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Physico-Chemical Characteristics of Exposed Saprolites and Their Suitability for Oil Palm Cultivation

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ABSTRAK

Kajian bertulis mengenai pengurusan tanah kawasan tinggi untuk tanaman kelapa sawit menunjukkan tanah ini adalah rendah kesuburan dan taraf kesesuaiannya. Kajian kami yang bertujuan mendalami masalah tersebut, mendapati bahan saprolit yang berada di bawah lapisan tanah telah terdedah atau hampir ke permukaan akibat kerja-kerja membuat teres pada tanah berbukit, menyebabkan tanah berkenaan kurang sesuai untuk penanaman kelapa sawit. Persampelan tiga profil saprolit yang berbeza kedalaman dan geologi telah dilakukan dan analisis sifat fizik kimia and kesuburannya telah dijalankan. Selain daripada variasi antara sifat saprolit yang berlainan geologinya, saprolit juga mempunyai taraf kesuburan dan sifat fizik yang rendah, mencadangkan bahawa bahan ini tidak sesuai untuk tumbesaran tanaman. Taraf kesuburan saprolit walaupun kurang terluluhawa, adalah rendah daripada tanah. Saprolit mempunyai keupayaan pengikatan phosporus yang tinggi, cas negatif yang rendah, dan dengan itu mempunyai keupayaan pertukaran kation yang rendah. Kesan fitotoksik Al adalah rendah dalam saprolit berbanding dengan tanahnya. Sifat fizik saprolit adalah masif dan tiada pembentukkan struktur dan mempunyai daya penyimpanan air yang tinggi yang kemungkinan tidak terdapat oleh tanaman. Analisis penjelmaan tak berubah isipadu batu kepada saprolit menghasilkan kehilangan ketara kation bes daripada profil, menyebabkan taraf kesuburan saprolit rendah berbanding dengan tanahnya. Penilaian kesesuaian bahan saprolit daripada geologi asal yang berbeza mendapati bahan ini tidak sesuai untuk tanaman kelapa sawit, dengan kecetekan, saliran dan kesuburan saprolit sebagai masalah utamanya.

ABSTRACT

The reviews on the management of upland soils for oil palm cultivation have indicated that these soils are poor in fertility and classified as marginal to unsuitable. Our study aimed at investigating the problem, found that saprolites laying below the soil layers are either exposed directly or near to the surface as the result of unavoidable terracing of slopes to enable cropping, rendering poor crop suitability. Samples from three different saprolitic profiles of varying depth and geology were collected and analyzed for their physico-chemical properties and chemical fertility characteristics. Besides variability in characteristics of different geological origin, the saprolites have poor fertility and physical properties, suggesting that they are poor substrate for crop growth. The fertility status of the saprolites, despite less weathered, were poorer than their soils. Comparatively, they have higher phosphorus retention capacity, lower net negative charge, and thus lower cation retention capacity. The Al phytotoxic effect, however, was lower in the saprolites than in their soils. The saprolites physical properties were characterized by massiveness and lacking of structural development, which enables high water retention but may not be available to plants. The isovolumetric transformation analysis of rock into saprolites showed a significant depletion of base cations from the profiles, instituting poor fertility status of saprolites in comparison to their respective soil layers.

The suitability assessment of saprolite materials of varying geological origin indicates that saprolites are unsuitable for oil palm cultivation, with shallowness, fertility and poor drainage conditions being the major constraints.

INTRODUCTION

Land terracing is an unavoidable procedure in the preparation of upland soils for oil palm cultivation. Depending upon the steepness of the slope, the cutting for terrace bench can reach down to more than a meter deep, which will expose the upper saprolite or commonly cited as the C horizon to the surface or near to the surface. In whatever cases, the crops planted on hilly and upland areas will eventually be utilizing saprolite as the growing substrate. Oil palm is one of the major plantation crops in Malaysia, and is cultivated on inland areas, some are rugged, hilly and sloppy in nature. In Malaysia, the utilization of slope >20° for agriculture is not recommended (Land Conservation Act, 1960), but in some cases, this is not so. Owing to increasing land pressure and also the lack of enforcement, this Act has not been strictly followed (Aminuddin *et al.* 1990). Some observations have shown that where slopes are >10°, terracing will expose saprolites directly to the surface (Burnham, 1978; Hamdan, 1995). These observations, however, noted that the tendency of saprolite exposure would depend upon the soil depth and terracing techniques.

The acid upland soils are known to have many fertility problems. In an undisturbed environment, these soils are inherently infertile. Like all acid soils of the humid tropics, these soils are low in pH, which bring with it many potential associated problems, including H, Al, and Mn toxicity, Ca deficiency, low CEC, high P fixation, and low microbial activity (Tessens and Shamshuddin, 1983; Foy, 1984). Their shallow topsoils are highly susceptible to erosion, and if not managed properly after clearing, can lose much of their original fertility and beneficial physical properties. Reviews on the characteristics and management of upland acid soils did not consider the exposed saprolites as a result of terracing. With the surface soils and subsoils already being considered problematic, one could only imagine what impact the saprolites pose to the fertility of upland soils. This paper attempts to characterize the fertility of saprolites as an agricultural substrate in comparison to their respective soil layers. It is hoped that the results of this study would change our perception on the management approach of these materials so that they may become more sustainable not only for oil palm, but also for cultivation of other perennial crops. To achieve this, three deep saprolitic profiles of different geology and location were selected for the investigation.

MATERIAL AND METHODS

The study was conducted in Peninsular Malaysia which is climatically equatorial with an annual precipitation of 2500 to 3500 mm, a potential evapotranspiration of 1130 mm, and a daily air temperature of 28 to 33°C. The soil moisture regime is udic while the soil temperature is isohyperthermic with a mean annual soil temperature of 28.70 C. The study involved three deep saprolitic profiles of different geology and location. Samples were collected along newly exposed road cuts in the state of Selangor and Pahang, with depths of 10, 15 and 26 meters for schist, basalt and granite regoliths, respectively. These deep profiles were differentiated into various horizons, morphologically described and sampled following the criteria outlined in the USDA Soil Survey Manual (1981), and were classified using the USDA Soil Taxonomy (USDA Soil Survey Staff, 1994) and FAO-Unesco (1988) soil classification systems.

Samples of soil, saprolite and rock were air dried, crushed and sieved through a 2-mm size. The undisturbed core samples were taken for the determination of bulk density and moisture-retention characteristics at 5 to 1,500 kPa using pressure plates. The aggregate stability index and water dispersible clay (WDC) properties were estimated using the methods of turbidity (Molope *et al.* 1985) and sedimentation (Tessens, 1984), respectively. Soil texture was determined using pipette method (Gee and Bauder, 1986). Soil pH was measured in suspension of 1:2.5 (soil:solution) ratio using a glass electrode pH meter, while soil organic carbon was determined by the Walkley-Black dichromate titration method (Walkley and Black, 1934). Soil nitrogen was determined by macro-kjedahl digestion method (Bremner and Mullraney, 1982), and the dithionite citrate bicarbonate method of Mehra and Jackson (1960) was employed to estimate free iron oxide content. For the CEC determination, the leaching method of 1M ammonium acetate buffered at pH 7 was used. The available P and extractable Al were determined by Olsen (Olsen *et al.* 1954) and aluminon (Hsu, 1963) methods, respectively. The phosphate sorption index was determined according to the method of Bache and Williams (1971). The land suitability classification system of Sys *et al.* (1993) was used to evaluate the soil and saprolite suitability for oil palm.

RESULTS AND DISCUSSION

Morphological Descriptions

The morphological properties of the three deep profiles are summarized in Table 1. The solum layers of the profiles were characterized by crumb structure that gradually changes into subangular blocky structure with depth. They had friable consistency with variation in colours from dark brown in basaltic profile to reddish or yellowish brown in schistic and granitic profiles. Drainage was excessive in basaltic, but moderate in schistic and granitic profiles.

The passage from solum to saprolite was shown by an increase in massiveness, a firmer consistency and a decrease in porosity. With depth, saprolites become still firmer and coherent and can be described as saprock (Zauyah, 1986). The granitic and basaltic saprolites were massive but slightly more friable than the schist saprolite. The high content of incompletely weathered crystals such as quartz, feldspar and muscovite in granite, at intense stage of weathering of basalt, could have accounted for the friability of the saprolites. Partly weathered rock fragments of various sizes, sometimes called corestones, are frequently found in the lower zones. All saprolites had variegated colours that vary between profiles of different geology. In basalt and schist saprolites, the matrices were dominantly reddish-brown to reddish-yellow with grayish colours in relict rock fragments. In granitic saprolite with high resistant minerals such as quartz and muscovite, dissolution of feldspars yielded a matrix of yellow-gray and white with reddish weathered stains. The grayish colour became more dominant with depth in all profiles.

Our field observations strongly suggest that the soil solum of the three profiles provide a good medium for crop growth, particularly those developed on basalt, where the soils are very

TABLE 1
Morphological descriptions of the profiles under study

Horizon	Depth (m)	Texture	Colour		Structure	Consistency
			Matrix	Mottles		
<u>Basalt Profile</u>						
Soil	0-2	Clay	10YR 4/4	Nil	Crumb-SAB	Friable-Fluffy
Transition	2-3	Clay	10YR 3/4	nil	SAB	Friable
Upper saprolite	3-6	Clay	2.5YR 3/4	10YR 4/1	Massive	Firm
Lower saprolite	6-10	Clay	2.5YR 3/4	10YR 4/1	Massive	Firm
Saprock	10-15	Silty Clay	2.5YR 3/4	Nil	Coherent	Hard
<u>Granite Profile</u>						
Soil	0-0.5	Clay Loam	2.5YR 7/6	5YR 6/8	Crumb-SAB	Friable
Transition	0.5-3.2	Silty Clay	7.5YR 7/6	2.5YR 6/8	SAB	Friable
Upper saprolite	3.2-12.5	Sandy Clay	10YR 7/8	2.5YR 6/8	Massive	Friable
Lower saprolite	12.5-24.5	Sandy Loam	7.5YR 6/0	2.5YR 6/4	Massive	Firm-Hard
Saprock	24.5-26	Sandy Loam	7.5YR 6/0	2.5YR .4	Coherent	Hard
<u>Schist Profile</u>						
Soil	0-1	Clay	7.5YR 5/6	Nil	Crumb	Friable
Transition	1-1.5	Silty Clay	2.5YR 5/8	10YR 7/2	SAB	Friable-Firm
Upper saprolite	1.5-6	Silty Clay	2.5YR 5/8	2.5YR 6/8	Massive	Firm
Lower saprolite	6-9	Silty Loam	2.5YR 5/0	2.5YR 6/6	Massive	Firm
Saprock	9-10	Silty Loam	2.5YR 5/0	Nil	Coherent	Hard

Note: SAB = Subangular blocky

friable and fluffy. The saprolites, however, are contradictory to the solum in nature, where they are compacted and massive. Such properties of the saprolites, on exposure, would result in low permeability and subsequently encourage surface runoff and soil erosion (Lal, 1986). Root establishment and growth in the massive materials would be hindered, resulting in slow or even stunted and unproductive plant growth.

PHYSICAL CHARACTERISTICS

Saprolite Porosity

Weathering breaks down rocks into saprolites and subsequently into soils. Differences in the geological origin and mineralogy would result in the formation of different saprolites and soils. All the three profiles studied showed drastic changes in bulk density values during the transformation of rock into saprock (Table 2). From the saprock zones onward, the changes in trend for bulk density and total porosity values were more gradual. Variability in the massiveness and porosity of saprolites were observed, with the schist saprolite being most compacted. The granitic and basaltic saprolites, particularly the upper layers, were as porous as their respective soil layers. The mineralogy of the materials, composed mainly of weatherable minerals as in basalt and resistant minerals with weathered materials as in granite, contributed to such high porosity. Despite being porous, the absence of structural development could have induced surface seal and crust, surface runoff and further reduced moisture availability.

The saprolites also exhibited variability in their particle size distribution, as being greatly influenced by their geological origin. The basalt rock dominantly composed of weatherable ferromagnesian minerals, which weathered easily and were responsible for high clay content in the soil (>70%) and saprolite (>55%). These clays were dominantly of kaolinite type (Hamdan, 1995). Schist and granite contained more resistant minerals of quartz, mica and feldspar in composition to weathered slowly forming clay particles, ranging from < 40% in the soils and <30% in the saprolites.

Erosion Risk Potential

Soil erosion through runoff process occurs extensively on exposed upland soils. Reports by Wan Sulaiman and Jamal (1981) and Mokhtaruddin *et al.* (1985) have indicated that oil palm plantations on different soil series with slopes of 8 to 10 %, lost an estimated 5 to 16 metric ton/ha/year of soils through erosion. Could the exposed saprolites pose similar or even greater erosion risk? Two laboratory studies were conducted to estimate the erosion risk on exposed saprolites, namely: (i) water dispersible clay (WDC), and (ii) aggregate stability to water, and the results are presented in Table 2.

The WDC values recorded were higher in surface horizons for all profiles which ranged from 20-34% and drastically declined to <0.5% in the subsoils and saprolite layers. The analysis indicated that high clay dispersion to water is evident in the soils but minimal in the lower subsoils and saprolites, and this consequently suggests that erosion of saprolite upon exposure was minimum. The results of the aggregate stability analysis showed that the upper saprolites of all profiles were generally less stable than their respective soil layers. The lower saprolites, however, were more stable and this is attributed to the high content of partly weathered rock fragments that still holds the materials intact together. The high content of free iron in basalt profile that binds the materials together, resulted in higher stability of aggregate to water in comparison to those of schist and granite.

The present laboratory studies demonstrated that saprolites have minimal risk to erosion upon exposure. Actual field investigation to estimate soil loss on these materials must be determined in order to provide a clearer risk potential.

Saprolite Moisture Retention Capability

Available moisture is crucial for plant growth and productivity, particularly in the upland areas, where water holding capacity is low (Kubota *et al.* 1982). In these soils, which are low in organic matter content, the slow water infiltration rate is further aggravated by surface seal and crust formation, thus inducing even low permeability and encouraging surface runoff (Lal, 1986).

The data in Table 2 shows the variation in the ability of saprolites to retain moisture as influenced by their geological origin and intensity of weathering. Generally, for all profiles, saprolites retained more moisture (130-480 mm/m-1) than soils (60-160 mm/m-1). However, composition of granite saprolites which largely comprised rock and mineral fragments and little

TABLE 2

Physical properties of the profiles under study

Horizon	Granulometry	(%)		B.D	Porosity	LOI	A.S	WDC	Water	Retention	Characteristics		(kPa)	Available Water
	Clay	Silt	Sand	(g/cm^3)	%	%	%	%	0	0.98	9.8	33	1500	(mm/m^{-1})
Basalt Profile														
Surface soil	77.6	12.5	9.9	0.98	62.9	16.8	85.5	33.0	58.5	29.7	26.5	26.1	21.6	61
Subsoil	79.7	13.2	7.1	1.09	58.8	10.8	80.1	0.4	79.8	57.5	35.1	31.2	26.2	163
Transition	66.1	13.6	20.3	1.37	48.3	15.0	83.9	0.6	63.2	55.3	33.7	31.5	22.8	172
Upper saprolite	64.3	20.6	15.1	1.17	55.9	13.2	75.8	0.4	74.9	55.4	46.7	38.1	37.1	129
Lower saprolite	56.5	31.0	12.5	1.07	59.8	10.6	73.2	0.1	107	85.4	60.8	55.6	35.5	375
Saprock	29.5	54.8	15.7	1.17	55.8	9.8	79.5	0.1	68.9	65.0	51.6	51.0	25.8	280
Rock	nd	nd	nd	2.41	nd	0.8	nd	nd	nd	nd	nd	nd	nd	nd
Granite Profile														
Surface soil	36.6	20.2	43.2	1.24	53.2	9.6	69.6	34.0	39.2	31.4	31.0	27.3	21.9	91
Subsoil	39.6	14.9	45.5	1.62	38.8	8.2	54.5	5.4	58.5	47.6	39.6	39.3	32.5	88
Transition	27.4	18.9	53.7	1.40	47.1	8.4	50.6	0.6	59.0	58.4	35.8	28.2	22.2	202
Upper saprolite	24.6	30.8	44.6	1.65	37.8	4.0	47.2	0.2	62.6	55.6	37.2	34.6	18.8	235
Lower saprolite	10.1	23.3	66.6	1.28	51.7	5.0	78.0	0.1	52.6	31.0	20.8	19.1	10.4	137
Saprock	5.4	20.0	74.6	1.89	37.8	3.4	91.5	0.1	46.5	29.1	19.9	15.8	8.3	144
Rock	nd	nd	nd	2.54	nd	0.4	nd	nd	nd	nd	nd	nd	nd	nd
Schist Profile														
Surface soil	41.9	35.7	22.4	1.09	61.6	6.0	43.5	19.6	70.0	39.2	33.4	30.0	26.1	91
Subsoil	50.2	34.1	15.7	1.28	58.8	6.8	18.4	29.0	74.7	59.3	46.2	39.6	35.8	142
Transition	44.3	42.9	12.8	1.58	47.3	5.8	23.2	0.4	82.2	55.6	43.1	39.2	31.2	158
Upper saprolite	39.4	43.2	17.5	1.59	44.8	5.8	24.3	0.4	72.0	66.5	45.9	42.1	12.4	403
Lower saprolite	10.9	79.1	11.0	1.85	49.3	4.2	42.2	0.1	88.7	60.2	57.1	42.2	10.3	480
Saprock	7.4	81.7	10.9	1.95	45.8	2.8	63.3	0.1	52.9	51.2	40.6	23.2	11.1	328
Rock	nd	nd	nd	2.16	nd	0.8	nd	nd	nd	nd	nd	nd	nd	nd

Note: B.D = Bulk density, LOI = Lost on ignition, WDC = Water dispersible clay, A.S = Aggregate stability, nd = not determined weathered matrices, particularly at the lower zones, accounted for the lower moisture retention in comparison to schist and basalt saprolites.

The moisture retention values at different kPa showed variability among profiles. The basalt profile had a low amount of available water in the soils, thus a reduced ability to retain water beyond 1,500 kPa tension, in contrary to its respective saprolites. The high degree of aggregation and abundance of large pores in the soils, and the abundance of micropores of <0.2 μm in diameter in the saprolites, accounted for the differences. The soils of the granite profile retained a reasonable amount of water while its saprolites lost much of its water between saturation-field capacity and much lower levels at 1,500 kPa tension. These characteristics suggest that most of the pores were macropores, developed probably from relict rock structure, dissolution of feldspar and breakdown of quartz or muscovite. The schist saprolites retained the most amount of available water. The moisture retention trend indicated that schist saprolites have high amount of medium pores, ranging from 0.5 to 50 μm in diameter, but not many micropores of <0.2 μm in diameter as demonstrated by the low amount of water retained at 1,500 kPa tension.

The ability of saprolites to retain moisture depends upon their mineralogy and weathering stage. Despite retaining large amount of moisture, as in schist and basalt saprolites, the moisture may not necessarily be accessible to plant roots. O'Brien and Buol (1984) suggested that in order to allow good root penetration, free drainage and storage of available water, there must be sufficient amount of large (>250 μm), medium (>50 μm) and fine (0.5-29 μm) pores in the soil materials, which were found to be lacking in the saprolites.

CHEMICAL FERTILITY CHARACTERISTICS

Organic Matter Contribution

It is universally recognized that soil organic matter plays a crucial role in determining the physico-chemical and microbiological properties of soils (Brady, 1974). The organic matter content of upland soil changes drastically upon clearing and under different land use system. Undisturbed forested upland soils in Thailand, for example, comprising organic matter content which varied from 6 to 11%, but upon cultivation under different crops, their organic matter content dropped to about 1% (Vangnai *et al.* 1986). In our study areas where secondary forest dominates, the organic matter content of the surface horizons was recorded to be in the range of 4 to 4.8% (Table 3). The content, however, dropped significantly to less than 2% and 1% in the subsoils and saprolites, respectively. The small amount of organic material in the upper saprolites and traces in the lower zones, can be attributed to the migration of these materials through cracks and relict of rock fragments, particularly in the granitic saprolites. The nitrogen content also followed a similar trend of distribution in all profiles. From the data, we can assume that the contribution of nutrients from organic matter decomposition to saprolites fertility is insignificant. Saprolite fertility in this situation would, therefore, depend much upon the release of nutrients during weathering.

Soil Reaction

The data in Table 3 show soil pH values indicating a gradual increase with depth that are in the acidic range of 4.12 to 4.65, except for the basalt profile which indicated a gradual decreasing trend. The variation can be explained by the fact that weathering occurred in basalt profile intensely even at the saprock zones in comparison to granite and schist profiles which were abundantly composed of minerals resistant to weathering. This is supported by the abrasion pH values that show a drastic change between rock to saprock transformation in basalt, i.e. from pH 8.91 to 4.95, but this was not observed in schist and granite profiles. The soil pH values, however, suggested that saprolites are as acidic as their respective soil layers.

Aluminium Toxicity

Aluminium is considered to be the major factor retarding plant growth on acid soils. Our study indicates that the exchange sites and soil solutions of the granite and schist soils, and saprolites were dominated by exchangeable Al as shown by the high extractable acidity values. The Al in all these materials exceeded 70% saturation. Throughout the basalt profile, the exchangeable Al was low, ranging from 30 to 40% saturation but the high extractable acidity values suggest that Al was crystallized into gibbsite in the soil layers. All saprolites, however, had high Al saturation values, and should therefore

TABLE 3

Selected chemical properties of the profiles under study

Horizon	Extractable Acidity	Al 1M KCl	Al sat %	Avail. P	P Sorption Index	Soil pH pH_{Water}	Soil pH pH_{KC}	Soil pH $pH_{Abrasion}$	O.C %	N %	Fed %	Feo %	Ratio Feo/Fed
	(cmol(+)/kg soil)			(mg/kg)									
<u>Basalt Profile</u>													
Surface soil	17.95	0.1	4.9	1.69	78	5.34	4.76	8.01	2.61	0.27	12.42	0.18	0.014
Subsoil	16.32	0.3	37.9	1.51	82	4.81	4.52	8.57	0.86	0.13	12.51	0.10	0.008
BC	15.37	0.1	19.6	1.51	82	5.14	5.44	8.21	0.06	0.02	14.92	0.09	0.006
Upper saprolite	15.06	0.4	41.7	1.54	82	4.84	4.47	8.74	0.01	0.01	12.45	0.05	0.005
Lower saprolite	14.51	1.8	81.1	1.51	78	4.73	4.11	8.93	tr	tr	12.32	0.05	0.004
Saprock	17.61	4.2	88.6	1.43	71	4.61	3.92	8.98	tr	tr	12.46	0.05	0.004
<u>Granite Profile</u>													
Surface soil	18.04	4.1	83.3	1.34	63	4.18	3.67	7.65	2.29	0.29	1.49	0.38	0.251
Subsoil	13.12	4.0	84.4	1.32	60	4.28	3.65	7.65	1.14	0.14	1.83	0.13	0.068
BC	10.81	3.0	86.5	1.69	66	4.49	3.91	7.72	0.89	0.11	1.85	0.01	0.005
Upper saprolite	10.23	4.4	88.6	1.31	58	4.65	3.94	7.83	0.14	0.03	2.12	0.01	0.003
Lower saprolite	3.76	3.4	89.9	1.38	57	4.66	3.95	7.58	tr	tr	0.56	0.00	0.004
Saprock	5.23	1.0	57.8	0.11	53	5.76	5.18	7.54	tr	tr	1.12	0.00	0.002
<u>Schist Profile</u>													
Surface soil	13.49	4.1	70.9	0.98	45	4.12	3.41	7.56	2.78	0.24	3.01	0.14	0.044
Subsoil	22.04	4.7	82.1	0.45	43	4.06	3.41	7.61	1.08	0.13	3.34	0.12	0.035
BC	14.78	3.1	82.2	0.27	68	4.31	3.71	7.61	0.23	0.02	3.33	0.05	0.015
Upper saprolite	15.14	3.4	78.5	0.98	54	4.31	3.73	7.62	0.21	0.01	3.49	0.04	0.011
Lower saprolite	3.45	0.2	28.2	0.09	31	4.42	4.03	7.58	tr	tr	3.26	0.01	0.001
Saprock	5.93	0.6	56.6	0.27	27	4.65	4.21	7.54	tr	tr	2.83	0.01	0.001

Continue Table 3...

Horizon	Cation Exchange Capacity		ECEC	%B.S	Exchangeable Cations				Micronutrients		
	NH_4OAc (pH 7)	NH4Cl	(unbuffered)		Ca	Mg	Na	K	Cu	Mn	Zn
	(cmol(+)/kg soil)				(cmol(+)/kg soil)				(mg/kg)		
Basalt Profile											
Surface soil	6.21	3.47	1.95	29	0.87	0.59	0.11	0.28	0.75	6.76	1.69
Subsoil	2.15	1.52	0.79	23	0.30	0.05	0.05	0.09	1.13	0.64	0.34
BC	1.13	1.02	0.51	40	0.26	0.05	0.05	0.05	0.46	0.01	0.07
Upper saprolite	2.91	1.97	0.86	16	0.29	0.04	0.03	0.10	0.56	0.01	0.24
Lower saprolite	2.99	2.14	2.22	14	0.28	0.06	0.02	0.06	1.32	0.01	0.44
Saprock	5.66	4.57	4.64	8	0.27	0.09	0.02	0.06	3.91	15.8	2.04
Granite Profile											
Surface soil	8.47	4.92	4.92	10	0.44	0.10	0.05	0.23	0.65	3.35	1.42
Subsoil	5.76	4.85	4.74	13	0.51	0.09	0.03	0.11	0.27	2.23	0.69
BC	4.96	3.31	3.47	10	0.31	0.07	0.03	0.06	0.46	0.41	0.82
Upper saprolite	5.61	5.19	4.96	10	0.35	0.08	0.03	0.09	0.17	0.96	0.19
Lower saprolite	3.96	3.69	3.78	10	0.22	0.06	0.02	0.08	1.25	0.17	0.32
Saprock	2.08	1.99	1.73	35	0.38	0.10	0.01	0.24	0.09	9.47	0.27
Schist profile											
Surface soil	8.09	5.81	5.08	12	0.49	0.16	0.05	0.28	6.69	0.72	1.19
Subsoil	7.04	5.73	5.23	8	0.28	0.08	0.03	0.14	10.5	0.48	0.89
BC	4.75	3.15	3.57	10	0.29	0.07	0.03	0.07	1.13	0.17	0.32
Upper saprolite	4.14	3.42	3.93	13	0.33	0.05	0.03	0.12	0.65	0.17	0.34
Lower saprolite	1.57	1.31	0.61	26	0.28	0.05	0.01	0.07	0.84	0.81	0.54
Saprock	1.22	0.74	0.96	29	0.24	0.04	0.01	0.06	0.94	0.33	0.52

Note: Al sat= Al saturation, O.C= Organic carbon, N= Nitrogen, Feo= Oxalate extractable iron, Fed= Dithionite extractable iron, Av. P= Available Phosphorus, ECEC= Effective cation exchange capacity, B.S= Base saturation, tr= traces constitute a reasonably high degree of Al toxicity (Sanchez and Logan, 1992). The Al toxicity test conducted by Hamdan (1995) on similar profiles showed that the subsoils of all profiles studied were Al phytotoxic to root growth in comparison to their respective saprolites. The higher soil pH values in the basalt saprolites accounted for their lower Al phytotoxic level as compared to those of granite and schist.

Phosphate Availability

The P content in all soils and saprolites was very low, recording values < 1.5 mg kg-1, with basalt profile exhibiting the lowest P availability. The data of P-sorption index (Bache and Williams, 1971) showed that P-retention capacity of the profiles studied ranged from high (i.e. granite and schist profiles) to very high (i.e. basalt profile) (Burnham and Lopez, 1982). High Fe oxides (Table 3), particularly in amorphous form, were responsible for the sorption of phosphate in large amounts (Burnham and Lopez, 1982; Fox *et al.* 1971). The saprolites, however, demonstrated slightly lower P-sorption index values in comparison to their respective soil layers, and this can be attributed to lower degree of weathering and subsequently lesser Fe amount in the saprolites.

Saprolite Fertility Status

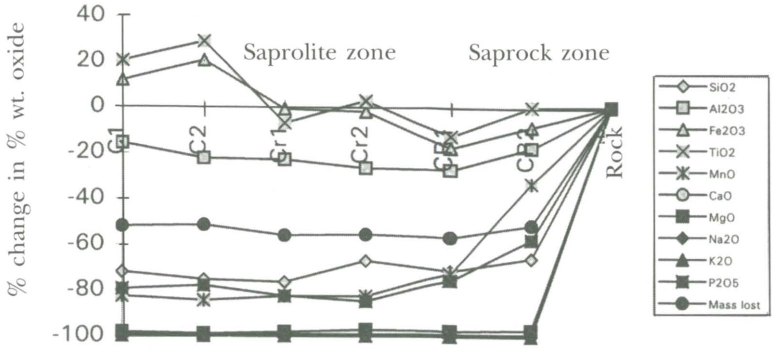
Low CEC values from all profiles indicated the dominance of kaolinite in the clay fractions of the soils and saprolites (Table 3). The x-ray diffraction analysis (Hamdan, 1995), suggested that kaolinite dominated the clay materials, with few or traces of 2:1 clay and mixed layer clay minerals as observed in granite and schist profiles. The high organic matter content of all surface horizons, accounted for the slightly higher CEC values. The CEC values in the three saprolites decreased in the order of granite>schist>basalt. A study on the surface charge characteristics (Hamdan, 1995) demonstrated that the net negative permanent charge of saprolites is slightly lower or similar to the soil layers for most profiles, except for basalt profile that exhibits positive charge values. Intense weathering stage and high Fe content have been shown to induce positive charge development (Tessens and Zauyah, 1982) that result in lower CEC values of the basalt saprolite. The ECEC values of the saprolite (<4 cmol(+) kg-1 soil) were also lower than their respective soil layers, and such levels are considered nutrient-poor (Sanchez and Logan, 1992). The base cations were lower in the saprolites as compared to their soils component. In a related study, the subsoils and saprolites of all profiles studied were found to be equally poor in macro- and micro-nutrients (Kanapathy, 1976), but were generally comparable to most Ultisols and Oxisols found in Malaysia.

Geological Contribution to Saprolite Fertility

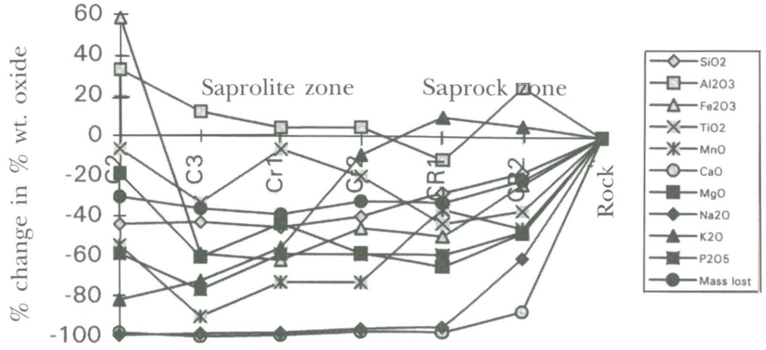
The chemical data clearly demonstrated the differences in fertility between the soils and their respective saprolites. It is common knowledge that bases in soils are contributed by the mineralization of organic materials accumulated at the surface, while those bases in the saprolite are bases released during weathering process of primary minerals. Generally, despite being less weathered, saprolites are less fertile than their respective soils. Our previous study (Hamdan and Burnham, 1996) conducted on similar profiles, perhaps can be used to justify this phenomenon, where an isovolumetric calculation was performed to determine the mobility of elements during weathering. The data in *Fig. 1* revealed that a significant amount of major elements was depleted from the profile during saprolitization, a process of isovolumetric transformation of rock into saprolite. In the basalt profile, (*Fig.1a*) composed of easily weathered ferromagnesian minerals, all basic cations were almost totally depleted (>95%) at the initial weathering stage, sometimes cited as saprock formation, while moderate to high (55 to 90%) removal occurred in the granite profile (*Fig.1b*). In the schist profile (*Fig. 1c*), only Mg was severely lost at this stage. During saprolite formation, the basic cations were totally, highly and moderately depleted in basalt, granite and schist profiles, respectively. Enrichment of Al_2O_3, Fe_2O_3 and TiO_2 occurred in most cases. The results indicated significant loss of these elements during weathering. This possibly explains the low fertility status of all saprolites studied in comparison to their respective soil layers.

Saprolite Suitability for Oil Palm

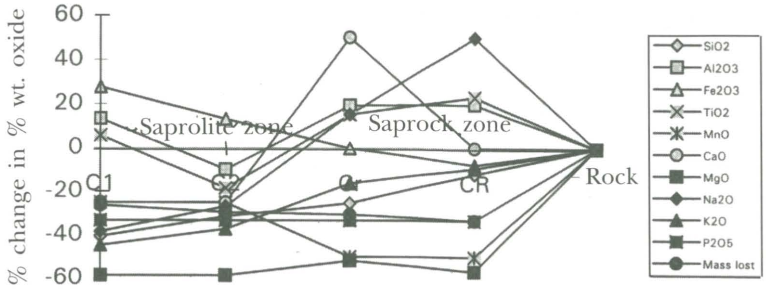
The results of the land suitability assessment (FAO, 1976) in Table 4 indicated that exposed saprolites, in comparison to their respective soils,



(a) The loss and gain of elements during the weathering of basalt



(b) The loss and gain of elements during the weathering of granite



(b) The loss and gain of elements during the weathering of schist

Fig 1. The loss and gain of elements during rock-saprock-saprolite isovolumetric transformation

TABLE 4
Summary of upland soils and the corresponding saprolites with regards to their suitability for oil palm

Parent Material	Land unit	Suitability Class	
Basalt	Soil	Moderately suitable	(S2tf)
	saprolite	Unsuitable	(N1twsf)
Granite	Soil	Marginally suitable	(S3tsf)
	Saprolite	Unsuitable	(N1tsf)
Schist	Soil	Marginally suitable	(S3tsf)
	Saprolite	Unsuitable	(N1twsf)

(Adapted from the FAO, 1976)

Note: S2 = Moderately suitable, S3 = Marginally suitable, N1 = Unsuitable
S = limitation due to shallowness of rooting zones.
f = limitation due to low fertility status.
w = poor drainage, wetness of high water table is the dominant problem.
t = topography (slope)

were only marginally suitable or non-suitable for oil palm cultivation. The physical limitations were attributed to the absence of aggregation, rock fragments, shallow rooting zone, and poor water availability. The absence of organic materials contributed to the lower fertility level of saprolites, while the contribution of nutrients from parent material weathering seemed insignificant (*Fig. 1*).

CONCLUSION

The soils of the humid tropics have shown to be managerially problematic, particularly with regards to their fertility. Reviews on research works and crop yields on current plantations in Malaysia, Thailand and Indonesia, have significantly shown that such fertility constraint could be improved. Poor fertility of the saprolite, as shown in this study, is more complex, and could pose a serious limitation to crop production in the upland soil areas. Their physical properties and the potential problems related to these properties is a greater cause for concern. Unlike ordinary soil materials which can be amended and improved to suite crop requirements, saprolites on the other hand, are more difficult as they are not soil but classified as parent material. At even deeper zones, these materials are only partly weathered, composing of rock fragments and corestones. The root permeability, moisture availability, water drainage, compaction, crust formation and runoff are some of the potential problems of saprolites that limit crop productivity.

The management and improvement of saprolitic materials to suite utilization by crops would be an expensive and difficult task. Presently, concerned efforts are being made to manage acid Ultisols and Oxisols in the humid tropics which include even soils of the upland areas. Upon clearing and terracing of these soils, saprolite materials that we know little about, would surface. There are a few, if any, experimental works that deal directly on the properties, utilization, problems and management of such saprolites. This paper highlights the characteristics and potential problems of saprolites that may be faced upon their exposure. Eswaran and Wong (1978) noted that in such steep terraced areas where saprolites are exposed and utilized by crops, the characterization and interpretation of soil potential for agriculture based on soil formation becomes less meaningful. Our results showed that soils of such nature were moderately to marginally suitable but their respective saprolites were rated as unsuitable, with the fertility status, slope, poor drainage and shallowness of rooting zones as the limiting factors. In Malaysia, soils developed on basalt comprising good physical properties, which upon improvement of their fertility level, may be upgraded to class one for oil palm (Paramananthan and Lim, 1979). Future work on the amelioration of exposed saprolite materials to improve their sustainability for oil palm production is necessary.

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