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Proposing a suitable soil quality index for natural, secondary and rehabilitated tropical forests in Malaysia

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There are numerous types and categories of soil indices developed for soil fertility and quality evaluation. However, there is still lacking in suitable indices for quantifying the fertility of degraded and rehabilitated forests in the tropics. The objective of this present study was to develop a suitable soil index from the existence soil indices which were suitable for natural, secondary and rehabilitated tropical forest soil known as Tropical Soil Quality Index (TSQI). This study was carried out at Chikus lowland dipterocarp (natural forest and planted *S. leprosula* plots) and Tapah Hill (enrichment planting and secondary forest plots) Forest Reserves, Perak. Soil samples were collected at 0 to 15 cm and 15 to 30 cm depth with six subplots (20 × 20 m) for each plot. Selected soil parameters include bulk density, coarse fragment, soil acidity, total carbon, total nitrogen, exchangeable magnesium, exchangeable potassium, exchangeable calcium, available phosphorus, sodium saturation, aluminium saturation, and microbial biomass. The proposed Tropical Soil Quality Index (TSQI) incorporates all important properties of soils mainly physical, chemical and biological which are able to give adequate information on the soil fertility status. Results presented in this proposed index were based on the score accumulated from parameters that have been analyzed. This index is suitable to be used for the evaluation of current fertility status of tropical soils by which the techniques used for soil analyses were based on the acidic nature of most soils in the tropics, including Malaysia. From the proposed TSQI, enrichment planting has the same level of 59.09% TSQI with natural forest which prove that rehabilitation of degraded forest land with mix tree after 42 years of planting is similar with undisturbed natural forest. In conclusion, the proposed TSQI incorporates selected soil physical, chemical and biological properties which are crucial for soil fertility evaluation of degraded forest land and this index will helps soil fertility evaluator to study and describe the current fertility status of degraded forest land soil especially for tropical regions.

Key words: Soil fertility, soil quality, Tropical Soil Quality Index, tropical forest soil.

INTRODUCTION

Productivity and the function of soil sustainability can be illustrated by using soil quality indices (Belotti, 1998; Knoepp et al., 2000; Griffiths et al., 2010). Sustainability

in forest management is crucial and must be concurrent with sustainability in food security, human sociality, and natural resources conservation (Abdu et al., 2011; Gray,

2011; Singh et al., 2011). Problem arise when soil scientists try to incorporate all the properties of soil comprising physical, chemical and biological aspects to form a universally reliable and acceptable soil quality index due to the diversity interaction of these properties influenced by various types of soil and ecosystem location (Gardi et al., 2002; Rezaei et al., 2006). There are vast interpretations of soil quality, but the widely acceptable definition of soil quality was described by Doran (2002), which explained that soil quality is the capacity and ability of the soil at particular site land to contribute and function within ecosystem, cultivated land with regards to sustainability in biological productivity, environmental quality, flora and fauna conservation. Hence, the use of soil indices for evaluating soil quality or fertility at particular forest or agricultural land is best to be taken as rational rather than absolute (Karlen et al., 1997; Herrick, 2000; Imaz et al., 2010). It means that the usage of soil indices would be able to give an earlier indication and information on the current status of soil health because all of the soil properties evaluations have been carried out all around the world which was based on assumption and estimation. Therefore, we will be able to address the current condition of the soil at particular forest or agricultural land by examining a number of selected soil properties through soil quality evaluation. Moreover, land cultivator and stake-holder can be informed and suggested with a better approach in their land usage management in order to maintain the soil productivity.

There are undeniable lacks of suitable soil indices to measure the quality of soil in tropical rainforest of Malaysia. Certain soil quality index might only be suitable to measure a particular agricultural land which has regular application of fertilizer (Andrews et al., 2003; Bastida et al., 2008). Moreover, forest rehabilitation projects do not use high application of fertilizer because the objective of most of the planted forest was to restore the condition of the forest to the same extent of its original state of natural forest. Unlike oil palm plantation, the application of fertilizer were done three times per year; hence, evaluation of the soil nutrients content will give rise to a tremendous amount of excess nutrients availability compared to unfertilized rehabilitation forest. Many soil evaluation indices also focuses on the physico-chemical properties and many soil scientists are aware of the importance of biological properties in maintaining the fertility and quality of soil (Schloter et al., 2003; García-Ruiz et al., 2009). However, less emphasize is being given on the importance of including biological properties in soil fertility evaluation even though it has an influence

on the rate of N mineralization, enzymatic regulation activity, macro-organism population and decomposition of forest litter (Knoepp et al., 2000; Laclau et al., 2008). Lack of emphasis on biological parameters could be due to the timid and time consuming procedure to evaluate the biological components available in the soil. In the forest soil, microbial communities' play an important role in the nutrient cycling (Preston et al., 2001; Reynolds et al., 2002, 2007). For example, forest litters which are abundant on the forest floor are decomposed by soil microbial which in turn releases important nutrients such as carbon, nitrogen, potassium and calcium. Some of the nutrients will be stored in layers of organic matter before being released gradually into the soil through decomposing activities. After that plant and other tree species in the forest would be able to utilize the nutrients for their physiological growth through root absorption. Rauland-Rasmussen and Vejre (1995) found that increasing rate of forest litter decomposition by microorganism will promote higher and greater nutrients cycling which subsequently increase the soil fertility. For example, *Nitrobacter* and *Nitrosomonas* are crucial in the N-mineralization process in leguminous plant roots. The rate of nitrogen available for plant uptake is also regulated by soil organic matter, microbial biomass, enzyme activity with simultaneous effects of soil temperature and moisture content (Bending et al., 2004; Bouillet et al., 2008). Therefore, emphasizing that microbial component in the soil will only be able to continue their decomposition process of litter with the presence of sufficient amount of surrounding moisture and suitable level of temperature for enzymatic activity to occur (Sainju et al., 2008; Salimin et al., 2010). Furthermore, many soil quality indicator used are made for agricultural land crops evaluation such as corn, apple, tomato, cotton, sugar beet, maize and rice for temperate region countries rather than for forest rehabilitation site at tropical region (Dinesh et al., 2003; Sharma et al., 2005; Lee et al., 2006; Puglisi et al., 2006; Erkossa et al., 2007; Masto et al., 2007; Mohanty et al., 2007).

Many soil fertility and quality index made are focusing more on temperate countries soil with limited information regarding the suitable soil indices to measure the quality of tropical soils (Sharma et al., 2005). This present study was done in order to establish a suitable soil quality indicator which incorporates physical, chemical and biological properties of the soil on rehabilitated degraded tropical soils. Hence, with this study, a suitable soil quality index which incorporates physical, chemical and biological properties which in turns is used to illustrate the quality of natural and rehabilitated forest was established. Slight changes was done on Amacher et al. (2007) Soil Quality Index by including selected biological properties to measure the soil quality at lowland Chikus Forest Reserve and Tapah Hill Forest Reserve in Perak, Malaysia.

Two physical properties parameter which were included

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as part of the soil indices determination was the coarse fragment and bulk density. Arvidsson and Håkansson (1997) stated that soil porosity will abruptly decrease following increase in soil compaction. This phenomenon reduces soil air and water pores which subsequently strengthen soil aggregates. However, soil compaction will later reduce plant root activities because less air and water space will be available by which this constraint also will cause plant growth to be stunted. Furthermore, Håkansson and Lipiec (2000) claimed that soil compaction is a very crucial soil parameter when characterizing soil quality.

At rehabilitated forest, the level of nutrients which are classified as one of the chemical property of soil was also found to be comparatively lower than agricultural land soil (Birkhofer et al., 2008). Soil acidity is very important when evaluating soil quality because it shows us the range or condition of free hydrogen ions in the soil. Microorganism could not withstand and function well in highly acidic soil. Tropical forest soil possesses acidic condition due to highly weathered soil status. Through soil acidity evaluation, soil scientist and land cultivator will be able to take necessary approach to stabilize the soil acidity at optimum level concurrently with the suitability of tree species planted at particular land (Arbestain et al., 1998; Bini and Bresolin, 1998; Wonisch et al., 2008).

Two important organic matter constituents are carbon and nitrogen where carbon is crucial in the formation of carbohydrate while nitrogen is important for plant growth and development (Aon et al., 2001; Arshad and Martin, 2002; Fissore et al., 2009). Bouwman and Arts (2000) investigated that total carbon and nitrogen decline by 55 to 63% over 60 years on cultivated soils. Furthermore, it becomes an important matter on the loss of carbon from soil to the atmosphere which contributes to global warming (Franzluebbers, 2002; García-Ruiz et al., 2008). Through C/N ratio, we can observe whether the soil is experiencing a high rate of carbon and nitrogen immobilization or mineralization. In general, available carbon and nitrogen in natural forest soil is higher compared to planted forests because of high number of organic matter layer and forest litter on the floor.

In this study, total carbon results were used instead of total organic carbon as described by Amacher et al. (2007). This was because the samples carbon content were elucidated using carbon analyzer rather than dry combustion technique or loss on ignition which always overestimates the amount of organic carbon in the soil. Besides that, organic carbon results obtained from dry combustion in furnace are mostly the carbonate constituent in the soil. Kjeldahl digestion technique was utilized for total nitrogen extraction. The concentration of nitrogen was then read using Auto-analyzer.

Salinity and sodicity in soils are also parts of the important aspects of describing a quality index. Increase in soil salinity problem in many areas around the world is affected by poor salinity irrigation and management

(McLeod et al., 2010; Feikema and Baker, 2011). Brady and Weil (2002) summarized that plants growth will be affected directly by salt-affected soils. High sodicity in the soil will also make the electrical conductivity to increase. On the other hand, excessive concentration of sodium ion in the soil will lead to salinity problem (Sonmez et al., 2008). Microbial activities in the soil will also be disrupted by high compaction due to less or even absolute absence of air and enough humidity to provide a suitable environment for enzymatic and nutrient cycling in the soil, respectively (Miransari et al., 2009; Pengthamkeerati et al., 2011). Establishment of forest plantation at degraded forestland could lower down the negative impact of high salinity in the soil (Turner and Ward, 2002).

Macronutrients are chosen as part of this new soil quality index establishment because these nutrients play major key role in the success of plantation trees establishment (Rezaei et al., 2006; Flores-Delgado et al., 2009). Many people confuse with the terminology 'macronutrients' by suggesting that these nutrients are available in large amount in the soil compared to micronutrients. Macronutrients are group of nutrients including carbon, nitrogen, sulphur, potassium, magnesium and calcium which are needed in large amount by plants for good growth performance (Millar and Baggs, 2004; Khormali et al., 2009). Lack of macronutrients will be easily noticed on plant physical appearance at short period of time (Hopmans and Elms, 2009; Heryati et al., 2011). However, excess nutrient does not occur in forest soil because the soil is not artificially fertilized using chemical fertilizer. In addition, application of fertilizers on forest floor normally takes place within the first two years of planting excluding oil palm plantation. Micronutrients were excluded from this study because micronutrients are needed by plants in lower amount compared to macronutrients. Although micronutrients were excluded, it does not mean that these nutrients are not essential for plant growth only that the effect of deficiency of it on plants are not shown as fast compared to macronutrients deficiency.

High phosphorus fixation under tropical soil is one of the problems that restraints the availability of phosphorus in the soils which are to be absorbed and used by plants. Shamshuddin and Fauziah (2010) described that even if the total phosphorus are high in a soil, it does not mean that the available phosphorus will be high too. Furthermore, phosphorus which is negatively-charged tends to bind strongly to aluminium and iron that are found abundantly in highly weathered soils of Ultisols and Oxisols. Under acidic condition, fixation of phosphate ion would be in short period of time. Plants would not be able to absorb phosphate ions because of the strong binding process which takes place between phosphate ion with aluminium and iron known as variscite and strengite, respectively (Iuliano et al., 2007; Iuliano et al., 2008).

Soil would be regarded as a castle for abundance of forest biodiversity like microorganism. Gil-Sotres (2005)

claimed that the importance of it in describing the soil health or quality cannot be avoided. Paolo and Stefano (1990) stated that there is a wide range of microbial activities and functions in the soil. Gregorich et al. (1997) and Dinesh et al. (2003) believed that disturbance on biological process will disrupt the nutrient supplies and ecological function. Microbial biomass carbon and nitrogen were selected to be included in the new soil quality index. Diaz-Ravina et al. (1993) who studied the contribution and relationship of microbial biomass towards availability of nutrients in forest soils found that microbial biomass possess both organic and inorganic nutrients with higher contribution on availability of nutrient pools such as nitrogen, potassium, phosphorus and magnesium. Jenkinson and Ladd (1981) stated that microbial biomass acts as an important storage of nutrient in the forest soils. Behera and Sahani (2003) also described that biomass measurement give early indication on the changes that occur in soil organic matter earlier than total soil carbon and nitrogen could. Moreover, both natural and secondary forest have distinctive layer of litter and organic matter particularly on 0 to 12 or 15 cm depths. This finding showcases the important microbial biomass in maintaining soil quality. Through establishment of forest plantation, it will affect or contribute to the changes on soil microbial biomass structure in the soil.

MATERIALS AND METHODS

Description of study site

Soil sampling was carried out at enrichment planting (N 04.179394° E 101.31998°, ± 46 m a.s.l) and secondary forest (N 04. 17336° E 101.31974°, ± 32 m a.s.l) of Tapah Hill Forest Reserve and at natural forest (N 04.10076° E 101.19411, ± 28 m a.s.l) and planted *S. leprosula* plot (N 04.09197° E 101.19499°, ± 28 m a.s.l) of Chikus Forest Reserve, Perak on July 2010. Tapah Hill Forest Reserve was classified as hill dipterocarp forest, while Chikus Forest Reserve was grouped under lowland dipterocarp forest.

Soil sampling

Soil samples were collected randomly at 0 to 15 cm and 15 to 30 cm depths with six subplots (20 m × 20 m) at each plot, respectively. The composite samples later were air-dried for 48 h and kept in polyethylene bags for further analysis.

Soil analyses

Selected physical, chemical and biological properties evaluation approaches were used in this study. Most of the selected soil analyses techniques were widely used and suitable to observe the soil quality status especially for tropical soils (Saga et al., 2010; Abdu et al., 2011; Ahmadpour et al., 20105; Heryati et al., 2011). Soil compaction of bulk density was determined using disturbed soil sample technique proposed by Gupta (2007). Coarse fragment of soil were elucidated using the universal pipette method (Gupta, 2007). Soil pH in water suspension were determined using glass electrode with calomel cathode as used in Akbar et al. (2010) in

1:2.5 soil to water ratio. Exchangeable bases including potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), sodium and (Na⁺) were extracted using pH 7.0, 1 M ammonium acetate through leaching technique. Exchangeable aluminium was extracted using 1 M potassium chloride solution and was titrated using 0.01 M hydrochloric acid (Arifin et al., 2008). After that the extracted solution obtained was analyzed by using Atomic absorption spectrophotometer. Total carbon was determined by carbon analyser through dry combustion mechanism. Kjeldahl digestion technique which was used for determining the total nitrogen in soil and the concentration of total nitrogen was read using auto-analyzer. Available phosphorus in the soil sample was extracted using Bray and Kurtz II solution. Bray and Kurtz II method was selected as the extracting reagent, and was found to be suitable for determining available phosphorus for acidic soil in tropical region like Malaysia. As for biological properties, microbial biomass carbon and nitrogen were determined using rapid chloroform extraction fumigation technique as proposed by Witt et al. (2002). Wet dichromate oxidation was used for biomass carbon (Vásquez-Murrieta et al., 2007) determination, while kjedahl digestion was used for biomass nitrogen (Simmons et al., 1997) evaluation. Exchangeable sodium percentage (ESP) (Brady and Weil, 2002) and aluminium saturation in soil were calculated as:

$$\text{ESP} = (\text{exchangeable sodium, cmol}_c \text{ kg}^{-1} / \text{cation exchange capacity, cmol}_c \text{ kg}^{-1}) \times 100 \dots (1)$$

$$\text{Al saturation (\%)} = (\text{exchangeable aluminium, cmol}_c \text{ kg}^{-1} / \text{effective cation exchange capacity, cmol}_c \text{ kg}^{-1}) \times 100 \dots (2)$$

Index validation

In order to validate the biological properties index with the existing selected physic-chemical properties of SQI by Amacher et al. (2007), Pearson correlation analysis was used to study the relationship between these soil parameters. The new index will be considered validated if there are no significant differences detected. All statistical analyses were done using SPSS version 16.0.

RESULTS

Modification of Soil Quality Index

Soil Quality Index by Amacher et al. (2007) was change slightly and new addition of biological properties parameters including microbial biomass C and N were added in to form a list of index which incorporates all three important soil properties (Table 1). This proposed index also implemented soil analyses which were suitable to quantify tropical soils; hence, it was named as Tropical Soil Quality Index (TSQI).

Table 2 shows some changes and alteration which have been made on Amacher et al. (2007) for the modified Tropical Soil Quality Index. Exchangeable potassium, calcium, magnesium and aluminium which were expressed in cmol_c kg⁻¹ rather than mg kg⁻¹ in soil was due do the fact that we were more interested on the available and exchangeable ion which could be taken up by plants rather than absolute total in soil. In Amacher et al. (2007), available phosphorus were proposed to be extracted using Olsen or Bray I method; however, those method favour more on alkaline soils which were

Table 1. Proposed selected biological properties and score limits.

Number	Parameter	Level	Interpretation	Index
1	Microbial biomass C ($\mu\text{g g}^{-1}$)	> 500	High – mostly on undisturbed forests	2
		200 to 500	Good indication of restoring of microbial biomass	2
		< 200	Restoration of microbial biomass at early stage of rehabilitation	1
		< 100	Microbial biomass C deficiencies – might be catalyzed by soil erosion	0
2	Microbial biomass N ($\mu\text{g g}^{-1}$)	> 50	Abundance amount of microbial biomass N	2
		10 to 50	Restoration of microbial biomass N at early stage of rehabilitation	1
		< 10	Microbial biomass deficiencies – might be catalyzed by soil erosion	0

possessed by many temperate regions. Hence, Bray and Kurtz II (what year) method was suggested for available phosphorus extraction on acidic soil in tropical forests. Mathematic expression or formula to calculate the total TSQI and its percentage were following Amacher et al. (2007), with slight changes to fit the current TSQI;

Total TSQI = Σ individual soil properties index values ... (3)

TSQI % = {Total TSQI/ [Σ value of individual TSQI measured (13 parameters)]} \times 100% ... (4)

Validation of Tropical Soil Quality Index (TSQI) using Pearson correlation analyses

Only correlation between extractable aluminium and microbial biomass C at 0 to 15 cm depth of planted *S. leprosula* plot and between extractable aluminium with microbial biomass N at natural forest shows relationship (Table 3). At planted *S. leprosula* plot, aluminium shows strong relationship with microbial biomass which could be explained that availability of extractable aluminium in the soil provides significant effects on microbial biomass C growth. As for microbial biomass N at natural forests, it shows that increase in extractable aluminium concentration will decrease the microbial biomass N, respectively. Through these analyses, TSQI can be considered as valid due to the fact that most of the correlation results show no significant differences.

DISCUSSION

Validation of TSQI

Soil quality index by Amacher et al. (2007) was applied on forest at Northeast, North Central, South, Interior West, and Pacific West of the Forest Inventory and Analysis (FIA) regions in United States of America and it was based on the score limits of selected soil parameters included in that respective index. However, there was no biological properties study taken into account because

only physico-chemical properties were given attention in that particular index. For proposed TSQI, selected biological parameters score limits were added and the results were based on 13 parameters only (Tables 1 and 2). The results for TSQI were also expressed in term of percentage exactly the same as SQI. Therefore, addition of two new parameters will not give significant difference on the results. Amacher et al. (2007) encouraged that the threshold level and weighting factors of soil properties selected be refined from time to time to suit and balance the differences in soil and forest classification at different countries across the world. Furthermore, TSQI also practiced soil analyses technique for available phosphorus using Bray and Kurtz II (what year) method which is suitable for phosphorus extraction on tropical acidic soil. Introduction of biological properties illustrates the physico-chemical changes towards soil microorganisms. Hence, incorporation of soil physico-chemical and biological properties in TSQI provides adequate information on soil fertility status of degraded forestland so that the management of respective forestland can take immediate action in restoring the degraded forestland soil fertility.

Soil fertility status based on proposed TSQI

Karlen et al. (2001) and Lee et al. (2006) stated that soil quality illustrates the relationship and integration of physical, chemical and biological properties between soils constituent. Through soil quality index, it provides a useful tool for us or land usage management such as forest plantation program, to look into physical, chemical and biological properties of soil that changes according to forest management practices (Masto et al., 2007; Zornoza et al., 2007). Many soil quality indices has been established or proposed, yet there is still no concrete index for evaluating soils around the world due to the variability and diversity of soils (Glover et al., 2000; Borken and Beese, 2002).

As for microbial biomass studies, distribution of microbial biomass at different soil series and regions gave different and varied results. These vast differences

Table 2. Selected soil properties for Tropical Soil Quality Index (TSQI).

Number	Parameter	Level	Interpretation	Index
1	Bulk density (g cm ⁻³)	> 1.5	Possible adverse effects	0
		≤1.5	Adverse effects unlikely	1
2	Coarse fragments (%)	> 50	Possible adverse effects	0
		≤50	Adverse effects unlikely	1
3	Soil acidity	3.01 to 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals	0
		4.01 to 5.5	Moderate acid – growth of acid intolerant plants is affected depending on levels of extractable Al and other metals	1
		5.51 to 6.8	Slightly acid – optimum for many plant species, particular more acid tolerant species	2
		6.81 to 7.2	Near neutral – optimum for many plant species except those that prefer acid soils	2
		7.21 to 7.5	Slightly alkaline – optimum for many plant species except those prefer acid soils, possible deficiencies of available P and some metals like Zn	1
		7.51 to 8.5	Moderately alkaline – preferred by plants adapted to this pH range, possible P and metal deficiencies	1
		> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities	0
4	Total carbon in mineral soils (%)	> 5	High excellent buildup of organic C with all associated benefits	2
		1 to 5	Moderate adequate levels	1
		< 1	Low – could indicate possible loss of organic C from erosion or other processes, particularly in temperate countries	0
5	Total nitrogen in mineral soils (%)	> 0.5	High – excellent reserve of nitrogen	2
		0.1 to 0.5	Moderate – adequate levels	1
		< 0.1	Low – could indicate loss of organic N	0
6	Exchangeable Na (%)	>15	High – sodic soil with associated problems	0
		≤15	Adverse effects unlikely	1
7	Exchangeable K (cmolc kg ⁻¹)	>1.28	High – excellent reserve	2
		0.26 to 1.28	Moderate – adequate levels for most plants	1
		< 0.26	Low – possible deficiencies	0

Table 2 Contd

	Exchangeable Mg (cmol _c kg ⁻¹)	> 4.17	High – excellent reserve	2
		0.42 to 4.17	Moderate – adequate levels for most plants	1
		< 0.42	Low – possible deficiencies	0
		> 5.00	High – excellent reserve, probably calcareous soil	2
9	Exchangeable Ca (cmol _c kg ⁻¹)	0.51 to 5.00	Moderate – adequate levels for most plants	1
		0.05 to 0.5	Low – possible deficiencies	0
		< 0.05	Very low – severe Ca depletion, adverse effects more likely	-
10	Exchangeable Al (cmol _c kg ⁻¹)	>1.11	High – adverse effects more likely	0
		0.12 to 1.11	Moderate – only Al sensitive plants likely to be affected	1
		0.01 to 0.11	Low – adverse effects unlikely	2
		< 0.01	Very low – probably an alkaline soil	2
11	Available P (mg kg ⁻¹)	>30	High – excellent reserve of available P in slightly acidic to alkaline soils, possible adverse effects to water quality from erosion of high P soils	1
		15 to 30	Moderate – adequate levels for plant growth	1
		< 15	Low – P deficiencies likely	0

Source: Modified from Amacher et al., 2007.

on microbial biomass make it harder to quantify and measure the exact level of microbial biomass that shows the condition of the soils whether the soil is fertile enough or vice versa (Aiko et al., 2000; Susyan et al., 2011). In this study, microbial biomass distribution in natural forest was used as the benchmark to differentiate the microbial biomass C and N distribution for secondary forest and rehabilitated forest. Natural forests provide a reliable comparison benchmark to illustrate the fertility and quality because natural forest soils are considered undisturbed and no human activities interference (Arifin et al., 2007, 2008; Anderson and Domsch, 2010; Baldrian et al., 2010); thus, it was chosen as high quality reference forest soils. Based on the study carried

out by Salamanca et al. (2002) on the relationship between different types of secondary forests with soil biological properties, planted forests show concentration of soil microbial biomass C not more than 500 µg g⁻¹ soil. Compared with natural forests like wet tropical and semi-evergreen forests as studied by Dinesh et al. (2003), the concentration of microbial biomass C exceeded 500 µg g⁻¹ soils. As for natural regenerated forest of secondary forest and also rehabilitated forests, the microbial range were found to be in the range of not more than 500 µg g⁻¹ soil (Dinesh et al., 2003). However, it shows that there is an increase in biomass C concentration in the range of 200 and 500 µg g⁻¹ soils. This condition shows us that there are considerably high and restoration

process of the soil fertility. Microbial biomass N was found to exceed 50 µg g⁻¹ soil in natural forest before in this study. This condition was proven to be consistent with the results obtained by Dinesh et al. (2003) on wet tropical and semi-evergreen forests. Natural regenerated forests and rehabilitated forests showed concentration of biomass ranging between 10 to 50 µg g⁻¹ soil which proved that there was an increase in microbial activity as planted trees gives certain impact on the increasing soil fertility. Lesser than 10 µg g⁻¹ soil of microbial biomass is considered as low which in turn facilitates the mineralization of nitrogen. Looking on the proposed Tropical Soil Quality Index (TSQI), enrichment planting and natural forests show the same TSQI level of

Table 3. Result of Pearson correlation analysis between soil biological with physico-chemical properties.

S/N	Parameter	EP		SF		NF		SL	
		0-15 cm depth							
		MBC	MBN	MBC	MBN	MBC	MBN	MBC	MBN
1	Bulk density	ns	ns	ns	ns	ns	ns	ns	ns
2	Coarse fragments	ns	ns	ns	ns	ns	ns	ns	ns
3	Soil pH	ns	ns	ns	ns	ns	ns	ns	ns
4	ESP %	ns	ns	ns	ns	ns	ns	ns	ns
5	Total carbon	ns	ns	ns	ns	ns	ns	ns	ns
6	Total nitrogen	ns	ns	ns	ns	ns	ns	ns	ns
7	K	ns	ns	ns	ns	ns	ns	ns	ns
8	Ca	ns	ns	ns	ns	ns	ns	ns	ns
9	Mg	ns	ns	ns	ns	ns	ns	ns	ns
10	Al	ns	ns	ns	ns	ns	ns	0.943**	ns
11	Average P	ns	ns	ns	ns	ns	ns	ns	ns

S/N	Parameter	15-30 cm depth							
		MBC	MBN	MBC	MBN	MBC	MBN	MBC	MBN
		1	Bulk density	ns	ns	ns	ns	ns	ns
2	Coarse fragments	ns	ns	ns	ns	ns	ns	ns	ns
3	Soil pH	ns	ns	ns	ns	ns	ns	ns	ns
4	ESP %	ns	ns	ns	ns	ns	ns	ns	ns
5	Total carbon	ns	ns	ns	ns	ns	ns	ns	ns
6	Total nitrogen	ns	ns	ns	ns	ns	ns	ns	ns
7	K	ns	ns	ns	ns	ns	ns	ns	ns
8	Ca	ns	ns	ns	ns	ns	ns	ns	ns
9	Mg	ns	ns	ns	ns	ns	ns	ns	ns
10	Al	ns	ns	ns	ns	ns	ns	-0.863**	ns
11	Average P	ns	ns	ns	ns	ns	ns	ns	ns

EP, Enrichment planting; SF, secondary forest; NF, natural forest; SL, planted *S. leprosula* plot; MBC, microbial biomass C; MBN, microbial biomass N; *, correlation is significant at the 0.05 level (2-tailed); **, correlation is significant at the 0.01 level (2-tailed); ns, non significant.

59.09% compared to secondary and planted *S. leprosula* plots (Tables 4 and 5). This result illustrated that rehabilitation of degraded forest land soil fertility shows similarity with natural forest which could be due to the effects of planting period. Planted *S. leprosula* plot TSQI score differ from secondary forest by one point lesser compared to secondary forest. From this situation, longer period of time instead of 18 years after planting by which if given to planted *S. leprosula*, would shows better soil quality index score compared to natural regenerated forest as was seen in secondary forests. As for enrichment planting, different types of trees species

planted at that area provided various types of forest litter with abundance of nutrients and medium for numerous types of soil macro organism and microorganism (Salamanca et al., 2002; Dinesh et al., 2003). Soil macro and microorganism utilized and decomposed, and released various types of enzymes involve in nutrients cycling which in turn is released into the soil. At monoculture plantation such as planted *S. leprosula* plot, it has lower quality index compared to mix-planted forest like enrichment planting due to only one type of tree planted. Singular species trigger only certain population of soil microbes because not all microorganisms have the

Table 4. Selected soil physical, chemical and biological properties at Tapah and Chikus forest reserves.

Parameter	Unit	0 – 15 cm depth				15 – 30 cm depth			
		Tapah Hill Forest		Chikus lowland Forest		Tapah Hill Forest		Chikus lowland Forest	
		EP	SF	NF	SL	EP	SF	NF	SL
Bulk density	g cm ⁻³	1.16 ± 0.01	1.24 ± 0.02	1.21 ± 0.05	1.36 ± 0.02	1.22 ± 0.01	1.26 ± 0.02	1.35 ± 0.06	1.39 ± 0.02
Coarse fragments	%	43.67 ± 1.78	49.46 ± 3.95	17.30 ± 1.52	44.14 ± 1.92	43.77 ± 1.35	47.85 ± 4.01	18.36 ± 2.01	43.13 ± 3.30
Soil acidity	pH	4.36 ± 0.11	4.19 ± 0.05	4.16 ± 0.08	4.22 ± 0.03	4.42 ± 0.10	4.23 ± 0.08	4.65 ± 0.10	4.40 ± 0.02
ESP	%	13.97 ± 0.71	17.34 ± 2.20	16.17 ± 1.63	17.62 ± 1.04	26.25 ± 2.67	24.74 ± 3.36	25.53 ± 1.14	21.20 ± 1.43
Total carbon	g kg ⁻¹	2.39 ± 0.18	1.57 ± 0.08	3.29 ± 0.44	2.29 ± 0.16	1.13 ± 0.08	1.08 ± 0.03	2.17 ± 0.33	1.68 ± 0.06
Total nitrogen	g kg ⁻¹	1.55 ± 0.09	1.11 ± 0.09	1.66 ± 0.20	1.10 ± 0.15	0.81 ± 0.05	0.77 ± 0.10	1.26 ± 0.25	0.87 ± 0.06
Exch. K	cmol _c kg ⁻¹	0.13 ± 0.02	0.15 ± 0.03	0.11 ± 0.01	0.11 ± 0.01	0.03 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	0.11 ± 0.01
Exch. Ca	cmol _c kg ⁻¹	0.09 ± 0.01	0.09 ± 0.02	0.10 ± 0.01	0.11 ± 0.02	0.04 ± 0.00	0.08 ± 0.02	0.08 ± 0.01	0.10 ± 0.01
Exch. Mg	cmol _c kg ⁻¹	0.02 ± 0.00	0.06 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00
Exch. Al	cmol _c kg ⁻¹	0.08 ± 0.01	0.06 ± 0.03	0.08 ± 0.02	0.05 ± 0.02	0.06 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	0.03 ± 0.01
Av. P	mg kg ⁻¹	7.22 ± 2.82	9.90 ± 0.97	18.84 ± 3.42	14.91 ± 3.97	6.49 ± 1.46	6.33 ± 1.28	14.74 ± 3.76	9.01 ± 1.96
MBC	µg g ⁻¹	465 ± 105	325 ± 58	824 ± 34	542 ± 329	158 ± 66	124 ± 35	524 ± 115	337 ± 233
MBN	µg g ⁻¹	239 ± 8	162 ± 18	149 ± 20	37 ± 4	134 ± 12	78 ± 11	113 ± 29	9 ± 4

EP, Enrichment planting; SF, secondary forest; NF, natural forest; SL, planted *S. leprosula* plot; ESP, estimated sodium percentage; MBC, microbial biomass; MBN, microbial biomass N.

same requirement of nutrients from the same forest litter from one type of tree species (Ilstedt et al., 2003; Li et al., 2004; Subrahmanyam et al., 2011). Furthermore, same type of forest litter available on the forest floor will cause faster rate of microorganism growth spreading all over the plots. Problem always arise on the infestation of pest and disease on monoculture plantation because of the same or similar biochemical and physiological characteristic of the tree species planted which enhanced the insect's infestation or bacteria and fungi inoculation (Chang et al., 2010;

Karam et al., 2011). At 0 to 15 cm depths, the forest soil was considered the most fertile with abundance of organic matter, humus with soil microbes. Abundance of soil microbes also found to be more concentrated at 0 to 15 cm depth due to many plant roots at that soil layer. At 15 to 30 cm depth, natural forest still had the highest TSQI, followed by secondary forests. Enrichment planting and planted *S. leprosula* plots show similar TSQI level of 45.45%. Low TSQI at enrichment planting was due to lack of exchangeable calcium which was below 0.05

cmol_c kg⁻¹. However, most of the soil quality evaluations focus on the topsoil rather than subsoil because most of the biology and biochemical reactions in the soil occurs in the topsoil.

Conclusion

In conclusion, this proposed TSQI incorporates all the three important soil properties which include physical, chemical and biological properties.

Table 5. Tropical soil quality index (TSQI) score limits.

Parameter	Full score	0 – 15 cm depth				15 – 30 cm depth			
		Tapah Hill Forest		Chikus lowland Forest		Tapah Hill Forest		Chikus lowland Forest	
		EP	SF	NF	SL	EP	SF	NF	SL
Bulk density	1	1	1	1	1	1	1	1	1
Coarse fragments	1	1	1	1	1	1	1	1	1
Soil pH	2	1	1	1	1	1	1	1	1
ESP	1	1	0	0	0	0	0	0	0
Total carbon	2	1	1	1	1	1	1	1	1
Total nitrogen	2	2	2	2	2	2	2	2	2
Exch. K	2	0	0	0	0	0	0	0	0
Exch. Ca	2	0	0	0	0	-1	0	0	0
Exch. Mg	2	0	0	0	0	0	0	0	0
Exch. Al	2	2	2	2	2	2	2	2	2
Av. P	1	0	0	1	0	0	0	0	0
MBC	2	2	2	2	2	1	1	2	2
MBN	2	2	2	2	1	2	2	2	0
Total Score	22	13	12	13	11	10	11	12	10
Percentage (%)	100	59.09	54.55	59.09	54.00	45.45	50.00	54.55	45.45

EP, Enrichment planting; SF, secondary forest; NF, natural forest; SL, planted *S. leprosula* plot; ESP, estimated sodium percentage; MBC, microbial biomass C; MBN, microbial biomass N.

Selected soil parameters included in TSQI will help land manager or soil fertility evaluator to illustrate the current status of degraded, natural and rehabilitated forests soil especially for tropics forest regions. Moreover, this TSQI also was easily used for forest soil evaluation because it utilized the concept of score accumulation rather than regression types of index which might be suitable for a certain type of soil. Besides that certain regression soil index might be suitable to use according to the soil class, types of plantation

and even location. Hence, it would be difficult to use the soil indices on different type of soil, planted tree species and location. Hence, the proposed TSQI seemed to be suitable for use by soil scientist, students and land manager. Simple mathematical expression used also made this proposed index easy to be understood rather than sophisticated and complex type of available soil indices which sometimes cause confusion due to its complexity. Each selected soil parameters in TSQI also have explanation based on the score

which gave easy and clear information regarding on the fertility and quality of particular study site.

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