. Reforestation via enrichment planting is one of the approaches to recover and restore overutilized and secondary forests. The study of soil properties is important to determine whether the soil has recovered after reforestation. Many studies that have been conducted in Sarawak are aimed to investigate the soil morphological and soil physicochemical properties on mono and mixed tree species plantations, and on different tree species. However, there is no study conducted on the soil morphological properties under different tree planting distances. Thus, this study is conducted to assess the soil morphological properties of the plot under different tree planting distances which are random tree planting distance, close tree planting distance and wide planting distance. A soil pit with a depth of 60 – 70 cm in each plot for soil profile description adopting the standard procedures by the International Soil Science Society (ISSS) (NRCS, 2002). Based on the field observation of the study plot, the growth performance of *S. macrophylla* at wide tree planting distance plot is better than the other two plots, this may be due to lesser intraspecific competition and also can improve soil condition. The soil morphological for all the study plot are similar which might be due to the same type of vegetation of the same age which is *Shorea macrophylla*. The soil texture for all plot are silty clay loam and no rock fragment found in most horizon. The soil color ranges from 10YR 5/6 to 10YR 7/8 which is yellowish brown, brownish yellow to yellow. Based on Sarawak Soil Classification System, the soil at these plots can be classified into Bekenu series of Red-Yellow Podzolic Soils group.

Keyword: *different tree planting distance, reforestation, soil morphological properties*.

ABSTRAK

Penebangan hutan telah mengurangkan litupan hutan di Sarawak dan membawa kepada degradasi tanah. Penghutanan semula melalui penanaman pengayaan adalah salah satu pendekatan untuk memulihkan dan memulihkan hutan yang terlalu banyak digunakan dan hutan sekunder. Kajian sifat tanah adalah penting untuk menentukan sama ada tanah telah pulih selepas penghutanan semula. Banyak kajian yang telah dijalankan di Sarawak bertujuan untuk menyiasat morfologi tanah dan sifat fizikokimia tanah pada ladang spesies pokok mono dan campuran, dan pada spesies pokok yang berbeza. Walau bagaimanapun, tiada kajian dijalankan mengenai sifat morfologi tanah di bawah jarak penanaman pokok yang berbeza. Justeru, kajian ini dijalankan untuk menilai sifat morfologi tanah bagi plot di bawah jarak tanaman pokok yang berbeza iaitu jarak tanaman pokok rawak, jarak penanaman pokok dekat dan jarak tanaman yang luas. Lubang tanah dengan kedalaman 60 – 70 cm dalam setiap plot untuk penerangan profil tanah yang mengguna pakai prosedur piawai oleh Persatuan Sains Tanah Antarabangsa (ISSS) (NRCS, 2002). Berdasarkan pemerhatian lapangan bagi plot kajian, prestasi pertumbuhan S. macrophylla pada plot jarak tanam pokok lebar adalah lebih baik berbanding dua plot yang lain, ini mungkin disebabkan oleh persaingan intraspesifik yang kurang dan juga dapat memperbaiki keadaan tanah. Morfologi tanah bagi semua plot kajian adalah serupa yang mungkin disebabkan oleh jenis tumbuh-tumbuhan yang sama pada umur yang sama iaitu Shorea macrophylla. Tekstur tanah untuk semua plot adalah tanah liat berkelodak dan tiada serpihan batu ditemui di kebanyakan ufuk. Warna tanah adalah antara 10YR 5/6 hingga 10YR 7/8 iaitu perang kekuningan, kuning keperangan hingga kuning. Berdasarkan Sistem Pengelasan Tanah Sarawak, tanah di plot ini boleh dikelaskan kepada siri Bekenu kumpulan Tanah Podzolik Merah-Kuning.

Kata kunci: jarak penanaman pokok yang berbeza, penghutanan semula, sifat morfologi tanah.

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LIST OF ABBREVIATIONS

UNIMAS	Universiti Malaysia Sarawak
JMA	Japan-Malaysia Association
N	Nitrogen
ISSS	International Soil Science Society
POM	Potential Organic Matter

1. INTRODUCTION

1.1. Research Background

Approximately, 140,200 ha or 0.65% of forest in Malaysia are lost annually since 2000 (Butler, 2006). Agriculture and forest conversion for oil-palm plantations and other forms of agriculture, urbanization and extraction of natural resources were the major causes of deforestation in Malaysia. The forests cover in Sarawak has decreased and degraded at a rate of 0.64% due to economic and agriculture activity such as expansion of oil palm plantation that has been increase 10.2% annually (Hon & Shibata, 1970). Deforestation of natural forest may lead to many negative impacts such as soil erosion, climate changes, biodiversity loss and flood. Karam et al., (2012) stated that forest clearance also leads to soil degradation which is one of the most concerning global issues. About 75% of the Earth's soils are spoiled and significantly degraded (Leahy, 2018).

Forest Department Sarawak cooperated with Japan-Malaysia Association to establish a tree planting project at Gurung Apeng Forest Reserve in 2005 to conserve the forest in the forest reserve (Sani et al., 2014). Reforestation is the best option to reduce and overcome these negative impacts by recovering the soil quality. Enrichment planting is an important technique that has been suggested for reforestation to restore overutilized and secondary forest (Doty, 2022).

Soil characteristic such as soil morphology and soil physicochemical properties information are important prior the reforestation. Preliminary assessment on soil properties essential to determine the soil productivity and type of species can be planted (Adanan et al., 2015). Hence, the information on soil properties will be a guide for reforestation program as it helps to determine the suitable species to be planted and planting technique to ensure the optimum growth and performances of planted tree achieved. However, the soil requires time to recover and restore its fertility and productivity. Different soil properties associated with landscape position usually attributed to differences in term of surface runoff, erosion and deposition process that will affect the soil genesis process (Adanan et al., 2016) .

Arifin et al. (2007), reported that it is important to study on the soil properties to obtain the information whether the soil has recovered after the reforestation. To ensure the successfulness of the planted tree, there are several factors should be considered such as species selection, the layout technique of reforestation, proper tree spacing and planting technique. All of these factors may affect the soil properties differently. Most study that has been conducted in Sarawak are aimed to investigate the soil morphological and soil physicochemical properties on mono and mixed tree species plantation, and on different tree species. However, Barrett and Youngberg (1965), concluded that tree distance and understory vegetation affecting the soil moisture required in which the moisture requirement increasing with the increases of the tree plantation density. A study by Yan et al. (2015) suggested that tree planting distance helps to enhance the nitrogen mineralization and nitrogen availability in soil. This study proved that different tree planting distance has impacted the soil chemical properties however, there is no study conducted on the soil morphological properties under different tree planting distance Hence, this study is very crucial to determine the changing in soil profile under different tree planting distance in the future. This is because different tree planting distance affect the tree growth and performances differently.

Thus, this study is conducted to assess selected soil morphological properties of the plot under different tree planting distances and obtain the soil profile for each plot. This study aims to assess soil morphological properties namely, soil horizon and boundary, soil structure, soil texture, soil color, roots presence, rock fragment, consistency and soil hardness. The data obtained from this study is important for future reference of related study on the effect of different tree planting distances on soil morphological properties. The data from this study can be used to compare the soil morphological properties of the three plots with different planting distance.

2. LITERATURE REVIEW

2.1. Enrichment planting for reforestation

Reforestation is a process of regenerating or replanting trees at deforested areas or an area that have been affected by natural disasters such as wildfire and drought. Enrichment planting is an important technique that has been suggested for reforestation to restore overutilized and secondary forest (Doty, 2022). A study by (Daljit S.K et al., 2012) proved that forest enrichment planting by the Forest Department Peninsular Malaysia had increased the productivity and fertility of previously degraded forest. Forest plantation helps provide environmental services such as restore the productivity of the land, reduce air pollution, control soil erosion, regulate the water quality and provide habitats for wildlife. Planting new trees and expanding the forested areas could help to reduce the carbon dioxide concentration in the atmosphere (Waring et al., 2020).

Reforestation helps to accelerate the development of forest structure and maintain the soil productivity by reducing soil erosion. In addition, reforestation can help soaking up pollution, restore the natural habitats and ecosystem as well as minimizing the global warming as forest facilitate bio sequestration of carbon dioxide in the atmosphere (Karam et al, 2011). Reforestation is an alternative way to restore degraded soil because help to regenerate back the affected area (Karam et al., 2012). Besides, forest plantation helps to improve the economy by supporting the demand of wood supply while sustaining our environment. Enrichment planting is an important technique that has been suggested for reforestation to restore overutilized and secondary forest (Doty, 2022). A study by (Daljit S.K et al., 2012) proved that forest enrichment planting by the Forest Department Peninsular Malaysia had increased the productivity and fertility of previously degraded forest. Reforestation establishment depended on its purposes such as for rehabilitation, forest plantation, timber production, paper production and others.

2.1.1. Takasago UNIMAS Educational Forest

On October 2018, Universiti Malaysia Sarawak (UNIMAS) has established an Educational Forest within the campus with an area of 10 hectares with the cooperation of Takasago Thermal Engineering Co. Ltd (Takasago) and the Japan-Malaysia Association (JMA). The activities planned for the establishment of educational forest are tree planting program that involve volunteers from Japan and local communities, conducting field teaching and learning exercise for education and research purpose among students, establishment of plant nursey for educational and tree planting activities (Jayasyaliny Jayaraj, 2019). As for 2019 around 2 ha of the area has been planted with more than 3000 trees from various species. The Educational Forest is aimed to be a model forest for teaching, researching and training of young generation towards promoting effort in conserving the tropical forest in Sarawak. There are four major sites in the Takasago UNIMAS Educational Forest which are Natural Secondary Forest, Enrichment planting site (2019), Enrichment planting site (2018) and Nursing tree site with an area of 1 ha, 1.51 ha, 1.1 ha and 1 ha respectively.

2.2. Tree planting distance in reforestation

Tree spacing between planted tree is a crucial factor for reforestation. Different tree species and different types of forest desired will need a different tree planting distance as it will affect future management practices. Determination of tree planting distance also important factors for site utilization and harvesting option (Yan et al., 2015). Tree planting distance affecting the height, diameter at breast height (DBH) and tree survival with DBH being most sensitive compare to height (Lahcen Benomar et al., 2012). Other than affecting the soil nutrient dynamics, above ground biomass and crown characteristic, Cassidy et al. (2013), mentioned that tree planting distance also affecting the wood quality. Wider tree planting distance also increase stem taper which will reduce the merchantable volume of the individual trees (Baldwin et al., 2000). However, A study by Hébert et al. (2016), concluded that tree planting distance of jack pine does have any significant effect on the wood quality attribute but it does have an effect on branch diameter and live crown ratio.

2.3. Soil morphological properties

2.3.1. Soil horizon boundary

Soil horizon is a distinct layer parallel to the Earth's surface due to the combination action of living organism percolating of water because these actions have various effect with increasing depth. One or more horizon known as soil profile, the vertical sequence of different layer. The soil profile differentiates into horizon using horizon nomenclature O, A, E, B, C, L, R and W. O represent the top layer which consist of organic matter. Next, A layer is called topsoil which is the mixture of parent material and organic matter. E is for minerals, B subsoil layer which consist of accumulation of clay, C for unconsolidated earth material, L is for Limnic soil material, R for bedrock and W is a layer of water.

2.3.2. Soil color and soil mottling

Soil color is one of the most significant characteristics of the soil because each horizon has different color. The differences of the soil color caused by some processes during the soil formation, the age, temperature, moisture characteristic of the climate and indicate other factors such as its mineral composition, water and organic content (Jackson, 2020). Soil organic matter, iron and manganese are the main coloring agent, when they are not present in soil, the natural color of the grain is visible which gray. Soils with white color are high in calcium meanwhile soils with high iron are reddish and soil with high organic matter content are dark brown or black in color. In moist and warm regions, the soils tend to be yellowish-brown to red meanwhile in cooler region the soil will be grayish to black due to accumulation of humus (Jackson, 2020). Mottled soils refer to the patches different color, usually grey or yellow. There are two type of mottling patterns which are redoximorphic that associated with soil wetness, and lithochromic mottles that associated with the color variation due to weathering of parent materials. The number, size and color of soil mottles is a good indicator of soil aeration. Soil colors usually determined by comparing the soil with Munsell color chart.

2.3.3. Soil texture

Soil texture is the composition of silt, clay and sand particles that make up the mineral element of soil. Sand particles are the largest with 2.0 to 0.05 mm in diameter followed by silt particles 0.05 to 0.002 mm in diameter and lastly clay particle with diameter smaller than 0.002 mm. soil texture is an important property as it can influence the biological soil crust. Soil texture also affects other soil properties including bulk density, water holding capacity, permeability, and porosity. There are 12 textural class of soil texture which are clay, silty clay, sandy clay, silty clay loam, clay loam, silt, silt loam, sandy loam, loamy sand and sand. The textural classification system shown in Appendix A, which consist of equilateral triangle with 10 zones that represent type of soil.

2.3.4. Soil structure

Soil structure is the arrangement of the soil particles and soil aggregates, which is the combination of sand, silt, clay and organic matter particles in soil. Soil structure can be altered by weathering, the penetration of roots and cultivation. Soil with high clay or organic matter has more stable structure compare to the soil that contained mostly sand or silt (Finch et al., 2014). Soil structure influenced the water movement in soil, amount of nutrients available for uptake by roots, aeration, and resistance to soil erosion and compaction. The soil structure can be classified into six groups as shown in Appendix .

2.3.5. Soil compaction

Soil compaction is a process in which the soil particles were pressed together, reducing the pore space between them. Soil with high compaction have a few large pores, less total pore volume and have a greater density. Singh et al. (2015), concluded that soil compaction increases the soil bulk density and penetration resistance but decrease the soil porosity, infiltration rate and hydraulic conductivity. Soil compaction is important properties of soil that affect the plant growth and survival. Compacted soil has less pore space which limiting the space for water and air for the tree (Shapiro & Elmore, 2017). Besides, soil compaction will weaken the roots system which caused the root susceptible to root rot disease infection (Laker & Nortjé, 2020).

2.3.6. Soil biological activity

Soil biological activities is an important indicator of soil health and important for nutrient cycling as well as developing and maintaining soil structure (Smith & Read, 1997). The biological activity is soil are soil enzymatic activity, basal respiration and microbial biomass. These activities are related to various soil properties including the soil pH, soil organic matter and soil texture (Ge et al., 2009). The enzymatic activity in soil is from the soil microorganism such as nematode, bacteria, fungi, protozoa and algae.

2.4 Relationship between soil properties and tree planting distance

Closer plantation spacing can lowered the tree volume growth and survival rate due to intraspecific competition (Hébert et al., 2016). In contrast, a wider tree spacing plantation will increase the tree growth and higher survival rate (Hébert et al., 2016). A study by Yan et al. (2015) suggested that suitable tree planting distance could improve the mineralization of nitrogen (N) and) N availability in soil. The annual net of N mineralization in soil with lower planting density (wide tree planting distance) is higher (Yan et al., 2015). Besides, a study by Hosseini Bai et al. (2017) reported that tree planting distance influenced the organic matter input in which closer planting distance caused the depletion of soil organic matter. Barrett and Youngberg, (1965), reported that the soil moisture required affected by tree distance and understory vegetation. This indicates that the moisture requirement increases with the increase of the tree plantation density. Thus, higher planting density (close tree planting distance) increased the competition for water availability. Therefore, tree planting distance affects the soil moisture (Barrett & Youngberg, 1965).

3. METHODOLOGY

3.1. Study area

The study was conducted at Secondary Forest of Takasago UNIMAS Educational Forest as shown in Figure 1, which located at West Campus of Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Sarawak with the latitude of 1˚27'51.53" N and 110˚25'25.32" E longitude. The forest in UNIMAS is categorized as a secondary forest which estimated about 30 years after the abandonment of shifting cultivation (wet rice). There are four major sites at the Takasago UNIMAS education forest which are Secondary Forest, Enrichment Planting Site (2018), Enrichment Planting Site (2019), and Nursing Tree Site. The Secondary Forest site was not cleared during the construction meanwhile both Enrichment Planting site 2018 and 2019 were cleared during the construction but were planted with various species of fruit and forest tree species in 2018 and 2019 to enrich the soil. The Nursing Tree site soil constitutions are mostly dumped soil from the construction debris including rock and brick pieces that can be found at the soil surface.

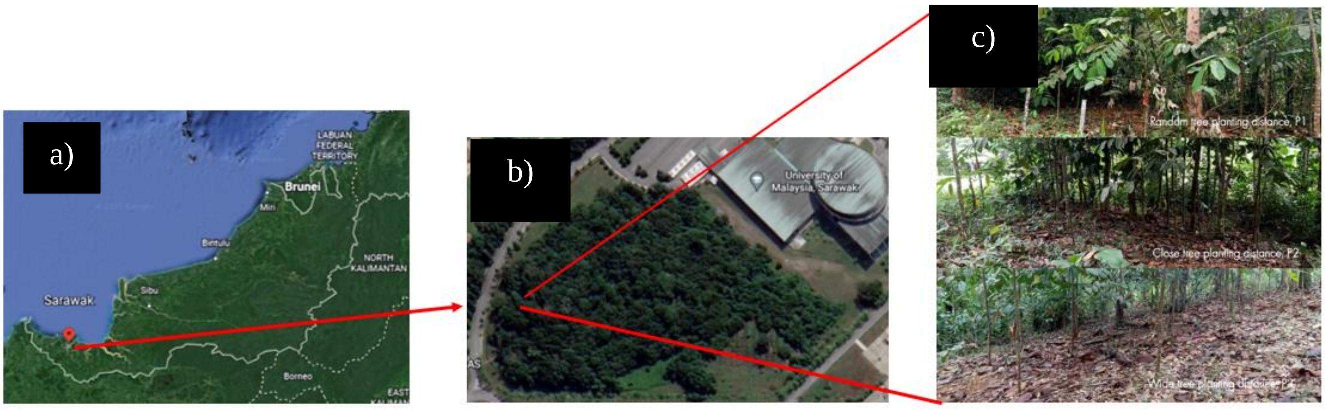


Figure 1: Study Area; a)Sarawak Map;b) Secondary Forest of Takasago UNIMAS Educational Forest; c)Study Plot at Secondary Forest of Takasago UNIMAS Educational Forest.

3.2. Soil survey and data collection

The soil profile description was conducted at the Secondary Forest site on a different trial planting plot. There are three types of trial plots with different planting spacing at the site with an area of 50×50 m^2 respectively; random tree planting distance (P1) (Figure 2), close tree planting distance (P2) (Figure 3) and wide tree planting distance (P3) (Figure 4) which planted with the same species of tree, *Shorea macrophylla* in 2016. In random spacing plot, the trees were planted randomly without any specific or uniform spacing among the trees. Meanwhile, in close and wide spacing, the trees were planted with uniform spacing between trees which are 2 meters and 3 – 4 meters respectively. There is no data collection have been done for plant growth and species identification on each plot. However, all the observation for each plot was guided by Dr. Hafsah bt. Nahrawi and some information were provided by AP Dr. Mohd Effendi b. Wasli.

Figure 2:Random Tree Planting Distance, P1

Figure 3:Close Tree Planting Distance, P2

Figure 4: Wide Tree Planting Distance, P3

3.3. Soil profile description

The soil description was conducted adopting the standard procedures by International Soil Science Society (ISSS) (NRCS, 2002). The soil pit was dug by hand using a hoe and shovel until 60 -70 cm depth. The picture of the soil profile was taken to be used as information in this study. The example of soil pit for soil profile description shown in Figure 4 below. The soil profile description was done by referring the Appendix H. The soil horizon, boundary soil texture, shapes, roots, rocks, color and structure were observed carefully to define the soil horizon and the observation was recorded in the soil profile description sheet (Appendix F). The site description must be done first by recording the name of surveyor, date of the observation, weather and geographical location of the point.

Figure 5:Example of Soil Profile

3.3.1. Determination soil horizon and boundary

The soil profile was distinguished in respective horizon by using horizon nomenclature show in the Appendix G. The soil horizon and boundary were identified by observing the soil color and texture. The depth of each horizon was measured using a long ruler or measuring tape. Each horizon was carefully observed to determine the topography and distinctness of the horizon as shown in the Appendix H. Then all the observation was recorded in the Soil Profile Description Sheet.

3.3.2. Determination of soil compaction (hardness)

The soil compaction or hardness was determined and measured using the push cone penetrometer. The soil hardness was measure by the relative force required by the device to crush the soil in each layer. The tip of the push cone penetrometer was dipped into the surface of soil profile, five times in each layer. The average reading of the push cone penetrometer was calculated and recorded in the Soil Profile Description Sheet.

3.3.3. Determination of soil structure

The soil sample from the horizon was removed using small shovel and dropped from about 1 m height to determine the grade of the soil. The samples were careful observed it structures whether the soil structure is granular, blocky, prismatic, columnar, platy. The soil structure was determined referring to the Appendix B.

3.3.4. Determination of soil color

The soil color was determined using the Munsell Soil Color chart. A ped was taken from each horizon was moistened with the water, and hold next to the Munsell Soil Color chart. The closest color matched with the soil was identified and recorded in the Soil Profile Description Sheet.

3.3.5. Determination of soil texture

The soil texture was determined using ‘feel’ method in the field. A soil sample from the horizon was pressed and crushed using hand to feel the texture. A gritty feel was produced by the sand particles meanwhile silt particles were smooth and clay particles can be either sticky or not. The soil textures classes were Sand, Loamy sand, Sandy loam, Loam, Silt loam, Silt sandy clay loam, Clay loam, Silty clay loam, Sandy clay, Silty clay and Clay. Each of the texture classes contain different proportion of the separate particles. Then few test by forming a ball, ring and ribbon were carried out to determine the texture class referring the flow chart in Appendix D. This method was repeated for each horizon of each soil profile and the observation was recorded in the Soil Profile Description Sheet.

3.3.6. Measuring roots present at the soil profile

The roots present at each horizon of each plot were observed and hands were placed on the surface of the soil to feel the presence of the roots in each horizon. The abundance and size of roots were determined by referring the figure shown in Appendix H. The data and observation were recorded in the Soil Profile Description Sheet.

4. RESULT

4.1. Field observation at the study site

There are three types trial plots at the study site with different tree planting distance; random tree planting distance (P1), close tree planting distance (P2) and wide tree planting distance (P3) which are planted with the same species of tree, *Shorea macrophylla*. In random tree planting distance, the trees were planted randomly without any specific or uniform spacing among the trees meanwhile in close and wide spacing the trees were planted with uniform spacing between trees which are 2 meters and 3 – 4 meters respectively. There is no data collected for the growth performances and species identification were conducted. However, based on the observation in the field guided by Dr. Hafsah and information provided by AP Dr. Mohd Effendi, the trees planted at close and wide spacing have a better growth and survival rate compared to the trees in random spacing plot as shown in Figure 6, Figure 7 and Figure 8. The tree planted at P1 plot does not have a uniform size despite their same age. All the trees in these plots were planted at the end of 2016. As shown in Figure 6, some of the trees have better growth and some are not based on their height. Then, the tree planted at P2 have a lower survival rate and unequal size compared to the trees planted at P3 but the trees are bigger as shown in Figure 7. The tree planted at P3 have a higher survival rate, uniform size but the tree is smaller than the one planted at close spacing plot as shown in Figure 8. The field observation also shown that, there are lot of terrestrial plants at P1 and P2 plot meanwhile there are very few terrestrial plants at P3. In term of litterfall and undecomposed leaves of *S. macrophylla*, P3 has more litterfall and undecomposed leaves compared to the other two plots. However, P1 has lesser litterfall and undecomposed leaves of *S. macrophylla*.

Figure 6:The growth of *S. macrophylla* at P1

Figure 7:The growth of *S. macrophylla* at P2

Figure 8:The growth of *S. macrophylla* at P3

4.2. Soil morphological properties of three different tree planting distance

Table 1 and Figure 9 show the soil morphological properties at three different plots with different tree planting distance; random tree planting distance (P1), close tree planting distance (P2) and wide tree planting distance (P3), planted with *Shorea macrophylla* at the end of 2016.

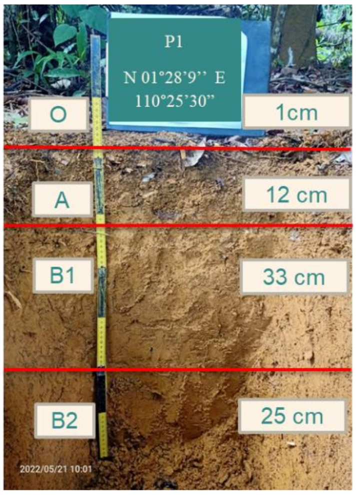
At P1, there are four horizons observed namely O, A, B1 and B2 horizons. The O horizon with a depth of 1 cm consisted of the litterfall and undecomposed leaves fallen from *Shorea macrophylla* planted at the plot. Horizon A with a depth of 12 cm has a clear and wavy horizon boundary of the surface layer. Based on the “feel” method, the soil texture of this horizon was classified as silty clay loam. The soil color was classified as yellowish brown (10YR 5/8) based on the Munsell Color Chart and no mottling was spotted. The soil in this horizon has a moderate subangular structure and the soil consistency was sticky and plastic.

There was no rock fragment found in this horizon and common coarse to medium roots abundance was observed. The average hardness of the soil in this horizon was14 mm. Then, for B1 and B2 horizons, the depth is 12 – 45 cm and 45 – 70 cm respectively. The boundary for B1 horizon was identified as gradual and wavy meanwhile B2 horizon has a diffuse and wavy boundary. The soil color for B1 and B2 horizons was brownish yellow (10YR 6/6) and yellowish brown (10YR 6/8) respectively and there was no mottling in both horizons. The soil texture for both horizons are classified as silty clay loam, have a very sticky and plastic consistency and moderate subangular structure. There was no rock fragment found at B1 horizon meanwhile there are few subangular rock fragments found at B2 horizon. Few roots at B1 horizon are coarse to medium and few medium roots at B2. The average hardness for horizon B1 was19 mm meanwhile the average soil hardness for B2 was 17 mm.

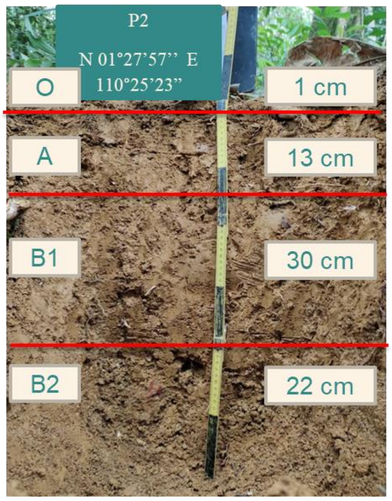
Next, at P2 there were four horizons observed, O, A, B1 and B2 horizons. O horizon is 1 cm depth which consists of litterfall and undecomposed fallen leaves from *Shorea macrophylla*. Next, Horizon A with 13 cm depth has a clear and wavy boundary with a weak subangular soil structure. Based on Munsell Color chart, the soil color was brownish yellow (10YR 6/6) and there was no mottling in the horizon. The soil in this horizon has a silty clay loam texture with sticky and slightly plastic soil consistency. The roots in this horizon are coarse to medium with common abundance. There is no rock fragment found in this horizon and the average soil hardness was 15 mm. Next, horizon B1 with a depth of 32 cm has a gradual and wavy boundary. The soil texture in this horizon is silty clay loam with sticky and plastic soil consistency, and moderate subangular soil structure. The soil on this horizon is brownish yellow (10YR 6/8) and there was no mottling and rock fragment found. There were many coarse to medium roots observed in this horizon and the average soil hardness in this horizon was 22 mm. As for horizon B2 the boundary was diffuse and wavy with 22 cm depth. The soil color was similar to horizon B1 which was yellowish brown (10YR 6/8) and have a strong subangular soil structure. Based on the “feel” method conducted at the field, the texture of the soil in this horizon was silty clay loam with very sticky and slightly plastic soil consistency. There was no rock fragment found in this horizon and only a few medium roots were observed. The average soil hardness in this horizon was 19 mm and no mottling was observed.

The P3 plot which planted with wide tree planting distance (3-4 meters between trees) had four horizons; O, A, B1 and B2. Similar to P1 and P2 the O horizon for this plot also consists of litterfall and undecomposed leaves from *Shorea macrophylla*. Horizon A has a depth of 2 – 19 cm with a clear and wavy horizon boundary of the surface layer. The soil color of in this horizon was yellowish brown (10YR 5/6) and no mottling was observed. The soil structure was moderate subangular with silty clay loam texture. The soil consistence is sticky and slightly plastic with the average hardness 12 mm. There is no rock fragment and common coarse to medium root observed in this horizon. As for B1 horizon, the depth was 23 cm with gradual wavy boundary and moderate subangular structure. The soil color was yellowish brown (10YR 5/8) and no mottling was observed. the soil texture was identified as silty clay loam with sticky and plastic soil consistency. The average soil hardness in this horizon was 19 mm. No rock fragment was found but few medium to fine roots were observed. Then, B2 horizon was 30 cm depth with diffuse wavy boundary and medium subangular soil structure. The texture of the soil was silty clay loam with sticky and plastic soil consistency. The soil was yellow (10YR 7/8) and no mottling was observed. The average soil hardness was 18 mm and no rock fragment was found but few fine roots were observed.

a)



b)



c)

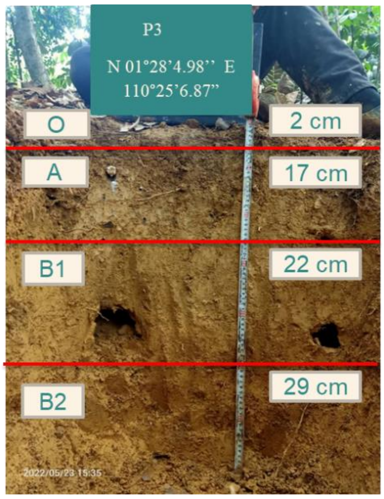


Figure 9: Soil Profile; a) Soil Profile at P1; b) Soil Profile at P2; c) Soil Profile at P3

Table 1: Soil morphological properties at tree plots with different planting distance

Plot	Horizon	Depth (cm)	Color	Field texture	Structure	Consistency	Roots	Boundary	Rock fragment	Mottling	Hardness (mm)
P1	N 01°28'9'' E 110°25'30"										
	O	0 – 1						C/W	N	N	
	A	1 – 12	10YR 5/8	ZCL	M/SB	S/P	C-M/C	C/W	N	N	14
	B1	12 – 45	10YR 6/6	ZCL	M/SB	VS/P	C-M/F	G/W	N	N	19
	B2	45 – 70	10YR 6/8	ZCL	M/SB	VS/P	M/F	D/W	F/SR	N	17
P2	N 01°27'57'' E 110°25'23"										
	O	0 – 1						C/W	N	N	
	A	1 – 13	10Y/R 6/6	ZCL	W/SB	S/SP	C-M/C	C/W	N	N	15
	B1	13 – 44	10Y/R 6/8	ZCL	M/SB	S/P	C-M/M	G/W	F/SR	N	22
	B2	44 – 66	10Y/R 6/8	ZCL	S/SB	VS/SP	M/F	D/W	N	N	19
P3	N 01°28'4.98'' E 110°25'6.87"										
	O	0 – 2						C/W	N	N	
	A	2 – 19	10YR 5/6	ZCL	M/SB	S/SP	C-M/C	C/W	N	N	12
	B1	19 – 41	10YR 5/8	ZCL	M/SB	S/P	M-F/F	G/W	N	N	19
	B2	41- 70	10YR 7/8	ZCL	S/SB	S/P	F/F	D/W	N	N	18

Abbreviations; Texture: ZCL: Silty Clay Loam; Structure: W: Weak, M: Medium, S: Strong SB: Subangular blocky; Consistency: S: Sticky, VS: Very sticky, S: plastic, SP: Slightly plastic; Roots: C: Coarse, M: Medium, F: Fine, C: Common, F: Few, M: Many; Boundary: C: Clear, W: Wavy, G: Gradual, D: Diffuse; Rock Fragment: F: Few, SR: Subangular, N: None; Mottling: N: none, Hardness was measured using a Push Cone penetrometer

5. DISCUSSION

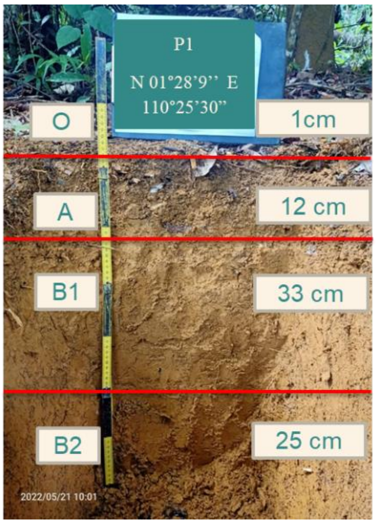
5.1. The growth of *Shorea macrophylla* at the study site

The growth performance of *S. macrophylla* at wide tree planting distance plot is better than the other two plot, this may be due to lesser intraspecific competition. A proper planting distance between trees is important for better growth as it helps to decrease competition for light, water and nutrients (Medves, 2009). Thus, a proper planting distance could help to promote the growth and development of a tree. A proper planting distance is also important for future management because it is easier to find the tree and easier for pest management as it is easier to identify and removed infected trees. Tree spacing could be influenced by the type of desired forest because according to Yan et al. (2015), tree planting distance is an important factor that influences site utilization and harvesting option. Based on the observation at the field, wide tree spacing may be suitable for forest plantation because the trees have uniform size and can be harvested at once. Meanwhile, close tree spacing and random tree spacing may be suitable for reforestation.

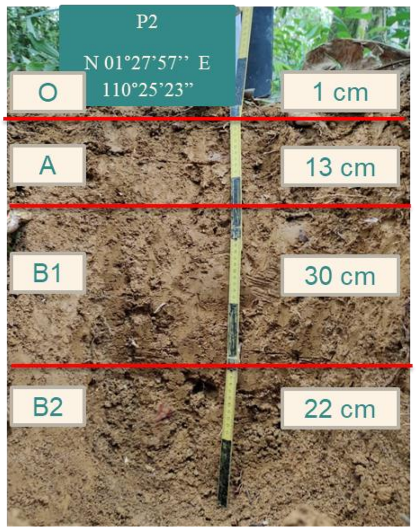
5.2. Soil morphological properties

The soil morphological properties for all of the study plots (Figure 10) are similar, which might be due to similar tree species (*Shorea macrophylla*) with similar age in all of the study plots. These *Shorea macrophylla* were planted at the end of 2016.

a)



b)



c)

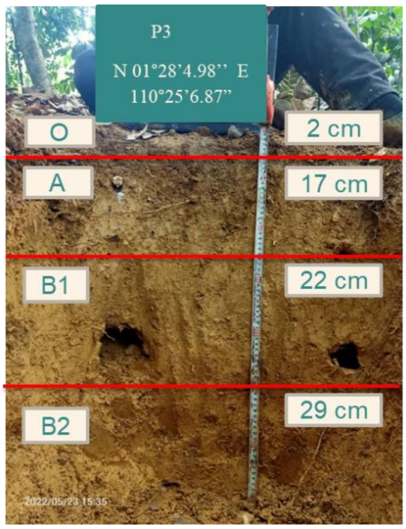


Figure 10:Soil Profile; a) Soil Profile at P1; b) Soil Profile at P2; c) Soil Profile at P3

The finding from the soil profile description shows that the depth of O horizon for P1and P2 are 1 cm meanwhile in P3 the O horizon is slightly higher which is 2 cm. The O horizon layer consists of the litterfall and undecomposed fallen leaves from *S. macrophylla* planted at the plots. The abundance and thickness of the litter layer on the forest floor promote high decomposing processes by soil microorganisms (Islam and Weil, 2000). Decomposition indicates the decomposer activity that soon returns the nutrients back to the soil. This can be used to indicate the soil fertility as it forms a layer that regulates the access of soil in getting enough requirements such as rainfall and sunlight to maintain its form and structure. The soil organic matter content at P3 may be higher compared to P1 and P2 because according to Yan et al. (2015), the annual net of N mineralization in soil with lower planting density (wide tree planting distance) is higher. Bu et al. (2015) concluded that potential organic matter (POM) is important for nitrogen mineralization. Besides, high N availability in shrub soil may promote the rapid stabilization of organic matter (Weintraub & Schimel, 2003).

Based on the result obtained from this study, there is not much difference in terms of soil color at P1, P2 and P3 plots. The soil color ranges from 10YR 5/6 to 10YR 7/8 which is yellowish brown, brownish yellow to yellow. This may be due to the accumulation level of organic matter at O and A horizon from the above vegetation as well as density of below ground biomass and can be assumed that high activity of soil microorganism leads to high decomposition rate of organic material. Yellow soil indicates the presence of iron oxide in the hydrate form meanwhile brown soil may be due to decaying plant material. Previous study in this site by Celistine Laujang (2020), reported that the soil organic matter is significantly high.

Based on the data collected from the soil profile from the three plots, the soil texture of the plots is the same which is silty clay loam. Based on Sarawak Soil Classification System, the soil at these plots can be classified into Bekenu series of Red-Yellow Podzolic Soils group. Red-Yellow Podzolic soil defined as a group of well-developed soil, well drained acidic soil that have a this organic (AO) and organic mineral (A1) horizons over a light colored bleached (A2) horizon, over a red, yellowish-red, or yellow and more clayey (B) horizon (Muir, 1961). This group of soil have a lot of limitation including low in soil pH, low in aggregate stability, low in nutrient content and susceptible to compaction (Pagiu et al., 2016). A study by Celistine Laujang (2020), also reported that the soil at this site is highly acidic shows that high decomposition of organic matter at the top layer of forest floor resulting in high production of carbon dioxide.

Then, coarse, medium and fine roots were found and observed from the upper horizon to the deeper part of each soil profile. This indicates that soil compaction does not occur because the roots penetrated to the deeper part of the soil profile (60 cm – 70 cm). However, soil compaction at P2 is slightly higher than P1 and P3. This may be related to the soil moisture content because Barrett and Youngberg (1965), reported that the water requirement increases with planting density. Meaning that, close planting distance may cause water competition between the tree and decreased the soil moisture content. The increase in soil moisture content could help to reduce soil compact (Udom & Ehilegbu, 2018). Celistine Laujang (2020) study reported that Secondary Forest site shows the lowest bulk density compared to the other sites which indicate that this site is suitable for root development. Soil macrofauna such as earthworm (Figure 11) was observed at P1 and P2 plots during the digging process. Generally, the earthworms were found at the deeper soil horizon and this may be due to the presence of numerous coarse roots at the upper horizon which is not suitable for earthworm's movement. Pavao-Zuckerman (2008) also mentioned that the movement of these soil macrofauna from one horizon to another affects the soil texture, bulk density and organic matter content of the soil. Besides, in P3 soil profile, there are few holes observed as shown in Figure 12 which presumably made by the ant species. This explained the absence of earthworm in this plot because the ant species are the predators of the earthworms.

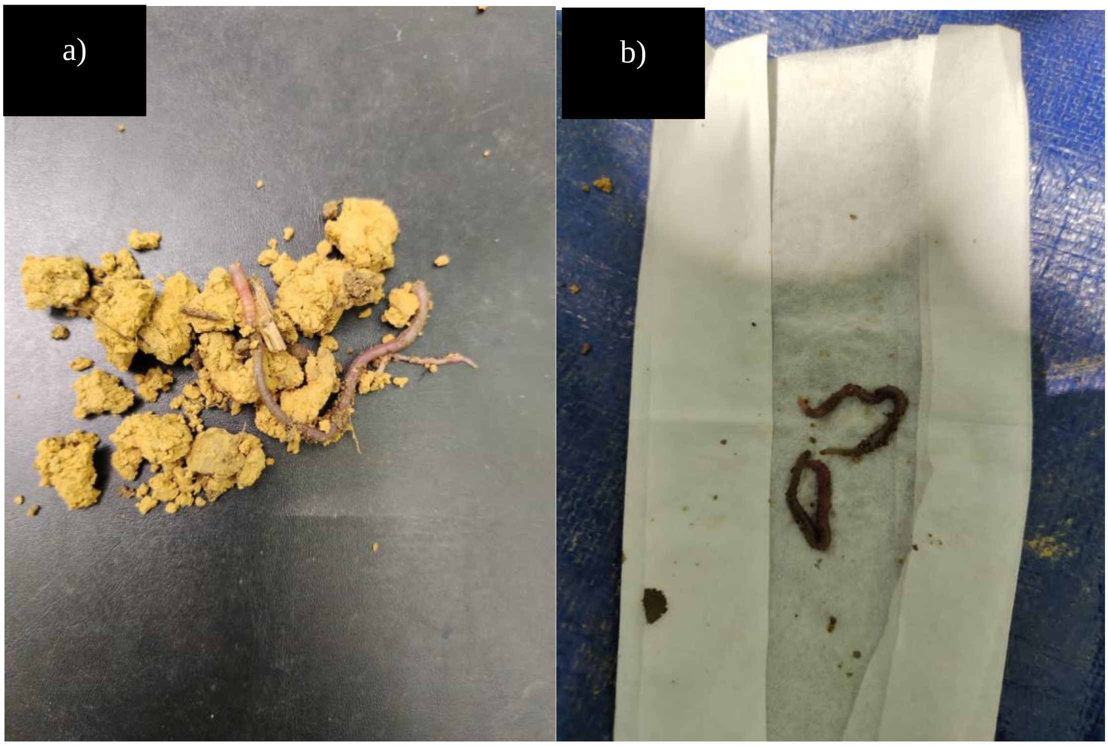


Figure 11:Earthworms found at the study sites; a)Earthworm found at P1; b)Earthworm found at P2

Figure 12:Holes found at P3 soil profile

6. CONCLUSION AND RECOMMENDATION

In conclusion, the objective of this study is achieved. The findings of this study show that the soil morphological properties of the three different plots with different planting distances have similar characteristics. The soil in P1, P2 and P3 have the same texture which is silty clay loam and their color are in the same hue of 10YR which range from brownish yellow, yellowish brown and yellow. Coarse, medium and fine roots were found from the top horizon to the deeper horizon of the soil profile which reflects that there is no soil compaction at the study plots. Fine subangular rock fragments were only found at B2 horizon of P1 and B1 horizon of P2 but the soil at P2 plot is slightly hard compared to P1 and P3. The structure of the soil at each soil horizon at P1 plot is moderate and subangular. Meanwhile, in P2 plot the soil structure is weak subangular at A horizon, moderate subangular at B1 horizon and strong subangular at B2 horizon. Next, in P3 horizon soil structure at A and B1 is moderate subangular. At B2 horizon the structure is strong subangular. Based on the 'feel' method conducted at the field, each horizon of the three plots has the same soil texture class which is Silty clay loam. Based on Sarawak Soil Classification System, the soil at these plots can be classified into Bekenu series of Red-Yellow Podzolic Soils group.

Different tree planting distances resulted in different growth performances of *Shorea macrophylla*, but the determination of the best tree planting distance depends the types of forest desired. This is because different forest desired will need a different tree spacing as it will affect future management practices. For instance, wider tree spacing is suitable for forest plantation because the trees have uniform size and can be harvest at once but closer planting distance may be suitable for reforestation.

Different tree planting distance affecting the growth performance of the tree planted at the plot, therefore future study on soil morphological and physicochemical properties on different tree planting distance is recommended to investigate the effect of different tree planting distances on soil. Detail studies on soil morphological and physicochemical properties on these different tree planting distance plots are recommended so this information can be used for future reference of similar or any studies related to this subject.

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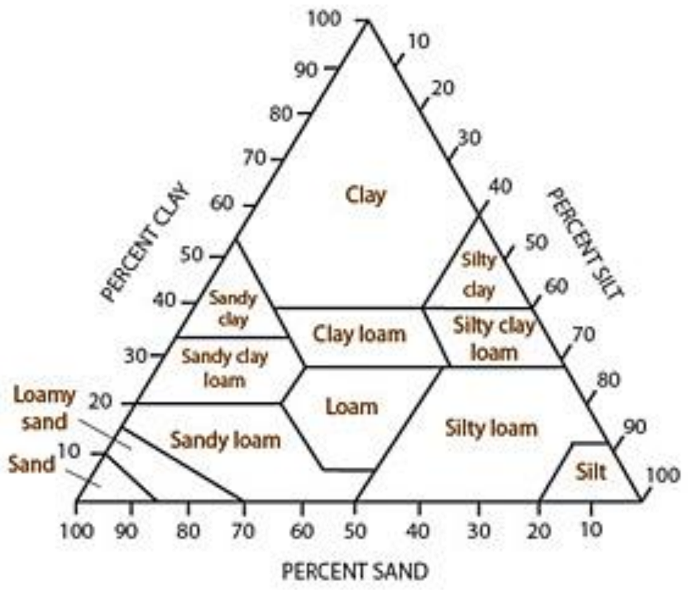
APPENDICES

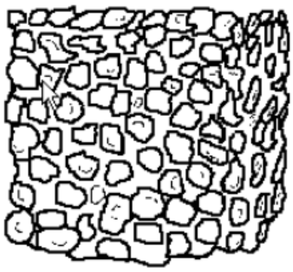
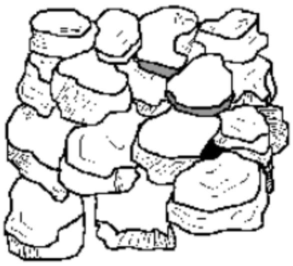
Appendix A. Soil textural classification system



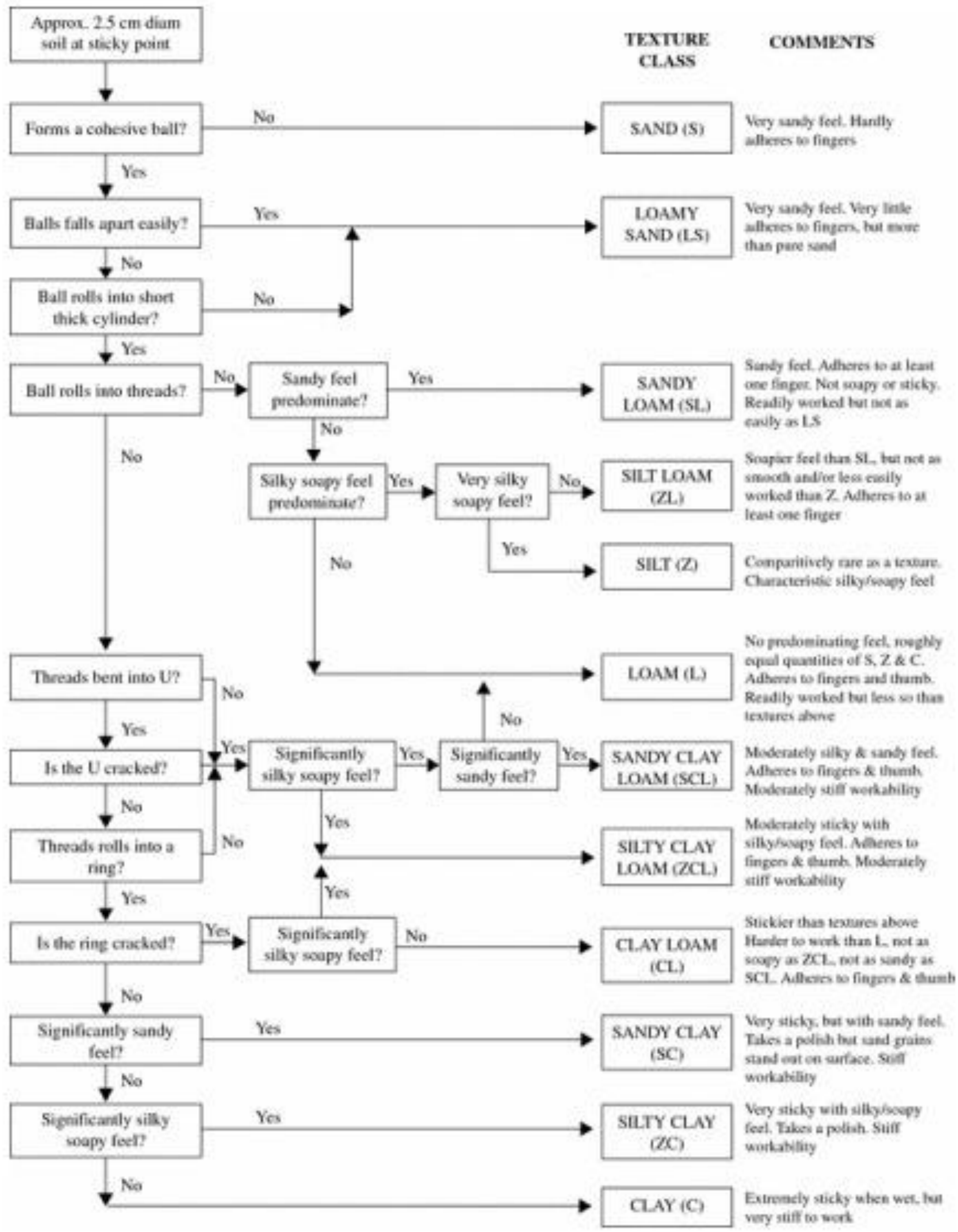
Appendix B. Soil structure classification

Soil structure	Description
Granular	Resembles cookie crumb and usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.
Blocky	Irregular block that usually 1.5 – 5.0 cm diameter
Prismatic	Vertical columns of soil that might be a number of centimeters long. Usually found in lower horizons.
Columnar	Vertical columns of soil that have a salt “cap” at the top. Found in soil of arid climates.
Platy	Thin flat plates of soil that lie horizontally. Usually found in compacted soil.
Single grained	Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

Appendix C. Soil structural shape.

		
Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.	**Blocky**: Irregular blocks that are usually 1.5 - 5.0 cm in diameter.	**Prismatic**: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.
		
Columnar: Vertical columns of soil that have a salt "cap" at the top. Found in soils of arid climates.	**Platy**: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.	**Single Grained**: Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

Appendix D. A guide to determine soil texture by feel method.



Appendix E. Summary of Morphological Properties of the Soils at Secondary Forest Trial Plot with Different Tree Spacing

Soil Morphological Properties at P1

Profile No: P1 **Location:** N 01°28'9'' E 110°25'30"

Horizon	Depth (cm)	Description
O	0 – 1	Litterfall, undecomposed leaves fallen from *Shorea macrophylla*
A	1 – 12	10YR5/8 (yellowish brown), clear wavy boundary, silty clay loam, sticky, plastic, moderate subangular structure, 14 mm average hardness, no rock fragment, no molting, common coarse to medium root.
B1	12 – 45	10YR6/6 (Brownish yellow), gradual wavy boundary, silty clay loam, very sticky, plastic, moderate subangular structure, 19 mm average hardness, no rock fragment, no molting, few coarse to medium root.
B2	45 – 70	10YR6/8 (yellowish brown), diffuse wavy boundary, silty clay loam, very sticky, plastic, moderate subangular structure, 17 mm average hardness, few subangular rock fragment, no molting, few medium roots.

Soil Morphological Properties at P2

Profile No: P2 **Location:** N 01°27’57’’ E 110°25’23”

Horizon	Depth (cm)	Description
O	0 – 1	Litterfall, undecomposed leaves from *Shorea macrophylla*
A	1 – 13	10YR6/6 (brownish yellow), clear wavy boundary, silty clay loam, sticky, slightly plastic, weak subangular structure, 15 mm average hardness, no rock fragment, no molting, common coarse to medium root.
B1	13 – 44	10YR6/8 (Brownish yellow), gradual wavy boundary, silty clay loam, sticky, plastic, moderate subangular structure, 22 mm average hardness, few subangular rock fragment, no molting, many coarse to medium root.
B2	44 – 66	10YR6/8 (yellowish brown), diffuse wavy boundary, silty clay loam, very sticky, slightly plastic, strong subangular structure, 19 mm average hardness, no rock fragment, no molting, few medium roots.

Soil Morphological Properties at P3

Profile No: P3 **Location:** N 01°28'4.98'' E 110°25'6.87"

Horizon	Depth (cm)	Description
O	0 – 2	Litterfall, undecomposed leaves from *Shorea macrophylla*
A	2 – 19	10YR5/6 (yellowish brown), clear wavy boundary, silty clay loam, sticky, slightly plastic, moderate subangular structure, 12 mm average hardness, no rock fragment, no molting, common coarse to medium root.
B1	19– 41	10YR5/8 (yellowish brown), gradual wavy boundary, silty clay loam, sticky, plastic, moderate subangular structure, 19 mm average hardness, no rock fragment, no molting, few medium to fine root.
B2	41 – 70	10YR7/8 (yellow), diffuse wavy boundary, silty clay loam, sticky, plastic, medium subangular structure, 18 mm average hardness, no rock fragment, no molting, few fine roots.

Appendix F. Soil Profile Description Sheet

Data sheet for Soil Profile Description

Profile No.		Location		Land use or vegetation		Elevation	Weather	Date	Surveyor
Physiography				Topography		Erosion		Soil name	
Parent material				Ground water (m)		Drainage		Slope	
Horizon symbol									
Depth of top and bottom of horizon									
Boundary horizon		A C G D	A C G D	A C G D	A C G D	A C G D	A C G D	A C G D	A C G D
Form of boundary		S W I B	S W I B	S W I B	S W I B	S W I B	S W I B	S W I B	S W I B
Color	Wet								
Texture									
Consistence	Stickiness	NS SS S VS	NS SS S VS	NS SS S VS	NS SS S VS	NS SS S VS	NS SS S VS	NS SS S VS	NS SS S VS
	Plasticity	NP SP P VP	NP SP P VP	NP SP P VP	NP SP P VP	NP SP P VP	NP SP P VP	NP SP P VP	NP SP P VP
	Consistence (moist)	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI	LO VFR FR FI VFI EFI
Structure	Grade	W M S	W M S	W M S	W M S	W M S	W M S	W M S	W M S
	Type	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA	PR CO AB SB PL GR CR SG MA
	Size	VF F M C VC	VF F M C VC	VF F M C VC	VF F M C VC	VF F M C VC	VF F M C VC	VF F M C VC	VF F M C VC
Hardness	(mm)								
Rock fragment	Abundance	N F C M A D	N F C M A D	N F C M A D	N F C M A D	N F C M A D	N F C M A D	N F C M A D	N F C M A D
	Shape	A SA SR R	A SA SR R	A SA SR R	A SA SR R	A SA SR R	A SA SR R	A SA SR R	A SA SR R
	Size	-	-	-	-	-	-	-	-
	Weathering	F SLW MW STW	F SLW MW STW	F SLW MW STW	F SLW MW STW	F SLW MW STW	F SLW MW STW	F SLW MW STW	F SLW MW STW
Mottling	Abundance	F C M	F C M	F C M	F C M	F C M	F C M	F C M	F C M
	Size	F M C	F M C	F M C	F M C	F M C	F M C	F M C	F M C
	Contrast	F D P	F D P	F D P	F D P	F D P	F D P	F D P	F D P
	Color	/	/	/	/	/	/	/	/
Organic matter		L M H V O	L M H V O	L M H V O	L M H V O	L M H V O	L M H V O	L M H V O	L M H V O
Root	Size & abundance								
Others. i.e. Moisture									

Prepared by M.Effendi. W, UNIMAS

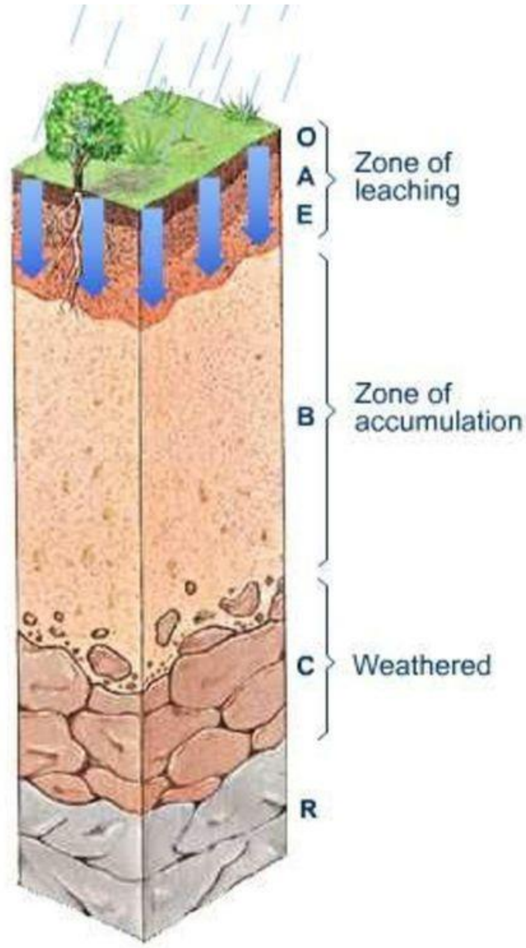
Appendix G. Soil Horizon Nomenclature

TABLE 3.5 Nomenclature of Soil Horizons.

Horizon[a]	Characteristics
O	Upper layers dominated by organic material above mineral soil horizons. Must have > 30% organic content if mineral fraction contains > 50% clay minerals, or > 20% organics if no clay minerals.
A	Mineral horizons formed at the surface or below an O horizon. Contains humic organic material mixed with mineral fraction. Properties may result from cultivation or other similar disturbances.
E	Mineral horizons in which main characteristic is loss of silicate clay, iron, or aluminum, leaving a concentration of sand and silt particles of resistant minerals.
B	Dominated by obliteration of original rock structure and by illuvial concentration of various materials including clay minerals, carbonates, sesquioxides of iron and aluminum. Often has distinct color and soil structure.
C	Horizons, excluding hard bedrock, that are less affected by pedogenesis and lack properties of O, A, E, B horizons. Material may be either like or unlike that from which the solum presumably formed.
R	Hard bedrock underlying a soil.

Adapted from the Soil Survey Staff, 1960, 1975, 1981.

[a]Horizons can be divided into subhorizons by adding Arabic numbers.



Appendix H. Soil profile description guideline

Horizon
Topography
Distinctness

Topography	
S : Smooth	
W : Wavy	
I : Irregular	
B : Broken	

Distinctness	
A : Abrupt	< 1cm
C : Clear	1~3 cm
G : Gradual	3~5 cm
D : Diffuse	>5cm

Consistence
Stickness
Plasticness

Stickness	
NS : Non sticky	Not stick with finger
SS : Slightly sticky	Stick one finger, but not two
S : Sticky	Stick both fingers
VS : Very sticky	Strongly stick both fingers

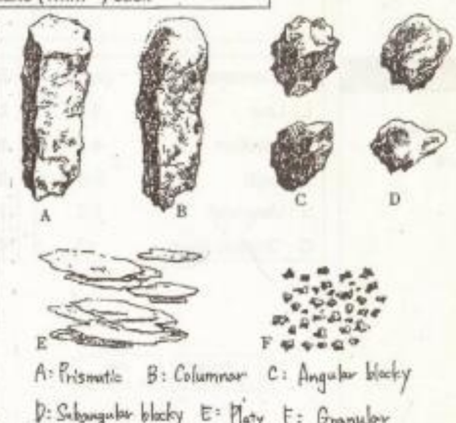
Plasticness	
NP : Non plastic	can't make a stick
SP : Slightly plastic	can make a stick, but easy to be cut
P : Plastic	can make (2mm <) stick
VP : Very plastic	can make (1mm <) stick

Structure
Grade
Type
Size

Grade	
NS : Non structure	
W : Weak	barely distinguishable
M : Moderate	distinguishable
S : Strong	clearly distinguishable

Size (mm)	G	B	Pr	Pl
VF : Very fine	<1	<5	<10	<1
F : Fine	1~2	5~10	10~20	1~2
M : Medium	2~5	10~20	20~50	2~5
C : Coarse	5~10	20~50	50~100	5~10
VC : Very coarse	>10	>50	>100	>10

Type
CR : Crumb
GR : Granular
AB : Angular blocky
SB : Subangular blocky
CO : Columnar
PR : Prismatic
PL : platy
(non-structure)
SG : Single grain
MA : Massive



Rock fragument
Abundance
Shape
Size
Weathering

Abundance	
N : None	0%
F : Few	0~5%
C : Common	5~10%
M : Many	10~20%
A : Abundant	20~50%
D : Dominant	>50%

Shape
A : Angular
SA : Subangular
SR : Subrounded
R : rounded

Size (cm)	
FG : Fine gravel	0.2~1
G : Gravel	1~5
S : Stone	5~10
LS : Large stone	10~20
B : Boulder	20~30
LB : Large boulder	>30

Weathering	
F : Fresh	fresh
SL : Slightly weathered	still hard
W : Weathered	breakable with hand
ST: Strongly weathered	easily breakable

Mottling

Abundance
Contrast

Abundance	
N : None	0%
F : Few	0-5%
C : Common	5-15%
M : Many	15-40%

Contrast		
F : Faint	barely distinguishable	(hue, value, chroma are very similar to original)
D : Distinct	distinguishable	(2 grade difference for hue, 1~2 grade difference for value, chroma)
P : Prominent	easily distinguishable	(more than 2 grade difference for hue, value, chroma)

Root

Size
Abundance

Size	
VF : Very fine	< 0.5 mm
F : Fine	0.5 ~ 2 mm
M : Medium	2 ~ 5 mm
C : Coarse	> 5 mm

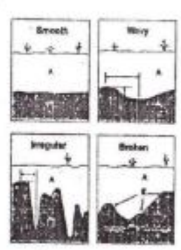
Abundance	
N : None	0%
F : Few	0~5%
C : Common	5~10%
M : Many	10~20%

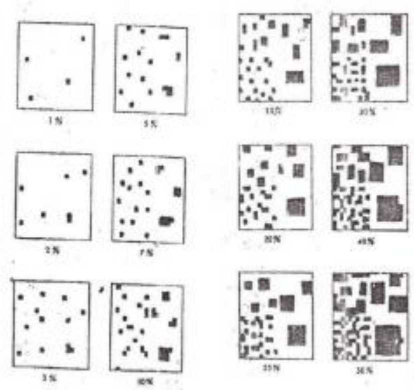
Others

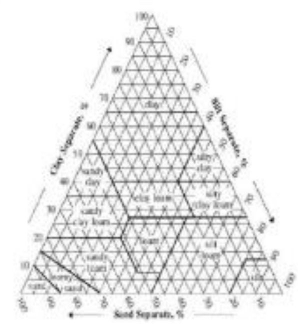
Organic matter
Moisture

OM Content	(value)
L : Low	5-7
M : Medium	4-5
H : High	2-3
V : Very high	1-2
O : Organic layer	<2

Moisture condition	
D : Dry	don't feel moisture
MD : Moderately dry	looks moist, but hardly feel moisture
MM : Moderately moist	feel moisture after strong grasping
M : Moist	being wet after strong grasping
W : Wet	Wet



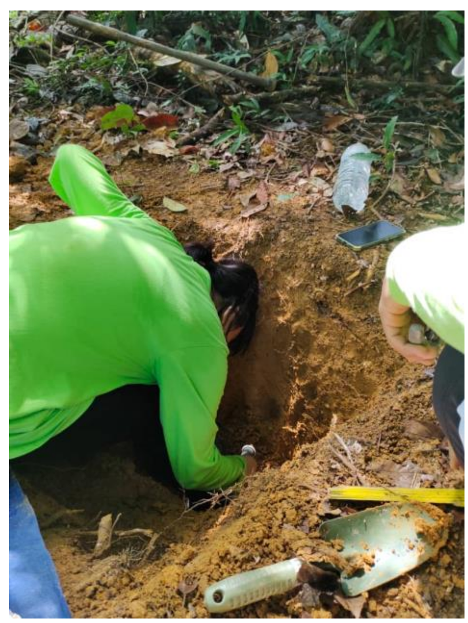




Appendix I. Soil description processes

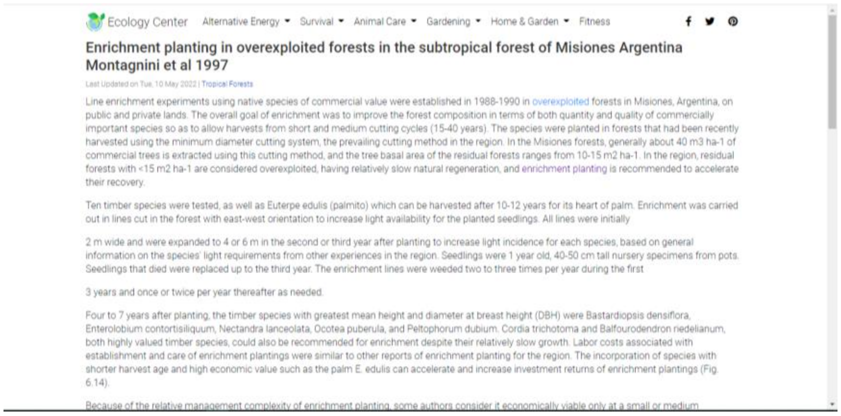
Soil digging process

Soil description process



Measuring soil hardness process

Appendix J. Web references



Ecology Center Alternative Energy Survival Animal Care Gardening Home & Garden Fitness

Enrichment planting in overexploited forests in the subtropical forest of Misiones Argentina Montagnini et al 1997

Last Updated on Tue, 10 May 2022 | Tropical Forests

Line enrichment experiments using native species of commercial value were established in 1988-1990 in overexploited forests in Misiones, Argentina, on public and private lands. The overall goal of enrichment was to improve the forest composition in terms of both quantity and quality of commercially important species so as to allow harvests from short and medium cutting cycles (15-40 years). The species were planted in forests that had been recently harvested using the minimum diameter cutting system, the prevailing cutting method in the region. In the Misiones forests, generally about 40 m3 ha-1 of commercial trees is extracted using this cutting method, and the tree basal area of the residual forests ranges from 10-15 m2 ha-1. In the region, residual forests with <15 m2 ha-1 are considered overexploited, having relatively slow natural regeneration, and enrichment planting is recommended to accelerate their recovery.

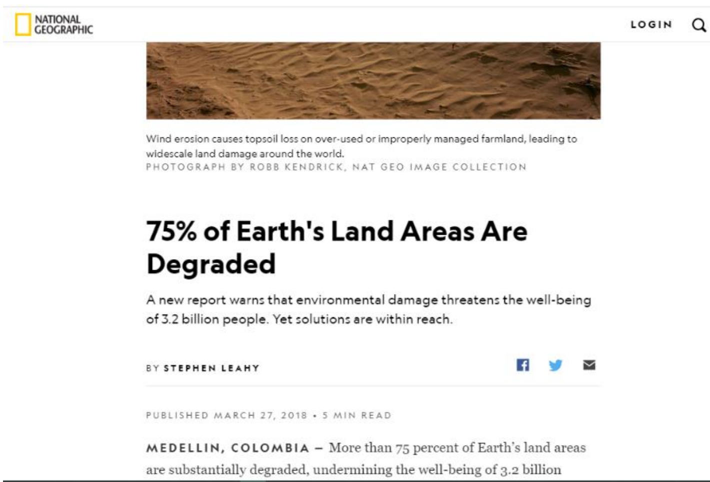
Ten timber species were tested, as well as Euterpe edulis (palmito) which can be harvested after 10-12 years for its heart of palm. Enrichment was carried out in lines cut in the forest with east-west orientation to increase light availability for the planted seedlings. All lines were initially

2 m wide and were expanded to 4 or 6 m in the second or third year after planting to increase light incidence for each species, based on general information on the species' light requirements from other experiences in the region. Seedlings were 1 year old, 40-50 cm tall nursery specimens from pots. Seedlings that died were replaced up to the third year. The enrichment lines were weeded two to three times per year during the first

3 years and once or twice per year thereafter as needed.

Four to 7 years after planting, the timber species with greatest mean height and diameter at breast height (DBH) were Bastardiopsis densiflora, Enterolobium contortisiliquum, Nectandra lanceolata, Ocotea puberula, and Peltophorum dubium. Cordia trichotoma and Balfourodendron riedelianum, both highly valued timber species, could also be recommended for enrichment despite their relatively slow growth. Labor costs associated with establishment and care of enrichment plantings were similar to other reports of enrichment planting for the region. The incorporation of species with shorter harvest age and high economic value such as the palm E. edulis can accelerate and increase investment returns of enrichment plantings (Fig. 6.14).

Because of the relative management complexity of enrichment planting, some authors consider it economically viable only at a small or medium



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PHOTOGRAPH BY ROBB KENDRICK, NAT GEO IMAGE COLLECTION

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