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Soil as A Fundamental Element of Silviculture for Sustainable Tropical Rain Forest Management

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Abstract. Soil is a fundamental element of a forest ecosystem. It provides physical support for plants, absorbs and retains water, retains and supplies essential nutrients and other chemical compounds for plant growth, and provides nutrients cycling services and habitats for organisms. Soils underlying tropical rainforest ecosystems have distinctive characteristics. The soils are old and highly-weathered and leached, highly-acidic, lacking of weatherable minerals and nutrient reserves, and dominated by low-activity clays with poor retention capacity to nutrients. Under such conditions, rainforest productivity relies heavily on the top layer of the soils, consisting of decaying plant materials and animal remains in which most biological activities such as nutrient cycling occur. These characteristics indicate that rainforest ecosystem is very fragile. When the forest trees overlying such soils are cut down, the logged over areas lose this thick layer and then the forest will seriously degrade. Therefore maintaining vegetation on soil surface is imperative. This paper aims to discuss properties of soils in the tropical rainforests, to identify soil-related damages due to silvicultural practices, and to find preventive and curative actions in order to promote sustainable tropical rainforest management.

1. Introduction

Soil, along with air, water, and sunlight, is a basic building block of a forest. In a forest ecosystem, soil has various functions. It provides physical support for plants, absorbs and retains water, retains and supplies essential nutrients and other chemical compounds for plant growth, and provides nutrients cycling services and habitats for organisms. Although playing such important functions, soil has not been fully integrated in the silvicultural system in most tropical countries.

Tropical rainforests are found in areas characterized by udic environment with sufficient rainfall, heat, and light for higher rate of biological processes throughout the year with little or no dry season [1]. Under such a climate, tropical rainforests become among the most productive ecosystems on the Earth. Many people even believe that tropical rainforests have been virtually unlimited potential as a future of the world's food and fiber resources. Because of the lush growth of the vegetations with large trees in the rainforests, some thought that the soils would be highly productive [2]. This belief then had stimulated efforts to exploit the area for commercial forestry and agriculture in the 1970s. However, the facts showed that the developments for cash crop production failed because of low productive potential of the soils, which are infertile and easily degraded. Indeed under natural forest vegetations for hundreds of years, the soils have been stable because of the accumulation of organic



matters from litterfalls and animal remains forming the forest floor, humic formation in the surface layer, and the nutrient conservation mechanisms. Therefore, the rainforest productivity relies heavily on the top layer of the soils, consisting of decaying plant materials and animal remains in which most biological activities such as a close nutrient cycling occur. These characteristics indicate that rainforest ecosystem is very fragile and readily degrade due to any disturbance, including silvicultural practices. Therefore, forest management must include maintaining soil productivity, and consequently, understanding characteristics of the soils in the rainforest is very important.

This paper aims to discuss properties of soils in the tropical rainforest ecosystem, to identify possible soil-related damages due to silvicultural practices, and to find preventive and curative actions to promote a sustainable forest management in the tropics.

2. Methods

This paper was written based on a brief review of literatures on tropical soils, especially those in rainforest ecosystems, which include soil characteristics, effects of litterfalls on soil properties, and potential soil damage due to silvicultural practices and efforts to reduce the impacts using principles of sustainable forest management.

2.1. Soils in Tropical Rainforest Ecosystems

According to United States Soil Taxonomy [3], the majority of tropical forest soils are classified primarily into five groups: Oxisols, Ultisols, Alfisols, Inceptisols, and Entisols [4]. However, most soils in rainforest ecosystem are generally classified into Ultisols and Oxisols. Ultisols are old soils with A/E/Bt/C profiles (Figure 1a), which are formed by a combination of laterization and podzolization in the warm humid regions to the humid tropics, where leaching processes are very pronounced, so these soils are highly-weathered with varying yellow to red colors due to the Fe and Al oxides accumulation in the A horizon [5]. One of important characteristics of Ultisols is the presence of an argillic horizon (Bt) which is formed by illuviation of clay particles migrating from surface horizon to deeper horizon, and contains at least 1.2 times as much clay as the topsoil [6]. Because of the drastic leaching process, the soils exhibit a very low content of basic cations with a low percentage of base saturation (<35%) in the subsoil. They are generally very acidic and high in exchangeable Al^{3+} , and therefore these soils have very low fertility. High concentrations of exchangeable Al and Fe and their oxides bring about phosphorus (P) fixation, resulting in low P availability in these soils. Ultisols include soils that are usually called *yellow podzolic*, *red-yellow podzolic*, or *red podzolic*. The surface horizons of the soils are relatively sandy texture and weak structure and are therefore sensitive to erosion. Nevertheless, under undisturbed forests, surface horizons of Ultisols are relatively stable because of high organic matter content resulted from the overlying forest vegetations.

Oxisols are mature soils with A/B/C profiles (Figure 1 b) formed by laterization process in the warm humid and tropical regions. These soils are very highly-weathered, even more than the Ultisols [5], and lack of weatherable minerals. Due to advanced weathering process, the horizon layers in the profiles can not be easily identified. These soils are characterized by the presence of oxic horizon (B) in the subsoil containing abundant amounts of hydrous-oxides or sesquioxide (Fe & Al oxides) such as goethite, hematite, and gibbsite and dominated by low-activity clays such as kaolinites [7], resulting in low cation exchange capacity (CEC). Because Oxisols are strongly weathered and leached, these soils are also low in basic cations, and therefore are infertile. Although they have very high clay contents, these soils have stable granular structures and are nonsticky, loose and friable, are much less prone to erosion than Ultisols [6].

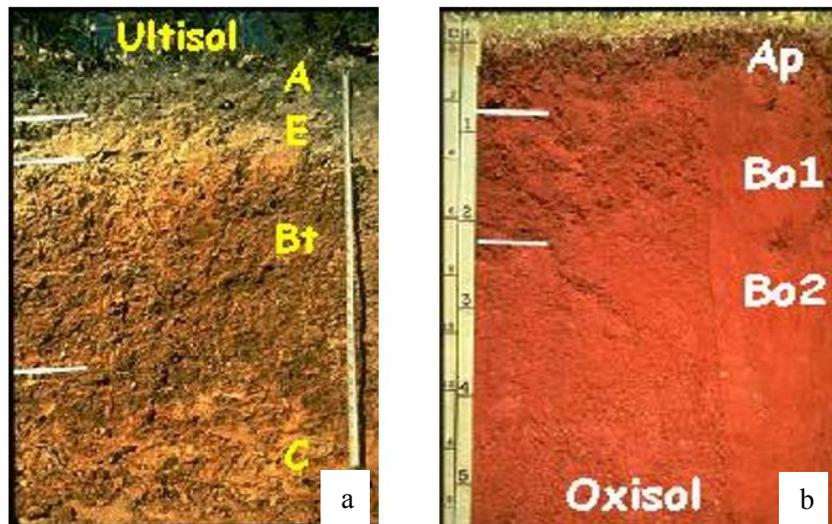


Figure 1. Profiles of Ultisol (a) and Oxisol (b)

Compared to Oxisols, Ultisols have relatively higher CEC derived from 2:1 types clay minerals such as vermiculite and smectite, with low base saturation, and the cation exchange sites are dominated by Al^{3+} ions. The concentrations of exchangeable Al^{3+} and K^+ ions in deeper layers are greater in Ultisols than Oxisols (Figure 2).

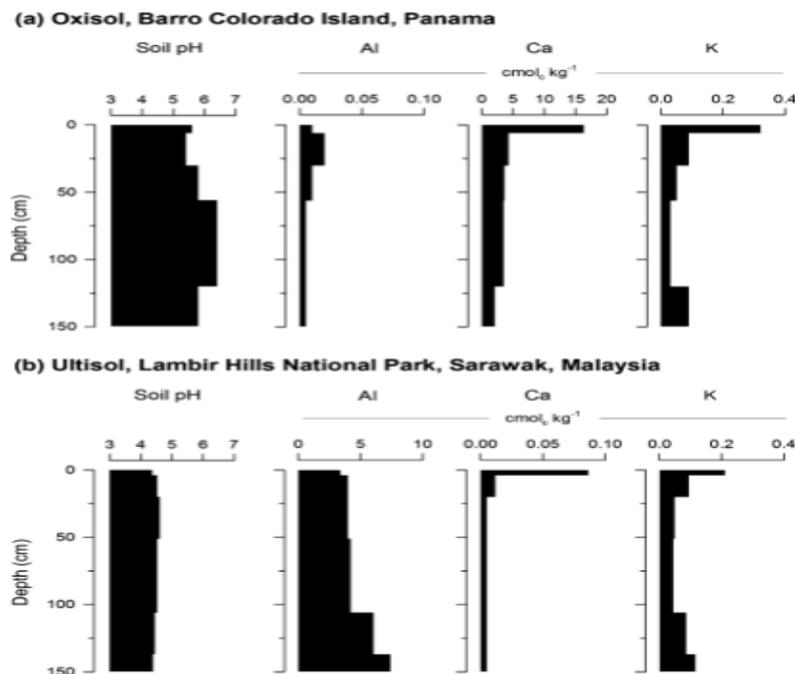


Figure 2. Depth distribution of pH and exchangeable K, Ca, and Al in Oxisols (a) and Ultisols (b)

Soils in the tropics actually vary as much as those in the temperate regions [1, 7]. The only property common to all tropical soils is their uniform temperature regime. Due to high rainfall and warm temperature conditions in the tropics, tropical soils are generally highly-weathered and leached, highly-acidic, lacking of weatherable minerals and nutrient reserves, and dominated by low-activity clays with poor retention capacity to nutrients. Besides Ultisols and Oxisols, there are other soil orders in the US Soil Taxonomy found in the tropics, namely Alfisols, Inceptisols, Entisols, Vertisols,

Mollisols, Andisols, Aridisols, Histosols, and Spodosols. Although generally formed in cool area in the temperate, Spodosols are sporadically found in tropical rainforests in Borneo island with unique vegetations called tropical heath forest which occurs as small and scatter patches [8].

2.2. Roles of Litterfall in Rainforest Ecosystem

Litterfall is a major source of organic matter and nutrients in a forest ecosystem [9-11]. The litterfall contributes to the major pathway of the return of dead organic mater and nutrients from aerial vegetation to forest soil [9]. In the forest system, litterfall reduces bulk density, increases water holding and cation exchange capacity of the soil. In addition, litter on the forest floor plays a significant role in determining the moisture status, run-off pattern, and release of nutrient accumulated in the aerial parts of the vegetation. The litterfall also influences through its decomposition, the growth of vegetation, and soil fertility through feedback mechanisms.

There are several factors affecting litter production and quality in a forest ecosystem, including soil fertility. Under a fertile forest soil, leaf renewal, litterfall and its decomposition are rapid because of a low energy investment for the synthesis of secondary metabolites. Contrary, under infertile soils as those in the tropical rainforests, leaf turnover, litterfall and its decomposition are low due to high energy investment in metabolites. Therefore, accumulation of litterfall is relatively higher in the tropical rainforest with low fertility soils compared to that in fertile soils. Ibrahim *et al.* [12] noted that even small litterfall was among the highest values of the rainforests developed on infertile soils (Oxisols and Ultisols). This means forest productivity on infertile soils heavily depends on accumulated organic matter coming from overlying vegetation which form forest floor (Figure 3). This layer consists of decaying plant litterfall and animal remains in which most biological activities such as nutrient cycling occur [1, 6, 13]. In a forest ecosystem this layer is not only an important source of nutrients but also as habitats of wide ranges of fauna, the richest part of biodiversity, a bridge between forest cover and underlying soils, a cover for soil surface which can increase water retention and structural stability, and together with the vegetation and the soil this layer contains sequestered carbon. Therefore it is crucial to protect this layer from losing out of the ecosystems.



Figure 3. Forest floor (a) and litterfall (b) in a forest system

3. Impacts of Silvicultural Practices on Soils

Disturbance due to silvicultural practices can have diverse impacts on the physical, chemical, and biological characteristics of the soils, which can, in return, impact long-term forest productivity. In his review paper on the impacts of forest management on long-term productivity of forests Fox [14] reported that harvesting and site preparation are two main silviculture activities that cause greatest impacts on soil productivity, followed by planting and weed control.

Timber harvesting involving skidding and forwarding or building roads to support the operation has both direct and indirect environmental effects. These include cutting or destroying all or a portion of trees and other vegetation on an area, and adding large amounts of coarse woody debris and/or slash to the surface; removing the organic surface layer portion from the area, exposing the underlying mineral soil; and disturbing the mineral soil during skidding, forwarding, and yarding and when

building roads and landing [15]. Removal of the organic layer along trail and may cut the surface and displace soil away. Operations of such heavy machineries and equipments compact soil along the trail system, resulting in increased bulk density and changing total pore space of the soil underneath. Extreme disturbance over large areas, including improperly designed cut banks along the roads might trigger land slides [15]. Timber harvest will reduce transpiration, increase soil temperature & reduce soil moisture which accelerate decay of litter and release of nutrients, deposits logging slash, and increases soil erosion. Because tropical rainforests are fragile ecosystem, soil destruction due to harvesting activities will be even worse than that in the temperate forests [16]. An example of the impacts of Mechanical harvesting can be seen in Figure 4.

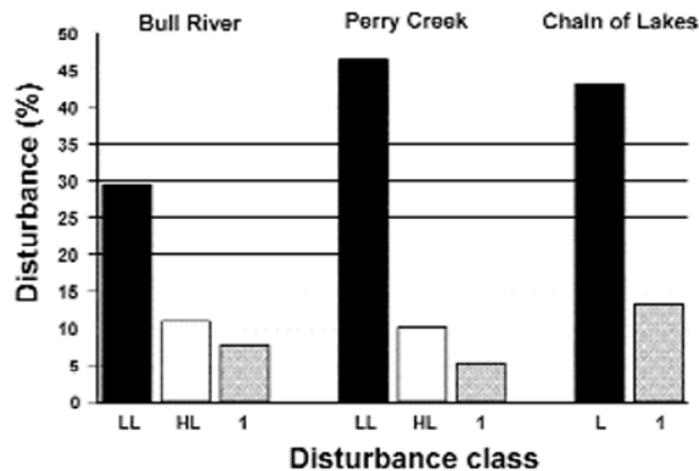


Figure 4. An example of soil disturbance coverage from mechanical harvesting (LL=light traffic trail, HV=heavy traffic trail, 1 = 5 & 10 cm deep ruts)

Mechanical site preparation usually leaves larger area of bare soil than does harvesting, thus increasing the amount of run-off and erosion. Mechanical preparation can displace large amount of forest floor and nutrient-rich surface soil horizons [17], potentially reducing site productivity. It can damage soil structures and increases soil bulk density, resulting in limited root proliferation and moisture storage capacity [17]. Nyland [15] summarized the impacts of site preparation on the soil as follows: destruction of soil structure due to disking, plowing, augering, and subsoiling; changing in soil drainage by ditching and breaking or puncturing an impervious surface or subsoil layer; scarifying or mixing the surface litter by disking, plowing, raking, and chaining; modifying the microrelief by plowing, disking, grading, mounding, and bedding; removing or disrupting protective organic cover; compacting the soils due to the use of heavy machineries and equipment; and removal of organic layers which can reduce nutrients in soils. An example of the impacts of mechanical preparation on soil disturbance is listed in Table 1. Mechanical preparation by chopping and ripping the soils result in lower soil disturbance compared with scraping the top soils.

Table 1. Impacts of mechanical site preparation on soil disturbance its degree of severity [17].

Mechanical site preparation	Type of soil disturbance	Potential severity
Chopping	Indentations	Low
Ripping	Narrow incisions up to 1 meter deep	Low
Disking	Mixing of surface soil layers	Medium
Bedding	Mixing of surface soil layers	Medium
Scalping	Removal of litter and soil in spot	Medium
Shearing and pilling	Scraping of topsoil into rows	High

4. Silvicultural Practices for Sustainable Forest Management

In the sustainable forest management silviculture is viewed as a process of sustaining ecosystem rather than a practice that simply produces commercial products such as timber and any intangible benefits from the forest. This means that silviculturists uses stand-level treatments to help sustain ecosystem conditions on a landscape scale and over the long term.

There are suggested principles of sustainable forest management by Jordan [2] which are still relevant with current forest ecosystem conditions in the tropics, namely maintenance of structural stability, maintenance of soil organic matter, minimization of soil disturbance, and control of the size and shape of disturbed area.

Structurally complex ecosystems can inhibit the exponential growth of herbivore populations because host plants are separated and because a diverse habitat can support a greater variety of predators. Diverse habitats enable vegetations to utilize a greater proportion of incoming solar radiation due to its complex spacing leaves. Denser canopies also lessen the impact of high-intensity rains on the soil. Fine roots and total roots are much more abundant in a complex community.

Maintenance of soil organic matter will prevent erosion, improves soil structure by agregating clay and other soil particles which then creates better drainage and mechanically penetrable by roots. Organic matter is an effective form of a slow-release fertilizer. Litterfalls and fine roots provide a continuous source of nutrient storage and active and diverse microbial community. Microorganisms are extremely important in preventing nutrient loss and in supplying nutrient to vegetation.

Minimization of soil disturbance reduces soil compaction, leaves more litterfall or other organic materials on soil surface, thus reducing run-off and evaporation and increasing infiltration and available water. Ground cover (slash) can reduce the impacts of ground-based logging equipment on forest soil.

Control the size and shape of disturbed area can reduce erosion and nutrient leaching. Uncut vegetation breaks the erosive force of surface water flow, take up nutrients in leachate water thus lessening nutrient loss from the area. Strip cutting reduces erosion and nutrient loss and encourage reestablishment of forest vegetation.

5. Conclusions

This paper briefly reviewed the characteristics of major soils underlying tropical rainforest ecosystems, significance of litterfalls and their effects on soil properties, potential soil damages due to silvicultural practices, and principles of sustainable tropical rainforest management. Soils in the tropical rainforest ecosystems are generally old, highly-weathered and leached, highly-acidic, lacking of weatherable minerals and nutrient reserves, and dominated by low-activity clays with poor retention capacity to nutrients, and therefore infertile. Most of the these soils are generally classified into Ultisols and Oxisols. Because most underlying soils are poor, rainforest productivity relies heavily on the top layer of the mineral soils and the forest floor consisting of decaying plant materials and animal remains in which most biological activities such as nutrient cycling occur. These characteristics indicate that rainforest ecosystem is very fragile. Therefore, silvicultural practices in the tropical rainforest should be viewed not only to produce commercial products from the forest, but more importantly to promote a sustainable forest management based on principles: (i) maintenance of structural stability, (ii) maintenance of soil organic matter, (iii) minimization of soil disturbance, and (iv) control of the size and shape of disturbed area.

Acknowledgments

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References

- [1] Sanchez P A 1976 *Properties and Management of Soils in the Tropics* (New York: John Wiley & Sons)
- [2] Jordan C F 1985 *Nutrient Cycling in Tropical Forest Ecosystems. Principles and Their Application in Management and Conservation* (New York: John Wiley & Sons)
- [3] Soil Survey Staff 2006 *Keys to Soil Taxonomy 10th Ed.* (Washington D C: United States Departement of Agriculture Natural Resources Conservation Service)
- [4] Sanchez P A and Logan T J 1992 *Myths and Science about the Chemistry and Fertility of Soils in the Tropics* ed R Lal and P A Sanchez (Madison SSSA Special Publication 29 SSSA and ASA), **3**, 35-46.
- [5] Tan K H 1994 *Environmental Soil Science* (New York: Marcel Dekker)
- [6] Burnham C P 1984. *The Forest Environment: Soils* ed T C Whitmore (Oxford: Clarendon Press)
- [7] Fujii K Shibata M and Kitajima K 2018 *Ecol Res*, **33**, 149-160.
- [8] Becker P 2006 *Tropics*, **15(3)**, 267-270
- [9] Visousek P M and Sanford R L 1986 *Annual Review of Ecology and Systematics*, **17**, 137-167
- [10] Devi N L and Singh E J 1999 *Journal of Applied and Advanced Research*, **2(1)**, 1-5
- [11] Azeez J O 2018 *J. For. Res.* <https://doi.org/10.1007/s11676-018-0753-z>
- [12] Ibrahima A Ntonga J C and Ze A D M 2018 *J. Ecol. Nat Environ*, 205-220
- [13] Brearley F Q Press M C and Scholes J D 2003 *New Phytologisty*, **160**, 101-110
- [14] Fox T R 2000 *Forest Ecology and Management*, **138**, 187-202
- [15] Nyland R D 2002 *Silviculture Concepts and Application*. Second Edition (New York: McGraw-Hill)
- [16] Pallardy S G 2008 *Mineral Nutrition (Physiology of Woody Plants)* chapter 10 pp 255-285
- [17] Neary D G, De Bano L F and Flolliott P F 2000 *Fire impacts on forest soils: a comparison mechanical and chemical site preparation* ed W K Moser and C F Moser C F *Tall Timber Ecology Conference Proc.* No 21 (Tallahase: Tall Timber Research Station Tallahase)