

Monitoring soil resilience via the dynamic changes of selected physicochemical properties of soil in a tropical rehabilitated forest

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ABSTRACT

Recovery of soil organic matter and mineral nutrient cycling are critical to the success of rehabilitation process of replanted forest. We investigated the dynamic changes in soil of selected physicochemical properties including organic carbon (C), nitrogen (N), phosphorus (P) and sulphur (S) of replanted forest rehabilitation that had been previously disturbed by anthropogenic activities. Soil samples were collected from the rehabilitated forest of three ages stands (3-, 12- and 23-years old) while samples from adjacent secondary forest was collected for comparison. Altogether, 36 samples were taken randomly with a soil auger at depths of 0-20 cm from a plot of 20 × 20 m² at each site. Soils were analyzed for pH, bulk density, C, N, P and S. The data obtained were statistically analyzed using ANOVA with Tukey's test performed by SAS 9.2 at $P \leq 0.05$. Results showed that total C, N, P, C/N ratio and C/S ratio increased with age of rehabilitated forest except for pH, S and C/P ratio. Forest rehabilitation by planting indigenous tree species has shown a potential of recovery, but further investigation into the process control of the dynamic changes of soil physicochemical properties, particularly in the event of further ecosystem disturbance is needed.

Keywords: Forest resilience, Soil carbon, Replanted tropical forest.

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1. INTRODUCTION

Soil resilience has been described as the soil ability to recover to its efficient and operational state after being disturbed (Pimm, 1984; Lal, 1997; Seybold et al., 1999). The concepts of resilience have emerged in many different fields (Olson et al., 2015) and in term of sustainability of environment, this terminology is considered as a crucial part (Marchese et al., 2017). Pimm (1984) defined the concept of resilience as the time required by a system to return to an equilibrium state after a disturbance. This concept has been applied into soil science to address sustainability of natural resources and to reduce soil degradation. The important component of soil quality can represent the soil resilience and resistance which also an important element of sustainability. Seybold et al. (1999) list three approaches in order to evaluate soil resilience: (i) direct measurement of recovery after disturbance, (ii) evaluating the ability of recovery mechanisms after a

disturbance, and (iii) measuring components that assist as indicators of those recovery mechanism. The recovery success of soil resilience can be influenced by several factors. The scientific literature shows ecological indicators are the most crucial components such as species diversity, vegetation structure and fauna on different restoration approach (Holl and Aide, 2011).

Tropical rainforest is one of the highest productive types of forest which only can be found in tropical climate of South America, Central America and Southeast Asia. Among this area, Southeast Asia tropical rainforest covered 15% of the world tropical rainforest (FAO, 2020) and is considered as one of the oldest and greatest biologically diverse ecosystems in the world. In Malaysia, tropical rainforest covers almost 60% of the land area at approximately 19.37 million hectares of which 8.71 million hectares located in Sarawak (Ahmed et al., 2012). However, forest degradation in Malaysia is inevitable as it competes with human needs for instance agriculture for food and survival of the increasing population. The degree of deforestation in Malaysia is accelerating faster than any other tropical country in the world because of the high pressure in human needs to agriculture and timber (Ahmed et al., 2012). Effort on rehabilitating degraded forestland have been successfully implemented in Sarawak, Malaysia. Various indigenous species have been successfully planted after selection for forest rehabilitation purposes (Wasli et al., 2014; Perumal et al., 2017). Among the common planted species comes from the Dipterocarpaceae family such as *Shorea macrophylla*, *Dryobalanops beccarii*, *Shorea falcifera*, *Shorea parvifolia* and *Calophyllum alboramulum*. Most of this climax species in the diverse Dipterocarp Forests of Borneo, can reach a height of 50 m tall, 4.0 m in trunk girth at chest height and 2.0 m in buttress height (Ashton, 1982).

According to FAO (2020), deforestation is the conversion of forest to another land use while forestland degradation refers to the intensity of deterioration physically and chemically of the area. The effects of loss forest cover like harvesting of timber give immediate impact on soil erosion. The loss of organic matter happened almost instantly after the forest being cut. The removal of trees causes an excess to soil water content and surface runoff that may intensify upslope erosion and transportation of sediment from upland channels (Kimble et al., 2003). The effect of declining of soil organic matter is directly related to land degradation (Young, 2003) and cause a significant reduction of various elements including soil organic C, total N and available P (McDonald et al., 2002).

The major factors of regeneration of forest ecosystems are microclimate, nutrient availability, seed fall and seed bank (Holl, 1999), that primarily affected by the escalation of degradation progressions. Soils of tropical forest mostly are highly weathered that have low natural fertility and soil pH. Therefore, these systems be subject to an effective nutrient cycling based on litter deposition and decomposition (Vitousek, 1984) to enhance the recovery

process. The environmental conditions and the level of disturbance have a high influence on the degree of soil regeneration. Thus, depending on the status of soil degradation, the methods used for degraded land restoration is designated to re-establish the ecosystem back to its equilibrium state.

In this preliminary study, the main objective is to investigate the potential of soil recovery in rehabilitated forest by monitoring the dynamic changes in selected soil physicochemical properties including nitrogen (N), organic carbon (C), sulphur (S) and phosphorus (P). This is made possible by comparing the data from different aged of rehabilitation forest (RF) to the nearest secondary forest that act as a reference.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out at a forest rehabilitation project started in late 1990 and was officially known as UPM-Mitsubishi Corporation Forest Rehabilitation Research Project at the beginning of 2008. Fig. 1 shows the study area that located at a latitude of 03°12' N, longitude of E 113°02' and 50 m above sea level.

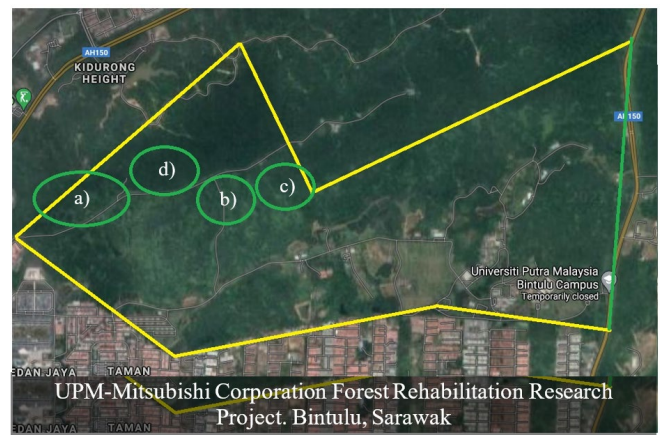


Fig. 1. Location of study site with a) 23-years old RF b), 12-years old RF, c) 3-years old RF, and d) secondary forest

The forest rehabilitation project was initiated to restore disturbed tropical forest by replanting various indigenous plants species. At these sites, the accelerating natural regeneration technique was practiced based on the concept introduced by Miyawaki (2011). The rehabilitated area was planted at high density with mixed of indigenous species mainly from Dipterocarpaceae such as *Shorea spp* and *Hopea spp* and Non-Dipterocarpaceae such as *Pometia pinnata*, *Macaranga gigantea*, *Mallotus leucodermis* and various *Syzygium spp*. Soil samples were collected from the rehabilitated forest of three ages stands (3-, 12- and 23-year-old) while samples from nearest undisturbed secondary forest was collected for comparison. Nine soil samples were randomly collected at depths of 0-20 cm from each site

within a plot of 20 × 20 m². In order to avoid bias, all samples were collected at the same day together with bulk density from each plot.

2.2 Sample Preparation and Analysis

All soils samples were air dried, homogenized and sieved to pass a 2 mm mesh prior to analysis. The soil pH was determined using a glass electrode (Peech, 1965) from water suspension of soil at ratio 1:2.5 of soil:distilled water. Soil total organic C, N and S were determined by Leco CHNS Analyser (LECO[®] Cooperation, 1987). Total P was analysed using the aqua regia and the blue methods (Murphy and Riley, 1962). An aqua regia solution (20 mL) was added to a 2 g of soil sample and placed in a 250 mL volumetric flask. The sample was heated under reflux for 30 min until the solution was clear. The solution was filtered through ashless filter (Whatman filter paper No. 2) into a volumetric flask of 50 mL and diluted to volume with distilled water. The total P was determined using a UV-VIS spectrophotometer. The soil bulk density was evaluated by core rings methods (Walter et al., 2016). Core rings were pressed into soil at field until it fully penetrated. The excess of soil at the top and bottom of the ring was carefully removed. The weights of the core rings together with media were recorded and then oven dried at 105°C for 24 h. The bulk density was determined by the following formula,

$$\rho_b = \frac{M_s}{V_b}$$

where ρ_b is the bulk density (g/cm³); M_s is the mass of oven dried soil (g) and V_b is the volume of the soil (cm³) in the cylindrical core. Where $V_b = \pi r^2 h$; r is internal radius and h is the height of the core (cm).

2.3 Statistical Analysis

All results were analysed using The Statistical Analysis System (SAS) version 9.4. Analysis of variance (ANOVA) and means separation by Tukey was used to detect significance difference of soil C stock, total concentrations of C, N, S, P, and pH of the different ages of the rehabilitated forest and secondary forest. A 95% confidence interval was used for all calculations ($p \leq 0.05$).

3. RESULTS AND DISCUSSION

3.1 Soil pH

Soil pH is one of a key measure of soil property that control various processes for instance soil biogeochemical processes, soil fertility and influences the structure and functioning of terrestrial ecosystems (Brady and Weil, 2017). The soil pH of the study area found to decrease by time. Data in Table 1 shows that the pH values of secondary forest were not significantly different with the 23-year-old RF both in water and KCl. The only site that has significantly different values of soil pH when compared to

secondary forest both in water and KCl is the 3-year-old RF. This indicates that the recovery process of soil pH to reach the equilibrium is visible from the site with 12-year-old RF while the 23-year-old RF has reached the stable values of undisturbed forest. Soil acidity in the forest is highly influenced by the concentration of Al, H and organic matter (Zaidey et al., 2010). The recovery process of pH values in rehabilitated forest may be influenced by organic matter content that comes from the litter of replanted plants.

Table 1. Soil pH and bulk density values from secondary forest and different ages of rehabilitated forest (RF)

Forest Type	pH (water)	pH (1 M KCl)	Bulk Density (g/cm ³)
1) Secondary Forest	4.26 ^c	3.35 ^b	0.734 ^c
2) 23-year-old RF	4.40 ^{bc}	3.38 ^b	1.142 ^{ab}
3) 12-year-old RF	4.67 ^b	3.33 ^b	0.998 ^{bc}
4) 3-year-old RF	5.34 ^a	3.71 ^a	1.416 ^a

Means within a column for a particular of forest type with different letters indicate significant difference by Tukey's test at $p \leq 0.05$

3.2 Soil Bulk Density

Table 1 demonstrate the values of soil bulk density from each site sampled in this study. The 3-year-old RF shows the highest values of 1.416 g/cm³ that significantly different when compare to secondary forest and 12-year-old RF at 0.734 g/cm³ and 0.998 g/cm³ respectively. However, the 23-year-old RF only shows a significant values of soil bulk density when compared to secondary forest. Soil bulk density tend to decrease with increase in organic matter (Catherine and Rock, 2008; Kavian et al., 2014). The secondary forest with the lowest value of soil bulk density indicates a high amount of organic matter due to long litter accumulation form older plants. The content of organic matter in soil has a high influence on bulk density and total porosity in soil (Gajić, 2013). However, the different regime of disturbance before the rehabilitation program at each site of the rehabilitated forest in this study were unknown. This is also can be the reason of the different values of soil bulk density in all rehabilitated forest in this study.

3.3 Soil Total C Concentrations and Stocks

Soil organic C sequestration is one of the most popular issues discussed in this millennium in regards to global warming and greenhouse gas emission. Deforestation and forest exploration for various purposes such as agriculture has caused a huge loss of C emitted to atmosphere. Table 2 shows the result of soil total C concentrations and soil C stock from this study. The lowest total C concentration and C stock found in the 3-year-old RF that recorded 0.61% and 17.28 t C/ha respectively. The highest amount of C stock was recorded in the 12-year-old RF with 28.34 t C/ha. This value is significantly higher than the 23-year-old RF (25.12 t C/ha) and secondary forest (24.77 t C/ha), displays the potential of rehabilitated forest program to sink more C in

the future. The results shown in Table 2 demonstrates the potential of forest rehabilitation program in this study to act as C sink. Total soil organic C shows an accumulation with the 23-year-old RF shows no significant different in both total soil C concentration and soil C stock when compared to secondary forest. The dynamic changes of total soil C concentrations and soil C stock need to be further studied in order to understand the mechanisms lies behind. The factors such as different species planted, plant canopy, plant litter quality, decomposition process, and microbial activity need to be calculated before a concrete conclusion can be made. Furthermore, the total C recorded need to be examined by fractionation of C pools for better understanding.

3.5 Soil Total N Concentrations and C/N Ratio

Table 2 demonstrates the total N and C/N ratio among sites sampled in this study. Total N was found higher in the 12-year-old RF followed by secondary forest, 23-year-old RF and 3-year-old RF with the values of 0.16%, 0.12%, 0.09% and 0.08% respectively. However, the C/N ratio recorded an increasing trend with age in all rehabilitated forest but the values was significantly lower; 3-year-old RF (7.30), 12-year-old RF (9.40), and 23-year-old RF (11.60) compared to secondary forest (13.29). This data shows the possibility to conclude that all rehabilitated forest sampled in this study were still in the process of recovery. In the process of forest rehabilitation and restoration of forest communities, studies indicates that N is probably the most important limiting factor (Vitousek et al., 1989). The concentration of N in forest always correlates with litter production. The production and decomposition of litter depends on plants species and age that contributes to litter accumulation and build-up of organic matter. This could be the main reason of dynamic changes in soil total N in all plots studied.

3.6 Soil Total P Concentrations and C/P Ratio

In terms of soil total P and C/P ratio, the statistical means comparison of the sites sampled showed in Table 2. The total P concentrations which significantly different when compared between all rehabilitated forest shown in the downward trend from 23-year-old RF (0.008%) > 12-year-old RF (0.0015%) > 3-year-old RF (0.00007%). This data indicates that total P was gradually increased with age of rehabilitated forest. However, only the 12-year-old RF shows no significant different when compared to secondary

forest with the concentrations of total P of 0.0017%. The value of C/P ratio in 3-year-old RF was significantly lower compared to other plots while the 23- and 12-year-old RF shows no significant different when compared to secondary forest. The high value of C/P ratio in 3-year-old RF demonstrates the possibilities of P immobilization because of low available P concentration to sustain both plants and microorganism. According to Schroth (2003), C/P ratio value of < 200 will result in initial net mineralization and the value of > 300 will result in initial net immobilization. Based from the findings, with the exception of the 3-year-old RF, all plots in this study exhibit the mineralization of P.

3.7 Soil Total S Concentrations and C/S Ratio

Table 2 shows the results of soil total S concentration and C/S ratio from this study. In the 23-year-old RH, both soil total S concentrations and C/S ratio shows no significant difference when compared to secondary forest. The 3- and 12-year-old RF shows a significant difference only in total soil S concentrations when compared to 23-year-old RF and secondary forest. In terms of C/S ratio, the data demonstrates and increasing trends with forest ages from 3-year-old RF (12.25) < 12-year-old RF (38.54) < 23-year-old RF (47.88) < secondary forest (49.66). With the exception of the 3-year-old RF, all plots show no significant difference in term of C/S ratio indicates a stable recovery process after 12 years of rehabilitation.

The values of C/S ratio in all plots shows a favour of net mineralization occurred. This is suggested by Schroth (2003) that recommend the C/S ratio values of < 200 will favour for initial net mineralization while the value of C/S ratio > 400 will results in initial net immobilization. The potential mineralization of S indicating that biological S mineralization will simultaneously enriches soil fertility and enhances forest productivity. Mineralization of essential nutrients, including N and S is an important process in forest soils.

4. CONCLUSION

The rehabilitated forest shown a potential of recovery by time when compared to secondary forest. Total C, N, P, C/N ratio and C/S ratio increased with age of rehabilitated forest except for pH, S and C/P ratio. The value of C stock increased by time with the 23-year-old rehabilitated forest shows no significant different when compared to secondary

Table 2. Soil C stock, total concentrations of C, N, P, S and ratio of C to N, C to P and C to S in soils from secondary forest and different ages of rehabilitated forest (RF)

Forest Type	Total C (%)	C stock (t C/ha)	Total N (%)	C/N Ratio	Total P (%)	C/P Ratio	Total S (%)	C/S Ratio
1) Secondary Forest	1.69 ^c	24.77 ^a	0.12 ^{ab}	13.29 ^a	0.0017 ^{bc}	130.20 ^b	0.0036 ^b	49.66 ^a
2) 23-year-old RF	1.10 ^{bc}	25.12 ^a	0.09 ^{bc}	11.60 ^b	0.008 ^a	11.60 ^b	0.0026 ^b	47.88 ^a
3) 12-year-old RF	1.42 ^b	28.34 ^b	0.16 ^a	9.40 ^c	0.0015 ^b	180.50 ^b	0.0055 ^a	38.54 ^{ab}
4) 3-year-old RF	0.61 ^a	17.28 ^c	0.08 ^c	7.30 ^d	0.00007 ^c	1183.90 ^a	0.0073 ^a	12.25 ^b

Means within a column for a particular of forest type with different letters indicate significant difference by Tukey's test at p≤0.05

forest indicate that the soil has recover. It is very important to take into consideration the various factors influencing the dynamic changes of the parameters studied to understand them appropriately. In the future, more data from various plant stand including plant litter and species need to be study to show the mechanism and the recovery process of disturbed soil in replanted forest.

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