# Properties of soils in the rehabilitated degraded tropical lowland and hill dipterocarp forests in Peninsular Malaysia

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## Abstract
A study was conducted to characterize the soil properties of two rehabilitated major forest types in Peninsular Malaysia, representing lowland and hill dipterocarp forests located at Bidor and Kinta Forest Reserves, respectively. Twelve soil profiles were dug both in rehabilitated lowland and hill dipterocarp forests including two profiles in natural forest as the control were selected at each site. The significant effect of rehabilitation forests could be seen by the accumulation of organic matter in the uppermost layer, which was assumed to be at an intermediate stage of mineralization. The soils at both sites were acidic, having low activity clay resulting in low CEC, available P, total nitrogen and exchangeable bases, but high in exchangeable Al. High exchangeable Al was the main cause of soil acidity, associated with high rainfall in the humid tropical region. The main source of negative charge was the organic matter, which affect the CEC, PZSE and $\sigma_p$ values which influence the soil fertility status. The soils are considered as strongly weathered, almost devoid of 2:1 type clay minerals. Kaolinite and gibbsite dominate the clay fraction of the soils at both sites. It is imperative that soil properties should be taken into consideration during rehabilitation of degraded forestland in tropical rainforests.

## Key Words
Clay minerals, deforestation, lowland and hill dipterocarp forests, rehabilitation, soil fertility

## Introduction
Tropical rainforest is an enormous complex ecosystem existed on the earth surface (Whitmore, 1998). They are prevailed at unprecedented rate by human activities due to overexploitation of forest areas through deforestation, excessive logging and shifting cultivation, leading to degradation of forestland. In Peninsular Malaysia, lowland and hill dipterocarp forests are regarded as the most important forest types which consist of many valuable timber trees (Appanah and Weinland, 1994). However, such forests have been deteriorating due to anthropogenic human activities such as the conversion of its natural forest to other land use types and excessive forest harvesting resulting in degraded forestland or secondary forests. Rehabilitation of degraded forestland becomes very important in order to curtail the loss of soil nutrients and poor vegetation stock as well as for environmental concern. In Malaysia, rehabilitation of degraded forestland due to abandoned shifting cultivation has been successfully implemented under the ecosystem rehabilitation in Sarawak (Ishizuka *et al.,* 2000) and degraded forest land due to excessive harvesting by the enrichment planting technique in Peninsular Malaysia (Appanah and Weinland, 1993; Arifin *et al.,* 2008; Affendy *et al.,* 2009). Rehabilitation of tropical rainforest on severely degraded land requires an acceleration of knowledge on soil science towards understanding the effective soil conservation and sustainable forest management. However, most of the previous studies have emphasized the growth performance of planted species along with the planting technique with less concern on the soil characteristics in particular morphological, physico-chemical and clay mineralogical properties. This study was conducted in the Multi-Storied Forest Management System, a technical cooperation project between the Forestry Department Peninsular Malaysia (FDPM) and Japan International Cooperation Agency (JICA) to elucidate the soil properties of degraded forestland under rehabilitation forest in comparison to an adjacent natural forest at lowland and hill dipterocarp forests in Perak, Peninsular Malaysia.

## Materials and Methods
### Study sites
This study was conducted at the Multi-Storied Forest Management System (MSFS), a joint collaborative

project between Government of Malaysia and Japan. Under these projects, two sites were selected namely Bidor and Kinta Forest Reserve, Perak, Peninsular Malaysia. The Bidor Forest Reserve, located at (4˚ 07' N and 101˚ 37' E), is classified as lowland dipterocarp forest having altitude ranging from 10 to 30 m above sea level (asl). The Kinta Forest Reserve located at (4˚ 40' N and 101˚ 60' E), is classified as hill dipeterocarp forest with a steep mountainous region 35 to 45 degree and elevation ranging from 400 to 700 m asl. The relative humidity at the Bidor site varies from 70 to 98% and less than 50% during wet and dry period, respectively. The average annual precipitation is 3,050 mm and the mean temperature is approximately 28.5 °C (1990 to 2002) and that of Kinta site the average annual precipitation, temperature and humidity from (1990 to 2002) are 2500 mm, 25.5˚ C and 92.4 %, respectively.

The soil at Bidor Forest Reserve is derived from sedimentary and metamorphic rocks and unconsolidated materials, while the soil at Kinta is derived from granite. The native tree species at both sites are dominated by dipterocarp and non dipterocarp species. However, both of the areas have been subjected to forestland degradation by the excessive logging and abandoned plantation of *Acacia mangium,* which is consequently regenerated into secondary forest as in Bidor site.

**Soil sampling**

Soil survey and sampling were carried out from August to October 2009 at Bidor and Kinta sites. A total of twelve soil profiles were dug; there were six profiles at Bidor and Kinta, respectively. The soil profiles were described accordingly, followed by soil sampling according to a depth of 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm, 100-120 cm and 120-150 cm. The soils at the Bidor site namely in the respective site hereafter designated as B1 and B2 at plot A, B3 and B4 at plot B and B5 and B6 at adjacent natural forest. The B1 and B2 profiles were located at a relatively high area (upper slope) of rehabilitated secondary forests with various dipterocarp species in 1995. The B3 and B4 profiles located at a lower slope was an area of fast growing tree plantations of *Acacia mangium* in the late 1980s. In addition, B5 and B6 profiles were situated at adjacent natural forest. The soil profiles at Kinta hereafter designated as K1 and K2 at the line planting technique (lower slope) and soil profiles at gap planting technique of K3 and K4 (upper slope), and K5 and K6 at adjacent natural forest were dug. The K1 and K2 profiles were located an elevation of 450 m asl with a relatively stable lower slope of less than 10 degree, whereas the K3 and K4 profiles were situated at the upper slope with an elevation of 550 m asl, respectively and slope of less than 40 degree. The adjacent natural forest (K5 and K6 profiles) was dominated by dipterocarp and non dipterocarp species. The slope and elevation at the adjacent natural forest were 35 degree and 650 m asl, respectively.

**Soil analyses**

The samples were air-dried and passed through a 2 mm mesh sieve for physico-chemical properties. Particle-size distribution was determined by pipette method. Soil pH was measured with a glass electrode using a soil to solution ($H_2O$ or 1 M KCl) ratio of 1:5 hereafter denoted as $pH_w$ and $pH_k$, respectively. Electrical conductivity (EC) was measured using the supernatant at soil to water ratio of 1:5. Total carbon (TC) and total nitrogen (TN) contents were determined by a dry combustion method using NC analyzer. Available P was determined by the Bray II method (Bray and Kurts, 1945). The contents of exchangeable bases (Ca, Mg, K and Na) were extracted twice with 1 M ammonium acetate at pH 7.0. The CEC was determined by the steam distillation method. Exchangeable Al, H and $NH_4$ were extracted with 1 M KCl. The amount of $NH_4$ was measured using the indophenols blue Bray II method (Mulvaney, 1996). The point of zero salt effect (PZSE) and the residual charge at PZSE (σp) were measured by the modified salt titration method of STPT (Sakurai *et al.,* 1988). The amounts of Al and Fe soluble in ammonium oxalate (Alo and Feo) were extracted by the method of Mackeague and Day (1966). The amounts of Al and Fe soluble in dithionate-citrate system buffered with sodium bicarbonate (Ald and Fed, respectively) were extracted by the method of Mehra and Jackson (1960). The concentration of extracted Fe and Al were determined by sequential plasma spectrometry. Clay mineral composition was identified by X-ray diffraction analysis using CuKα radiation.

**Table 1. Physico-chemical, charge and clay minerals properties of the soils in Bidor and Kinta sites.**

| Plot | Depth (cm) | $pH_w$ | $pH_k$ | T-C ($g\ kg^{-1}$) | T-N ($g\ kg^{-1}$) | C/N ratio | CEC[a] ($cmol_c\ kg^{-1}$) | Exchangeable cations: Ca | Mg | K | Na | Al | H | ECEC[b] | Al.S[c] | Av.P ($mgP\ kg^{-1}$) | Clay (%) | Silt (%) | Sand (%) | PZSE | $\sigma_p$[d] | Clay minerals: HIV | It | Kt | Gb | Qz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 0-20 | 4.55 | 3.99 | 21.7 | 1.53 | 14.2 | 4.81 | 0.22 | 0.12 | 0.08 | 0.06 | 1.57 | 0.43 | 2.05 | 76.59 | 11.9 | 10.5 | 2.9 | 86.6 | 3.70 | 0.80 | - | - | +++ | ++++ | ± |
| | 20-40 | 4.65 | 4.41 | 10.8 | 1.17 | 9.2 | 3.41 | 0.06 | 0.04 | 0.05 | 0.05 | 1.31 | 0.39 | 1.51 | 86.75 | 8.6 | 12.9 | 3.3 | 83.9 | 4.02 | 0.51 | - | - | +++ | ++++ | ± |
| | 40-60 | 4.85 | 4.52 | 5.0 | 0.54 | 9.3 | 2.48 | 0.09 | 0.03 | 0.06 | 0.05 | 1.43 | 0.34 | 1.66 | 86.14 | 7.6 | 20.5 | 3.8 | 75.8 | 4.02 | 0.40 | - | - | +++ | ++++ | ± |
| B2 | 0-20 | 4.45 | 3.56 | 25.3 | 1.65 | 15.3 | 5.20 | 0.25 | 0.11 | 0.09 | 0.10 | 1.34 | 0.32 | 1.89 | 70.90 | 13.2 | 19.2 | 4.5 | 76.3 | 3.54 | 1.12 | - | ± | +++ | ++++ | ± |
| | 20-40 | 4.53 | 3.61 | 15.4 | 1.34 | 11.5 | 3.54 | 0.21 | 0.12 | 0.09 | 0.05 | 1.32 | 0.21 | 1.79 | 73.74 | 10.4 | 17.1 | 4.9 | 78.0 | 3.45 | 0.98 | - | - | +++ | ++++ | ± |
| | 40-60 | 4.40 | 3.50 | 10.2 | 1.21 | 8.4 | 4.90 | 0.19 | 0.09 | 0.07 | 0.04 | 1.12 | 0.20 | 1.51 | 74.17 | 12.1 | 12.6 | 5.4 | 82.0 | 4.12 | 0.67 | - | - | ++ | ++++ | ± |
| B3 | 0-20 | 4.45 | 3.97 | 39.8 | 3.86 | 10.3 | 12.10 | 0.29 | 0.15 | 0.12 | 0.09 | 2.31 | 0.58 | 2.96 | 78.04 | 23.1 | 10.2 | 4.6 | 85.2 | 3.15 | 1.20 | - | - | +++ | +++ | ± |
| | 20-40 | 4.58 | 4.45 | 21.3 | 2.43 | 8.8 | 13.50 | 0.26 | 0.11 | 0.10 | 0.06 | 2.11 | 0.39 | 2.64 | 79.92 | 21.0 | 8.9 | 3.6 | 87.5 | 4.08 | 0.90 | ± | ± | +++ | +++ | ± |
| | 40-60 | 4.57 | 4.49 | 40.2 | 3.54 | 11.4 | 11.80 | 0.23 | 0.12 | 0.07 | 0.04 | 1.86 | 0.26 | 2.32 | 80.17 | 25.6 | 15.4 | 4.5 | 80.1 | 4.49 | 0.43 | ± | ± | +++ | +++ | ± |
| B4 | 0-20 | 4.76 | 4.45 | 35.5 | 2.34 | 15.2 | 12.80 | 0.23 | 0.18 | 0.15 | 0.12 | 2.22 | 0.35 | 2.90 | 76.55 | 25.4 | 15.0 | 6.5 | 78.5 | 3.23 | 1.65 | ± | - | +++ | +++ | ± |
| | 20-40 | 4.80 | 4.20 | 34.2 | 2.12 | 16.1 | 10.30 | 0.21 | 0.17 | 0.08 | 0.06 | 1.81 | 0.21 | 2.33 | 77.68 | 20.3 | 12.8 | 7.5 | 79.7 | 3.56 | 1.23 | - | - | +++ | +++ | ± |
| | 40-60 | 4.90 | 4.60 | 28.0 | 2.09 | 13.4 | 9.98 | 0.19 | 0.16 | 0.07 | 0.07 | 1.34 | 0.33 | 1.83 | 73.22 | 22.1 | 9.0 | 7.8 | 83.2 | 4.32 | 0.98 | ± | ± | +++ | +++ | ± |
| B5 | 0-20 | 4.23 | 3.82 | 47.7 | 5.18 | 9.2 | 15.60 | 0.29 | 0.21 | 0.15 | 0.10 | 4.13 | 0.56 | 4.88 | 84.63 | 29.4 | 4.5 | 5.5 | 90.0 | 3.54 | 1.87 | - | ± | ++ | +++ | + |
| | 20-40 | 4.50 | 4.42 | 36.5 | 4.71 | 7.7 | 14.32 | 0.25 | 0.19 | 0.12 | 0.09 | 3.39 | 0.42 | 4.04 | 83.91 | 25.6 | 8.6 | 11.5 | 79.9 | 4.54 | 1.34 | - | - | +++ | ++++ | + |
| | 40-60 | 5.07 | 5.01 | 32.3 | 3.15 | 10.3 | 12.12 | 0.14 | 0.18 | 0.09 | 0.07 | 2.18 | 0.28 | 2.66 | 81.95 | 20.5 | 9.8 | 12.3 | 77.9 | 4.40 | 1.09 | - | - | +++ | ++++ | + |
| B6 | 0-20 | 4.30 | 3.65 | 44.8 | 4.23 | 10.6 | 14.20 | 0.31 | 0.24 | 0.19 | 0.12 | 3.68 | 0.32 | 4.54 | 81.06 | 26.5 | 14.0 | 6.2 | 79.8 | 3.25 | 2.76 | ± | ± | ++ | ++++ | + |
| | 20-40 | 4.42 | 3.92 | 30.6 | 3.40 | 9.0 | 12.10 | 0.26 | 0.20 | 0.17 | 0.08 | 3.30 | 0.24 | 4.01 | 82.29 | 21.0 | 18.8 | 6.0 | 75.2 | 4.08 | 1.85 | ± | ± | +++ | ++++ | + |
| | 40-60 | 4.56 | 4.32 | 21.6 | 2.34 | 9.2 | 10.50 | 0.19 | 0.18 | 0.16 | 0.07 | 3.45 | 0.19 | 4.05 | 85.19 | 18.9 | 7.0 | 7.6 | 85.4 | 4.15 | 1.60 | ± | ± | + | ++++ | + |
| K1 | 0-20 | 4.21 | 3.54 | 26.5 | 3.45 | 7.7 | 12.50 | 0.32 | 0.15 | 0.10 | 0.06 | 4.12 | 0.89 | 4.75 | 86.74 | 12.5 | 35.8 | 8.9 | 55.3 | 3.30 | 1.60 | ± | ± | ++++ | ++ | + |
| | 20-40 | 4.31 | 3.71 | 21.0 | 2.89 | 7.3 | 9.60 | 0.12 | 0.10 | 0.08 | 0.05 | 3.87 | 0.75 | 4.22 | 91.71 | 11.2 | 36.5 | 8.4 | 55.1 | 3.65 | 0.80 | ± | ± | ++++ | ++ | + |
| | 40-60 | 4.70 | 3.93 | 6.7 | 2.16 | 6.5 | 6.61 | 0.09 | 0.07 | 0.05 | 0.04 | 3.58 | 0.60 | 3.83 | 93.47 | 9.0 | 37.1 | 10.5 | 52.4 | 3.78 | 0.60 | ± | ± | ++++ | +++ | + |
| K2 | 0-20 | 4.35 | 3.42 | 22.4 | 3.12 | 7.2 | 14.20 | 0.28 | 0.18 | 0.15 | 0.08 | 5.23 | 1.10 | 5.92 | 88.34 | 11.3 | 38.2 | 11.1 | 50.7 | 3.25 | 1.89 | - | - | ++++ | + | ± |
| | 20-40 | 4.52 | 3.58 | 18.5 | 3.05 | 6.1 | 10.10 | 0.26 | 0.14 | 0.11 | 0.06 | 5.12 | 0.96 | 5.69 | 89.98 | 10.4 | 39.3 | 11.9 | 48.8 | 3.43 | 1.45 | ± | - | ++++ | ++ | + |
| | 40-60 | 4.69 | 3.80 | 10.6 | 2.85 | 3.7 | 11.20 | 0.21 | 0.12 | 0.11 | 0.05 | 4.56 | 0.89 | 5.05 | 90.30 | 10.1 | 43.2 | 13.2 | 43.6 | 3.67 | 1.32 | - | ± | ++++ | + | + |
| K3 | 0-20 | 4.23 | 3.86 | 36.0 | 2.70 | 13.3 | 10.62 | 0.17 | 0.13 | 0.11 | 0.05 | 2.62 | 0.33 | 3.07 | 85.24 | 10.9 | 31.0 | 8.3 | 60.8 | 3.40 | 2.00 | ± | ± | ++++ | ++ | ± |
| | 20-40 | 4.30 | 4.12 | 14.8 | 2.45 | 6.0 | 6.01 | 0.16 | 0.08 | 0.04 | 0.03 | 2.53 | 0.42 | 2.84 | 89.08 | 6.6 | 35.4 | 9.0 | 55.6 | 3.70 | 0.75 | ± | ± | ++++ | ++ | ± |
| | 40-60 | 4.33 | 4.14 | 10.7 | 2.39 | 4.5 | 7.81 | 0.06 | 0.03 | 0.06 | 0.04 | 2.39 | 0.23 | 2.58 | 92.64 | 9.0 | 36.8 | 9.6 | 53.5 | 3.92 | 0.60 | ± | ± | ++++ | ++ | + |
| K4 | 0-20 | 4.34 | 3.63 | 30.4 | 2.54 | 12.0 | 16.50 | 0.21 | 0.19 | 0.13 | 0.10 | 3.45 | 0.42 | 4.08 | 84.56 | 16.5 | 43.2 | 10.2 | 46.6 | 3.70 | 1.76 | + | + | ++++ | ++ | ± |
| | 20-40 | 4.50 | 3.76 | 28.9 | 2.21 | 13.1 | 7.40 | 0.19 | 0.17 | 0.11 | 0.09 | 3.32 | 0.34 | 3.88 | 85.57 | 13.2 | 44.5 | 14.3 | 41.2 | 3.65 | 1.31 | + | + | ++++ | ++ | ± |
| | 40-60 | 4.55 | 3.80 | 19.9 | 2.01 | 9.9 | 6.50 | 0.17 | 0.14 | 0.08 | 0.12 | 3.10 | 0.29 | 3.61 | 85.87 | 10.1 | 40.3 | 9.6 | 50.1 | 3.98 | 1.21 | ± | ± | ++++ | ++ | + |
| K5 | 0-20 | 4.34 | 4.20 | 53.0 | 3.21 | 16.5 | 20.70 | 0.52 | 0.32 | 0.29 | 0.18 | 4.23 | 0.52 | 5.54 | 76.35 | 23.4 | 34.4 | 7.6 | 58.1 | 3.92 | 1.70 | + | + | ++++ | ++ | ± |
| | 20-40 | 4.61 | 4.21 | 14.5 | 2.77 | 5.2 | 12.23 | 0.35 | 0.23 | 0.22 | 0.13 | 3.76 | 0.43 | 4.69 | 80.17 | 17.2 | 35.1 | 7.7 | 57.2 | 3.98 | 0.65 | + | - | ++++ | + | ± |
| | 40-60 | 4.72 | 4.37 | 13.2 | 1.89 | 7.0 | 10.30 | 0.14 | 0.20 | 0.20 | 0.10 | 3.42 | 0.39 | 4.06 | 84.24 | 15.9 | 36.9 | 6.6 | 56.5 | 4.00 | 0.30 | + | - | ++++ | ++ | ± |
| K6 | 0-20 | 4.15 | 4.10 | 46.9 | 3.89 | 12.1 | 18.30 | 0.42 | 0.29 | 0.19 | 0.12 | 4.56 | 0.65 | 5.58 | 81.72 | 31.3 | 39.8 | 9.6 | 50.6 | 3.45 | 1.45 | + | + | ++++ | ± | ± |
| | 20-40 | 4.32 | 4.07 | 40.8 | 2.56 | 15.9 | 15.40 | 0.29 | 0.22 | 0.14 | 0.10 | 4.21 | 0.43 | 4.96 | 84.88 | 26.5 | 43.1 | 10.3 | 46.6 | 3.87 | 1.34 | + | + | ++++ | ± | ± |
| | 40-60 | 4.26 | 4.12 | 38.7 | 2.21 | 17.5 | 9.70 | 0.21 | 0.25 | 0.11 | 0.07 | 3.41 | 0.30 | 4.05 | 84.20 | 22.7 | 44.5 | 10.9 | 44.6 | 3.90 | 1.05 | + | + | ++++ | ± | ± |

[a]Cation exchange capacity
[b]Sum of exchangeable Ca+Mg+K+Na
[c]Al saturation; exchangeable Al/ECECx100
[d]Residual charge at PZSE
[e]HIV: hydroxy-interlayered vermiculite, It: illite, Kt: kaolin minerals, Gb: Gibbsite, Qz: quartz
±: 0-5%, +;5-20%, ++: 20-40%, +++:40-60%, ++++:>60%

## Results and Discussion

The main features of the soil morphological properties at the study sites appeared to be highly weathered, with deep solum. The most significant morphological difference between the soils at Bidor and Kinta sites was soil texture, presumably related to the parent materials. In terms of physico-chemical properties, the textural composition of the soils at the study sites seems to be affected by the weathering processes of the parent materials. Apparently, soils at both sites can be divided into two textural classes based on the clay and sand contents. In the Kinta site, clay content was more pronounced, attaining a value of more than 30 %, while sand content was less than 60 %. The pHw and pHk values both in the lowland and hill dipterocarp forests were low with the values tended to increase with depth. It seems that the soil acidity of the area undergoing rehabilitation is not much different from that of the natural forest. The lower pH values at the surface layer across the study sites correspond to the larger amounts of organic matter in the topsoil, reflecting organic matter is responsible for acidity through litter decomposition. In general, the contents of total carbon, nitrogen, exchangeable bases were low but high in exchange Al resulting in high level of Al saturation. Moreover, the contents of Al, Fe Si oxides throughout the profiles were low indicating strongly leached out under heavy rainfall in tropical region. The PZSE and σp were low throughout the profiles both in the lowland and hill dipterocarp forests. The clay mineral composition in lowland was dominated by gibbsite and kaolinite, while that of hill forest dominated by kaolinite and gibbsite to a lesser extent of 2:1 type minerals, indicating strongly weathered soils.

## Conclusions

Rehabilitating degraded tropical rainforest such as in the present study requires sufficient knowledge on soils towards better soil and forest management. High level of Al saturation with predominance of kaolin minerals and gibbsite are the main cause of low fertility status both in rehabilitated and natural forests. Since the soils are highly weathered which result in low fertility status, input of fresh organic matter from the trees by means of forest rehabilitation is an important effort to improve degraded tropical forests. Characterizing the soil in terms of physico-chemical properties, charge characteristics and clay mineralogical composition need to be taken into consideration prior to establishment of forest rehabilitation.

## References


Affendy H, Aminuddin M, Razak W, Arifin A, Mojiol AR (2009) Growth increments of indigenous species planted in secondary forest area. *Research Journal of Forestry* **3(1),** 23-28.

Appanah S, Weinland G (1993) Planting Quality Timber Trees in Peninsular Malaysia*. A review.* Malayan Forest Records No. 38. Forest Research Institute Malaysia, Kepong, Kuala Lumpur, Malaysia. 247 p.

Arifin A, Tanaka S, Jusop S, Majid NM, Ibrahim Z, Wasli ME, Sakurai K (2008b) Assessment on soil fertility status and growth performance of planted dipterocarp species in Perak, Peninsular Malaysia. *Journal of Applied Sciences* **8(21),** 3795-3805.

Bray RH, Kurtz LT (1945) Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* **59**, 39-45.

Ishizuka S, Sakurai K, Kendawang JJ, Lee HS (2000) Soil characteristics of an abandoned shifting cultivation land in Sarawak, Malaysia. *Tropics* **10**(2), 251-263.

Mehra OP, Jackson ML (1960) Iron oxide removal from soils and clays by dithionite-citrate system buffered with sodium bicarbonate. *Clays Clay Minerals* **7**, 317-327.

Mulvaney RL (1996) Nitrogen-Inorganic forms. In: Method of Soil Analysis. Part 3-Chemical Methods. (Eds. Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT, Sumner ME), pp. 1123-1184. Soil Sci. Soc. America, Inc. and American Soc. Agronomy, Inc., Wisconsin.

Sakurai K, Ohdate Y, Kyuma, K (1988) Comparison of salt titration and potentiometric titration method for the determination of zero point charge (ZPC). *Soil Science & Plant Nutrition* **34,** 171-182.

Whitmore TC (1998) An introduction to tropical rain forests, 2nd edition. Oxford University Press, Oxford, 282 p.