5 Soil Properties (Physical, Chemical, Biological, Mechanical)

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INTRODUCTION

Soil is an anchor for plant roots and as a water holding reservoir for needed moisture, soil delivers a hospitable place for a plant to take root. Some of the soil properties affecting plant growth include soil texture (coarse or fine), aggregate size, porosity, aeration (permeability), and water holding capacity. A significant function of soil is to store and supply nutrients to plants. The capability to perform this function is referred to as soil fertility. The clay and organic matter content of a soil directly influence its fertility. Greater clay and organic matter content will generally lead to greater soil fertility. The rate of water movement into the soil (infiltration) is influenced by its texture, physical condition (soil structure and tilth), and the amount of vegetative cover on the soil surface. Coarse (sandy) soils allow rapid infiltration but have less water storage ability, due to their usually large pore sizes. Fine-textured soils have an abundance of micropores, allowing them to retain a lot of water but also causing a slow rate of water infiltration. Organic matter tends to increase the ability of all soils to retain water and also upsurges infiltration rates of fine-textured soils.

Soil resources serve as a basis for food security. Soil properties, together with climate, govern what type of plants will grow in a soil or what particular crops will grow in a region. The properties of a soil play a big part in determining the plant's ability to extract water and nutrients. If plants are to grow to their maximum yield potential, the soil must provide a conducive or satisfactory condition for plants to grow.

Malaysia has an extensive variety of soils. These soils have been mapped on mountainous, hilly, rolling, undulating, level, and swampy terrain. So far over 500 soil series have been identified in Malaysia. These various soil types have developed over different topographic conditions and over different parent materials or rock types and alluvial deposits. The fact that Peninsular Malaysia, Sabah, and Sarawak used different soil classification systems further complicates the identification of these soils (Paramananthan, 2012). Residual soils are developed from the weathering process of rocks. Although several researches have been shown on engineering properties of residual soils, the study on mineralogy, microstructure, microfabric, and chemical composition of residual soils, despite of its status, is still lacking. In addition, correlations developed between the engineering properties of granitic residual soils are also still lacking. The generated correlations can be used as guides for preliminary designs for geotechnical structures created on or in residual soil of Peninsular Malaysia (Amination and Fauziah, 2003).

PHYSICAL PROPERTIES OF MALAYSIAN SOILS

Soil Physical Properties

Soil physical properties refer to properties such as soil texture, bulk density, aggregation, aggregate stability, and soil water content and water retention. Malaysian soils vary widely in texture from as low as 3% (sandy soils) to over 90% (clayey soils) of clay content. The mean sand content of Malaysian soils is 41%, which is nearly the same as that of the clay content, 43%. Bulk density is an indication of soil compaction, which is determined as the weight of dry soil per unit soil volume. Soil compaction is highly dependent on soil management practices, but typically, Malaysian soils have bulk density values ranging from 0.8 to 1.9 Mg/m^3, although peat soils have much lower bulk density values, as low as 0.09 Mg/m^3, depending on the organic matter types and their degree of decomposition.

Aggregation refers to the distribution of aggregate sizes, whereas aggregate stability is the resistance of these aggregates to withstand the disruptive forces from water or wind. Aggregation and aggregate stability are important soil physical properties because they indicate not only soil fertility but also how well the soil can resist erosion. In agriculture, we desire aggregates that are not unstable as they will easily crumble and aggregates that are not too stable as they behave like stones or rocks, which can complicate field-planting practices.

Organic matter is one key ingredient in the soil that affects aggregation and aggregate stability. More specifically, the organic matter components, primarily fulvic acids and humic acids, have differing impacts on aggregate stability. The effects of organic matter constituents vary between temperate and tropical soils. In tropical soils, fulvic acids are more effective in increasing aggregate stability than humic acids, most probably because there are more fulvic acids in tropical soils than in temperate soils (which have more humic acids than in tropical soils). In Peninsular Malaysia, for example, 75%–90% of the organic carbon are fulvic acids (Zainab, 1977). Because of the higher organic matter turnover rate in tropical soils than in temperate soils (Greenland et al., 1992), the humic acids are converted into fulvic acids at a faster rate in tropical soils. Other important factors are free iron and aluminum oxides and exchangeable cations.

Teh (2012a) used multiple linear regression to show that silt, followed by free Fe oxides, fine sand, fulvic acids, then humic acids were the most important soil constituents to explain the observed differences in aggregate stability between four Malaysian soil types (Ultisols and Oxisols). Moreover, the physical and chemical properties of individual aggregate size fractions are often different from one other. The amount of clay, organic matter, and cations, for example, often differs from one aggregate size fraction to another. Teh (2012b) and Teh et al. (2005) observed that as the aggregate size decreased, the amount of clay, silt, organic matter, and free Fe oxides would increase, and the aggregation and the amount of sand would decrease. Generally, it was observed that aggregate stability would increase with decreasing aggregate size until aggregate size fraction becomes <0.3 mm below which the stabilities of aggregate size fractions between soils were generally similar to one another. Table 5.1 shows the mean soil physical properties of some Malaysian soils.

Another important soil physical property is the soil water content and the water retention. There are three important points in the soil water content: saturation, field capacity, and permanent wilting point. Saturation is the point of maximum amount of water that a soil can hold below which gravity will be able to pull away the water from the soil until a certain point known as the field capacity. At this point, water is more tightly bound to the soil and held stronger by the soil than the pull of gravity. At the permanent wilting point, water is held too strongly by the soil that even plant roots are unable to obtain the water. Consequently, the amount of soil water between field capacity and permanent wilting point is known as the available water content. Different soils have different saturation, field capacity, and permanent wilting points, depending on the soil compaction, organic matter content, and soil texture. For Malaysian soils, the volumetric soil water content at saturation, field capacity, and permanent wilting point can range between 36%–89%, 10%–67%, and 3%–49%, respectively, giving the available volumetric soil water content between 1% and 13%. Generally, the soil water content at permanent wilting point is more influenced by soil texture than soil management practices, whereas the latter plays a greater role in affecting the soil water content at saturation and field capacity.

Instead of measuring the soil water retention, we can estimate it by using the Saxton and Rawls (2006) set of equations. However, Teh and Iba (2010) calibrated

TABLE 5.1
Mean Physical Soil Properties (and Organic Carbon Content) for Some Malaysian Soils

	%Sand	%Clay		%Volumetric			mm/hour
Series	**0.05–2 mm**	**<2 µm**	**%OC**	**SAT**	**FC**	**PWP**	**Ks[a]**
Awang	75.1	14.6	0.3	47.9	19.4	11.4	70.9
Batu Anam	19.8	35.1	0.2	55.3	42.2	24.5	5.9
Batu Lapan	31.1	56.7	1.5	60.9	42.7	35.8	24.9
Briah	16.4	54.4	1.0	70.8	57.9	38.4	7.0
Bukit Tuku	34.9	26.0	0.3	50.1	27.5	20.8	27.6
Bungor	49.5	40.2	0.5	53.9	36.8	30.0	18.6
Chat	12.0	64.6	1.0	58.4	47.3	39.2	3.2
Cherang Hangus	62.2	27.7	0.4	46.7	28.7	21.3	16.0
Chuping	35.4	33.3	0.3	76.1	35.7	20.8	157.6
Durian	30.6	49.3	0.8	55.4	42.6	34.7	5.1
Gong Chenak	38.5	41.7	0.4	49.7	37.2	29.4	5.6
Halu	53.2	25.2	0.3	60.0	44.6	37.0	17.3
Harimau	61.8	34.7	0.8	54.7	27.3	20.8	67.0
Holyrood	61.8	29.0	0.7	76.5	28.8	16.2	244.6
Jintan	18.7	60.8	0.2	69.4	47.3	37.1	23.7
Kampong Pusu	43.3	34.3	1.8	54.5	34.4	28.5	27.0
Kaning	47.7	43.7	0.3	58.2	27.2	24.4	61.6
Katong	5.1	87.5	0.9	62.3	51.5	46.8	3.9
Kawang	56.1	28.5	0.6	43.8	30.0	22.0	6.1
Kuantan	13.2	65.0	0.5	71.7	35.4	27.9	98.3
Kulai	30.1	37.2	0.4	58.9	39.4	32.0	18.1
Lambak	36.7	59.2	0.4	46.6	25.3	21.3	20.4
Lanchang	25.9	59.9	0.3	71.0	47.0	43.1	27.8
Langkawi	23.9	69.1	0.4	77.2	43.0	32.8	83.9
Lintang	77.8	17.5	0.3	78.2	20.1	12.7	405.6
Lunas	56.1	36.2	0.2	50.3	35.6	26.6	9.2
Marang	61.0	25.8	0.2	48.1	29.9	23.9	20.1
Munchong	10.6	80.7	0.9	63.1	50.2	44.7	5.5
Nangka	71.4	14.9	0.7	53.6	22.4	13.1	88.2
Napai	68.2	12.2	1.7	59.9	20.3	10.7	140.0
Padang Besar	54.3	39.0	1.2	50.2	34.5	29.1	9.2
Patang	32.7	39.0	0.6	58.9	38.8	30.5	18.3
Penambang	56.9	20.9	1.3	49.5	36.2	30.4	5.2
Prang	22.7	65.6	0.9	64.7	44.3	35.2	28.9
Rasau	35.4	29.7	1.2	69.4	34.2	20.0	113.6
Rengam	44.9	49.3	1.5	55.2	38.3	31.6	13.4
Ringlet	42.1	36.1	0.5	56.3	36.8	31.2	16.4
Sagu	19.5	64.0	0.1	72.7	43.1	39.6	52.5
Segamat	6.4	72.1	0.9	69.6	44.6	39.1	40.9

(*Continued*)

TABLE 5.1 (*Continued*)
Mean Physical Soil Properties (and Organic Carbon Content) for Some Malaysian Soils

	%Sand	%Clay		%Volumetric			mm/hour
Series	**0.05–2 mm**	**<2 µm**	**%OC**	**SAT**	**FC**	**PWP**	**Ks[a]**
Senai	23.0	56.9	0.8	56.2	37.6	32.2	14.4
Serdang	68.2	28.2	0.6	52.8	29.7	21.3	35.7
Sg. Buloh	92.5	3.1	0.5	41.7	8.1	4.7	86.4
Sg. Mas	41.3	37.1	0.5	57.0	39.2	31.3	15.6
Sogomana	16.9	52.6	0.6	56.7	41.6	31.3	9.1
Subang	72.9	12.1	1.2	54.1	23.2	12.5	72.3
Tampin	51.3	32.3	0.4	46.2	28.4	18.5	14.5
Tanah Rata	64.3	19.3	0.6	63.8	47.7	35.2	10.2
Tavy	26.0	60.7	0.9	51.5	29.9	23.0	35.2
Tebok	36.6	38.1	0.6	59.5	33.2	24.3	75.1
Ulu Dong	34.8	56.8	0.3	65.7	36.9	34.6	64.1
Ulu Tiram	65.7	30.6	0.6	47.1	29.3	22.4	12.7

Source: Maene, L. et al., *Register of Soil Physical Properties of Malaysian Soils*. Technical Bulletin, Faculty of Agriculture, Universiti Pertanian Malaysia, Serdang, Malaysia, 1983.

OC–organic carbon; SAT, FC, and PWP–the soil water content at saturation, field capacity, and permanent wilting point, respectively; and Ks–saturated hydraulic conductivity.

[a] Ks is estimated (From Saxton, K.E. and Rawls, W.J., *Soil Sci. Soc. Am. J.*, 70, 1569–1578, 2006).

the Saxton and Rawls (2006) equations for Malaysian soils. Their developed equation for calibration was as follows:

$$\hat{P}_i = a \cdot P_i \left(1 - P_i\right)$$

where P_i and $\hat{P}_i$ are the uncalibrated and calibrated estimated values, respectively, for soil sample no. i, and the parameter a values were 2.225, 1.605, and 1.528 for saturation, field capacity, and permanent wilting point, respectively. The calibrated method was validated against three independent soil datasets. Validation tests showed that the calibrated method remained stable and was more accurate than that without calibration by an average of between 8% and 49%.

The soil water retention also provides us information on the point of soil water content below which the crop begins to feel the effects of water stress as presented in Figure 5.1.

The relative soil water content (RWC; m^3/m^3) is calculated by

$$\text{RWC} = \frac{\Theta_v - \Theta_{v,\text{pwp}}}{\Theta_{v,\text{sat}} - \Theta_{v,\text{pwp}}}$$

where:

Θ_v is the volumetric soil water content (m^3/m^3)

$\Theta_{v,\text{sat}}$ and $\Theta_{v,\text{pwp}}$ are the volumetric soil water contents at saturation and permanent wilting point, respectively (m^3/m^3)

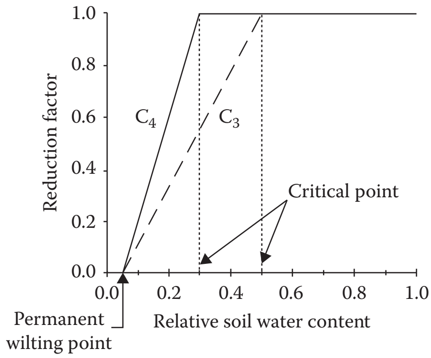

FIGURE 5.1 Plants will start to be water stressed at soil water content below the critical point. C_4 plants are less sensitive than C_3 plants to water stress.

The soil's critical point $\Theta_{v,\text{cr}}$ (m^3/m^3) below which the plant begins to encounter the effects of water stress is some point along the relative soil water content, and it can be determined by

$$\Theta_{v,\text{cr}} = \Theta_{v,\text{pwp}} + p\left(\Theta_{v,\text{sat}} - \Theta_{v,\text{pwp}}\right)$$

where p is 0.5 and 0.3 for C_3 and C_4 plants, respectively.

Soil physical properties often respond slower than soil chemical properties due to organic matter amendments. For instance, no significant changes were observed for soil bulk density and total porosity even after 3–10 years of soil organic mulching, as reported by Acosta-Martinez et al. (1999), Bescansa et al. (2006), Karlen et al. (1994), and Onweremadu et al. (2007). Similarly, Teh and Zauyah (2001) observed no difference in soil physical changes (such as bulk density, aggregation, and aggregate stability) even after 10 years of annual mulch application using empty fruit bunches (EFB).

Nonetheless, Moraidi et al. (2015) reported that annual EFB application as a mulching material for 3 years improved nearly all soil physical and chemical properties that were measured. They compared EFB with oil palm fronds and an EFB mat (called as Ecomat). EFB was found to be the most effective material to increase soil aggregation, aggregate stability, soil water retention at field capacity, available soil water content, and the relative proportion of soil mesopores. Due to these improved soil physical properties, EFB also gave the highest soil water content. Unlike Ecomat and oil palm fronds that concentrated more water in the upper soil layers, EFB distributed the soil water more uniformly throughout the whole soil profile.

Malaysia experiences high rainfall, where the country's annual rainfall is 2000–3000 mm. Consequently, water erosion is of particular importance, whereas erosion by wind, in contrast, is of little importance because the soil tends to be continuously wet from frequent and heavy rainfall, and Malaysia experiences slow average daily wind speeds, typically only about 2 m/s.

Improving the soil physical properties is one of the most important methods to reduce soil erosion. Soil erodibility is often represented as the K factor in the RUSLE soil erosion model, where smaller K values denote that a soil has a stronger resistance

TABLE 5.2
Range of Soil Erodibility Based on Soil Texture of Peninsular Malaysia Soil Series

Soil Texture	*K* Factor (tonne ha)(ha hour/MJ mm)
Clay	0.042–0.065
Clay loam	0.030–0.047
Sandy clay	0.031–0.043
Sandy clay loam	0.028–0.059
Sandy loam	0.004–0.036
Silt loam	0.014–0.027
Silty clay loam	0.032

Source: Yusof, M.F. et al., Modified soil erodibility factor, K, for Peninsular Malaysia soil series, in *3rd International Conference on Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisi of Flooding*, Pollution and Water Scarcity (RIVER 2011), Penang, Malaysia, December 6–9, 2011, pp. 799–808, 2011.

against erosion, whereas larger *K* values denote a weaker soil against erosion. *K* factor depends on soil texture, organic carbon content, soil structure, and soil permeability. Using the soil properties of 76 soil series in Peninsular Malaysia, Yusof et al. (2011) developed a range of *K* values for Malaysian soils based only on their soil texture as presented in Table 5.2. This table shows that soils with higher clay content are more susceptible to erosion than soils having higher silt and sand content. For instance, Yusof et al. (2011) determined that 56% of the 74 soil series they used had high clay content such as Akob, Batu Anam, and Chengai, which were more erodible than soils with higher silt or sand content (e.g., Rudua, Holyrood, Lunas, and Marang).

In Malaysia, soil erosion is controlled using three basic principles: (1) agronomic methods, (2) soil management methods, and (3) mechanical methods. Agronomic methods include the use of vegetation to protect the soil, and soil management methods are ways to improve soil fertility and soil structure to increase soil resistance against erosion, and mechanical methods are the use of physical and artificial structures such as walls and hill terraces to reduce soil erosion.

Agronomic and soil management methods are cheaper, but they require time before they can give full or effective soil protection. The key to agronomic methods is to provide physical cover to the ground, covering it against rain splash erosion and soil and water loss via runoff. It is not necessary to have full ground cover to have a significant reduction in soil losses: 70% ground cover is sufficient (Morgan, 2005). In Malaysia, legumes are typically used as cover crops. Popular cover crops are *Pueraria phaseoloides*, *Calopogonium mucunoides*, *Centrosema pubescens*, and *Mucuna bracteata*. These legumes are popular because they are fast growing, able to fix N, and provide thick and complete ground cover. Vetiver grass is also a popular grass typically planted along hill slopes in urban areas. This grass has a very deep, wide, and dense rooting system (>2 m deep).

TABLE 5.3
Isohumic Factor of Several Types of Organic Materials

Organic Material	Isohumic Factor
Plant foliage	0.20
Green manures	0.25
Cereal straw	0.30
Roots of crops	0.35
Farmyard manure	0.50
Deciduous tree litter	0.60
Coniferous tree litter	0.65
Peat moss	0.85

Source: Kolenbrander, G.J., *Trans. Int. Congr. Soil Sci.*, 2, 129–136, 1974.

The aim of soil management is to improve or maintain high soil fertility and soil structure levels so that the soil is able to support a good growth of plants, thus reducing the impact of rain drops, runoff, and wind. Addition of organic matter is vital because its addition will increase, among others, the water retention capacity and higher aggregate stability. Green manures decompose rapidly, but its rapid beneficial effects on the soil are short lived. Straw decomposes less rapidly, so its beneficial effects are less rapid but more prolonged. The slowest to decompose is manure. A measure of the quantity of humus produced per unit quantity of organic matter is called isohumic factor as given in Table 5.3.

Moraidi et al. (2013) reported that after four consecutive annual applications of EFB mulch, 23.42 kg C was added to the unit area of the land surface of which only 12% is converted into the soil organic C at 0–0.30 m depth. This corresponds to 1.0 million tonne/year EFB C sequestrated into the soil globally, of which Malaysia contributes 35%.

Mechanical methods include structures such as walls, gabions, and terraces. Terraces are built on hill slopes to reduce the length and slope of hills, thus reducing the amount and speed of runoff. However, terraces involve the use of heavy machinery that can compact the soil and involve the removal of the fertile topsoil. Consequently, some plantations in Malaysia have put an end to the use of terraces and built silt pits instead. These so-called silt pits are long, narrow, and close-ended soil trenches, built in perpendicular to the hill slope direction. The idea is for the silt pits to capture the runoff during the period of rainfall, thus trapping the water, sediments, and nutrients from the runoff that would otherwise be lost from the hill.

Bohluli et al. (2014) was one of the few studies that examined not only the effectiveness of silt pit as a soil and water conservation method but also the effect of silt pit size. The examined four dimensions (width × length × depth in meters) of silt pit: 1 × 3 × 1, 1.5 × 3 × 1, 2 × 3 × 1, and 2 × 3 × 0.5. They also compared the effects of these silt pit sizes on the soil with control (no silt pit and with oil palm fronds as mulch). They determined that silt pits increased soil water content between 3% and 19% compared to control and that the silt pits also conserved more soil nutrients than the control. Results showed that the silt pit with the smallest opening area conserved more soil water content in oil palm active root zone and is the best effect to improve soil chemical parameters inside and outside of the pit compared with other treatments. This is because pits with smaller opening area had bigger wall-to-floor area (W:F) ratio, which caused higher lateral water infiltration through silt pit's walls than water percolation through silt pit's floor area. Moreover, silt pit with narrower opening area helped the water head to be higher than other wider pits and redistributed dissolved nutrients in topsoil.

CHEMICAL PROPERTIES OF MALAYSIAN SOIL

The two main soil chemical properties controlling chemical processes in the soil system are cation exchange capacity (CEC) and soil acidity.

Cation Exchange Capacity

In the soil system, the main soil component controlling chemical reactivity is clay, due to its small particulate size (<2 μm) and high surface area. The adsorption process, which is the main chemical process controlling the availability of nutrients to the plant system takes place at the clay colloidal surface. Isomorphous substitution or the substitution by another cation of similar size and form but of lower oxidation state, during the formation of silicate clays, resulted in negative charges on the clay surfaces. The adsorption of cations on the clay surfaces is necessary to balance these electrostatic charges. The other soil component responsible for cation retention in the soil system is the organic colloids. The retention of the cations on the clay surfaces or organic colloids is termed as the CEC.

The CEC is highly related to the mineralogical composition of the soil. The CEC of the soil is influenced more by the type of mineral rather than the amount of mineral present in the soil system. Table 5.4 presents the common clay types.

TABLE 5.4
Examples of Some Common Different Clay Types

No.	Clay	CEC me /100 g
1	Organic matter	150–500
2	Kaolinite	3–15
3	Aluminum and ferum hydroxide	4
4	Illite	10–40

Soil Acidity

Besides CEC, the other main soil chemical process controlling reaction in the soil system of highly weathered tropical soils is soil acidity. Soil acidification is a natural process and has long been known as a form of chemical degradation of the soil. Soil acidity can either be accelerated by the activity of plants, animals, and humans, or it can be impeded by sound management practices. Brady and Weil (1999) described soil acidity in the following manner.

> No other single soil characteristic is more important in determining the chemical environment of higher plants and soil microbes than the pH. There are few reactions involving any component of the soil or of its biological inhabitants that are not sensitive to soil pH. The sensitivity must be recognized in any soil management system.

PROCESSES OF ACID GENERATION IN SOILS

Processes of acid generation in soils can be broadly grouped into two categories: (1) those occurring under natural ecosystems through weathering processes, pyrite oxidation in acid sulfate soil, and organic matter deposition or accumulation forming peat and (2) those occurring under managed ecosystems through farming activities. The most significant H^+ and hydroxyl ion (OH^-) generating processes occur during the biogeochemical cycling of C, N, and S. Although these processes occur both under natural and managed ecosystems, under the latter system, these processes are accelerated by the activities of humans through intensive land-based crop and animal production. Overall, the main contribution toward soil acidification is from the utilization of the ammoniacal forms of N in fertilizers and legumes, which are oxidized to nitric and other acids, and in crop removal of basic cations (nutrients mining) and acid rain. In rubber plantations of Malaysia, it has been reported that due to more than 100 years of ammonium sulfate application, the soil pH had been reduced by 1 unit to about pH of 4.00 (Shamshuddin et al., 2015).

NATURAL ECOSYSTEMS

Highly Weathered Soils

Malaysian soils dominantly (about 70%) fall into the Ultisol and Oxisol Orders in Soil Taxonomy. These soils are acidic in nature, with pH values ranging from 4 to 5. These soils contain mainly sesquioxides and kaolinite both of which are essentially variable charge minerals. The phosphorus present in the soil system is highly fixed by the sesquioxides in the soil system, and thus these soils are extremely poor in available phosphorus. Infact, phosphorus is considered as the most limiting nutrient for crop production in the tropics. These soils also have very low basic cation status and effective CEC as presented in Table 5.5. Accessions of acidity by these soils contribute to soil degradation as a result of reactions, which liberate toxic levels of Al^{3+} and Mn^{2+}, reduce the CEC, increase the anion exchange capacity, and promote

TABLE 5.5
Selected Chemical Properties of Ultisols and Oxisols

Series	pH H_2O	pH $CaCl_2$	Exch. Cations ($cmol_c$/kg) Na	K	Ca	Mg	% bas. sat.	% Al sat.	CEC ($cmol_c$/kg)	Exch. Al ($cmol_c$/kg)	O.M (%)
Ultisols											
Rengam	4.3	3.8	0.09	0.08	0.23	0.11	10.41	26.65	4.90	1.09	1.98
Serdang	4.6	3.8	0.06	0.05	0.02	0.06	5.85	26.46	3.25	0.86	1.05
Bungor	4.1	3.6	0.07	0.15	0.24	0.13	18.15	52.33	6.00	3.14	1.45
Kuala Brang	4.4	3.9	0.06	0.17	0.18	0.07	5.05	55.89	9.50	5.31	2.03
Lanchang	4.5	4.1	0.06	0.15	0.12	0.18	5.71	15.23	8.93	1.36	2.78
Oxisols											
Segamat	4.9	4.6	0.04	0.12	1.10	0.96	24.18	3.38	9.18	0.31	3.00
Sg. Mas	4.6	3.9	0.04	0.18	0.24	0.46	12.11	8.64	7.18	0.62	1.60
Muchong	4.4	4.1	0.06	0.30	0.84	0.14	14.81	16.68	9.05	1.51	2.41

Source: Shamshuddin, J., *Pertanika,* 12, 109–111, 1989.

the loss of basic cations (Ca^{2+} and Mg^{2+}) by leaching. The activities of soil organisms are generally reduced under such conditions. This can take a toll on crop yield and impair biological N fixation. Therefore, amelioration involves both the neutralization of exchangeable Al and Mn and restoration of higher levels of exchangeable basic cations, namely Ca, throughout the soil profile.

Acid Sulfate Soils

In Malaysia, the area covered by these soils is quite extensive about 0.5 million ha most of which is still in its pristine condition under waterlogged environments as shown in map in Figure 5.2. The pyritization process that began in the past is still ongoing in the coastal plains of Peninsular Malaysia. Pyrite forms when sulfate from seawater and ferric ions from marine sediments are reduced to sulfide and ferrous ions, respectively. These reactions occur under extremely reducing or anaerobic condition where microorganisms feeding on the organic matter present in the sediment play an important role in the reduction process.

Under flooded conditions and in the presence of organic matter, ferric ions in the seawater are readily reduced to ferrous ions with the help of microbes. The organic matter needed for the reduction process will be provided by the native vegetation. The chemical characteristics of selected acid sulfate soils are shown in Table 5.6.

Acid sulfate soils are highly buffered at pH 5–9. At this pH range, Al plays an important role in the buffering process. Also, the high Fe content in some acid sulfate soils can also buffer the acid sulfate soils from pH changes. Thus, acid sulfate soils require high amount of lime to increase the pH by just one unit.

FIGURE 5.2 A map of Peninsular Malaysia showing the distribution of acid sulfate soils. (Courtesy of the Department of Agriculture, Peninsular Malaysia.)

Peatland

In Malaysia, peatland occupies 2.7 million ha, accounting for about 8% of the total land area of the country. The state of Sarawak in East Malaysia has the largest area of peat in the country, covering about 1.66 million ha (65% of the total peat area). Tropical peatlands make a significant contribution to terrestrial C storage because of their considerable thickness, high C content, and most importantly, their rapid peat and C accumulation rates that have often exceeded those of boreal and temperate peatlands (Figure 5.3).

TABLE 5.6
Selected Chemical Properties of Typical Sulfate Soils of Peninsular Malaysia

Series	Depth	pH	EC (mS/cm)	Exchange Cations ($cmol_c/kg$) Na	K	Ca	Mg	% bas. sat.	% Al sat.	CEC $cmol_c/kg$	Exchange Al $cmol_c/kg$	Water-Soluble SO_4^{2-}%
Kranji	0–22	6.6	8.00	41.8	4.2	9.1	26.1	226	0	35.8	0	0.48
	>63	7.1	12.00	58.3	5.1	19.1	26.4	379	0	28.7	0	0.96
Telok	0–17	4.1	0.11	0.2	0.3	2.7	4.3	24.5	26.14	30.6	8.0	0.03
	110–130	2.2	2.50	0.8	0.4	1.8	6.2	32.25	17.41	24.7	4.3	0.58
Jawa	0–5	4.2	0.14	0.7	0.7	4.2	6.0	52.48	11.31	22.1	2.5	0.01
	130–150	2.4	4.01	7.4	0.3	6.0	14.0	92.64	56.86	29.9	17.0	10.42
Sedu	0–5	4.0	0.25	0.6	0.8	1.9	3.8	32.42	16.89	21.9	3.7	0.01
	125–162	2.4	3.59	5.0	0.6	4.7	14.7	92.59	58.15	27.0	15.7	8.78

Source: Shamshuddin, J. (ed.), *Acid Sulphate Soils in Malaysia*, UPM Press, Serdang, Malaysia, 2006.

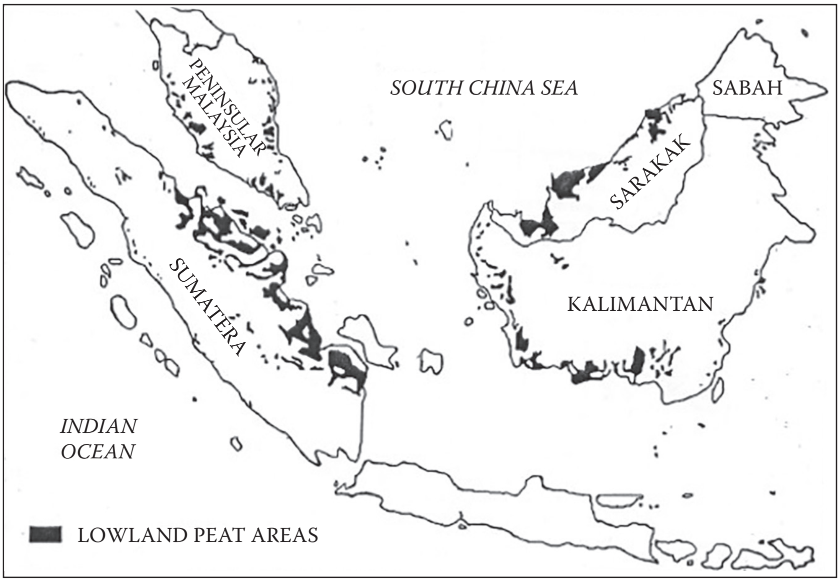

FIGURE 5.3 Distribution of lowland peatlands in Malaysia and Indonesia.

Tropical peat soils are generally very acidic with pH values of less than 4.0. The peat soil is highly buffered with respect to pH changes. The buffering capacity of the peat soil is primarily due to the carboxyl and phenolic functional groups in the humic substances of organic matter as given in Table 5.7.

TABLE 5.7
Selected Chemical Properties of Peat and Their Liming Requirement

Peat	Depth (cm)	pH	% HA	Buffer Capacity[a] mole (OH)/kg	LR[b] (tonne $CaCO_3$/ha)
1	0–15	4.53	21.23	1.95	2.74
2	0–15	3.41	26.88	1.91	18.59
3	0–15	3.93	18.30	0.71	12.78
4	15–30	3.51	25.43	0.97	18.07
5	0–15	3.42	23.78	0.91	15.42
6	15–30	3.86	8.40	0.02	10.14
7	0–15	3.37	35.67	2.26	22.29
8	0–15	3.48	20.68	0.10	13.31
9	0–15	3.36	23.45	1.09	15.42
10	0–20	3.38	39.52	5.94	25.99
11	20–40	3.17	12.38	0.48	16.48
12	0–15	3.34	19.82	0.34	15.94
13	20–40	4.54	8.30	0.04	1.68
14	0–15	3.43	26.92	4.56	21.24

[a] Buffer capacity (×1000).

[b] Lime requirement to attain a pH of 5.0.

WAYS TO OVERCOME SOIL ACIDITY

There are several ways to mitigate soil acidity, the common practice being liming. Liming with ground magnesium limestone is the standard practice to improve the fertility of the soils, except for rubber and oil palm, which are tolerant to soil acidity. Other methods include organic matter amendment and gypsum application. Most of the studies conducted on soil acidity focus mainly on the liming of topsoils under conventional tillage. Relatively little research effort has been devoted to subsoil acidity and strategies for correcting acidification for cultivation with minimum or no tillage such as grassland or cultivated forests.

Acidity in both top- and subsoils often produces toxic levels of Al and Mn and deficiencies of Ca. Root extension and proliferation are limited by toxic levels of Al and/or deficient levels of Ca with the result that the crop suffers both drought and nutrient stresses because the limited root system is no longer efficient in taking up water and essential elements for growth. These stresses lead to reduced crop yield and quality.

Severe acidification of topsoil can lead to the transfer of acidity to subsoil, which would then be negatively impacted. Once subsoil has been acidified, amelioration by lime incorporation is impractical and expensive. Alternative strategies such as the use of surface applied gypsum are recommended in this situation.

There is no natural deposit of gypsum in Malaysia, and for that reason ameliorating subsoil acidity of Malaysian soils has never been emphasized. However, by-product of gypsum or red gypsum is available in the country, but unfortunately, it is still classified as scheduled waste. Thus, more testing need to be conducted to provide evidence of its usefulness in crop production without adverse effect on the quality of the crops and the environment.

For acid sulfate soils, a large amount of liming material is required to raise the soil pH by one unit. Therefore, the recommended practice is to keep the pyrite layer unoxidized by keeping this layer under submerged condition. For areas where the pyrite layer forms right to the surface, growing flooded rice with proper liming rate is recommended.

The problem for peatland area is the injury caused by proton pressure to the roots of the plants due to low pH. In general, raising the soil pH to above 4.0 will overcome the root injury due to proton pressure. According to Husni et al. (1995), pH, percent humic acid, and buffer capacity are factors influencing the lime requirement of tropical peat.

SOIL ORGANISMS, THEIR BENEFICIAL ACTIVITIES, HABITAT, AND DIVERSITY IN THE SOILS OF MALAYSIA

Introduction

From the moment a natural system is modified by human activities for agricultural purposes, major changes occur to the soil environment and to the flora and fauna populations and community present. The intensity of the change induced when compared with the original ecosystem and the ability of the various organisms to adapt to these changes will determine the ultimate community present after the perturbation. This community will further be modified as the agricultural practices are altered to suit human needs and changing agricultural paradigms. Practices that are generally considered as beneficial mostly involve the management of organic matter, particularly the control of the quality or quantity of residues added or kept on the soil surface (litter) and the reduction or complete absence of soil disturbance (tillage) (Hendrix et al., 1990). Crop rotation and diversification also play an important role in increasing the diversity of food resources and environmental conditions for the soil biota. Other corrective practices such as fertilization and liming are also important and are generally considered to have positive effects on most organisms (although negative effects may occur under some conditions for some organisms).

SOIL ORGANISMS

Most of the soils contain abundant living organisms that affect soil structure and nutrient cycling. These microorganisms live in the rhizosphere, or the root zone, the area of partnership between plant roots, soil, and soil organisms. Figure 5.4 shows three broad groups of belowground organisms: microfauna, mesofauna, and macrofauna. Microfauna are an enormous, microscopic class that includes protozoa and fungi (primary agents of organic matter decay, bind soil aggregates), actinomycetes

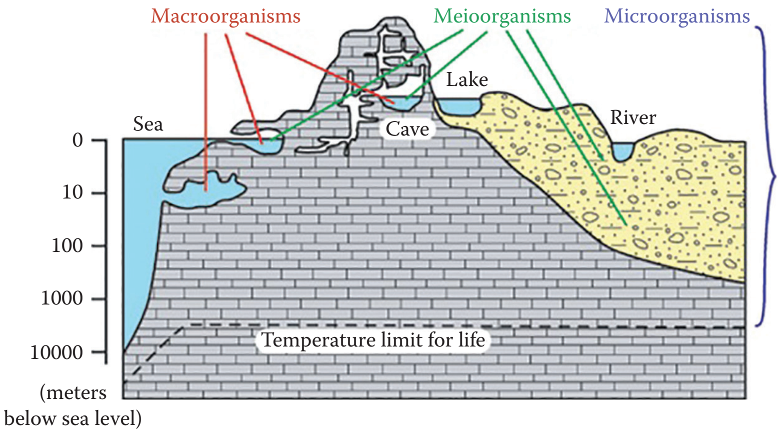

FIGURE 5.4 Soil organisms in the soil. (From Plant & Soil Sciences eLibrary^{PRO}, Soil genesis and development, lesson 6—Global soil resources and distribution. Accessed December 11, 2014. http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447033&topicorder=12&maxto=12&minto=1, 2014.)

(decomposers of organic matter, the *smell* of soil), and bacteria (decomposition of organic and inorganic material, fixation of nitrogen). Mesofauna (nematodes and rotifers) help regulate microbial populations.

Normally, soils under agricultural use have a huge number of microfauna and mesofauna. A gram of dry weight soil may contain approximately 10^7–10^9 bacteria, 10^7–10^8 actinomycetes, 10^5–10^6 fungi, 10^4–10^5 protozoa; and 10–100 nematodes. Macrofauna (earthworms, insects) accelerate organic matter decomposition, mix organic matter and soil together, and aerate the soil by channeling and burrowing.

Soil organisms such as insects (e.g., corn root worm) and plant disease pathogens (e.g., seed rotting fungi) could be harmful to crops, but some bacteria (rhizobia) and fungi (mycorrhizae) associated with roots are helpful. Other bacteria and fungi are accountable for vital soil processes such as plant residue degradation and nitrogen mineralization from organic matter. Earthworms are a positive indicator of soil quality and productivity. Reduced tillage systems have more earthworms than conventional tillage systems. Similarly, other beneficial organisms can be promoted through organic practices (Hendrix et al., 1990).

Microorganisms are abundant in soil, but to observe their beneficial effects on plants and environment their population in soil must be increased. Hence, the application of the effective microbes intensified the biological soil activity and improved the physical and chemical soil properties, hence contributing healthier plant growth and development (Lee et al., 2008).

Macroorganisms

More than 20 taxonomic groups of macrofauna could be grouped into a variety of different functional classes, depending on their activity and effects on the soil environment. Representatives of the macrofouna in the soil-surface litter is as shown in Figure 5.5. One of the most important and widely used division is that of beneficial

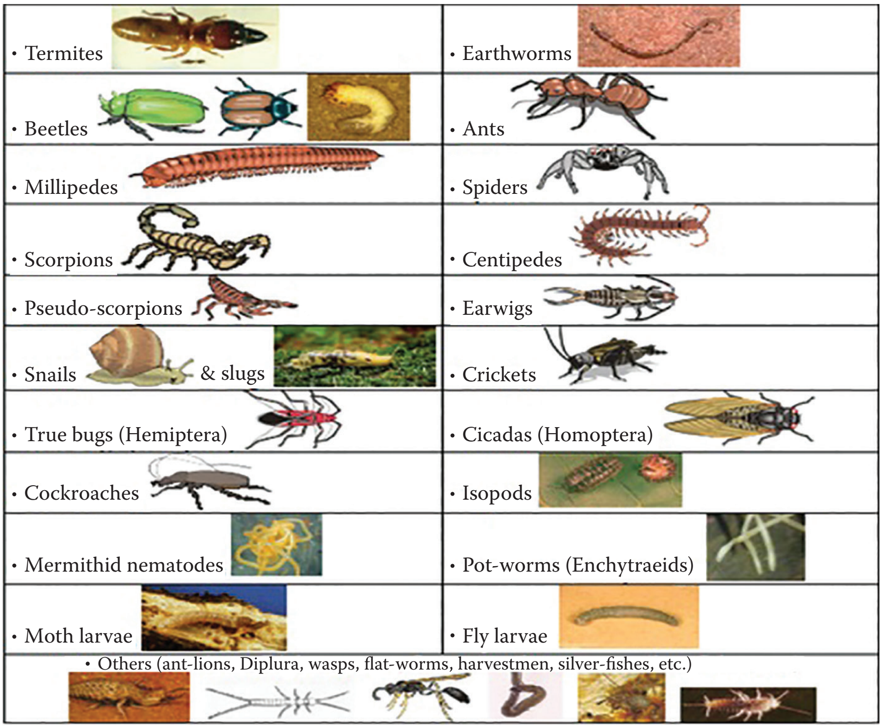

FIGURE 5.5 Representative of the soil-surface litter macrofauna. (From Plant & Soil Sciences eLibrary^{PRO}, Soil genesis and development, lesson 6—Global soil resources and distribution. Accessed December 11, 2014. http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447033&topicorder=12&maxto=12&minto=1, 2014.)

and adverse (or pest) soil organisms. Therefore, most of the characterizations of the soil macrofauna communities at a particular site are restricted to identification of better known groups such as earthworms, termites, ants, and beetles, and the complete presentation of the data is generally limited only to taxonomic group level (higher taxa) or morphospecies. Soil fauna are highly variable and they are adaptable to the environment. They can feed on various available food sources ranging from herbivores to omnivores and carnivores. Several by-products of these organisms are used as food resources by other soil fauna.

Population of earthworms can be influenced by several factors. In Malaysia, the earthworm population densities in oil palm are affected by plant age and soil type. Four major factors that dictate the heterogeneity of earthworm population in oil palm plantation are: (1) food and soil physical habitat, (2) exchangeable calcium, (3) pH, and (4) exchangeable potassium (Sabrina et al., 2009). A higher number of earthworms are observed under 7–14-year old compared to >14-year old palms.

Functions of the Macroorganisms

Macroorganisms are the soil-feeding (geophagous) bioturbators, important in opening channels within the soil and on its surface, affecting hydrological processes and gaseous exchanges, as well as modifying soil structure, aggregate formation, and even soil formation rates. Lastly, the predatory organisms that act at the top of the soil food chain are also counted between the beneficials, feeding on other soil and surface dwelling or active organisms, controlling their populations, and often helping to counteract pest outbreaks (thus acting as bio-control agents). Earthworms constitute the largest part of invertebrate biomass in most soils (Tondoh et al., 2007). Soil macrofauna increased with leaf litter calcium and decreased with leaf litter carbon in the plantations (Reich et al., 2005). Although we did not find any differences in soil macrofauna abundance and in biomass of nitrogen fixing tree plantations in comparison with nonnitrogen fixing tree ones, *Acacia salicina* (as a nitrogen fixing tree species) had the highest soil macrofauna abundance and biomass (especially of earthworms) in comparison with other tree plantations, and *Eucalyptus camaldulensis* (as a nonnitrogen fixing tree species) plantation had the lowest.

Soil communities affect on the processing of organic matter and nutrients. Soil faunal activity could improve soil physiochemical properties. The studies in the tropics have proved the vital role of soil fauna in the regulation of plant litter decomposition and nutrient release. Litter-feeding organisms hasten N mineralization in temperate, deciduous woodlands (Anderson et al., 1985). Earthworms constitute the largest part of invertebrate biomass in most soils (Tondoh et al., 2007). The activity of the organisms affects the soil processes that control the availability of plant nutrients such as nitrogen (Zou & Bashkin, 1998), organic matter dynamics and land productivity (Reich et al., 2005; Barrios, 2007). The soil and litter arthropods can be the useful bioindicators of the effects of land management on nutrient dynamics and site productivity (Bird et al., 2004). At the local level, soil properties (Mathieu et al., 2004) and litter quality and quantity (Aubert et al., 2003) are the most important factors that regulate macroinvertebrate communities (Tsukamoto and Sabang, 2005).

Soil macroinvertebrates can be associated with litter quality more than with litter quantity. Tree species rich in calcium were associated with increased native earthworm abundance and diversity, as well as with increased soil pH, exchangeable calcium, percent base saturation, and forest floor turnover rate (Reich et al., 2005).

Biologically, higher plants influence the life of most of the organisms (Antunes et al., 2008). Distribution of earthworms is regulated by leaf litter quality (Ca, C, and N), whereas the macrofauna richness is regulated by leaf litter mass, soil organic carbon, and leaf litter Mg. As the soil macrofauna is an important factor regulating the litter decomposition, more studies should be conducted on the relationship of soil mac- rofauna abundance and richness with litter decomposition, particularly the influence of seasonal variation (Sayad et al., 2012).

One of the earthworm species, *Eisenia fetida* (Figure 5.6) is viewed as a possible alternative of protein source in fish meal. The earthworms are being used as fish

FIGURE 5.6 An earthworm in its burrow mixing the residues on the soil surface into the subsoil. (Courtesy of USDA-NRCS.)

bait, and this practice is common in fishing activity throughout Malaysia. Owing to their high reproductive rate, low feeding costs, and ease of breeding in captivity, earthworms constitute an extremely interesting protein source for fish feed. Having high protein content earthworms are also used to feed chickens and pigs, and as a dietary supplement for ornamental fish and for fish cultivation (Shim and Chua, 1986; Zakaria et al., 2013).

Consumption of the finished product can help in improving soil biological, physical, and chemical properties and hence can improve the soil environmental quality (Ismail 2005). Vermicomposting complicated feeding of the epigeic earthworms with organic waste for the production of vermicast. Epigeic earthworms such as *E. fetida*, *E. andrei*, *Perionyx excavatus*, and *Eudrilus eugeniae* have been used to convert organic waste into vermicast or the worm feces that can be used as organic fertilizer and soil conditioner (Garg et al., 2006).

The nutrient contents of the oil palm biomass fibers were analyzed prior to the vermicomposting process. Due to the presence of earthworms in the vermicomposters, the decomposition was higher than the other treatments as depicted in Figure 5.7. Subsequently, the earthworms can ameliorate the polluting materials and are focused on biological degradation processes (Thambirajah et al., 1995). The application of earthworms in vermicomposting of oil palm empty fruit bunch (EFB) has been shown to increase the heavy metals as earthworms can accumulate a considerable amount of heavy metals in their tissues as shown in Table 5.8. Reduction in weight and volume of organic substrate during vermicomposting may be the reason for the increase in heavy metal concentration in the end product. The palm oil sludge from palm oil mill could be applied as efficient soil conditioner for sustainable land practices, after processing by composting with earthworms (Nahrul Hayawin et al., 2012).

In the natural Malaysian environmental conditions, the capability of *E. fetida* to convert organic waste into vermicast differs with type and quality of the substrate

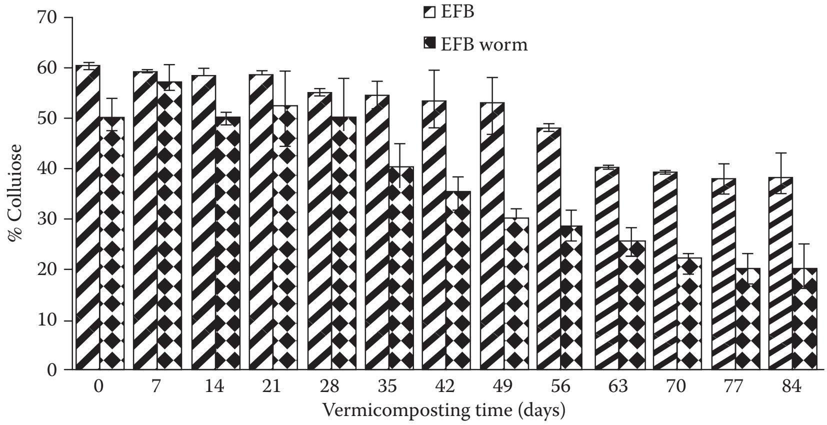

FIGURE 5.7 Trends in empty fruit bunches (EFB) cellulose degradation during vermicomposting (With and without earthworms).

TABLE 5.8
Heavy Metal Content (mg kg^{-1}) in Initial Feed Substrates and Vermicomposts Obtained from Empty Fruit Bunch (EFB) + Palm Oil Mill Effluent (POME) Vermicomposters

Feed Mixtures	Cu	Fe	Zn	Mn
Heavy Metal Content in Initial Mixtures[a]				
V_1	$3 \times 10^{-2} \pm 3 \times 10^{-3}$	$1.6 \pm 1 \times 10^{-3}$	$0.56 \pm 2 \times 10^{-2}$	1.3 ± 0.1
V_2	$0.18 \pm 2 \times 10^{-3}$	18.2 ± 2.3	0.59 ± 0.1^{-2}	1.5 ± 0.2
V_3	$0.18 \pm 6 \times 10^{-3}$	23.9 ± 0.1	$0.79 \pm 1 \times 10^{-2}$	2.1 ± 0.3
V_4	$0.19 \pm 1 \times 10^{-2}$	23.6 ± 0.6	$0.78 \pm 2 \times 10^{-2}$	2.3 ± 0.3
V_5	$0.3 \pm 8 \times 10^{-3}$	25.6 ± 1.2	$0.8 \pm 2 \times 10^{-2}$	2.5 ± 0.1
V_6	$0.4 \pm 2 \times 10^{-3}$	23.9 ± 1	$1.1 \pm 8 \times 10^{-2}$	2.6 ± 0.3
Heavy Metal Content in Final Vermicomposts Obtained from Different Vermicomposters[b] **(mean + S.E., *n* = 3)**				
V_1	$7 \times 10^{-2} \pm 4 \times 10^{-3}$	2.8 ± 1.4	$0.7 \pm 2 \times 10^{-2}$	2.0 ± 0.5
V_2	$0.4 \pm 3 \times 10^{-2}$	27.2 ± 1	$1.4 \pm 3 \times 10^{-2}$	2.8 ± 0.9
V_3	$0.77 \pm 5 \times 10^{-2}$	27.9 ± 1.9	$1.7 \pm 4 \times 10^{-2}$	3.6 ± 0.6
V_4	$0.8 \pm 2 \times 10^{-2}$	28.7 ± 0.9	$1.8 \pm 6 \times 10^{-2}$	4.1 ± 0.5
V_5	0.82 ± 10^{-2}	29.5 ± 0.8	$2.0 \pm 4 \times 10^{-2}$	4.8 ± 0.4
V_6	$1 \pm 3 \times 10^{-2}$	29.8 ± 1	$2.1 \pm 4 \times 10^{-2}$	5.4 ± 1.6

[a] Initial physicochemical characteristics of the feed in the vermicomposters have been calculated based on the percentage of EFB and POME.

[b] Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$). Units of all the parameters, mg/kg.

Symbols; V_1 = EFB(100), V_2 = EFB(90) + POME(10), V_3 = EFB(80) + POME(20), V_4 = EFB(70) + POME(30), V_5 = EFB(60) + POME(40), V_6 = EFB(50) + POME (50)

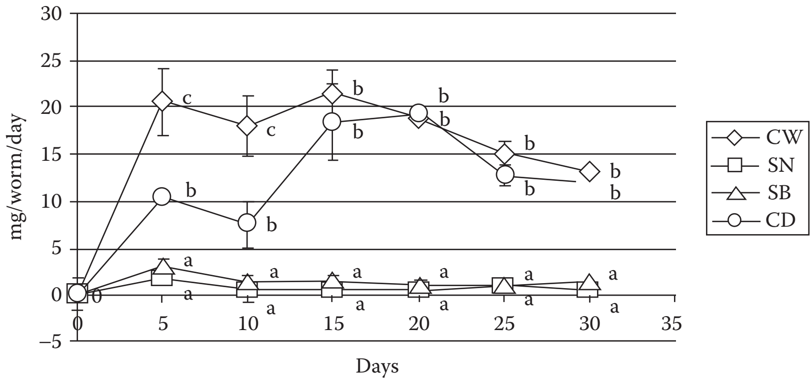

FIGURE 5.8 Growth increment of *E. fetida* given four types of the respective organic wastes (CW, cafeteria waste; SB, shredded banana trunk; SN, shedded newspaper; CD, cow dung).

used. Growth increment of *E. fetida* paralleled with the rate of waste conversion into vermicast, for example, higher growth increment resulted in faster conversion of wastes into vermicast (Jais and Hassan, 2008).

The growth increment of *E. fetida* given different types of substrates is shown in Figure 5.8. The increase in weight occurred immediately after the earthworms were fed with the waste in the order, cafeteria waste > shredded banana trunk > shredded newspaper > cow dung. In general, exponential increase in weight of the earthworm in all the organic wastes tested occurred until the 5th day of vermiculture and declined after the 15th day.

Furthermore, the use of earthworms in manure management has enhanced extremely in recent use of organic wastes, such as crop residues, animal manure, biosolids, and industrial waste (Edwards, 1998). Vermicompost is a distinctive organic manure source due to its plentiful amounts of nutrients, growth-enhancing substances, and many favorable microbes, which include P solubilizing and cellulose decomposing organisms (Sultan, 1997). The vermicomposting has increased the solubility of phosphate rock. The extractable P was 17% higher in vermicompost with the addition of phosphate rock. In addition, extractable macronutrients N and K were also found to be significantly higher in vermicomposting with the addition of phosphate rock (Wei et al., 2012).

Many species of nematodes are well known as important and devastating parasites of humans, domestic animals and plants. Nevertheless, most species are not pests, they occupy any niche that provides an available source of organic carbon in marine, freshwater and terrestrial environments. There may be 50 different species of nematodes in a handful of soil and millions of individuals can occupy 1 m^2. The nematodes that do not feed on higher plants may feed on fungi or bacteria and others are carnivores or omnivores.

Nematodes (Figure 5.9) have the potential to respond rapidly to disturbance and enrichment of their environment; increased microbial activity in soil leads to changes

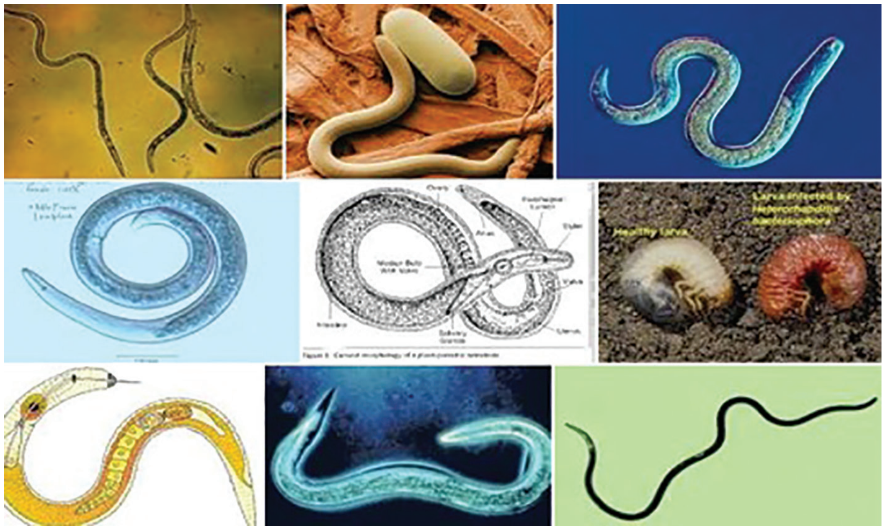

FIGURE 5.9 Beneficial nematodes in the soil. (From Plant & Soil Sciences eLibrary[PRO], Soil genesis and development, lesson 6—Global soil resources and distribution. Accessed December 11, 2014. http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447033&topicorder=12&maxto=12&minto=1, 2014.)

in the proportion of opportunistic bacterial feeders in a community. Over time, the enrichment opportunists are followed by more general opportunists that comprise fungal feeders and different genera of bacterial feeders (Bongers and Ferris, 1999). This succession of nematode species performs an important role in decomposition of soil organic matter, mineralization of plant nutrients, and nutrient cycling (Hunt et al., 1987).

Bacterial-feeding nematodes have a higher carbon:nitrogen (C:N) ratio ($\pm$5.9) than their substrate ($\pm$4.1) 12 (Ferris et al., 1997), so that in consuming bacteria they take in more N than necessary for their body structure. The excess nitrogen is excreted as ammonia (Rogers, 1989). The C:N ratio of fungal-feeding nematodes is closer to that of their food source. However, for nematodes of both feeding habits, a considerable proportion of the C consumed is used in respiration (perhaps 40% of the food intake) (Ingham et al., 1985). The N associated with respired C that is in excess of structural needs is also excreted. The excreted N is available in the soil solution for uptake by plants and microbes. Because microbivorous nematodes exhibit a wide range of metabolic rates and behavioral attributes, the contribution of individual species to nitrogen cycling and soil fertility may vary considerably.

Soil nematode communities may also provide useful indicators of soil condition. Nematodes vary in sensitivity to pollutants and environmental disturbance. Recent development of indices that integrate the responses of different taxa and trophic groups to perturbation provides a powerful basis for analysis of faunal assemblages in soil as *in situ* environmental assessment systems. Application of nematode faunal composition analysis provides information on succession and changes in decomposition pathways in the soil food web, nutrient status and soil fertility, acidity, and the effects of soil contaminants (Bongers and Ferris, 1999).

Soil Microorganisms

The natural soils comprise huge populations of microscopic plants and animals present in a state of dynamics equilibrium and changing balances. Microorganisms perform a vital role in agriculture by supplying nutrients to the plants and lessen the demand of chemical fertilizers (Cakmakci et al., 2006). Several bacteria, fungi, and actinomycetes are prominent to execute for the plant growth and have abundant quantity in the soil. Bacteria are more effective in phosphate solubilization than fungi (Alam et al., 2002). Bacteria have potential to be associated with the plants in roots by adhering at its rhizosphere or endosphere regions. Figure 5.10 shows Transmission Electron micrographs of some beneficial bacteria isolated from the wetland, aerobic, and acid sulfate rice areas in Malaysia. Bacterial strains isolated from maize soils are found to produce phytase enzyme important in releasing phosphorus for organic material (Hussin et al., 2010). One of the important fungi is the mycorrhiza which is the symbiotic association between fungi and vascular host plants. Mycorrhizal fungi colonize the root systems of several plants and aid in the uptake of nutrients, thereby improving plant growth and overall health. The beneficial effects of mycorrhiza on growth of several tropical crops have been highlighted by Naher et al., (2013). *Glomus mosseae* is well known to colonise

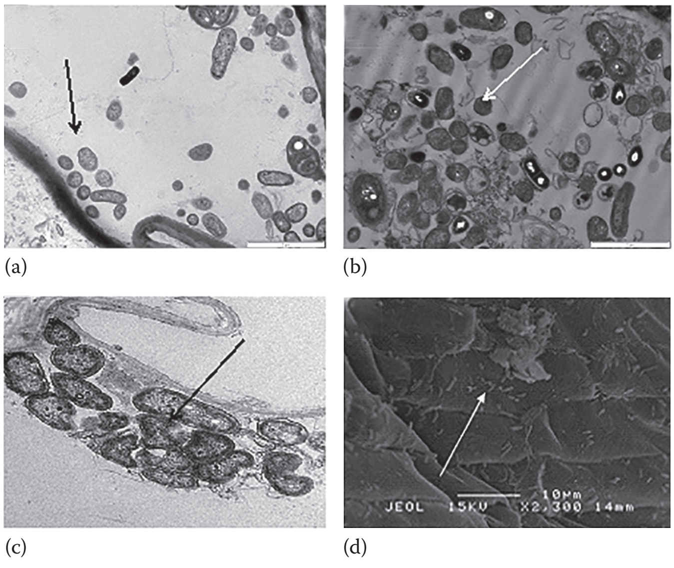

FIGURE 5.10 Transmission electron microscopic micrographs showing (a and b) nitrogen-fixing bacteria isolated from wetland rice at Tanjung Karang, Selangor, (c) PSB isolated from aerobic rice at Kepala Batas, Penang (d) acid sulfate bacteria isolated from acid sulfate soils at Semerak, Kelantan, Malaysia.

several crops and assist the plants to efficiently uptake nutrients and increase the plant's tolerance to diseases and other stresses. The soil bacteria and fungi form relationships with plant roots that provide important nutrients such as nitrogen and phosphorus. Fungi can colonize the plants and can supply numerous benefits, including drought and heat tolerance, and resistance to insects and plant diseases. Soil properties, vegetation, and fertilizer usage can influence the distribution and population of soil microorganisms.

FUNCTIONS AND BENEFICIAL CHARACTERS OF THE SOIL MICROORGANISMS

Releasing Nutrients from Organic Matter

Soil microorganisms are accountable for most of the nutrient release from organic matter. When microorganisms decompose organic matter, they use the carbon and nutrients in the organic matter for their own growth. They release extra nutrients into the soil where they can be taken up by plants. If the organic matter has a low nutrient content, microorganisms will take nutrients from the soil to meet their requirements. For example, applying organic matter with C:N ratios lower than 22:1 to soil generally increases mineral nitrogen in soil. In contrast, applying organic matter with C:N ratios higher than 22:1 usually results in microorganisms taking up mineral nitrogen from soil (Hoyle et al., 2011).

Fixing Atmospheric Nitrogen

Biological nitrogen fixation is an important source of nitrogen for agriculture and may account for up to 80% of total nitrogen inputs (Unkovich, 2003). In symbiosis, rhizobia or bradyrhizobia fix nitrogen gas from the atmosphere and make it available to the legume. In exchange, they receive carbon from the legume. The symbiosis is highly specific, and particular species of rhizobia and bradyrhizobia are obligatory for each legume. Fixation of N can also be occurring in the non-symbiotic association by several bacteria living in the rhizosphere.

Legumes

Legumes are the two most significant flowering plants used in agriculture. Legumes are benefitted as human and animal food, as wood, and as soil-improving components of agricultural and agroforestry systems. In Malaysia only a few legumes are being grown as agricultural crops and limited *Rhizobium* inoculants are being applied. Many forest trees are legumes, which nodulate with the bacterium *Rhizobium* (fast growing) or *Bradyrhizobium* (slow growing) and fix gaseous nitrogen thus using some of the 84,000 tonnes of nitrogen gas in the air above each hectare of land. There are more than 18,000 species of legumes of which about 7,200 species are woody. Only about 18% of these woody species have been inspected for nodulation and of this 92%–94% of the mimosoids and papilionoids nodulated, but only about 34% of the caesalpinoids form nodules (Dobereiner, 1993). It is not easy to determine if tree legumes nodulate as nodules are both difficult to find in forest soils and difficult to assign to a particular tree. Therefore, observations on young plants are helpful to assess the nodulation status of the plant.

Symbiotic Nitrogen Fixation

Most of the soils contain several types of *Rhizobium*, and in some soils, populations of suitable strains may be absent or too small for nodulation formation. In this situation the response to nodulation inoculation with *Rhizobium* might not be expected. Therefore superior strains to be used as inoculants need to be selected. The process of selection usually starts with collection of strains by isolation from nodules of a particular legume under consideration. This is followed by an assessment of their ability to fix nitrogen in a strain trial in pots using a rooting medium that does not comprise rhizobia (Trinick, 1980). For example, root nodules formed on the root system of a soybean plant. Nitrogen-fixing root nodule bacteria (*Bradyrhizobium*) present inside the nodule provide valuable organic nitrogen to the host plant, which promotes plant growth.

Nonsymbiotic Nitrogen Fixation

Biological nitrogen fixation also occurs through nonsymbiotic bacteria growing on roots and in degrading litter; through blue–green algae or cyanobacteria on soil and plant surfaces; and through associations of cyanobacteria with fungi and lichens, or with higher plants such as liverworts, mosses, cycads, and the angiosperm *Gunnera*. Most of the nitrogen in forest ecosystems is derived from biological nitrogen fixation. These systems are very efficient in recycling nitrogen that is leached to lower depths in the soil through uptake by deep roots, and through leaf fall, concentrating this nitrogen in the litter and upper soil horizons. Disturbing this natural cycle, which conserves scarce nutrients so effectively can lead to rapid loss of soil fertility. Maintenance of the litter layer as a soil mulch to reduce erosion as well as to conserve nutrients is a very important aspect of maintaining soil fertility around trees and shrubs.

Diazotrophs Associations in Rice

Diazotrophs are N_2-fixing bacteria that colonize and contribute biological nitrogen to the crops (Kundu and Ladha, 1995). Rice plant can form natural associations with various N_2-fixing bacteria, both phototrophs and heterotrophs. These diazotrophs can improve the growth and development of rice plant by transferring fixed N_2 or by producing phytohormone. The N_2 fixed by asymbiotic diazotroph may not be immediately available for plant growth. The plant may benefit from asymbiotic N_2 fixation in the long term, as nitrogen gets released through biomass turnover (Dobbelaere et al., 2003). Endophytic diazotroph can supply nitrogen more efficiently to the plants. The endophytic association is competitively accomplished to occupy associable niches within this nutrition-enriched and protected habitat of the root interior without showing any pathological symptoms on the host plant (Cocking, 2003). For example, the colonization of wheat roots by strains of *Azospirillium*, a bacterial inoculant that acts as a phytosimulator. Moreover *Azospirillum* induces the proliferation of plant root hairs, which can result in improved nutrient uptake.

Increasing Phosphorus Availability

Phosphatic fertilizers applied to low pH soil are precipitated by complexes with aluminium and iron immediately after application and making them not available to plant. Besides correcting the soil pH, another alternative to overcome this problem is through the use of phosphate- solubilizing bacteria.

Phosphate-Solubilizing Bacteria

The quantity of phosphate-solubilizing bacteria (PSB) is more abundant in the rhizosphere than nonrhizosphere soil and is metabolically more dynamic than from other sources (Vazquez et al., 2000). The PSB are found everywhere in the soils with different forms and their populations. The population of PSB is affected by various soil properties such as physical and chemical properties, organic matter, P content, and cultural activities (Kim et al., 1998), whereas higher populations of PSB are found in agricultural and rangeland soils (Yahya and Azawi, 1998).

It has been found that the poorly soluble P is usually dissolved by microorganisms, which can then be converted into soluble forms by the process of acidification, chelation, and exchange reactions (Chung et al., 2005). Microorganisms, especially PSB and arbuscular mycorrhizal (AM) fungi have the ability to solubilize P in soil and reduce inputs of chemical fertilizers (Arpana and Bagyaraj, 2007). Species of *Pseudomonas*, *Bacillus*, *Rhizobium*, *Burkholderia*, *Achromobacter*, *Agrobacterium*, *Micrococcus*, *Aereobacter*, *Flavobacterium*, and *Erwinia* are the plant growth-promoting rhizobacteria that have the ability to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and phosphate rock (Goldstein, 1986). Several PSB isolates from aerobic rice in Kepala Batas, Penang, Malaysia, are able to solublize insoluble P by producing organic acids (Panhwar et al., 2012). Phosphate solubilizing fungi have also been shown to have the ability to convert insoluble phosphatic compounds into soluble P form. These microorganisms may compensate higher fertilizer cost and also may mobilize the fertilizers added to soil (Pradhan and Sukla, 2005).

Actinomycetes

Actinomycetes are numerous and widely distributed in soil and are next to bacteria in abundance. They are widely distributed in the soil (Fierer et al., 2009). Actinomycetes are fungi-like bacteria creating long filaments that stretch through the soil. They have sometimes been classed as fungi because they both look similar and decompose similar material as fungi. However, they do not have defined nucleus. Also, antibacterial agents work against them but antifungal agents do not. As a decomposer, the actinomycetes specialize in breaking down tough cellulose and lignin found in wood and paper and the chitin found in the exoskeletons of insects. The breakdown of these materials makes nutrients once again available to plants.

The population of actinomycetes increases with depth of soil even up to horizon *C* of a soil profiler. They are heterotrophic, aerobic, and mesophilic (25°C–30°C) organisms, and some species commonly present in compost and manures are thermophilic growing at 55°C–65°C temperature (e.g., *Thermoactinomyces*, *Streptomyces*).

Actinomycetes degrade/decompose all sorts of organic substances such as cellulose, polysaccharides, protein fats, organic acids, and so on. Organic residues/substances added soil is first attacked by bacteria and fungi and later by actinomycetes, because they are slow in activity and growth than bacteria and fungi. They decompose/degrade the more resistant and indecomposable organic substance/matter and produce a number of dark black to brown pigments, which contribute to the dark color of soil humus. They are also responsible for subsequent further decomposition of humus (resistant material) in soil. They are not only able to survive under extreme soil condition such as low level of moisture or high salinity, but actinomycetes are also reported to promote plant growth (Hamdali et al., 2008). Actinomycetes are one of the predominant members of soil microbial communities, and they have beneficial roles in soil nutrients cycling and agricultural productivity (Elliot and Lynch, 1995).

Degrading Pesticides

The degradation of agricultural pesticides in the soil is primarily performed by microorganisms. Some microorganisms in soil produce enzymes that can break down agricultural pesticides or other toxic substances added to the soil. The length of time these substances remain in soil is related to how easily they are degraded by microbial enzymes.

Controlling Pathogens

Microorganisms and soil animals infect plants and decrease plant yield. However, many organisms in the soil control the spread of pathogens. For example, the occurrence of some pathogenic fungi in soil is decreased by certain protozoa that consume the pathogenic fungi. The soil food web contains many relationships similar to this that decrease the abundance of plant pathogens.

Improving Soil Structure

Biological processes in soil can develop soil structure. Some bacteria and fungi produce substances during organic matter decomposition that chemically and physically bind soil particles into microaggregates. The hyphal strands of fungi can cross-link soil particles helping to form and maintain aggregates. A single gram of soil can contain several kilometers of fungal hyphae (Young and Crawford 2004). In addition, soil animals increase pores by tunneling through soil and increase aggregation by ingesting soil.

Ecological Significance of Soil Microorganisms

Soil microorganisms are very important as almost every chemical transformation taking place in the soil involves active contributions from soil microorganisms. In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients such as carbon and nitrogen, which are required for plant growth. For example, soil microorganisms are responsible for the decomposition of the organic matter entering the soil (e.g., plant litter) and therefore in the recycling of nutrients in soil. Certain soil microorganisms such as mycorrhizal fungi can also increase the availability of mineral nutrients (e.g., phosphorus) to plants. Other soil microorganisms can increase the amount of nutrients present in the soil. For instance, nitrogen-fixing bacteria can transform nitrogen gas present in the soil atmosphere into soluble nitrogenous compounds that plant roots can utilize for growth. These microorganisms, which improve the fertility status of the soil and contribute to plant growth, have been termed *biofertilizers* and are receiving increased attention for use as microbial inoculants in agriculture. Similarly, other soil microorganisms have been found to produce compounds (such as vitamins and plant hormones) that can improve plant health and contribute to higher crop yield. These microorganisms (called *phytostimulators*) are currently studied for possible use as microbial inoculants to improve crop yield.

Biodiversity and Habitat

Each animal, plant, and microbe species requires a slightly different habitat. Thus, a wide variety of habitats are required to support the tremendous biodiversity on earth. At the microbial level, diversity is beneficial for several reasons. Many different organisms are required in the multistep process of decomposition and nutrient cycling. A complex set of soil organisms can compete with disease-causing organisms and prevent a problem-causing species from becoming dominant. Many types of organisms are involved in creating and maintaining the soil structure that is important to water dynamics in soil. Many antibiotics and other drugs and compounds used by humans come from soil organisms. Hence, preserving the diverse and healthy ecosystem is crucial. (Pankhurst, 1997).

The large quantity of living things on Earth requires a few basic elements: air, food, water, and a place to live. The decomposers in soil have need of an appropriate physical environment or habitat to do their work. All soil organisms require water for their activities and in condition of less water, some of them can still survive for long periods by transforming into a spore-like structure. A majority of the living organisms are aerobic requiring oxygen for growth, though some have evolved to thrive when oxygen is absent (anaerobes). Greater soil porosity and a wide range of pore sizes in the soil allow these organisms to get the oxygen. Soil texture has a great influence on the available habitat for soil organisms. Finer soils have a larger number of small micropores that provide habitat for the microorganisms. In addition, all soil organisms require organic material to use as energy and carbon source. Those requiring complex carbohydrates are known as the heterotrophs and those require carbon from carbon dioxide and energy from the inorganic materials are known as the autotrophs. Supply of fresh organic materials to soil will stimulate vigorous growth of soil organisms. Soil supports the growth of a variety of unstressed plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat. The ability of soil to support plant and animal life can be assessed by measuring the following indicators: Biological activity indicators include active fungi, earthworms, microbial biomass, potentially mineralizable nitrogen, respiration, and soil enzymes. Biological diversity indicators include habitat diversity and diversity indices for organisms such as bacteria, macro and microarthropods, nematodes, and plants.

The importance of knowledge in biological diversity provides opportunities in biotechnology and commercialization. Soil is full of living organisms of various sizes, ranging from large, easily visible plant roots and animals, to very small mites and insects, to microscopically small microorganisms (e.g., bacteria and fungi.) Microorganisms are the primary decomposers of the soil and perform processes such as transforming and recycling of organic materials, thereby mineralizing nutrients for growth of new plants and organisms.

The plant growth-promoting rhizobacteria from different states of Malaysia (Kedah, Kelantan, Selangor, and Terengganu) have potential for the multiple beneficial characteristics such as N2 fixation, P solubilization, K solubilization, indole acetic acid (IAA), and enzyme production (Tan et al., 2014a). Several N-fixing bacterial species have been isolated from rice growing area in Tanjung Karang, Selangor (Naher et al.,2009). The bacterial strains able to carry out N fixation are as presented in Table 5.9. Panhwar et al. (2012) isolated phosphate solubilizing bacteria from aerobic rice grown at Kepala Batas, Penang, Malaysia, having the ability to produce different organic acids for phosphate solubilization as presented in Table 5.10.

TABLE 5.9
Nitrogen-Fixing Bacteria, their habitat and Mechanisms of Crop Improvement

Bacterial Strain	Habitat	Energy Source	Mechanism of Effect	References
Azospirillum spp.	Rhizosphere, midly endophytic in roots, stems and leaves	Root exudates and plant tissue Organics in soil	BNF, PGP	Reinhold and Hurek (1988) Mirza et al. (2000)
H. seropedicae	Endophytic rhizosphere	Root exudates	BNF, PGP	Baldani et al. (2000)
Azoarcus sp.	Endophytic	Root exudates	BNF	Hurek et al. (1994)
B. vietnamiensis	Rhizosphere, endophytic	Root exudates Organics in soil	BNF, PGP	Baldani et al. (2000)
R. leguminosarum bv. Trifolii	Endophytic in roots	Root exudates	BNF, PGP	Biswas et al (2000)
R. etli bv. Phaseoli	Endophytic in roots	Root exudates	PGP	Guttiérrez-Zamora and Martínez-Romero (2001)
Rhizobium and *Corynebacterium* spp.	Endophytic in roots	Root exudates	BNF, PGP	Naher et al. (2009)
Bacillus sp. (Sb 42)	Endophytic in roots	Root exudates	BNF, PGP	Mutalib et al. (2012)
Rhizobium sp. *Bradyrhizobium* sp. *Bacillus* sp.	Endophytic in roots	Root exudates	BNF, PGP	Tan et al. (2014)

Source: Kennedy, I.R. et al., *Soil Biol. Biochem.*, 36, 1229–1244, 2004; Naher et al. (2009); Tan, K.Z. et al., *Am. J. Agric. Biol. Sci.*, 9, 342–360, 2014a.

BNF, biological nitrogen fixation; PGP, plant growth promotion.

TABLE 5.10
Productuion of Organic Acid by Phosphate-Solubilizing Bacteria

Bacterial Species	Organic Acids Produced	Reference
Bacillus sp. (PSB1)	Oxalic, citric acid, succinic acid, malic acid	
Bacillus sp. (PSB6)	Oxalic, citric acid, succinic acid, malic acid	
Bacillus sp. (PSB9)	Oxalic, citric acid, succinic acid, malic acid	
Bacillus sp. (PSB10)	Oxalic, citric acid, succinic acid, malic acid	Panhwar et al. (2012)
Bacillus sp. (PSB14)	Oxalic, citric acid, succinic acid, malic acid	
Bacillus sp. (PSB15)	Oxalic, citric acid, succinic acid, malic acid	
Bacillus sp. (PSB16)	Oxalic, citric acid, succinic acid, malic acid	

Source: Panhwar, Q.A., *African J. Biotechnol*., 11, 2711–2719, 2012.

The microbial activities were conducted at forest plantation in Sabah, Malaysia. The soil disturbance affected the microbial activities severely, but slowly it was improved after 2 years. Hence, microbial growth kinetics were proven to be the promising tools for assessing the effect of soil disturbance and rehabilitation (Ilstedt, 2002). Moreover, a study was conducted at Sungai Buluh, Selangor, and Malaysia to observe the effects of herbicides (alachlor and metachlor) on the microbial population especially on the bacterial and fungal population. It was found that application of alachlor has less effect on bacterial population when compared with metachlor. It shows that the herbicide application significantly influences the microbial activities in the soil (Ismail and Shamshuddin, 2005).

Soil bacterial communities of tropical rainforest in Malaysia are affected by the environmental distance that was highly correlated with community dissimilarity at both spatial scales, stressing the greater role of environmental variables rather than spatial distance in determining bacterial community variation at different spatial scales. Soil pH was the only environmental parameter that significantly explained the variance in bacterial community at the local scale, whereas total nitrogen and elevation were additional important factors. In total, our results support a strong influence of the environment in determining bacterial community composition in the rainforests of Malaysia. (Tripathi et al., 2014). Similar results were found earlier by that bacterial community composition, and diversity was strongly correlated with soil properties, especially soil pH, total carbon, and C/N ratio. Soil pH was the best predictor of bacterial community composition and diversity across the various land-use types, with the highest diversity close to neutral pH values (Tripathi et al., 2012). Moreover, the herbicide application to soil of oil palm plantation causes transient impacts on microbial population growth, when applied at recommended rate or even as high as double (2×) of the recommended field application rate (Zain et al., 2013).

Many earlier studies of Malaysian fungi were of a floristic nature with the most important work being contributed by the late E.J.H. Corner (Watling and Ginns, 1998). Chin (1988) reported the edible and poisonous fungal species of Sarawak, in particular those used by the indigenous Iban, Melanau, and Malays. The edible and medicinal species of macrofungi are listed in Table 5.11.

TABLE 5.11
Edible and Medicinal Species of Macrofungi

Source	Edible Species	Medicinal Species
Burkill (1966)	21	11
Chin (1981, 1988)	50	–
Chang (1997)	8	9
Chang and lee (2001)	4	3
Total number of species	83	23
Total number of different species	71	12

There is a gradual loss of knowledge in traditional wild edible fungi in the world including Malaysia. A documentation of known wild edible fungi in Malaysia was reported by Abdullah and Rossea (2009) and among those that have been successfully documented were *Cookeina* and *Galiella* of the class *Ascomycetes* and *Termitomyces*, *Schizophyllum*, *Hygrocybe*, *Lentinus*, *Calvatia*, *Calostoma* and *Auricularia*, from the *Basidiomycetes* that make up a total of 13 or 14 species belonging to 9 genera. Other reports on utilization of macrofungi by local communities in Peninsular Malaysia also have been reported (Chang and Lee, 2001).

Microbial activities can be observed in all soil types. In forest soil, differences can be observed in microbial population and biomass carbon between a natural forest and an 18-year-old stand of *Shorea leprosula* in Chikus Forest Reserve, Perak, Malaysia (Daljit Singh et al., 2011). Several fungal strains from different locations in the state of Perak and National Park in Pahang, Malaysia with potential antimicrobial activities have also been observed (Siti Hajar, 2011).

Actinomycetes are widely distributed in different habitats and they are involved in important processes such as composting and acts as a biocontrol agent for plant diseases. Several actinomycetes have been isolated from soil in Serdang, Bangi, Petaling Jaya, and Putrajaya areas showing the ability to degrade cellulose, mannan, and xylan components. A few of them have the ability to produce antimicrobial activity against selected phytopathogens such as *Xanthomonas campestris* (Jeffrey et al., 2007).

Microbes in Agriculture and Environment

Microorganisms in soils are the important component that helps to improve agricultural productivity. Men use naturally occurring organisms to develop biofertilizers and biopesticides to assist plant growth and to control weeds, pests, and diseases. Microorganisms that live in the soil actually help plants to absorb more nutrients. Plants and these friendly microbes are involved in nutrient recycling. The microbes help the plant to take up essential energy sources. In return, plants release organic compounds into the rhizosphere zone for the microbes to use as their carbon and energy sources. Scientists use these friendly microorganisms to develop biofertilizers. The broad application of microbes in sustainable agriculture is due to the genetic dependency of plants on the beneficial functions provided by symbiotic cohabitants (Noble and

Ruaysoongnern, 2010). The agronomic potential of plant–microbial symbioses proceeds from the analysis of their ecological impacts, which have been best studied for N_2 fixing (Franche et al., 2009). This analysis has been based on applied coevolutionary research (Arnold et al., 2010), addressing the ecological and molecular mechanisms for mutual adaptation and parallel speciation of plant and microbial partners.

The major impact of agricultural microbiology on sustainable agriculture would be to substitute agrochemicals (mineral fertilizers, pesticides) with microbial preparations. However, this substitution is usually partial and only sometimes may be complete. Improvement of the legumes symbioses for increased N_2 fixation is crucial. Importance is given to breeding of the leguminous crops for the preferential nodulation by highly active rhizobia strains, for the ability to support N_2 fixation under moderate N fertilization levels and to ensure a sufficient energy supply of symbiotrophic nitrogen nutrition (Provorov and Tikhonovich, 2003). This approach is most promising in legume–rhizobia symbioses where the strong correlations between the ecological efficiency of mutualism and its genotypic specificity are evident (Provorov and Vorobyov, 2010).

The extreme erosion of topsoil from farmlands caused by intensive tillage and row crop production may cause extensive soil degradation that contributed to the pollution of both surface and groundwater. The organic wastes from animal production, agricultural and marine processing industries, and municipal wastes (i.e., sewage and garbage), have become major sources of environmental pollution in both developed and developing countries. In addition, the production of methane from paddy fields and ruminant animals and production of carbon dioxide from the burning of fossil fuels, land clearing, and organic matter decomposition have been linked to global warming as greenhouse gases (Parr and Hornick, 1992). Chemical-based conventional system of agricultural production is one of the major causes to create many sources of pollution that, either directly or indirectly, can contribute to degradation of the environment and destruction of our natural resource base. This situation would change significantly if these pollutants could be used in agricultural production as sources of energy.

Therefore, it is necessary that future agricultural technologies should be compatible with the global ecosystem and with the solutions to such problems in areas different from those of conventional agricultural technologies. An area that appears to hold the greatest promise for technological advances in crop production, crop protection, and natural resource conservation is that of beneficial and effective microorganisms applied as soil, plant, and environmental inoculants (Higa, 1995).

DETRIMENTAL EFFECTS OF ORGANISMA IN SOIL

Highly specialized interactions between soil pathogen and plants can adversely affect seedlings and even adult trees. Several organisms target younger plants but others appear as problems at later stages in the life of the plant. Other pathogens are able to cause disease in many different plant species. Some plant pathogens depend on their host plant for survival and are unable to complete their life cycle without infecting their host plant. Biotrophic organisms of this type are often difficult to grow in laboratory media.

Insect pests are a problem in agriculture production. They attack by defoliating, sucking, stem-mining, and gall-forming species can delay seed ripening, reduce seed production and individual seed weights, reduce the rates of shoot and root growth, enhance the susceptibility of plants to disease, and decrease the competitive potential of plants relative to their unattacked neighbors (Crawley, 1989). Termites are one of the major causes for low yield of the several crops. These insects mostly attack on the roots of the plants and finally cause death of the plants. Method of controlling these insects through agrofriendly techniques such as utilizing some plants as a cheap source of natural pesticides against termites is of importance (Thamer, 2008).

Nematodes such as *Meloidogyne incognita* and many others are associated with plant disease and is a serious threat to crop production worldwide. Several species have been known to cause damage to fruit crops such as guava, banana, and other crops such as chilli, black pepper, and turf grass. Kenaf (Hibiscus cannabinus) cultivated in Telaga Papan in Terengganu, Malaysia has been observed to be affected by the root-knot nematode resulting in reduced plant growth with symptoms of decoloration, drying, and wilting of leaves along with development of galls on roots (Tahery et al., 2011). Population and distribution of this plant parasitic nematodes have been surveyed in banana plantations in various states in the Peninsula Malaysia and found that several nematode species exist in different locations of banana plantations (Sayed Abdul Rahman et al., 2014).

CONCLUSION

The soils of Malaysia contain huge populations of micro- and macroorganisms that are present in a state of dynamics equilibrium and changing balances. These organisms need to be increased in quantity and functionality to benefit the soil productivity. The major impact of these soil organisms on sustainable agriculture would be to substitute agrochemicals with microbial inoculants. The combination of a diversity of biological activities and functions and natural and regulatory mechanisms in the soil forms long-term sustainability. More attention should also be focused on evaluating the role of specific groups of soil organisms, their diversity on the multiple biological interactions in soil to reduce the chemical (herbicides, insecticides, and fertilizers) dependence, and their detrimental effects on human and environment.

MECHANICAL PROPERTIES OF SOIL BASED ON ENGINEERING CHARACTERISTICS

Importance of Soil in Construction

Soil is used as bedding or support for all types of heavy structures, such as roads, highways, infrastructure and for foundation of structures. The deterioration or collapse of these structures actually depends on soil behavior, that is, strength parameters of soil.

Structural response of soil is expressed in terms of stress, strain, and deflection, which depend on base soil (Brown, 1996). The desirable properties of foundation soil are as follows:

1. Adequate shear strength
2. Adequate permeability
3. Ease and permanency of compaction
4. Volume stability
5. Permanency of strength

Strength parameters of materials are expressed in terms of California bearing ratio (CBR), which were developed in the year 1930. CBR of foundation soil plays the most vital role for structures in terms of durability. CBR of soil fluctuates with variation in water table or flood water. Support provided by the soil in place (subgrade) is the most basic factor for all structural design procedures. Surface deflection of roads is highly dependent on subgrade support.

Some of the available soil parameters are very old. Proctor and modified Proctor test, maximum dry density (MDD), and optimum moisture content (OMC) were developed around the year 1933. Field density test (FDT) was also developed at that time with Proctor tests. Presently, all these soil parameters are used, but they are not reliable. The resilient modulus of soil is measured in the laboratory for MDD and OMC to reflect the conditions under which the subgrade soil is usually prepared. Presence of water in subgrade soil is limited by OMC and controls the strength of soils.

Water is a polar molecule and plays an important role in all types of structures as it determines the durability of structures. Many tests are involved in soil characterization. They are as follows:

1. Innovative soil classification (USC)
2. Consistency of soil-Atterberg limits (McBride, 2002)
3. FDT
4. Resilient modulus test, *Mr*
5. Resistance value, *R*
6. Modulus of subgrade reaction, *K*
7. The standard Casagrande soil test (1932, 1948)
8. CBR
9. Dynamic cone penetration (DCP)
10. Hveem resistance value
11. Plate load test
12. Triaxial tests

Support provided by the soil in place (subgrade) is the most basic factor for all structural design procedures. Surface deflection is highly dependent on subgrade support.

AVAILABILITY OF SOIL IN MALAYSIA

Soils are of low cost and light weight construction materials, which have gained popularity in building industry. Peat is one of the major soils in Malaysia. About 3.0 million ha or 8% of the area is covered with peat. It is located in all over the earth except in the arctic and desert areas and amounts to about 30 million ha or 5% to 8% of the earth's surface (Harden and Taylor, 1983). Two-thirds of the earth coverage of tropical peat is in South East Asia, that is, about 23 million ha. Peat soils encompass 2,457,730 ha; 7.45% of Malaysia's total land mass (32,975,800 ha) (Huat et al., 2005). Sarawak supports the largest area of peat soils in Malaysia, about 1,697,847 ha; 69.08%, Peninsular Malaysia about 642,918 ha; 26.16%, Sabah about 116,965 ha; 4.76% (Wetlands International—Malaysia Ministry of Natural Resources and Environment, 2012). Organic and peat soil are more difficult to stabilize due to lower solid content, higher water content, lower pH, and its potential to interfere chemically and biologically with time and environmental condition (Hernandez Martinez and Al Tabbaa, 2009; Huat, 2002). Laterite soils are also available in many locations of Malaysia. Its CBR is as high as 80%, whereas the required CBR of soil is greater or equal to 5% for major infrastructure construction.

LANDUSE IN MALAYSIA: AN ENGINEERING PERSPECTIVE

About 72% of Malaysia's land is still forested or marshlands according to 1990 data. The remaining land (about 28%) is mostly utilized for agricultural cultivation of palm oil (*Elaeis guineensis*), rubber (*Hevea brasiliensis*), cocoa (*Theobroma cacao*), coconut, and paddy. In Peninsular Malaysia, the general pattern of landuse is one of extensive cultivation in areas where the terrain is less rugged and easily accessible. A large part of the steep mountainous area is comprised of forest. Pockets of steep areas in the lowlands have been opened up for large-scale agricultural development schemes. In Peninsular Malaysia, about 5000 ha of steep mountainous land in the Cameron Highlands has been developed for plantation of tea, temperate vegetables, and fruit trees. In Sabah and Sarawak, much of the cocoa and pepper are planted on steep lands. Other landuse in steep areas is now shifting from cultivation mainly found in East Malaysia. In Sarawak, this amounts to about 0.08 million ha (or 2.7 million ha, including fallow area). The usage of lateritic soils that are found in less steep areas is more extensive despite their stony nature, indicating that the limitations of stony soil are more acceptable to the farmers (Aminuddin et al., 1990). The strength of laterite soils that are expressed in terms of CBR possesses higher strength and is used as construction materials. In general, laterite possesses 80% CBR, which is why it is used as construction material. In many parts of Malaysia, laterite is used for construction of road shoulder such as Rawang, Assam Jawa in state of Selangor.

As landuse is devoted to human activities, it will affect the surrounding areas. Changes in landuse can cause transformation in surface runoff, flood frequency, base flow, and annual mean discharge of water as well as deforestation (Huntington, 2006). Clearing of land plays an important role in soil degradation and loss of soil in catchment areas throughout the world (Gharibreza et al., 2013).

The combined impacts of changing large swaths and climate variability have resulted in increased surface runoff, water yield, soil water content, and evaporation. Moreover, it decreases groundwater flow and percolation. These findings show that the variation of landuse plays a vital role in local water cycle changes, especially for the water movement within the soil layers (Tan et al., 2014b).

Impact of Landuse in Malaysia

The topography of Peninsular Malaysia is dominated by the main range, which runs almost centrally along the middle of the Peninsula to a height of about 2000 m above mean sea level. From these mountainous systems, many rivers flow toward the flood plains and the coast. The west coast is dominated by alluvial marine deposits, whereas the east coast has exposed riverine deposits and sandy beach ridges. About 8% of the land area is swamp land, mainly in the coastal depressions. Sarawak and Sabah are generally mountainous and drained by an intricate system of rivers. Almost 70% of Sarawak consists of very steep areas. The highest peak is Mount Mulu with a height of 2371 m. The interior of Sabah has a series of mountain ranges and hills, the most prominent of which is the Crocker Range that rises abruptly to Mount Kinabalu with a height of 4175 m, and it is the highest mountain in South East Asia (Aminuddin et al., 1990). The mountainous area will affect several aspects of landuse in Malaysia such as erosion, degradation, siltation, and so on. It will also cause problem in the development of structure and infrastructure in particular areas (Aminuddin et al., 1990).

Soil Erosion in Upland and Crop Area

A large proportion of land described as upland and steep land whose soil erosion and the associated process of nutrient depletion are important forms of land degradation. The problem is exacerbated by failure to implement erosion control measures that are appropriate for the prevailing circumstances in a timely manner. Very often, cleared land is left exposed for extended periods before erosion control work is carried out. In some cases of highland areas, where high-value subtropical crops are produced, the effects of erosion are offset by the large application of manure and fertilizer. Although the practice of applying high rates of fertilizer and manure helps in maintaining reasonable levels of crop production, the unchecked losses of soil, nutrients, and chemicals through erosion processes contribute to downstream pollution and sedimentation. These are major environmental problems in some highland districts. Further improvements in erosion control, especially in terms of increased awareness, selection of appropriate measures and timely implementation, are necessary in view of the limited extent of good arable land. These measures as well as a total embrace of soil conservation will contribute in preserving the considerably large area of potentially productive upland.

Development Constraints

In general, farmers in steep land areas do not utilize good soil conservation practices, as they are usually motivated by short-term profit. As such in the Cameron Highlands catchment, soil loss is more than 125 kg/ha/year. This has caused extensive siltation of the hydroelectric dam downstream and shortened its life span to a mere third of initial projection. Moreover, the hydroelectric power generator cannot be operated during peak downpours as the sediment load is too high. The quality of drinking water is equally affected. Indiscriminate farming in such an area cannot be sustained. In some places, soil has to be brought from outside areas to replenish what was lost by erosion after a period of about 30 years. The removal of forest has also caused an increase of the surrounding temperature by 10°F or 2°C. However, in other steep areas, where cover crops are used, very low erosion rates are experienced. The practice of shifting cultivation on steep land was found to be ecologically stable and sustainable when the fallow period was about 10–15 years. Recently, however, the erosion problems have become severe as the fallow period decreased, in some cases to less than 3 years. Such a landuse is unproductive and wasteful, and a workable alternative farming system must be introduced (Aminuddin et al., 1990).

Construction Problem in Steep Land

A major constraint in steep areas is the slope length. This coupled with heavy tropical rainfall causes excessive runoff and erosion. Proper choice of crops on steep areas minimizes the developmental constraints. A technological package for growing rubber on such a slope is available. In contrast, such soils are not at all suitable for the cultivation of annual crops. Continued erosion under annual crops would reduce the soil depth and soil fertility as the organic matter and clays are removed. Other technological constraints include unfavorable effects of land clearing. In land development projects, areas as large as 2000 ha are cleared at one time mostly using heavy machines. Some research showed that mechanical clearing resulted in a lowering of CEC, organic carbon, and potassium (K) content in topsoil (Ling et al., 1979). CEC is a measure of the soil's ability to hold positively charged ions. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilizers, and other ameliorants (Hazelton and Murphy, 2007). Besides that, mechanical clearing also compacted the soil and reduced infiltration, and removed vegetative cover, making it more vulnerable to erosion (Pimentel and Kounang, 1998). From an economic point of view, a major constraint is seen in the added cost of development, especially the cost of conservation measures. Moreover, as machinery usage is not encouraged in very steep areas, higher costs are incurred during manual land clearing and terracing (Aminuddin et al., 1990).

Poorly Developed Infrastructure

Presently, the road system to the hinterland is poorly developed. Development of such infrastructure is extremely expensive because of dissected terrain. It is also difficult to justify when rural settlements are so widely scattered. As a result, farm inputs and basic human necessities are costly to deliver to these communities. Extension efforts to those are equally costly, arduous, and inefficient (Aminuddin et al., 1990).

Negative Impact to the Environment

Natural life systems or ecological systems are also among the most sensitive to environmental changes brought about by human activity. Such changes may directly impact species of plants and animals or indirectly through alteration to their habitat(s) and life support system. Besides that, it can also affect the areas identified as important or potentially important sources of groundwater supply. It should be avoided by those developments or activities, which have a high potential of contaminating groundwater or reduce its capacity for recharge. This is because once contaminated, groundwater is difficult to remediate. Similarly, turtle landings during the breeding season are affected by noise and light, which are likely to cause them to move elsewhere (Malaysia Ministry of Natural Resources and Environment, 2012).

Water in Soil

The role of water content in soil material is a critical factor for its compaction to get maximum density. Currently, the conventional methods are unable to predict the proper moisture content for its compaction effort. For the strength parameter of soil, CBR mainly depends on moisture content. Probably, this physical property does not properly predict soil behavior under load conditions resulting from heavy traffic. Moisture content of soils is not properly investigated in design and construction stages. The dielectric constant of water is 78 (approximately) at 25°C at a microwave frequency of 100 MHz; this value varies with the amount of substrates present in soil materials. To get proper Proctor value of compaction effort, microwaves are able to provide proper moisture content of soil in terms of dielectric constant. It can provide valuable information as water is very sensitive to microwaves. Unsuitable soils are not desirable for construction; they need major modification and are costly.

LAND CHARACTERISTICS OF MALAYSIA

Damages Due to Seismic Hazard

Major earthquakes originating from these interplate boundaries (subduction zone) volcanic arcs have been felt in Malaysia. Sabah and Sarawak have experienced moderate earthquake of local origin that appeared to be related to several possible active faults. In 1976, in the district of Lahad Datu, an earthquake of magnitude 5.8 on the Richter scale developed some cracks in walls of buildings. Several flexible roads were also cracked as reported in the area. A four-storey police complex nearing completion suffered severe structural damages. An earthquake of magnitude 5.2 caused extensive damage to a four-storey teacher's quarter and was declared unfit for occupation. On May 2, 2004, a state near Miri in Sarawak similarly caused damage to the nonreinforced concrete buildings and cracks developed in the ground.

Soil Settlement Issue

Bentong Lipis Road

Soil settlement is a major issue for Malaysian roads. Bentong Lipis Road was a project undertaken by Malaysian JKR (Jabatan Kerja Raya) in November 2001 and completed in October 2004. The subgrade soil was clayey in nature. The road was built on this clayey soil without proper treatment. Consolidation was taking place.

The maintenance cost was five million Malaysian Ringgit (average) per year (Unit, 2001). The original contract's cost was RM 140 million. The bottommost layer of pavement subgrade was not treated properly. The cost of repair each year was higher compared to the original construction cost of the project (Information from Maintenance unit, Road branch, Jabatan Kerja Raya [JKR/PWD] Head quarters).

Unsuitable Soil Materials

Unsuitable soil material exists in many parts of Malaysia, for example, Bukit Jalil, Kuala Lumpur, and the place of 16th Commonwealth games, held in the year 1998. Many structures were built in this area to facilitate the games. At one of the site support facilities, a crawler excavator moved on the soil surface to work. The ill-fated excavator sunk into the soil within a few minutes, as it was unable to move to a safer place. This depicts a clear picture of unsuitable soil materials in Malaysia. The surrounding areas of KL International Airport (KLIA) also have unsuitable soil material. During construction of roads in that locality (Road B20, Eastern access to KLIA), a replacement of unsuitable soil material by sand upto a depth of 3.0 m, was carried out. The depth was calculated by the Mackintosh Probe results.

Slope Failures

In Malaysia, usually many slope failures occur during the monsoon season after a prolonged intense rainfall period. Recent cases showed that some major roads especially those constructed in rugged mountainous terrain were totally cut off during these slope failures. A typical example is the 112 km East–West highway linking the western and eastern region of Peninsular Malaysia (Lloyd et al., 2001). Failures of cut slopes along the highway are quite common because their natural formation is subjected to weathering and erosion. Surface water infiltration to the cut slope causes increased water pressure inside the soil and corresponding reduction in soil's shear strength.

Cavities and Fractures

Subsurface cavities and fractures are associated with foundation and pilling problems. The topographical model was used to automatically extract minimum surface curvature, slopes, and pits. More than 14 regional faults affect the Kuala Lumpur limestone bedrock and the surface topography from South to North (Hashim and Islam, 2008). These fractures often show higher probability of piling and constructions problems.

SOIL AND CONSTRUCTION IN MALAYSIA

Peat soil is problematic soil in the construction field and is located all over the earth except in the arctic and desert area. The amount of this land is about 30 million ha, 5%–8% of the earth's total surface (Harden and Taylor, 1983). In South East Asia alone, it is about 23 million ha. Research was carried out to find ways of improving engineering techniques and using peat soil as a construction material by using different techniques and additives (Hebib and Farrell, 2003; Huat, 2006). A study on traditional fired bricks and stabilized compressed peat-based bricks both in experimental and field investigation construed that it will be possible to use peat soil as building wall materials. Such soil can help decrease material cost, create opportunities to use peat soil, reduce energy consumption, and minimize environmental damage.

During the rainy season, there is heavy rain in Malaysia, and in summer it is extremely hot. There is a definite need to investigate and develop the properties of compressed stabilized peat bricks to withstand extreme weather conditions, which are expected to intensify due to global warming.

Roads and Highways

The bottommost layer of a road is known as subgrade layer, which is constructed from natural soil or imported soil depending on the soil's properties. The investment in road industry is the largest in many countries. A well-constructed road lasts long and requires less maintenance, depending mainly on subgrade formation level (soil). Rutting deformation occurs at subgrade formation level, which is the base and bottommost layer of roads and highways for carrying design axle loads. All the deterioration of roads, especially rutting deformation occurs at subgrade level.

SOIL IMPROVEMENT AND STABILIZATION

Additives in Soil

Ordinary Portland Cement (OPC) is normally used as a soil additive particularly in the arid region, as it stabilizes clayey and sandy soils. In sediment soils, cement has the power to increase the plasticity index and to decrease the liquid intake, thus increasing the workability of soil. Theoretically, all kinds of soil can be stabilized with cement. Experimentally, with the increase of silt and clay content in the soil, more cement is required for stabilization of the soil. The addition of inorganic chemical stabilizers such as cement and lime has twofold effects on the soil, namely, acceleration of flocculation and promotion of chemical bonding. This bonding is subjected to characters of the additive (Deboucha et al., 2008) and strength of clay, and silt can develop up to 30-fold (Janz and Johansson, 2002). In the stabilizing process of soil, any kind of cement or lime can be used. OPC is commonly used (Janz and Johansson, 2002). In the case of soft and organic soil stabilization, adding additives such as lime, cement, and fly ash to soft soil helps develop its strength.

Ground Improvement for Infrastructure Development

Several soil improvement methods are available for the problematic soils in Malaysia (Raju and Yandamuri, 2010). Among them are jet grouting, deep soil mixing, vibro concrete column, and vibro stone column. Table 5.12 shows the soil problem in infrastructure development and the application of soil improvement.

TABLE 5.12
Soil Problem in Infrastructure Development and Corrective Techniques

Project Background	Problem/Soil Condition	Solution/Improvement
A project involved the construction of a 13 m diameter bored tunnel in Kuala Lumpur, over a distance of approximately 10 km. The tunnel will mainly function as a storm water storage and diversion channel as well as incorporating a 3 km triple deck motorway. Construction of a 13 m diameter bored tunnel over a distance of approximately 10 km. The cutter head of the tunnel boring machine (TBM) required maintenance at regular intervals. During such TBM stops (referred as *cutter-head intervention*), the slurry pressure is switched off and stability of the rock/soil face in front of the TBM relies on air pressure and the inherent strength of in situ rock/soil.	The geology encountered along the tunnel path was ex-mining soils and for limestone formation. Due to the existence of loose sandy material, there was a risk of ground disturbance and subsequent ground subsidence, if left untreated.	Jet grouting. The capping shield made of jet grout columns was designed to form a stable block at the cutter-head intervention location.
Three-storey commercial complex with two-level basement car park floors (about 7 m depth below the existing ground level) is under construction in the middle of Kuala Lumpur city centre. The project site is confined between a newly completed four-storey commercial lot, light rail transit track, and existing old warehouse.	Subsoil comprised loose silty sand deposits and ex-mining soils. Karstic limestone formation was found underlying these loose soil layers, with extremely varying rock-head levels ranging between 3 and 15 m below the existing ground level.	Deep soil mixing. The gravity wall is built to act as a temporary retaining structure during the basement excavation works. Wet deep soil mixing columns of 0.85 m diameter were interlocked at 0.75 m centers to form the rigid gravity wall block.
Huge sewage treatment plant is under construction in Penang Island, and after completion it will serve as a centralized sewage treatment facility. It will include 12 sequential batch reactor (SBR) tanks and associated process tanks.	The site was reclaimed from the sea and approximately half of the SBR tanks area was covered by former domestic landfill waste dumps (3–5 m thick).	Vibro concrete columns and deep soil mixing were utilized to support the SBR tanks on the ground.

(*Continued*)

TABLE 5.12 (*Continued*)
Soil Problem in Infrastructure Development and Corrective Techniques

Project Background	Problem/Soil Condition	Solution/Improvement
Modern expressway with dual three-lane carriageway forms the main interchange at Kampung Pasir Dalam to connect three distinct routes in the city. Due to site constraints at the interchange, high reinforced soil walls were constructed to form approaches and other ramps to the bridge according to the required design heights (maximum up to 13 m).	Subsoil conditions at Pantai Dalam interchange varied from very soft silts to soft sandy silts down to a depth between 5 and 12 m followed by hard sandy silts.	Vibro stone columns are used to support reinforced soil walls, which used to support the soil. The combination has proven economical and has intrinsic technical advantages; that is, the stone columns ensure relatively quick consolidation as the embankment is built, whereas the wall is constructed in stages (lifts) with wall panels placed progressively and adjusted for any movement.

Source: Raju, V. R., Yandamuri, H. K., *Proc. ICE-Ground Improv.,* 163, 251–263, 2010.

Ground Improvement of Slope

Common techniques adopted for remedial work on failed fill slopes along the East–West highway included the reconstruction of slope for a stable gradient, improvement of overall drainage, reinforced slope, and retaining structures. In most cases, the remedial work involved a combination of the techniques (Anderson et al., 2000). Reconstruction of the failed fill slope consists of excavation and removal of debris and loose soil from the existing failure surface up to a stronger layer. The depth of excavation is determined from the Mackintosh probe results where 80 blows/300 mm is the limit. The new fill slope is then reconstructed in layers and compacted according to the standard Proctor compaction method.

1. In instances where seepage points are located within the fill slopes, sufficient discharge facility is provided in the stabilized fill area by installing layers of 300 mm thickness of sand drainage blanket. This sand layer is also incorporated between the excavated surface and the newly placed fill material.
2. Reinforced earth techniques are also employed for some remedial work for fill slopes at the East–West highway. This method applies to the combination of soil and reinforcing elements introduced into the body of the fill slope.

Fill slope remedial work, which involved realignment since cutting through the hill is inevitable, requires retaining structures in the form of bored piles. This method is applicable when there is a lack of space, and site conditions are restricted due to certain geological conditions. Installation of bored piles of 1000–1200 mm diameter spaced closely to retain a fill slope is quite common under the prevailing circumstances.

Other Ground Improvement

Other soil improvement methods associated with the soil problem are as follows:

1. Soil stabilization by applying modifiers
2. Surcharge
3. Removal of unsuitable soil by sand with geotextiles
4. Prefabricated vertical drain
5. Piling

SOIL INVESTIGATION

The basic reasons for conducting soil investigation are to determine the geotechnical engineering properties of the soil and to evaluate the groundwater level. It can be done by conducting in situ test and by collecting disturbed and undisturbed soil samples for testing in the laboratory. Also, soil investigation must be carried out in accordance with the specifications and guidelines stated in the approved standards.

Standard penetration test (SPT) and standpipe piezometer methods of field exploitation would be briefly discussed. SPT can be performed at an interval of 1.5 m by driving a split spoon of 50 mm diameter into the soil using a 65 kg hammer with a falling height of 760 mm. The numbers of blows for the initial 150 mm was recorded as seating blows, and the following numbers of blows for the next 300 mm penetration was recorded as the N value (or the blow count) of the soil strata encountered.

The standpipe piezometer consists of a tube with a porous filter element at the end that can be sealed into the ground at the appropriate level. It has a cylindrical (low air entry) porous element protected by performed rigid sheath about 3.5 mm diameter and 300 mm long. This element is connected to a 19 or 25 mm internal diameter pipe. The response time of this type of standpipe piezometer is comparatively low, but it generally does not become a significant factor until the soil permeability is less than 10–7 m/s. At this permeability, the response time should not be more than a few hours when the piezometer is installed within 150 mm diameter by 400 mm long sand pocket.

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