Classification and Management of Highly Weathered Soils in Malaysia for Production of Plantation Crops

J. Shamshuddin[1] and Noordin Wan Daud[2]
[1]*Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor,*
[2]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor*
Malaysia

1. Introduction

In Malaysia, Ultisols and Oxisols containing kaolinite, gibbsite, goethite and hematite in the clay fraction are very common especially in the upland areas, occupying about 72 % of the country's land area. The soils are highly weathered as they exist under tropical environment with high rainfall and temperature throughout the year, resulting in leaching of plant nutrients and accumulation of sesquioxides (Anda et al., 2008a). They are by nature devoid of basic cations (Ca and Mg) and available P (due to fixation by the oxides) and hence, their productivity is generally considered as low. The soils are mainly utilized for oil palm and rubber cultivation with great success due to excellent soil management practices. With the expertise available in the country, palm oil and rubber are produced in large amounts for the world market. However, cocoa growing on these soils produces low yield which are attributed to low pH and aluminum and/or manganese toxicity.

The problems of low productivity can be overcome by liming using ground magnesium limestone (Shamshuddin et al., 1991; Ismail et al., 1993; Shamshuddin and Ismail, 1995; Shamshuddin et al., 1998; Shamshuddin et al., 2009; Shamshuddin et al., 2010) or by applying basalt (Gillman et al., 2001; Anda et al., 2009; Shamshudin & Kapok, 2010). Basalt releases Ca, Mg, K, P and S on its dissolution into the soils (Gillman et al., 2002). Out of the six macronutrients needed by the growing crops in the field only N is not present in basalt.

Most of the Ultisols and Oxisols in the tropics is lacking in organic matter which can supply essential plant nutrients as well as improve soil structures. Normal organic matter applied for alleviating the infertility of Ultisols and Oxisols in Malaysia is compost (Anda et al., 2008b; Anda et al., 2010) and palm oil mill effluents.

This paper intends to classify the highly weathered soils in Malaysia and discusses the management of the soils for sustainable production of oil palm, rubber and cocoa. The information given in this paper is useful to students and researchers alike.

2. Highly weathered soils of Malysia

2.1 Classification

Due to high temperature in Malaysia silicate minerals become unstable due to the changes in the chemistry of their environment. The new chemical conditions are dominated by aqueous state. The consequence of such an environment is a tendency to hydrate the high-temperature silicate minerals. Major effect of hydration is a large portion of the minerals is dissolved integrally into the altering aqueous solution and it is transported as such into lakes and ocean. This process of chemical weathering is very intense in Malaysia due to the prevailing high rainfall and temperature. Residual products of rock and mineral weathering under this condition are quartz, secondary phyllosilicates and sesquioxides with or without muscovite, depending on the degree of weathering.

A chemical reaction denoting dissolution of feldspar (orthoclase) in water is as follows (Duff, 1993):

$$6H_2O + CO_2 + 2KAlSi_3O_8 \rightarrow A1_2Si_2O_8(OH)_4 + 4SiO(OH)_2 + K_2CO_3$$

(feldspar) (kaolinite)

In this reaction, K is lost via leaching into the groundwater. Further weathering of the clay mineral results in the formation of colloidal materials according to the following reaction (Duff, 1993):

$$H_2O + A1_2Si_2O_8(OH)_4 \rightarrow A1_2O_3.nH2O + SiO(OH)_2$$

Exposure of granite, shale, schist, sandstone, basalt, andesite and serpentinite in Malaysia over a long period of time to the forces of weathering results in the formation of highly weathered materials, dominated by kaolinite, halloysite, gibbsite, goethite and hematite in the clay fraction (Tessens & Shamshuddin, 1983). The overall products are collectively termed as soil materials, which are usually devoid of plant nutrients. The soils are classified as

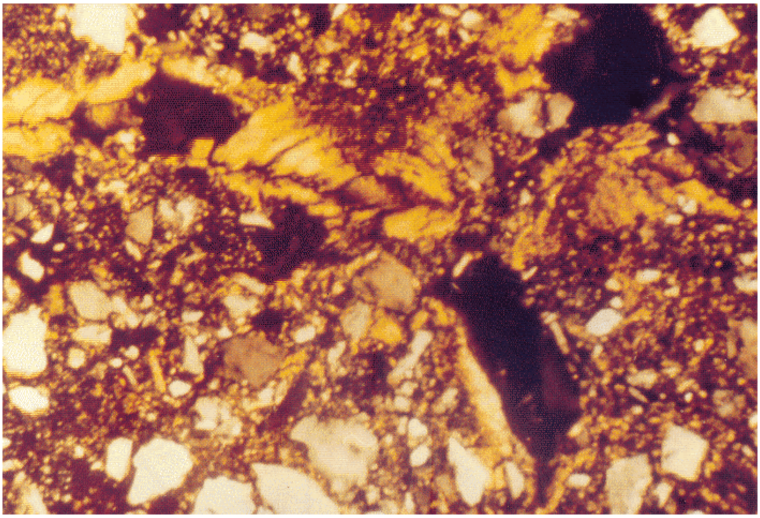

Fig. 1. Argillic horizon present in the B horizon of Ultisols (Courtesy of S Paramananthan)

either Ultisols or Oxisols according to Soil Taxonomy (Soil Survey Staff, 2010). Ultisol is defined by the presence of argillic horizon in the subsoil (Figure 1). Clays from the topsoil are moved and accumulated in the B horizon under intense leaching environment in the tropics.

By nature, Oxisols are considered as more weathered than Ultisols. They are dominated by kaolinite and sesquioxides (Anda et al., 2008a). The soils are defined by the presence of oxic horizon in the subsoil (Figure 2). The CEC of the soils is extremely low, with value < 16 $cmol_c$/kg clay. As such, plant nutrients are mostly lost via leaching, further lowering the productivity of the soils.

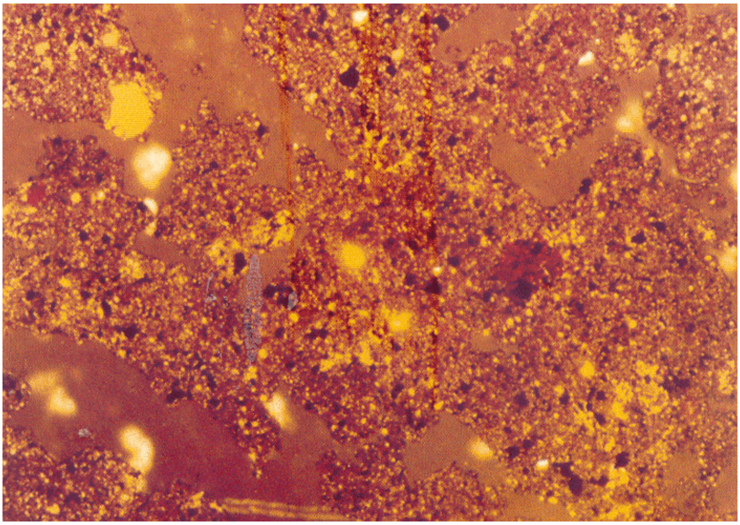

Fig. 2. Oxic horizon present in the B horizon of Oxisols (Courtesy of S Paramananthan)

2.2 Charge properties of Ultisols and Oxisols

It is known that soil materials are negatively- and/or positively-charged. A certain amount of negative charge in the soils is derived from within the phyllosilicates themselves via a process called isomorphic substitution. For instance, replacement of Si by Al in kaolinite present in the soils would result in excess of negative charges. Such charges are termed as negative permanent charges. Positive permanent charges are also existed in soils, being produced by isomorphic substitution of Fe by Ti in soils containing high amount of oxides of Fe (Tessens & Shamshuddin, 1983). This kind of isomorphic substitution is common in Oxisols having high amount of hematite and goethite, the active minerals in the soils.

Oxides of Fe and Al and the broken edges of phyllosilicates have another kind of charge known as variable charge. As the pH of the ambient solution changes the charge on the surfaces of these minerals also changes. When the pH is low, protons are chemisorbed onto the minerals to become net positively-charged. On the other hand, the minerals are net negatively-charged at high pH. The pH at which the net charge of the variable-charge mineral is zero is termed as pHo.

Each mineral has its own pHo value. The value for silicate is low, but for oxides it is high. Generally, soil is composed of many variable-charged minerals. The value reported for a particular soil is actually the resultant pHo value of the whole minerals in the soils. Silicate is abundant in Ultisols, while oxides are abundant in Oxisols. Hence, the pHo value of Ultisols is lower than that of Oxisols (Tessens & Shamshuddin, 1983). This means that the mineralogy of the soil affects its pHo value.

We do not have soils completely composed of variable-charged minerals. Thus, overall charges in the soils have to be considered for the meaningful interpretation of the soil properties. The pH at which the net charge is zero, taken into account the whole soil materials, is termed as point of zero net charge (PZNC). Studies in Malaysia showed that PZNC is lower than pHo in the Ultisols and is higher than pHo in the Oxisols (Tessens & Shamshuddin, 1983). It is also observed that both pHo and PZNC values increase with increasing stage of soil weathering. As the soils weather more oxides are formed, leading to an increase in pHo and PZNC. The soils then become less productive and need special management practices for sustainable crop production.

Total charge in the soil can be subdivided into permanent and variable charge components, and can be represented by the following equation:

$$Qt = Qp + Qv$$

where

Q = charge

t = total

p = permanent v = variable

The amount of total charge in the soils can be manipulated by changing the Qv.

Qv is related to (pHo - pH)

Taking soil having net negative charge as an example, Qt can be increased by increasing the difference between pHo and pH. This can readily be done either by lowering pHo or increasing pH. The former can be implemented by incorporating basalt into the soils (Anda et al., 2009), while the latter is easily accomplished by liming (Shamshuddin et al., 1991) or applying basalt (Shamshuddin & Kapok, 2010). pHo can also be lowered, to a certain extent, by incorporating organic matter into the soil (Shamshuddin et al., 1987; Anda et al., 2008b).

A soil system is stable when the charge in it is low or at the minimal, suggesting that soil potential decreases as the charge decreases. Therefore, the potential in the soil is very low when pH is near its pHo. Under natural condition, soil pH tries to move to its pH_o in order to achieve maximal stability.

As soil pH increases with weathering, its pHo increases. It has been shown clearly that soil pH increases with increasing pH_o (Tessens & Shamshuddin, 1983). Primary minerals break up during the course of weathering and new minerals are formed, meaning that the silicates in the soils changes to oxides of Fe and Al, and consequently the pHo of the soils increases.

2.3 Soil pH

We have analyzed pH of hundreds of soil samples from all over Peninsular Malaysia and found that the values are mostly between 4 and 5 (Tessens & Shamshudin, 1983). The values are generally lower for the Ultisols than that of the Oxisols. The former ranges from 4.0 to 4.5, while the latter ranges from 4.5 to 5.0. The explanations for this phenomenon are as follows:

a. Soils will be at their greatest stability when the potential in them is zero, that is at the pH = pHo. The pHo of majority of the highly weathered soils in Malaysia is 4-5. Therefore, pH of the soils tries to approach 4-5 in order to remain stable; and

b. On weathering, Al^{3+} and Fe^{3+} in the phyllosilicates are released into the soil solution. Al^{3+} in the soil solution undergoes hydrolysis.

This allows us to determine the pK_a of Al which is 5. Likewise, Fe^{3+} hydrolysis releases proton into the soil solution. The pK_a value of Fe is 3.0. If these free reactions are allowed to take place without interruption, then the pH of the soil solution will go near their pK_a value in order to achieve equilibrium.

2.4 Effects of low pH on Al and Mn availability

As the soil pH of highly weathered Malaysian soils is low (< 5), Al on the exchange complex of the soils readily dissolves into the soil solution. In many cases, the Al in the soil solution is present at toxic level. The Al concentration in the soil solution increases as the pH lowers. Likewise, Mn may exist at toxic level at low pH. Exchangeable Al is lower in the Oxisols than in the Ultisols. It follows that there is less soil solution Al in Oxisols than in the Ultisols. This is consistent with the higher pH of the Oxisols as compared to that of the Ultisols. Low pH and high exchangeable Al have little effect on the growth of either oil palm or rubber, but they are expected to reduce the yield of cocoa significantly.

3. Oil palm cultivation

The most important agricultural crop in Malaysia right now is oil palm (Figure 3). The area covered by the so-called golden crop is estimated to be about 4.6 million ha, sporadically distributed throughout the length and breadth of the country. Currently, most of the oil palm is grown on upland areas where Ultisols and Oxisols occur. With good soil management practices oil palm grows very well, contributing to the wealth of the nation. At the current of production rate and high price in the marketplace some USD 16.7 billion is added into the economy annually, and so oil palm is indeed helping the economy of Malaysia going for a long run. In the case of Malaysia, the industry has to be protected at any cost in order to become a developed country comes the year 2020. By then Malaysia would have become a country with high income. If we keep doing what we do now and stick to the principle of sustainable crop production, it certainly will.

For oil palm cultivation, fertilizer input is very necessary where NPK fertilizers need to be applied regularly at the appropriate rates. This is because the Ultisols and Oxisols in the country are devoid of macronutrients, resulting from extreme leaching and weathering. As the soils are acidic in nature P-fertilizer recommended for application is phosphate rock, which is a slow release fertilizer of sort. As it dissolves slowly under low pH condition P is released and made available to the growing oil palm in the field. Phosphate is known to react with oxides/hydroxides of Fe in the soils, resulting in a slight increase in negative charge and pH (Tessens & Zaharah, 1983). This phenomenon has, to some extent, improved the productivity of the soils. However, we should not forget the fact that some of the applied P is fixed by the oxides of Fe, especially in Oxisols and consequently lost into the soils indefinitely or until some other reactions that dissolve the so-formed $FePO_4$. As such, phosphate fertilizer efficiency study is a popular topic of research in the tropical region, such as Malaysia and Brazil.

Oil palm is found to be acid tolerant, and hence, it can still grow even at the soil pH of 4.3 and at high Al concentration (Auxtero & Shamshuddin, 1991). Due to that Ultisols and Oxisols in Malaysia are considered suitable for oil palm cultivation. There is no need to apply lime onto the soils for oil palm cultivation as the area under oil palm is very large and therefore not economical. For sure, soil moisture has to be maintained at the optimal level for oil palm growth. We know for sure that oil palm can only be grown if the annual rainfall exceeds 1800 mm and it must be evenly distributed throughout the year. There should not be a dry period exceeding a few months. That it is so because oil palm is originated from swampy areas in African countries. The best growing areas in Peninsular Malaysia for cultivating oil palm is southern part (Johor) where rainfall is evenly distributed at 3000 mm/year. Kedah and Perlis (northern part) are probably a bit too dry for oil palm cultivation.

Under estate management, the yield of oil palm grown on Ultisols and Oxisols ranges from 20 to 30 tones fresh fruit bunches (ffb) per hectare per year. It will be higher on well managed soils planted with high yielding oil palm clone. According to a reliable source, this special clone can produce yield up to 40 t ffb/ha/year under special soil management practices. In the near future, we can expect more of this clone to be planted in Malaysia. On the average, the rate of oil extracted by the oil palm factory in Malaysia right now is 20 % of the ffb. So, we can get at least 4 tones of oil/ha/year. Malaysia is now aiming for a rate of 25 % extraction in the near future considering the advent of new extracting technology coming from R&D by the industry.

Fig. 3. A well managed oil palm estate in Malaysia

As seen in Figure 3 oil palm fronds are placed in between the planting rows. This practice helps maintain soil moisture in the oil palm estates. When the organic matter is decomposed (mineralized) plant nutrients (N, P, K) are released into the soils and can be taken up by the growing oil palm in the field.

After 25 years of production it is time to replant the oil palm. At this age the palm is no longer productive. Furthermore, it is too tall for harvesting the fresh fruit bunches using standard practice (knife stuck to a long wooden pole). Under the current practice burning of oil palm fronds and trunks are not allowed, not eco-friendly. Oil palm estates are now forced to practice zero-burning technology. In this technique of estate management, the fronds and trunks are cut and chopped off into small pieces and are buried into the ground. In this practice, we return the oil palm biomass to the soils for good. Again on mineralization, essential nutrients are added into the soils. It has been found that zero-burning technology is able to cut down the cost of production considerably where less fertilizer is applied to keep the oil palm growing. In the beginning a teething problem has arisen. The burying of plant biomass has encouraged the outbreaks of pests and diseases. However, these problems have since been taken care of by the estate management in the country.

Many areas under oil palm cultivation in Malaysia are undulating to steep land. These areas need to be protected lest soil erosion removes the fertile topsoil comes rainy season. In these areas contour terraces are constructed perpendicular to the slope of the land. The bare areas in between the terraces are planted with leguminous cover crops before oil palm canopy closes up. The cover crops fix some nitrogen from the air and added to the soils when they die. This is an excellent management practice for sustaining the productivity of Ultisols and Oxisols in Malaysia.

4. Rubber cultivation

Rubber has been grown commercially in Malaysia since 1903 when the first rubber estate was established in Melaka. Malaysia is the biggest consumer of pure latex and fifth in the consumption of natural rubber in the world. Asia is the biggest producer of natural rubber, led by Thailand, Indonesia and Vietnam. Surgical latex gloves and condoms are known for their high quality and accepted by the consumers. Currently, Malaysia is the biggest exporter of these products. The export earning from rubber in 2009 was worth USD 8.3 billion. Demand for natural rubber is expected to increase and it is projected that there will be a shortage of natural rubber in the near future. The price of SMR 20 was USD 0.77/kg in 2003 and USD 3.52/kg in 2010 (Malaysian Rubber Board, 2010). Rubber prices reached their highest in decades, fuelled by strong demand from China’s auto industry.

Clones, in the case of rubber, refer to rubber plants produced from selection breeding process, which have been field-tested. There are several selection criteria in rubber breeding. These include vigor, resistance to diseases, resistance to wind damage, fewer and higher branches, bark thickness and yield. The clones are produced to improve the yield of rubber trees. In recent time, yield is not only latex but also timber from the trees, which has high demand in the marketplace. To satisfy for demand in latex and timber, the Malaysian Rubber Board has conducted research to produce rubber trees that can give high yield of latex and timber, resulting in the introduction of RRIM 2000 and RRIM 3000 series of clones. Clone RRIM 3000 is superior to that of RRIM 2000. Clone RRIM 3001, because of its vigorous growth and high yield, has been assigned a new name, i.e. Klon 1 Malaysia. Rubber plants exhibit a variety of responses to different water regimes. The ability of rubber plants to cope with water stress varies across and within clones (Shafar Jefri Mokhatar & Noordin Wan Daud, 2011).

For many years Malaysia was the major exporter of rubber. Now the country is number three in terms of latex production; Thailand and Indonesia have overtaken us of late. However, we still export rubber (scrap or solid rubber) to the world market, although we import some rubber (latex) in order to feed our own growing rubber industry. Due to the acute shortage of labor in Malaysia some rubber trees are left not tapped. The current area under rubber in Malaysia stands at 1.2 million ha, much less than what it used to be some 40 years ago. Most of our rubber are grown on Ultisols and Oxisols with little problem (Figure 4). Rubber seems to grow quite well on soils under well drained condition. Like oil palm it is acid tolerant and pH of 4-5 does not affect its growth. Under normal fertilizer input, rubber grows very well, giving high yield and contributing to the country's economic growth.

Like oil palm, the P-fertilizer for rubber cultivation is phosphate rock. This fertilizer has been applied in rubber estates for as far as we could remember. The benefit of phosphate rock has been clearly explained before. It works very well under acidic condition prevailing in the highly weathered soils of Malaysia. The preferred N-fertilizer in rubber estates is $(NH_4)_2SO_4$. The ammonium from this fertilizer undergoes nitrification which releases H^+ and hence, its long-term application would increase soil acidity slightly. Beside nitrogen, this fertilizer supplies S to the soils, which is another macronutrient. Rubber plant is said to be acid tolerant and so the acidity so produced by the application of the fertilizer would not affect its growth much. Unlike oil palm, Kedah and Perlis are quite suitable for rubber cultivation. If the rainfall is too high it will affect latex production because farmers are reluctant to tap rubber trees.

Fig. 4. A well managed rubber estate in Malaysia

Many rubber estates in the country are located on undulating or steep land, which are prone to soil erosion during rainy season. As such, contour terraces are needed to be constructed to prevent or reduce soil erosion, very much the case of oil palm estate. If this practice is carried out coupled with modern tapping technique there is no reason why Malaysia should not be a great rubber producer again, like it once was. Right now the price of rubber in the marketplace is very good and many farmers have since returned to the industry, for the good of the country.

Like oil palm estates, rubber estates are practicing zero-burning technology without fail. Malaysia is now in the forefront in promoting this eco-friendly technology for the good of us all. As has been said, practicing zero-burning in rubber estate management has reduced the cost of production and improved or protected the environment. This technology has won worldwide recognition and as such other countries are learning from us. Zero-burning technology is Malaysia's contribution to the world in reduction of global warming.

5. Cocoa cultivation

The fortune of cocoa industry in Malaysia is in the balance or in limbo. Way back in the 1970s, Malaysia was the 6th biggest cocoa bean producer in the world. The area under cocoa then was > 400,000 ha. Since then it is in the downward trend. Many cocoa plantations are either abandoned or replaced with oil palm. The cocoa area now is about 50,000 ha with production not enough to feed our own factories producing cocoa products. The government is now encouraging farmers to go back to planting cocoa by offering lucrative subsidy.

Some of the cocoa trees are planted on highly weathered soils with low fertility (Figure 5). Beside low price in the marketplace, outbreak of diseases has created havoc in cocoa industry. Furthermore, the Europeans are so used to the good taste of cocoa imported from Ivory Coast, Africa, which is grown on fertile soils with high pH and low Al saturation. Our soils, Ultisols and Oxisols, are acidic with pH ranging from 4 to 5, lower pH for the Ultisols. These soils contain toxic amount of Al and/or Mn, which also affect the taste of cocoa although it has been improved somewhat via innovative fermentation technology.

Current national average rate of cocoa production in Malaysia is low, only 0.8 t/ha/year. This is far too low compared to that of our counterpart in African countries. The target rate of production for country is 1.5 t/ha, which is still way below the potential cocoa yield of > 10 t/ha/year. In Sabah, a yield of > 2 t/ha/year can be obtained for cocoa planted on weathered soils with good soil management practice. At this rate of cocoa production, farmers can make money because the price of cocoa in the marketplace now is quite high.

For growing cocoa on the Ultisols and Oxisols, soil pH needs to be raised to above 5. At this pH, Al in the soil solution starts to precipitate as inert Al-hydroxides, rendering it unavailable to the growing cocoa in the field. Simultaneously, Mn in the soil solution is eliminated. Soil pH can be increased by liming (Shamshuddin et al., 1991; Shamshuddin et al., 2010). Likewise, soil pH can be increased by ground basalt application (Gillman et al., 2002; Shamshuddin & Kapok, 2010). Besides increasing pH, basalt supplies Ca, Mg, K, P and S into the soils for the crop's requirement. This agronomic practice helps reduce the cost of production as less fertilizer needs to be applied. The best technique is to apply basalt in combination with organic fertilizer. The organic fertilizer supplies nitrogen needed by cocoa for its healthy growth. Basalt is, however, taking a long time to disintegrate and dissolve completely. But it gives a long-term ameliorative benefit to the cocoa plant. As soil pH increases negative charges on the exchange complex of the variable charge minerals increases (Shamshuddin & Ismail, 1995). This helps retain basic cations in the topsoil and hence, soil productivity is further improved.

If the rainfall at an area is too much, the area is less suitable for cocoa cultivation. Under this condition, cocoa can be infested by diseases, resulting in the abortion of cherelles. This in the end would reduce the yield of cocoa. This being the case, it is not wise to grow cocoa in areas with heavy rainfall like Johor where the annual rainfall can exceed 3,000 mm. As it is

Sabah is the best growing area in Malaysia for cocoa production in terms of soils and climatic conditions.

Fig. 5. A well managed cocoa estate in Malaysia (Courtesy of Malaysian Cocoa Board)

6. Conclusion

Oil palm and rubber are suitable to be grown on Ultisols and Oxisols in Malaysia because the crops are acid and Al tolerant, but cocoa is not unless the soils are amended with lime or basalt. However, climate can somewhat affect their production except oil palm. With proper soil management practices, the yield of oil palm and rubber are high, contributing money that sustains the Malaysian economy. As the crops are planted either on undulating and/or sloping land, contour terraces are needed to be constructed to reduce or to prevent soil erosion that removes the fertile topsoil. Planting leguminous cover crops in between the rows of oil palm or rubber trees further helps improve soil conservation. On the other hand, cocoa requires lime or basalt application at the appropriate rate and time to increase soil pH, lower Al and increase basic cations. In so doing, cocoa can be grown sustainably on Ultisols and Oxisols in Malaysia.

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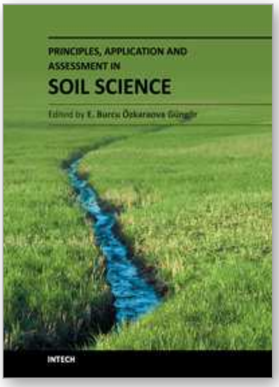

Principles, Application and Assessment in Soil Science
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Our dependence on soil, and our curiosity about it, is leading to the investigation of changes within soil processes. Furthermore, the diversity and dynamics of soil are enabling new discoveries and insights, which help us to understand the variations in soil processes. Consequently, this permits us to take the necessary measures for soil protection, thus promoting soil health. This book aims to provide an up-to-date account of the current state of knowledge in recent practices and assessments in soil science. Moreover, it presents a comprehensive evaluation of the effect of residue/waste application on soil properties and, further, on the mechanism of plant adaptation and plant growth. Interesting examples of simulation using various models dealing with carbon sequestration, ecosystem respiration, and soil landscape, etc. are demonstrated. The book also includes chapters on the analysis of areal data and geostatistics using different assessment methods. More recent developments in analytical techniques used to obtain answers to the various physical mechanisms, chemical, and biological processes in soil are also present.

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University Campus STeP Ri
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Phone: +86-21-62489820
Fax: +86-21-62489821