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A Narrative Review of the Impact of Forest Rehabilitation Programs on Soil Quality in Peninsular Malaysia

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ABSTRACT

The rehabilitation of forest areas is not new to Malaysia as forest replanting activities have been carried out throughout the country for years to meet the demand for woody and non-woody products as well as to nurture degraded forestland. Thus it is important for a soil to be evaluated to ascertain the degree to which rehabilitation activities have succeeded in restoring forest health, particularly in sustaining soil quality in rehabilitated forests. This review article aims to provide a corpus of information for forest managers and related agencies who work closely with forestry. The aim is to provide an overview on the importance of soil quality in measuring the success of forest rehabilitation programs. Research articles on the evaluation of soil properties at selected rehabilitated forests in Peninsular Malaysia were included in the review. The impact of forest rehabilitation in relation to soil properties comprising soil compaction, moisture, acidity, macronutrients, cation exchange capacity, microbial count, microbial enzymatic activity, and microbial biomass is discussed. Natural forest is used as a benchmark to see the effect of forest rehabilitation programs. Our review indicates that rehabilitated forests that were established earlier and have gone through a longer period of time have better soil quality compared to the soil of forests established later. This shows that rehabilitated forests are able to restore their soil quality and achieve fertility on par with natural forests, if given longer periods of time for recovery. Soil quality analyses should be done regularly to measure the extent of success in rehabilitation programs.

Key words: multi-storied forest management, enrichment planting, soil quality

INTRODUCTION

The Food and Agriculture Organization (FAO) (2010) defines a forest as land not classified as agricultural or urban, covering more than 0.5 hectares and containing trees of height more than five meters with 10% canopy covering that is able to reach the threshold *in situ*. Forests can be categorised as natural forest, primary forest, closed forest, permanent forest estate and planted forest (Hertel *et al*. 2009; Blaser *et al*. 2011). *Dipterocarpus, Dryobalanops*, *Hopea* and *Parashorea* are among the tree genera present in dipterocarp forests which cover approximately 17.15 million hectares across Malaysia with 31.9% in Peninsular Malaysia, 45.66% in Sarawak and 22.39% in Sabah (Blaser *et al*. 2011). Of the 13.1 million hectares of peat swamp forest in Malaysia, Sarawak has the largest area with, 890, 000 hectares.

Mangrove forests cover 709, 700 hectares in Malaysia with 418,723 hectares located in Sabah (Blaser *et al*. 2011). They need to be well managed in order to maintain and sustain forest health. Forest health can be defined as the capacity of the forest to supply and allocate sufficient amounts of water, nutrients and energy needed by the flora and fauna while maintaining the resistance towards biotic and abiotic stress or disturbance (Percy and Ferretti 2004; Karam *et al*. 2016). Forest health is usually evaluated through soil property analyses, ecosystem productivity or soil biota (Karam *et al*. 2016). Table 1 shows tropical forest cover in several countries from 2001 till 2020.

TABLE 1
Tropical forest covers (2001-2020)

Year	Indonesia	Laos	China	Myanmar	India	Malaysia	Thailand	Philippines
	Primary forest extent (million hectares)							
2001	93.8	8.3	1.7	14.0	10.2	15.9	5.9	4.6
2010	90.2	8.1	1.7	13.8	10.1	15.0	5.9	4.5
2020	84.4	7.5	1.7	13.5	9.9	13.3	5.9	4.4
	Tree cover extent (million hectares)							
2001	159.8	8.3	42.8	42.8	35.1	29.1	19.8	18.3
2010	157.7	8.1	41.1	40.9	31.4	28.6	18.1	18.1
2020	141.7	7.5	38.5	38.2	30.4	23.8	17.4	17.4

Source: Butler 2020

NATURAL FORESTS

Forests that have attained great age and exhibit a unique biodiversity are known as natural forests. Natural forests sometimes also referred to as virgin forests, possess large numbers of trees, shrubs and herbs, multi-layered tree canopies, debris and forest litter (Hackl *et al.* 2004). In Malaysia, natural forests were excessively logged in the 1960s, no doubt contributing to the economy of the country (Arifin *et al.* 2008). Currently concerns about the over-exploitation of natural forest resources have increased as methods of logging and harvesting have not taken into account the negative environmental impacts caused by heavy machinery and clear-felling on soil quality. As a result of logging activities, natural forest soil has being degraded. Absence of proper silviculture treatment to restore the health of the forest has led to soil infertility (Moran *et al.* 2000).

Deforestation of Tropical Forests

Deforestation is the act of forest clearing for agricultural, logging or urban development purposes. Deforestation alters climate, vegetation and animal ecology (Yasuoka and Levins 2007). According to Aquilar-Amuchastequi and Henebry (2007), forests tend to be converted or deforested if they do not have any economically valuable resources such as timber or other non-woody products. In Malaysia, most trees species such as *Shore*a and *Dipterocarpus* are logged due to their high economic value. The total average annual harvesting production of *S. parvifolia* and *S. macroptera* is highest followed by *Shorea* spp, *Dipterocarpus* and *Koompasia*. Non-sustainable forest opening or development has led to serious environmental problems namely soil erosion, landslides and flooding. In such situations, biodiversity vanishes if no initiative is taken to preserve or nurture it. Table 2 shows primary forest loss and tree cover changes of selected tropical countries including Malaysia.

TABLE 2
Primary forest loss and tree cover change in selected tropical countries

Year	Indonesia	Laos	China	Myanmar	India	Malaysia	Thailand	Philippines
	Primary forest loss [M ha (%)]							
2002-2009	-3.63 (-3.9%)	-0.23 (-2.7%)	-0.03 (-1.9%)	-0.19 (-1.4%)	-0.13 (-1.2%)	-0.98 (-6.2%)	-0.07 (-1.2%)	-0.05 (-1.1%)
2010-2019	-5.83 6.5%)	-0.55 (-6.8%)	-0.04 (-2.4%	-0.38 (-2.8%)	-0.20 (-2.0%)	-1.65 (-11.0%)	0.05 (-0.9%)	0.55 (-6.8%)
	Tree cover change [M ha (%)]							
2002-2009	-2.09 (-1.3%)	-0.23 (-2.7%)	-1.67 (-3.9%)	-1.90 (-4.4%)	-3.67 (-10.5%)	-0.47 (-1.6%)	-0.75 (-3.8%)	-0.18 (-1.0%)
2010-2019	-15.98 (-10.1%)	-0.55 (-6.8%)	-2.66 (-6.5%)	-2.70 (-6.6%)	-1.18 (-3.8%)	-4.84 (-16.9%)	-1.31 (-6.9%)	-0.80 (-4.4%)

Source: Butler, 2020. Note: “-“ shows the rate of forest loss/decrease

FOREST REHABILITATION

Natural Regeneration

A secondary forest is a forest that undergoes natural regeneration after severe disturbances such as fire, pest infestation, shifting cultivation or timber logging for a long period of time. After logging activities, the forest is left idle to re-grow naturally without any forest treatment. In these forests, pioneer species such as *Macaranga* spp. will colonize the area due to the opening of canopy that allows direct exposure of sunlight. In tropical countries such as Malaysia, Thailand, Laos and Indonesia, the opening of forestland for agriculture and timber logging causes extreme soil nutrients loss (Arifin *et al.* 2008; Hamzah *et al.* 2009).

Enrichment Planting

Montagnini *et al.* (1997) stated that the introduction of valuable tree species to degraded forest areas without the elimination of valuable individual trees that already exist is known as enrichment planting. Enrichment planting is a good technique for restoration of overexploited forests because it can increase total tree volume and economical value of the forest (Adjers *et al.* 1995; Karam *et al*. 2012). Moura-Cousta (1993) states that enrichment planting is more effective in lowering negative impacts on soil quality compared to the monoculture technique because it results in less susceptibility to pests and diseases, higher biodiversity, better water conservation and less soil erosion.

Multi-storied Forest Plantation

Multi storied forest management is a technique of forest rehabilitation in which high quality timber trees are employed to create two or more layers of canopies . The upper canopies are secondary forest or planted *Acacia mangium* while the lower canopy consists of the planted or introduced dipterocarps trees species. In Malaysia, the Multi-Storied Forest Management Project ran from 1991 to 1999 and was divided into two distinctive phases. Multi-storied planting technique is a method of replanting trees by using fast growing trees to act as a canopy sheltering shade tolerant tree species. The Forest Department Peninsular Malaysia (2003) stated that multi-storied forest management has gained significant attention as an ideal forest management technique for conserving biodiversity, preserving the environment and producing timber. Chikus and Bukit Kinta Forest Reserves in Perak have been subjected to this planting technique. *Acacia mangium* and indigenous high quality timber species including *Shorea* and *Hopea* were planted in the early stage of the project (Karam *et al.* 2016).

FOREST SOIL QUALITY

In the forest, soil is the source of nutrients essential to the successful growth of plant species. Soil helps in maintaining forest productivity because it is the site of biological and biochemical processes for nutrient cycling (Karam *et al*. 2012; Daljit *et al.* 2013). It is a complex biodiversity environment because in order for soil to function well, integration between physical, chemical and biological properties is essential in maintaining soil quality and sustaining forest productivity. The opening of natural forests for logging and agriculture leads to massive soil degradation. Without a tree canopy to cover the soil, the direct impacts of sunlight and rainfall promote soil erosion at a rapid pace (Jennings *et al.* 2001; Pariona *et al.* 2003). For example, an increase in soil compaction due to machinery decreases air and water pores in the soil and inhibits the activities of soil macro-organisms and other microbes (Canillas and Salokhe 2001; Hamza and Anderson 2005). On the floor of undisturbed forests such as natural forests, the available organic matter layer is a rich source of nutrients from decaying plant and animal parts broken down by microorganisms known as decomposers (Banning *et al.* 2008). In return, these microorganisms obtain the habitat and food resources they require to survive. Deforestation distorts this process and renders the land unproductive unless appropriate silviculture treatment approaches are carried out. Karlen *et al.* (1997) suggested that the evaluation of forest soil quality should not neglect any of the three important aspects of soil, that is, physical, chemical and biological because all of these parameters affect each other when soil is disturbed as a result of human activities. Hence, it is important to select appropriate parameters to evaluate soil quality so that one gains a clear picture of current soil conditions.

There are no review articles focusing on soil fertility of forests in Peninsular Malaysia. Most of the research work focuses on the physiological growth of trees as a measurement of success. Furthermore, there are also no review articles compiling studies on soil quality of forest rehabilitation in Peninsular Malaysia. Hence, this review aims to provide a set of information for forest managers and related agencies who work closely with forestry to have an overview of the importance of soil quality in measuring the success of forest rehabilitation programs.

Approach

Several research articles on the soil properties of forest rehabilitation programs in Peninsular Malaysia were selected. All research on soil properties of forest rehabilitation was obtained from Scopus**.** Table 3 shows studies on the soil properties of rehabilitated forests in Malaysia. We also included natural or primary forests as a base for comparing the impact of forest rehabilitation on soil properties.

Most of the species grown or replanted are Dipterocarpaceae (Abdu *et al*. 2008; Zaidey *et al*. 2010; Karam *et al*. 2012; Daljit *et al*. 2013; Malik *et al*. 2015) and non-dipterocarpaceae species (Zaidey *et al*. 2010; Heryati *et al*. 2011; Daljit *et al*. 2013; Malik *et al*. 2015; Rosazlin *et al*. 2015; Hamad-Sheip *et al*. (2021). Dipterocarps species planted include *Shorea pauciflora*, *S. macroptera* and *Swietenia macrophylla*. These dipterocarps species are highly valuable timber trees. However, these trees are shade-tolerant which requires the mother tree to protect them from direct sunlight while in the early stages of replanting. Hence, *Acacia mangium* is a favourite species for providing shade for this tree. In multi-storied management, *Acacia mangium* was planted before the sapling of dipterocarps species were transferred and planted on the field. Then, when the dipterocarps tree reaches a certain age, the *Acacia mangium* will be felled. One of the main advantages of *Acacia mangium* is that it is a fast-growing species. However, due to its fast-growing nature, it also causes competition with other planted tree species for limited nutrients in the soil.

TABLE 3

Selected research work on soil fertility of forest rehabilitation in Peninsular Malaysia

Site	Forest types	Species	Rehabilitation	Focus	References
Pasoh Forest Reserve	Secondary forests	Dipterocarpaceae	Natural regeneration for secondary forest	Soil respiration	Adachi *et al*. 2005
Bukit Kinta Forest Reserve	Hill dipterocarp forest	*Shorea pauciflora* *Shorea macroptera*	Line and gap planting	Soil fertility	Abdu *et al*. 2008
Bidor Forest Reserve	Lowland dipterocarp forest	*Acacia mangium* which consequently regenerated into secondary forest	Multi-storied forest management system	Soil characterization	Zaidey *et al*. 2010
Kinta Forest Reserves	Hill dipterocarp forest	Dipterocarp and non-dipterocarp species	Multi-storied forest management system	Soil characterization	Zaidey *et al*. 2010
FRIM Research Station, Segamat, Johor	-	*Khaya ivorensis*	Reforestation	Soil fertility	Heryati *et al*.2011
Tapah Hill Forest Reserve	Lowland dipterocarp forest	Secondary forest and *Shorea leprosula*	Enrichment planting	Soil biological properties	Karam *et al*. 2012
Chikus Forest Reserve	Lowland dipterocarp forest	*Shorea leprosula* & *Acacia mangium*	Multi-storied forest management system	Soil biological properties	Daljit *et al*., 2013
Jengka 18, Pahang	Tropical lowland forest	Natural forest	Natural regeneration	Soil carbon pool and selected soil properties	Jeyanny *et al*. 2014
Sungai Kial	Montane forest	Natural forest			Jeyanny *et al*. 2014
Krau Wildlife Reserve		Secondary forest	Natural regeneration	Soil chemical properties	Amlin *et al*. 2014
Sungai Menyala forest	Lowland forest	Secondary forest	Natural regeneration	Soil CO2 efflux	Mande *et al*. 2015
UPM	Lowland forest	*Pinus caribeae*	Rehabilitation of degraded land	Soil fertility	Malik *et al*. 2015
Ayer Hitam Forest Reserve	Lowland forest	*Swietenia macrophylla*	Reforestation	Soil fertility	Malik *et al*. 2015
University Agricultural Park, Puchong, Selangor	-	*Khaya ivorensis* *Orthosiphon stamineus*	Agroforestry	Soil properties	Rosazlin *et al*. 2015
Ayer Hitam Forest Reserve	Lowland dipterocarp forest	*Acacia mangium*	Rehabilitation	Soil properties	Hamad-Sheip *et al*. 2021

Soil Compaction

Soil physical properties affect the state and transport all forms of matter and energy in the soil. The degree of compaction in the soil determines the success of plant growth. Lack of air and water pores cause plants roots to experience stress because they must expand more energy to penetrate bulky soil to obtain and absorb ground water and nutrients (McQueen and Shepherd 2002). Soil texture, compaction and moisture content are a few of the important soil physical indicators that need to be included in soil quality evaluation (Sharma and Bhushan 2001; Reynolds *et al*. 2002).

Soil compaction creates conditions of stress for plant roots making it difficult for them to penetrate the soil effectively (Canilass and Salokhe 2001). Furthermore, the activities of soil microbes are restricted due to less or no water and air being available in the soil to carry out the nutrient cycling process (Miransari *et al.* 2009; Beylich *et al.* 2010). Pengthamkeerati *et al.* (2011) found that an increase in soil bulk density had a significant impact on soil microbial distribution and activities. Bulk density and porosity are frequently used parameters to evaluate the degree of soil compaction (Håkansson and Lipiec 2000).

In the forest reserve of Tapah Hill, the bulk density value is higher compared to the adjacent forest (Table 4). This shows that after 48 years of enrichment planting, it does reduce the soil compaction as compared to the natural regeneration of the secondary forest. Malik *et al.* (2015) found that bulk density is higher in the *Pinus caribeae* plantation compared to the *Shorea macrophylla* plantation which could be due to *P. caribeae* being located in the city and one of the important attraction sites in UPM. The montane forest of Sungai Kial Forest Reserve exhibits a lower compaction degree compared to the natural forests of Jengka (Jeyanny *et al*. 2015). This could be due to the elevation of the montane forest.

Soil Moisture

Forest trees, shrubs and herbs require an adequate supply of water that is absorbed from the soil through roots. Humidity in the soil also triggers microbial activities because microorganisms require a certain level of surrounding humidity for physical movements and enzyme hydrolysing activation for decomposition of materials belonging to decaying plants and animals and for successful nutrient cycling in the soil (Kosmas *et al*. 1998; Cook and Orchard 2008). Plant transpiration will decrease when there is less moisture available in the soil. Furthermore, plant roots will no longer be able to extract and absorb water from the soil once it reaches the wilting point (Menyailo and Hungate 2003). An adequate amount of moisture in the soil helps to maintain plant cell turgidity and gives certain herbs and shrubs their physical strength (Wang *et al.* 2006).

As shown in Table 4, the natural forest of Chikus Forest Reserve has the highest moisture content. This is due to the fact that the soil in the natural forest is organic. The range of moisture content for all of the forest is between 19.50 to 27.3%. However, the rate of moisture largely depends on rainfall rates. These rates of moisture content are common for Ultisols and Oxisols in Malaysia.

TABLE 4
Soil moisture and bulk density of selected forests in Peninsular Malaysia

Sites	Types	Soil moisture (%)	Bulk density (g cm^{-3})	References
Pasoh Forest Reserve	Primary forest	27.3		Adachi *et al*. 2005
	Secondary forest	26.7		
FRIM Station Segamat, Johor	*Khaya ivorensis* plantation		1.26	Heryanti *et al*. 2011
Tapah Hill Forest Reserve, Perak	Enrichment planted forest	26.33	1.16	Karam *et al*. 2012
	Secondary forest	20.50	1.24	
Chikus Forest Reserve, Perak	Natural forest	52.83		Daljit *et al*. 2013
Chikus Forest Reserve	Multi-storied forest system	19.50		
Sungai Kial Forest Reserve	Montane forest		0.62	Jeyanny *et al*. 2014
Jengka VJR	Natural forest		1.17	
UPM Arboretum	*Pinus caribeae*	21.70	2.27	Malik *et al*. 2015
Ayer Hitam Forest Reserve, Selangor	*Shorea macrophylla*	25.90	1.49	

Soil Acidity

Soils are tested to determine whether essential plant nutrients are present and if the pH value is correct for raising the desired plants. If the appropriate conditions do not exist, the soil test aid in determining what must be done to provide the correct balance of nutrients and create the proper soil reaction (Collof *et al*. 2008). By conducting an analysis on chemical properties of soil, the amount of nutrients in the soil and the ability of the soil to supply the nutrients to plants can be assessed (Campen and Glahn 1999; Li *et al*. 2007; Sidari *et al.* 2008). Chemical property analyses include soil acidity, electrical conductivity, salinity nutrients and cation exchange capacity.

Soils become acidic due to excessive leaching of basic cations such as potassium, calcium, magnesium and sodium down the soil profiles and loss through ground water. Soil acidity is an important soil quality evaluation indicator that cannot be neglected in any land use management evaluation (Brunet *et al.* 1996.). In a tropical forest, soils are at acidic conditions in the pH range of 4.5 to 5.5 for most soil series. However, certain tropical soils such as Ultisols and Oxisols, which are known as highly weathered soils have pH of about 4.0 (Shamshuddin and Fauziah 2010). Hence, through soil acidity evaluation, we can educate land managers on what should be done to decrease soil acidity within acceptable limits that would be suitable for plant growth.

All of the forests show an acidic nature as the pH level is below 7 (Table 5; Figure 1). This pH level is common for highly weathered soils. The pH can be increased if liming programs are included in forest rehabilitation. However, liming is usually not done for forest soils as most of the trees planted are neither fertilized nor the soil amended. The main reason for this is to allow the tree to grow naturally by absorbing available nutrients in the forest soil. Sungai Kial Forest Reserve and Jengka VJR show a pH that is lower than 4. The acidity level of the forest could be affected by the composition of forest litter which releases humic acid.

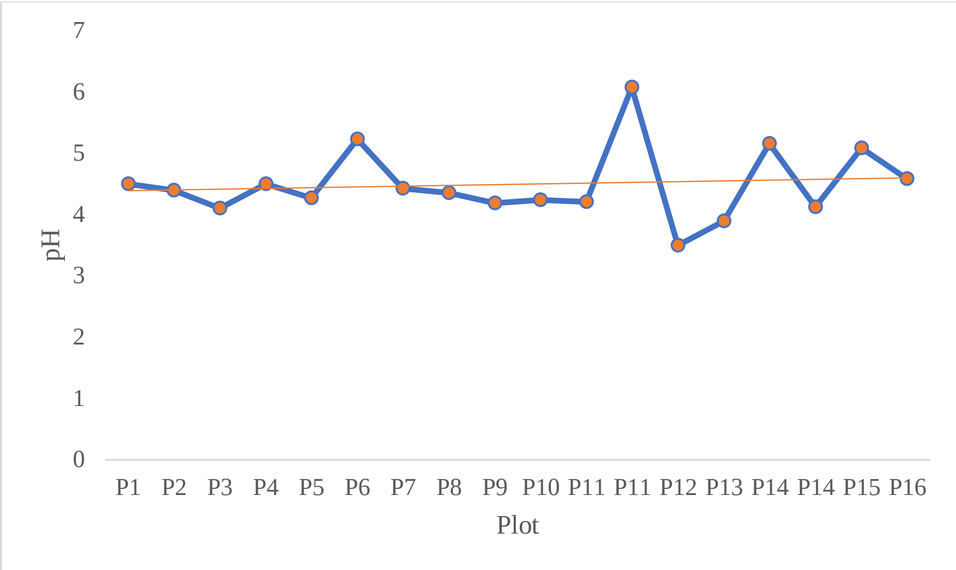

Figure 1. pH values of selected forest reserves of Peninsular Malaysia

TABLE 5
pH of selected forest reserves of Peninsualr Malaysia

Plot	Sites	pH	References
P1	Line planting (multi-storied managed forest)	4.5	Abdu *et al*. 2008
P2	Gap planting (multi-storied managed forest)	4.40	
P3	Natural forest	4.10	
P4	Bidor	4.5	Zaidey *et al*., 2010
P5	Kinta	4.27	
P6	Planted forest	5.23	Heryanti *et al*. 2011
P7	Secondary forest	4.43	
P8	Enrichment planting	4.36	Karam *et al*. 2012
P9	Secondary forest	4.19	
P10	Planted *S. leprosula*	4.24	Daljit *et al*. 2013
P11	Natural forest	4.21	
P11	Secondary forest	6.08	Amlin *et al*. 2014
P12	Sungai Kial FR	3.5	Jeyanny *et al*. 2014
P13	Jengka VJR	3.9	
P14	Secondary forest after 50 years	5.16	Mande *et al*. 2015
P15	*P. caribeae*	4.12	Malik *et al*.2015
P16	*S. macroptera*	5.09	
P17	*Khaya ivorensis*	4.59	Rosazlin *et al*. 2015

Nutrients

Macronutrients include phosphorus, sulphur, nitrogen, potassium, magnesium and calcium which are needed in larger amounts by plants; it is observed that nutrient deficiency is noticed in a shorter period of planting compared to micronutrient deficiency (Kong *et al.* 2006). However, forest plantations normally apply fertilizer at the beginning of planting activities while some rehabilitation activities do not involve the application of any fertilizer because the land manager wants to prompt the seedlings to adapt to stressed and degraded land. Carbon is an important soil constituent as it influences soils physical structure, and water-holding capacity, and also aids in the formation of strong complexes with metal ions and the nutrient supply in the soil. Nitrogen plays a vital role in all protein building blocks, including enzymes, which regulate all biological processes in the soil. Potassium in exchangeable form is essential for carbohydrate synthesis, enzyme activation and osmotic regulation (Qiu *et al.* 2007). The maintenance and integrity of cell walls and membranes are influenced by calcium (Scoones and Toulmin 1998). Exchangeable magnesium plays a major role in the photosynthesis process (Shamshuddin and Fauziah 2010). As for nitrogen, this nutrient is the major constituent of amino acids and proteins that play essential roles in healthy plant growth and development (Abanda *et al*. 2011).

The carbon to nitrogen ratio (C/N) is an important part of ensuring effective composting because microorganisms require a balance of carbon and nitrogen in order to remain active. The C/N ratio of less than 25 shows that the rate of mineralization is high while a C/N ratio higher than 30 shows that the immobilization rate is high. The best range of C/N ratio is 20-30 which indicates a balance of mineralization and immobilization rates. Table 6 shows the rate of total carbon, total nitrogen, and C/N ratio. Based on the table, all forests exhibit mineralization of nutrients except for the *Khaya ivorensis* plantation and secondary forest in FRIM Station Segamat, Johor. *Khaya ivorensis* plantation exhibits net nitrogen mobilization. In contrast, the secondary forest in FRIM Station shows net nitrogen immobilization. This could be due to very low nitrogen content as compared to the carbon content.

TABLE 6
Total carbon, total nitrogen and C/N Ratio

Site	Types	C (g kg^{-1})	N (g kg^{-1})	C/N ratio	References
Bukit Kinta Forest Reserve	Line planting	20.50	2.20	9.30	Abdu et al., 2008
	Gap planting	21.90	2.50	8.80	
	Natural forest	42.90	3.90	11.10	
Bidor Forest Reserve	Lowland dipterocarp	35.8	3.13	12.47	Zaidey et al., 2010
Kinta forest reserve	Hill dipterocarp	35.87	3.15	11.4	
FRIM Station, Segamat, Johor	*Khaya ivorensis*	13.78	0.97	22.27	Heryanti et al., 2011
	Secondary forest	16.03	0.58	49.38	
Sungai Kial Forest Reserve	Montane	40.22	0.06		Jeyanny et al., 2014
Jengka VJR	Natural forest	2.20	0.32		
Krau Wildlife forest	30 years of Secondary forest	2.76	0.28	10.33	Amlin et al., 2014
UPM Arboretum	*P. caribeae*	2.70	2.09	1.29	Malik et al., 2015
Ayer Hitam Forest Reserve	*S. macrophylla*	0.95	1.52	0.63	

Table 7 shows macronutrients and cation exchange capacity. The hill dipterocarp of Kinta Forest Reserve, montane forest of Sungai Kial Forest Reserve, and Jengka VJR have a CEC that is higher than 15 cmol$_c$ kg^{-1}. The level of CEC higher than 15 cmol$_c$ kg^{-1} shows that the forest soil is able to hold nutrients well compared to forest soil with CEC less than 15 $cmol_c$ kg^{-1}. Other forests exhibit nutrient leaching. However, macronutrients are considerably low in forest soil due to the absence of fertilizer application. Furthermore, the application of fertilizer is not necessary for forest rehabilitation.

TABLE 7
Macronutrients of selected forest reserves in Peninsular Malaysia

Site	Types	Ca ($cmol_c$ kg^{-1})	Mg ($cmol_c$ kg^{-1})	K ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	References
Kinta Forest Reserve	Line planting	0.42	0.17	0.13	5.70	Abdu *et al*. 2008
	Gap planting	0.57	0.20	0.14	5.80	
	Natural forest	0.84	0.28	0.20	12.20	
Bidor Forest Reserve	Lowland dipterocarp	0.18	0.16	0.13	10.79	Zaidey *et al*.2010
Kinta Forest Reserve	Hill dipterocarp	0.32	0.21	0.16	15.47	
FRIM Station	*Khaya ivorensis* plantation	0.51	0.21	0.18	7.86	Heryanti *et al*. 2011
	Secondary forest	0.50	0.19	0.17	0.50	
Sungai Kial Forest Reserve	Montane forest	161.7	217	439	26.36	Jeyanny *et al.* 2014
Jengka VJR	Secondary forest	47.90	98.00	382	15.79	
Krau Wildlife Reserve	Secondary forest	1.92	0.30	0.08		Amlin *et al*. 2015
UPM Arboretum	*P. caribeae*	2.24	0.23	0.21	12.51	Malik *et al*. 2015
Ayer Hitam Forest Reserve	*S. macrophylla*	0.15	0.02	0.10	8.83	
University Agriculture Park UPM	Agroforestry	0.70	1.54	0.11	11.66	Rosazlin *et al*. 2015

Microbial Population Count and Enzymatic Activity

The evaluation of forest soil quality in terms of biological properties is essential due to the sensitive nature and rapid response of soil microorganisms to environmental changes (Karam *et al.* 2012; Daljit *et al.* 2013). The growth of the microbial population is controlled by nutrient supply and moisture content. The growth medium, the energy source, and a variety of other chemical and physical factors also define the surrounding environment for the growth of the microbes.

Enzymes are an integral part of nutrient cycling in the soil and are usually associated with viable proliferating cells and specific enzyme activities such as dehydrogenase, phosphatise, β-glucosidae and many others that can be measured as an estimation of soil microbial activity (Trasar-Cepeda *et al.* 1998; Bandick and Dick 1999). Changes in soil microbial activities reflect the degree of disturbance in the affected soil, whereby opening of forest due to logging and deforestation activities causes rapid turnover and changes in microbial activities (Priess and Fölster 2001). Much nutrient cycling in the soil takes place on the root surface; in forests, this biochemical process is part of microbial activities on tree roots (Gaspar *et al.* 2001). When trees and ground vegetation are cleared in the forest, biochemical processes are disrupted; hence, microorganisms cannot synthesize food resources and nutrients effectively.

Natural forests have a higher bacterial and fungal count (Table 8). However, the rates for rehabilitated forests including multi-storied forests, and secondary and enrichment planted forests show improvement in the bacterial and fungal count. As for microbial enzymatic activity, enrichment planted forests show a higher level. This could be due to the effect of enrichment planting practices which enhance the forest macro and microorganism activities in the soil. The enrichment planting technique enriches the forest canopy through replanting of trees at the spot which lacks trees due to deforestation. Furthermore, most of the succession species grown wild in the secondary forest are *Macaranga* spp. As for multi-storied managed forests, the microbial enzymatic activity is lower than in natural forests and this is expected as the period after planting for the multi-storied forests is only 18 (as of 2010 at the time of sampling was done) compared to 48 years of enrichment planted forests. Hence, this shows that a longer period of rehabilitation will show an increase in soil quality over time.

TABLE 8
Bacterial count and enzymatic activity of selected forest reserves in Peninsular Malaysia

	Bacterial count	Fungal count	Enzymatic
Natural forest	5.37	4.37	58.54
Multi-storied forest	4.91	4.06	52.34
Secondary forest	4.04	3.99	54.92
Enrichment planted forest	4.21	4.16	64.34

Source: Karam *et al*. 2012; Daljit *et al.* 2013

Microbial Biomass

Microbial biomass is the mass of living microorganisms in a particular ecosystem at a given time. Microbial biomass responds rapidly to different land use management techniques under different climatic conditions (Debosz *et al.* 1999; Raubuch and Joergensen 2002). Kwabiah *et al.* (2003) explained that microbial biomass enhances the process of transforming organic compounds into an inorganic form that will be made available for uptake by plants. Groffman *et al.* (2001) and Salamanca *et al.* (2006), in a study on soil microbial biomass and activity in tropical forests, found that in disturbed forests left for natural regeneration growth, microbial activity was low, but there was a faster growth rate for vegetation that supplies soil microbial biomass with a considerable and adequate amount of organic matter. Jia *et al.* (2004), in a study on the distribution of soil microbial biomass and nutrients at different stages of natural regeneration forests, found that organic matter quality has a greater effect on the quality of soil microbial biomass than quantity. This finding indicates that microbial biomass is an important constituent of soil organic matter, and the availability of soil microbes in organic matter shows the recovery process of rehabilitated and natural regenerated forests.

Microbial biomass C (MBC) levels in all of the forests was higher than microbial biomass N (MBN) (Table 9). The reason for levels of MBC and MBN in rehabilitated forests being relatively low compared to natural forests could be due to compaction that decreases soil microbial biomass due to lower availability of organic matter and soil moisture content (Hakansson and Lipiec 2000; Xiao *et al*. 2005). The abundance of forest litter in undisturbed natural forest promotes the growth of microbial C and N.

TABLE 9
Microbial biomass C and N of selected forest reserves in Peninsular Malaysia

	MBC	MBN	MBC/MBN Ratio
Natural forest	824	149	6.35
Multi-storied forest	542	37	16.79
Secondary forest	325	162	1.03
Enrichment planted forest	465	239	1.91

Source: Karam *et al*. 2012

CONCLUSION

Soil is undeniably the most important earth constituent for plants to grow and humans to live. In the forest, the soil is the source of nutrients essential to the successful growth of plant species. It is a complex biodiverse environment because in order for soil to function well, integration between physical, chemical, and biological properties is essential in maintaining soil quality and sustaining forest productivity. The opening of natural forests for logging and agriculture leads to massive soil degradation. Without a tree canopy to cover the soil, the direct impacts of sunlight and rainfall promote soil erosion at a rapid pace. The objective of forest rehabilitation is not only to provide a continuous supply of economically important woody and non-woody products but also to restore the deforested area to its initial or original state. Evaluation of forest soil quality should not neglect any of the three important aspects of soil physical, chemical and biological properties because all of these parameters affect each other when soil experiences disturbance as a result of human activities. Findings in different forest management systems as discussed in this article shows the impact of forest treatment on soil quality. In short, it is important to select appropriate parameters to evaluate soil quality so that one can gain a clear picture of current soil conditions to ensure proper actions can then be taken to restore the condition of problematic soils to its optimum level.

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