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ASSESSMENT OF ABORIGINAL SMALLHOLDER SOILS FOR RUBBER GROWTH IN PENINSULAR MALAYSIA

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This study assesses an array of physiochemical soil properties from a sample of rubber smallholdings managed by a group of *Orang Asli* (original people) in northwest Pahang, Peninsular Malaysia. Malaysian smallholders in general face significantly lower productivity levels than the large rubber estates and plantations (Malaysian Rubber Board, 2002). Among smallholders, *Orang Asli* households generate the lowest rubber yields, earn the lowest non-rubber income, and are most threatened by land scarcity (RISDA, 2003). Furthermore, little is known about the soils of these smallholdings since most rubber-related soil surveys focus on estates and experiment stations (Pushparajah & Amin, 1977). An understanding of the morphological and physiochemical soil properties of *Orang Asli* rubber fields is a crucial step toward the efficient allocation of government resources that aim to enhance productivity, promote sustainable agriculture, and improve household welfare. The objectives of this project were to (1) determine the predominant physiochemical characteristics of these soils, (2) evaluate them with an established rubber suitability classification system, (3) group soils according to region, geomorphic position, and estimated soil series in order to make generalizations about soil limitations for certain soil types, and (4) offer methods by which to mitigate the effects of these limitations. We find that there is a great deal of heterogeneity within our sample with regard to both soil type and limitation. The most common physical limitations were related to flooding, uprooting, soil texture, and slope. Almost all soils were severely depleted in organic nutrients and base cations. Overall, these limitations were correctable via drainage, terracing, or establishment of a cover crop. It is recommended that any application of chemical fertilizer take soil type into account.(Soil Science 2005;170:1034–1049)

Key words: Rubber, *Hevea*, smallholdings, Malaysia, Orang Asli.

NATURAL rubber is one of the most prominent agricultural enterprises in Peninsular Malaysia, comprising more than one third (1.3 M ha) of commercially cropped land (4.1 M ha) and covering more than 10% of total land area (Department of Agriculture, 2005). The main producers of rubber are large commercial estates (400 ha or more) and individual smallholdings (<4 ha; Pushparajah & Yew, 1977). Most smallholders face cash constraints, soil fertility problems, and, hence, significantly lower yields than their estate counterparts (Malaysian Rubber Board, 2004). However, their importance to the Malaysian rubber industry cannot be overstated. Numbering more than 500,000, smallholders collectively supply almost 90% of total production and manage more than 87% of total land under rubber (Malaysian Rubber Board, 2004).

Because of the rubber industry's heavy reliance on smallholder production, improving the

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yields and overall livelihoods of smallholders has become a priority for the Malaysian government (Chan et al., 1986; Pushparajah, 1994; United Nations Economic and Social Commission for Asia and the Pacific, 2002; Yew, 1991). The Rubber Smallholder Development Authority (RISDA) was thus established to provide smallholders with the training, technologies, subsidies, and input products (e.g., stimulants, fertilizers, herbicides, clones) that have proven successful on estates. However, estate success is partly due to the fact that estate rubber is grown on Malaysia's best soils. Furthermore, management decisions and techniques (i.e., clone type, fertilizer application, establishment of leguminous cover crops, tapping system) tend to be fine-tuned and soil-specific (Yew and Chan, 1992). Studies have shown that the capability of a soil can only be fully exploited when land use decisions incorporate knowledge of soil properties and their interactions with planting materials, inputs, and management (Chan, 1977). Since very limited information, if any, exists regarding smallholder soils and their suitability for rubber production, an evaluation of these soils seems warranted and necessary to ensure the efficient allocation and appropriate targeting of rubber subsidies and programs.

Background: Malaysian Soils and Rubber Research

Over the past three decades, a great deal of research in Malaysia has been devoted to identifying and quantifying those soil factors that most influence the growth and productivity of natural rubber, *Hevea brasiliensis* (Chan & Pushparajah, 1972; Chan et al., 1975; Yew, 1991). Physiographic factors include effective soil depth, susceptibility to flooding, soil texture, structure, consistence, and slope (Chan et al., 1975). These properties are inherent and durable, less amenable to change by management, and can override chemical fertility with regard to influencing growth (Chan et al., 1984; Yew, 1991). Fertility factors include pH, cation exchange capacity (CEC), available nutrients, mineral reserves, and chemical toxicity, some of which may be improved through fertilization and management (Chan et al., 1975). When measured, the entire array of physiochemical soil properties can be evaluated with an empirically established soil suitability classification system and rated on the degree to which they inhibit rubber performance (Chan et al., 1975; Yew & Chan, 1992).

A rating system can be particularly useful when making land use or management decisions as the types and degrees of the limitations may dictate the type and level of the response. For example, some soil limitations (e.g., high water table, chemical toxicity) effectively prevent healthy rubber growth and indicate that the land may be better used for another function (Chan et al., 1984). Other factors (e.g., shallow soil, stoniness, steep slopes) can reduce the effectiveness of yield-enhancing technologies, such as stimulants and fertilizers and thus may not return positive economic benefits if large financial investments are made to improve yields (Bouma, 2002; Chan and Pushparajah, 1972; Chan et al., 1975). Further, certain textural classes warrant soil-specific management strategies (i.e., fertilizer types and schedules; Chan, 1977) and are more suitable for certain breeds of high-yield clone (Chan et al., 1984).

Past applications of various classification systems suggest that most soils of Peninsular Malaysia have at least one serious or very serious limitation with regard to rubber production (Chan et al., 1975; Yew and Chan, 1992). Classification systems have been widely used to evaluate and map large-scale areas (e.g., forests, estates) in Peninsular Malaysia for proper land use but do not appear to be sufficiently detailed to capture the morphological and physiographic variability of smallholder regions (Chan et al., 1984; Min, 1967). Thus, if applied to smallholder soils, a rubber suitability index could serve as an important and rapid assessment tool to inform land managers, and perhaps RISDA officials, as to which soil properties are most limiting in certain areas, thereby allowing the most effective and targeted agro-management responses for improving yields (Chan et al., 1984).

Objectives

In this study, we quantify and evaluate the important rubber-related soil characteristics of smallholder rubber fields managed by the *Jah Hut* subgroup of *Orang Asli* (aboriginal people). Of the ethnic groups that manage smallholding rubber farms in Peninsular Malaysia, *Orang Asli* smallholders face the lowest yields as well as the lowest total income per capita (RISDA, 2003). In fact, although the *Orang Asli* comprise only 0.5% of the Malaysian population, a disproportionate 81% live below the poverty line (Nicholas, 2002). In our sample of *Jah Hut* smallholders, each household is allocated a fixed amount of land (0.25 to 2.0 ha) on which they can grow rubber, and land expansion is usually not an option. There is thus a need to manage current land in such a manner that optimizes productivity in the present, while ensuring sustainability decades into the future.

In this study, we intended to ascertain the prevalence and severity of deficiencies in soil properties that may be affecting rubber production, which is the main income-generating activity for many *Jah Hut* households in the sampling region. Since most government programs allocate aid at the village level (as opposed to the household level), we identify those characteristics and limitations that seem to be

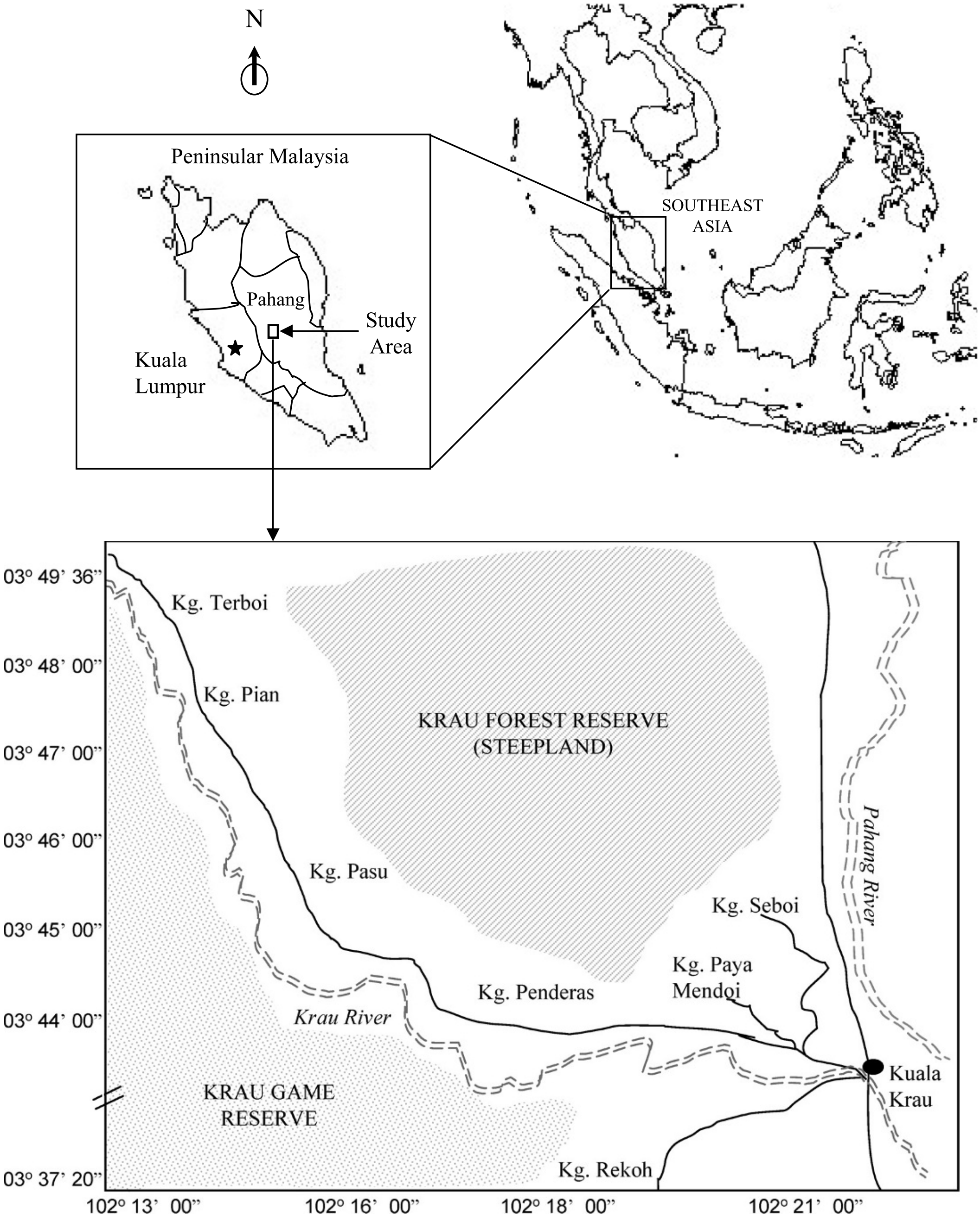

Fig. 1. Map of study area.

prevalent for each village and analyze any significant mean differences within or between villages. Finally, we will discuss any management-related implications of our findings that may be helpful to government aid programs or RISDA officials. Such information may not only improve the efficiency of government expenditures, but may also increase the future incomes of *Orang Asli* households.

METHODS

Study Area

The study area in northwest Pahang can be divided into three distinct regions: Krau River Valley, Mendoi-Seboi, and Rekoh. The four villages (*kampungs*) of the Krau River Valley are located 150 km northeast of Kuala Lumpur along a 50 km stretch of a two-lane road (route C-141) that leads west out of Kuala Krau and continues northwest to Ulu Cecka. The Mendoi-Seboi region is located in the hill country just northwest of Kuala Krau, between the villages of Paya Mendoi and Seboi. The Rekoh region is situated southwest of Kuala Krau, just west of Jenderak Selatan. The entire study area lies between latitude 3° 37′ N and 3° 50′ N and stretches from longitudes 102° 13′ E and 102° 21′ E and is bordered by the Krau Forest Reserve to the north and the Krau Game Reserve to the south and west (Fig. 1).

The natural vegetation of the study area is lowland riverine forest and lowland dipterocarp forest (Min, 1967), although most accessible areas have been cleared and are currently under agriculture or secondary forest. Data from the nearest weather station in Jerantut (3.90° N, 102.4° E) show mean annual rainfall for this region to be approximately 2100 mm and mean annual temperature to be 28 °C. Since climatic variation in Peninsular Malaysia is relatively small (Chan et al., 1984), soil types are largely the result of different parent material and topography (Chan & Pushparajah, 1972; Min, 1967; Ooi, 1976).

The Krau River Valley is bordered on the eastern side by a ridge consisting mainly of Triassic volcanics and volcaniclastics, interbedded shales, and granitic intrusions. To the west of the river are interbedded tuffs and shales of the same age. The Mendoi-Seboi area is part of the Seboi River Basin, which is underlain by volcanic-bearing conglomerates, quartz pebble conglomerates and sandstones of Cretaceous-Jurassic age. The Rekoh area is underlain by coarse, porphyritic granite and granodiorite (Thani, 1988). Due to silicate leaching from frequent and heavy rainfall, all soils of the study regions are poor in organic plant nutrients and base cations (Ooi, 1976) and have kaolinitic (1:1 SiO_2/Al_2O_3) mineralogy (Min, 1967).

The main soil classes that have been mapped in the study area include the poorly drained alluvial soils on the low river terraces, the quartzite and shale-derived soils on the high river terraces and lower hillslopes, and the well-drained sandstone and granitic loams of the hilly country. These soils are classified as Typic Paleudults. The andesitic soils on the rolling and hilly terrain are Tropeptic Haplorthoxes. A large fraction of the Krau River Valley region extends above the foothills and is broadly categorized as ‘‘steepland.’’ The soils of these areas are not specifically classified.

Data for the study were acquired from a 60-household subsample of 322 *Jah Hut* households that participated in a household income survey in March 2003. The 60 households chosen to be part of the soils study managed at least a single parcel of actively tapped rubber for which a yield estimate could be accurately recalled. A knowledgeable adult household member accompanied the soil sampling team to the field and all fields were within a 30-minute walk of the respondent's residence. The Mendoi-Seboi area differs from the others in that the rubber plantings were part of a RISDA project, carried out in the early 1970s, in which the land was terraced, divided into smallholdings, and planted with rubber clones.

Land Evaluation Techniques and Soil Sampling

A number of soil and land properties were measured and recorded at each rubber field, including parent material (if detectable), geomorphic position, soil consistence (measured as the resistance of a soil ped to crushing between the thumb and forefinger), soil structure, and slope. Soil sampling followed a methodology recommended for soil quality assessment, particularly for rubber production (Dick et al., 1996; Olson et al., 1996; Pushparajah and Yew, 1977). At each parcel, 10 to 15 samples were taken along a grid pattern every 50 to 100 paces from nonpath areas at two depths, 0 to 15 cm (referred to here as topsoil) and 15 to 45 cm (referred to as subsoil), which correspond to the depths at which there is the largest concentration of *Hevea* feeder roots (Landon, 1984;

Pushparajah, 2002). Samples from each depth were mixed in separate containers, and a composite sample was drawn for each depth, sealed, and labeled for further analysis. Stratified composite sampling was used if a field was not uniform and could be divided into subareas. Thus, although there were 60 fields sampled, there are a total of 64 parcels in the analysis. All laboratory analyses were conducted by the Soil, Plant, and Fertilizer Lab unit of the Malaysian Rubber Board.

Field Measurements: Depth, Drainage, Consistence, Slope

It was not possible to obtain an unbiased estimate of depth at each field, therefore percent uprooting (a consequence of shallow soil) was used as a proxy for depth limitation (Chan et al., 1975; Chan & Pushparajah, 1972). Shallow soils cause poor tap root formation and anchorage, which can result in uprooting of more than 10% of trees (Chan, 1977). In deep soils, losses due to uprooting are usually absent unless the soils have a high water table (Chan, 1977). Thus, a household respondent indicated the number of trees that had uprooted since planting, and a tree loss percentage was computed. The respondent also recalled the frequency and duration of flooding events. The presence or absence of a high water table was determined by auguring to 100 cm at the lowest point in the field. Moist consistence was evaluated at each field with the conventional hand pressure method (Schoeneberger et al., 2002), and slope was measured with a hand clinometer.

Laboratory Analysis: Particle Size, pH, CEC, Macronutrients, and Micronutrients

Particle-size distribution was determined by sieving and pipette (Gee & Or, 2002). Size fractions were defined from Min (1967) as coarse sand (0.2 to 2 mm), fine sand and coarse silt (0.02 to 0.2 mm), fine and medium silt (0.002 to 0.02 mm), and clay (<0.002 mm). Soil pH was measured by using a pH meter and a soil:solution ratio of 1:2.5 (Thomas, 1996). To measure CEC, soils were leached with 1N ammonium acetate at pH 7, washed with ethanol, and leached with 0.1N K_2SO_4 to extract ammonium (NH_4^+) retained on the exchange (Sumner & Miller, 1996). Concentrations of K, Ca, Mg, and Na extracted by the ammonium acetate leaching were measured by using an atomic absorption spectrometer. The amount of retained ammonium in the soil was measured by using an autoanalyzer. Total C, N, and S were obtained through dry combustion with a CNS analyzer (Nelson & Sommers, 1996). The soil was extracted using a mixture of 0.1N HCl and 0.03N NH_4F (pH 1.8), and available P was measured colormetrically (an adaptation of Bray's procedure); total P, Mn, Al, Co, Mg, and Ni were analyzed with a wet soil digest using a 1:1 H_2SO_4:$HClO_4$ mixture (Kuo, 1996). Total P was measured colormetrically, and the remaining elements were measured by using ICP-OES spectrometry.

Data Analysis, Soil Suitability Ratings, and Outline of Results

We used the Statistical Package for the Social Sciences (SPSS) to generate descriptive statistics for each soil property at each depth. Soils were then grouped by village, and a one-way analysis of variance was used to determine whether significant variation in measured soil properties existed between villages. To determine the rubber-related deficiencies of these soils, a minimum data set of soil quality indicators was identified and each property was rated as 1 (very serious limitation), 2 (serious limitation), 4 (slight limitation), or 5 (no limitation). This scale intentionally excludes the midpoint rating (3). Table 1 displays the suitability classification system used in this smallholder study. This system has been widely used in Malaysia to assess the suitability of undeveloped and estate soils for growing rubber (Chan et al., 1975; Chan et al., 1984; Yew and Bachik, 1990; Yew and Chan, 1992).

The results of the fieldwork and soil analyses will first be described at the village level to provide general information about these soils and to illuminate any variability within or between villages that may exist with regard to soil attributes or rubber suitability limitations. We then summarize the regional and geomorphological patterns that were detected along with their most common rubber growth limitations. We propose soil classifications for groups of soils in each region based on shared mineralogical, physiographic, and chemical properties with an identified soil series (Chan et al., 1984; Min, 1967). Finally, we discuss the overall suitability of *Jah Hut* rubber soils and make recommendations regarding soil management strategies that may improve future productivity and sustainability.

TABLE 1

A soil suitability classification system for rubber growth and performance

Soil property	No limitation (5)	Minor limitation (4)	Serious limitation (2)	Very serious limitation (1)	Growth/performance limitation
Physical property					
Depth (cm)[a] (uprooting %)	>100 (0)	60–99 (<5)	25–59 (5–10)	<25 (>10)	Stunted root development and root expansion, uprooting
Slope (%)[a]	0–14	15–27	28–65	>65	Erosion, loss of nutrient-rich topsoil, and poor infiltration
Flooding[a,b,c]	No flooding/ water stagnation	Water stagnates for less than 1 day	Water stagnates for 1–3 days	Water stagnates for >3 days	Reduces soil oxygen, roots atrophy, leaves senesce, latex production ceases, in some cases trees die
Texture[d]	Proportionate amounts of sand and silt + clay	55–70% sand or silt + clay	70–90% sand or silt + clay	>90% sand or silt + clay	Balanced permeability and water/nutrient retention; clayey soils can inhibit root development and can inhibit internal drainage
Moist consistence[a]	Friable to very friable	Firm	Very firm or loose	Extremely firm	Very firm or loose consistence detrimental to root establishment and nutrient retention
Chemical property					
pH[a,e]	4.3–4.6	4.7–5.0	5.1–6.0	>6.0	Highly acidic/basic pH can cause stunting or death
		4.0–4.2	3.5–3.9	<3.5	
Total C (%)	>2.5	1.5–2.5	0.5–1.49	<0.5	Deficiency inhibits soil build-up of N; suboptimal productivity
Total N (%)	>0.4	0.2–0.4	0.1–0.19	<0.1	Deficiency increases immature stage of tree, delays tapping; inhibits K uptake
Total P (ppm)[e]	>600	350–600	250–349	<349	Suboptimal growth and productivity
Available P (ppm)[e]	>30	20–30	10–19	<10	Deficiency increases immature stage of tree; inhibits growth
K ($cmol_c$ kg^{-1})[e]	>4	2.0–3.9	0.5–1.9	<0.5	Deficiency results in slow/weak bark renewal
Mg ($cmol_c$ kg^{-1})[e]	>8.0	3.0–8.0	0.8–2.9	<0.8	Deficiency reduces production potential and tree health
Ca ($cmol_c$ kg^{-1})[e]	<2.0	2.0–3.0	3.1–4.0	>4.0	Tree stunting; latex may coagulate too quickly
CEC ($cmol_c$ kg^{-1})[e]	>16	10.1–16	5.1–10	<5.0	Deficiency reduces production potential and tree health

The rating system adopted here was developed and used by Chan et al. (1975), Pushparajah and Yew (1977), Chan et al. (1986), Yew and Chan (1992) and others, with some minor adjustments to maintain continuity.

[a]Chan et al. (1975).

[b]Pushparajah (2002).

[c]Yew (1991).

[d]Chan et al. (1986).

[e]Pushparajah (1994).

RESULTS AND DISCUSSION

Data Analysis by Village

Means and standard deviations of measured soil characteristics are shown for each village in Table 2, and significant mean differences between villages are also indicated. Table 3 displays the maximum, minimum, and median soil suitability ratings for each soil property by village. Our village-level analysis will begin with

TABLE 2

Raw mean (s.d.) values for chemical soil properties of the samples grouped by village

Soil property	Depth (cm)	Terboi (N = 6)	Pian (N = 10)	Pasu (N = 10)	Penderas (N = 18)	Mendoi (N = 7)	Seboi (N = 6)	Rekoh (N = 7)
pH	0–15	4.73 (0.85)[a]	4.40 (0.34)[a]	4.37 (0.29)[a]	4.32 (0.34)[a]	4.67 (0.39)[a]	4.47 (0.29)[a]	4.16 (0.24)[a]
	15–45	4.53 (0.29)[ab]	4.35 (0.28)[ab]	4.31 (0.26)[ab]	4.18 (0.21)[a]	4.67 (0.38)[b]	4.45 (0.27)[ab]	4.13 (0.28)[a]
Total C (%)	0–15	1.32 (0.21)[abc]	1.44 (0.22)[a]	1.42 (0.30)[a]	1.67 (0.32)[a]	0.80 (0.29)[b]	0.87 (0.37)[bc]	1.32 (0.47)[ac]
	15–45	0.66 (0.12)[ab]	0.80 (0.13)[a]	0.83 (0.14)[a]	0.93 (0.17)[a]	0.42 (0.16)[b]	0.82 (0.50)[a]	0.71 (0.32)[ab]
Total N (%)	0–15	0.14 (0.02)[abc]	0.14 (0.02)[bc]	0.14 (0.03)[bc]	0.16 (0.04)[c]	0.08 (0.03)[a]	0.10 (0.04)[ab]	0.11 (0.04)[ab]
	15–45	0.08 (0.01)[abc]	0.09 (0.01)[ac]	0.09 (0.01)[ac]	0.10 (0.02)[a]	0.05 (0.02)[bd]	0.10 (0.05)[ac]	0.07 (0.03)[cd]
Total P (ppm)	0–15	279.33 (103.53)[ab]	260.70 (72.71)[ab]	554.70 (416.90)[a]	435.89 (327.42)[ab]	272.71 (106.04)[ab]	529.00 (320.01)[ab]	150.29 (65.29)[b]
	15–45	278.50 (204.32)[a]	332.80 (329.02)[a]	347.27 (250.49)[a]	388.39 (279.07)[a]	257.71 (109.91)[a]	448.33 (162.75)[a]	146.00 (71.54)[a]
Avail. P (ppm)	0–15	8.83 (2.23)[a]	6.30 (2.36)[a]	8.30 (8.56)[a]	8.89 (4.75)[a]	10.29 (3.99)[a]	7.33 (2.50)[a]	5.29 (1.98)[a]
	15–45	5.67 (0.82)[ab]	4.70 (0.95)[a]	5.50 (2.01)[a]	6.78 (1.93)[ab]	9.29 (5.50)[b]	7.50 (2.26)[ab]	6.14 (1.68)[ab]
Exch. K ($cmol_c$ kg^{-1})	0–15	0.26 (0.06)[a]	0.20 (0.07)[a]	0.27 (0.15)[a]	0.27 (0.15)[a]	0.12 (0.04)[a]	0.14 (0.06)[a]	0.15 (0.07)[a]
	15–45	0.13 (0.04)[a]	0.11 (0.04)[a]	0.16 (0.08)[a]	0.14 (0.08)[a]	0.07 (0.02)[a]	0.15 (0.13)[a]	0.09 (0.07)[a]
Exch. Ca ($cmol_c$ kg^{-1})	0–15	1.63 (3.04)[a]	1.22 (1.29)[a]	1.49 (1.06)[a]	1.74 (1.58)[a]	2.41 (2.25)[a]	1.19 (1.09)[a]	0.36 (0.39)[a]
	15–45	0.42 (0.46)[ab]	0.81 (0.96)[ab]	0.97 (0.66)[ab]	0.72 (0.73)[ab]	1.72 (1.78)[a]	1.39 (1.43)[ab]	0.13 (0.11)[b]
Exch. Mg ($cmol_c$ kg^{-1})	0–15	0.45 (0.50)[a]	0.42 (0.29)[a]	0.58 (0.40)[a]	0.77 (0.71)[a]	1.18 (1.07)[a]	0.84 (0.86)[a]	0.21 (0.17)[a]
	15–45	0.21 (0.23)[a]	0.22 (0.19)[a]	0.42 (0.27)[a]	0.47 (0.54)[a]	0.98 (1.13)[a]	0.92 (0.97)[a]	0.11 (0.09)[a]
Exch. Na ($cmol_c$ kg^{-1})	0–15	0.04 (0.03)[a]	0.04 (0.01)[a]	0.08 (0.11)[a]	0.03 (0.01)[a]	0.04 (0.04)[a]	0.02 (0.02)[a]	0.02 (0.01)[a]
	15–45	0.03 (0.02)[a]	0.03 (0.01)[a]	0.04 (0.01)[a]	0.03 (0.02)[a]	0.06 (0.08)[a]	0.02 (0.02)[a]	0.01 (0.01)[a]
CEC ($cmol_c$ kg^{-1})	0–15	13.32 (7.31)[a]	10.54 (1.86)[a]	14.74 (4.32)[a]	15.14 (5.16)[a]	9.13 (4.28)[a]	9.79 (6.16)[a]	8.88 (2.77)[a]
	15–45	9.70 (1.40)[abc]	9.88 (1.29)[abc]	13.12 (3.03)[ab]	13.30 (3.80)[a]	8.32 (3.79)[bc]	9.43 (6.00)[abc]	7.74 (3.09)[c]
Total Mg (mg kg^{-1})	0–15	1306.17 (463.42)[a]	1193.20 (413.02)[a]	1387.30 (609.23)[a]	1155.67 (569.66)[a]	668.86 (434.70)[ab]	1007.33 (893.10)[ab]	197.71 (194.44)[b]
	15–45	1448.17 (593.79)[ab]	1322.00 (429.91)[ab]	1497.80 (582.21)[a]	1204.67 (561.76)[ab]	661.14 (439.07)[bc]	877.67 (701.29)[abc]	195.86 (170.67)[c]
Total Mn (mg kg^{-1})	0–15	329.17 (320.52)[a]	261.30 (134.18)[a]	505.80 (288.00)[a]	516.89 (536.13)[a]	431.29 (233.03)[a]	505.17 (245.89)[a]	204.57 (102.80)[a]
	15–45	235.83 (195.38)[a]	216.90 (112.42)[a]	367.50 (151.72)[a]	382.17 (384.88)[a]	377.86 (207.59)[a]	455.50 (265.51)[a]	200.14 (140.12)[a]
Total Al (%)	0–15	4.82 (0.85)[ab]	5.01 (0.98)[a]	6.15 (1.68)[a]	7.13 (1.97)[a]	1.86 (0.52)[b]	4.55 (3.50)[ab]	5.10 (1.99)[b]
	15–45	5.50 (0.68)[abc]	5.81 (0.90)[abc]	6.75 (1.59)[ab]	7.64 (1.49)[a]	1.96 (0.44)[d]	4.19 (2.30)[cd]	4.98 (2.86)[bc]

continued

TABLE 2—*Continued*

Raw mean (s.d.) values for chemical soil properties of the samples grouped by village

Soil Property	Depth (cm)	Terboi (N = 6)	Pian (N = 10)	Pasu (N = 10)	Penderas (N = 18)	Mendoi (N = 7)	Seboi (N = 6)	Rekoh (N = 7)
Total Co (mg kg^{-1})	0–15	7.33 (2.34)^{a}	6.30 (1.49)^{a}	10.60 (3.66)^{a}	14.39 (13.60)^{a}	11.71 (4.42)^{a}	16.33 (9.14)^{a}	9.14 (1.77)^{a}
	15–45	6.33 (2.34)^{a}	6.50 (1.51)^{a}	10.40 (3.24)^{a}	13.78 (13.04)^{a}	11.14 (4.60)^{a}	14.83 (7.11)^{a}	8.86 (2.41)^{a}
Total Ni (mg kg^{-1})	0–15	72.17 (25.82)^{ab}	55.00 (20.33)^{ab}	40.00 (45.51)^{a}	46.50 (37.72)^{a}	192.71 (54.04)^{c}	109.00 (56.53)^{b}	93.00 (42.33)^{ab}
	15–45	56.50 (24.91)^{abc}	38.40 (14.75)^{ab}	31.00 (36.05)^{a}	29.39 (22.09)^{a}	145.86 (18.28)^{d}	96.17 (54.69)^{cd}	80.29 (53.90)^{bc}
Coarse sand (%)	0–15	25.35 (10.79)^{ab}	26.14 (8.14)^{ab}	18.64 (13.14)^{a}	22.85 (12.74)^{a}	50.00 (7.59)^{c}	39.02 (11.12)^{bc}	41.63 (9.91)^{bc}
	15–45	30.50 (14.37)^{abc}	20.05 (6.62)^{ab}	15.80 (12.90)^{a}	16.99 (11.34)^{a}	48.30 (9.31)^{c}	37.02 (9.19)^{bc}	37.47 (15.67)^{c}
Fine sand (%)	0–15	29.08 (8.10)^{a}	27.62 (6.55)^{a}	25.02 (6.43)^{a}	14.21 (6.53)^{b}	25.26 (6.97)^{a}	20.65 (10.27)^{ab}	19.31 (5.03)^{ab}
	15–45	28.12 (4.10)^{a}	25.16 (7.95)^{ab}	19.34 (6.98)^{abc}	12.48 (5.42)^{c}	27.73 (8.21)^{a}	21.72 (9.45)^{abc}	16.67 (4.41)^{bc}
Silt (%)	0–15	21.92 (5.77)^{abc}	22.93 (6.30)^{ab}	31.60 (9.61)^{a}	29.96 (10.21)^{a}	13.31 (4.44)^{bc}	14.47 (6.91)^{bc}	9.23 (3.61)^{c}
	15–45	15.82 (5.19)^{ac}	21.47 (4.58)^{ab}	30.63 (8.79)^{b}	27.33 (11.12)^{b}	11.61 (2.55)^{ac}	13.98 (7.30)^{ac}	8.26 (2.11)^{c}
Clay (%)	0–15	23.67 (7.92)^{ab}	23.30 (6.14)^{ab}	23.72 (9.20)^{ab}	32.96 (9.34)^{a}	11.41 (3.06)^{b}	25.87 (14.82)^{ab}	29.83 (14.01)^{a}
	15–45	25.60 (10.12)^{bc}	33.30 (8.33)^{ab}	34.20 (9.24)^{ab}	43.19 (8.51)^{a}	12.34 (2.42)^{c}	27.30 (13.95)^{bc}	37.59 (19.95)^{bc}

Mean soil properties within a row sharing one or more superscripted letters are not significantly different ($P < 0.05$).

the western-most village (Kg. Terboi) and move east (Kg. Pian, Kg. Pasu and Kg. Penderas) to northeast (Kg. Paya Mendoi and Kg. Seboi) and then south (Kg. Paya Rekoh).

Kampung Terboi

In the six sampled rubber fields of Kg. Terboi, the soils tended to be loams and clay loams with subangular blocky structure and friable to firm consistence. Most fields were located on the relatively flat or undulating high river terraces (slope <5%) and were formed from sandstone or subrecent granitic alluvium. These soils were mapped as Typic Paleudults in the Serdang and Klau Series, respectively. One field, located in the Steepland Association map unit (no specific soil classification), was on an 18% slope and had chemical characteristics that were distinct from the other fields of Terboi. This soil had a near-neutral pH (6.4), contained relatively high total P (486 ppm), high Ca (7.82 cmol kg^{-1}), more than twice the village average for total Mg (2198 ppm), and Mn (892 ppm), and had a CEC of 27.29 cmol kg^{-1}. Although no parent material was detected, this soil resembled several shale-derived soils that were sampled in the hills of other villages in the Krau River Valley region and probably belonged to the same soil series, perhaps Kuala Brang, an Oxic Dystropept formed on gray shale and quartzite (Min, 1967; Pushparajah & Amin, 1977).

From a rubber suitability standpoint (Table 3), none of the soils of Kg. Terboi faced serious limitations related to flooding or slope, yet one soil had very serious uprooting (>10% of trees). Two soils had seriously limiting sand content (>70%), and all soils had serious or very serious C, N, available P, and exchangeable K and Mg deficiencies at one or both depths. The shale-derived soil mentioned earlier had a very seriously limiting pH and Ca levels, which may have been causing tree sickness. The owner of this field mentioned that disease was the biggest factor affecting yields.

Kampung Pian and Kampung Pasu

The 19 parcels sampled in Kgs. Pian and Pasu tended to be intermingled and thus, data from these villages have been combined. The samples taken on the high alluvial terraces and hillslopes had textures of loam to clay loam with granular to subangular blocky structures and friable to firm consistence. The high terrace

TABLE 3

Median (range) soil suitability ratings by village

Soil Property	Depth	Terboi (*N* = 6)	Pian (*N* = 11)	Pasu (*N* = 8)	Penderas (*N* = 19)	Mendoi (*N* = 7)	Seboi (*N* = 7)	Rekoh (*N* = 7)
Slope		5 (2–5)	5 (1–5)	4.5 (1–5)	5 (2–5)	5 (2–5)	4 (2–5)	4 (2–5)
Depth		5 (2–5)	5 (4–5)	5 (2–5)	5 (1–5)	5 (5–5)	5 (2–5)	5 (2–5)
Flood		5 (5–5)	5 (2–5)	2 (2–5)	5 (2–5)	5 (5–5)	5 (1–5)	5 (1–5)
Consistence		4.5 (4–5)	5 (4–5)	5 (4–5)	5 (2–5)	2 (2–5)	5 (2–5)	2 (2–5)
Texture	0–15	4 (2–5)	4 (4–5)	4 (2–4)	4 (1–5)	2 (2–4)	4 (2–4)	4 (4–5)
	15–45	4 (2–5)	4 (4–5)	4 (2–4)	3 (1–5)	2 (2–4)	4 (2–4)	4 (2–4)
pH	0–15	5 (1–5)	5 (4–5)	4.5 (4–5)	5 (2–5)	4 (4–5)	5 (4–5)	4 (4–5)
	15–45	5 (4–5)	5 (4–5)	5 (2–5)	5 (4–5)	4 (2–5)	5 (4–5)	4 (2–5)
C (%)	0–15	2 (2–4)	2 (2–4)	3 (2–4)	4 (2–4)	2 (2–2)	2 (2–2)	2 (2–4)
	15–45	2 (2–2)	2 (2–2)	2 (2–2)	2 (2–2)	1 (1–2)	1 (1–4)	2 (1–2)
N (%)	0–15	2 (2–2)	2 (2–2)	2 (2–2)	2 (1–4)	1 (1–2)	1 (1–2)	2 (1–2)
	15–45	1 (1–2)	1 (1–2)	1.5 (1–2)	2 (1–2)	1 (1–1)	1 (1–2)	1 (1–2)
Total P	0–15	1 (1–4)	2 (1–4)	4 (1–5)	3 (1–5)	2 (1–4)	2 (2–5)	1 (1–1)
	15–45	1 (1–5)	1 (1–5)	4 (1–5)	2 (1–5)	2 (1–4)	2 (2–5)	1 (1–1)
Avail. P	0–15	1 (1–2)	1 (1–4)	1 (1–1)	1 (1–2)	1 (1–2)	1 (1–1)	1 (1–1)
	15–45	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–2)	1 (1–2)	1 (1–1)	1 (1–1)
Exch. K	0–15	1 (1–1)	1 (1–1)	1 (1–2)	1 (1–2)	1 (1–1)	1 (1–1)	1 (1–1)
	15–45	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)
Exch. Ca	0–15	5 (1–5)	5 (2–5)	5 (2–5)	5 (2–5)	4 (1–5)	5 (2–5)	5 (5–5)
	15–45	5 (5–5)	5 (4–5)	5 (4–5)	5 (4–5)	5 (1–5)	5 (2–5)	5 (5–5)
Exch. Mg	0–15	1 (1–2)	1 (1–2)	1.5 (1–2)	1 (1–4)	2 (1–4)	1 (1–2)	1 (1–1)
	15–45	1 (1–1)	1 (1–1)	1 (1–2)	1 (1–2)	2 (1–4)	1 (1–2)	1 (1–1)
CEC	0–15	4 (2–5)	4 (2–4)	4 (4–5)	4 (2–5)	2 (1–5)	2 (1–5)	2 (1–4)
	15–45	4 (2–4)	4 (2–4)	4 (4–5)	4 (2–5)	2 (1–4)	2 (1–5)	2 (1–4)

samples contained coarse quartz grains and are mapped as the Klau Series, whereas soils on the rolling and undulating hillslopes contained quartz grains and laterized shale pieces in the lower depths and are mapped as the Bungor Series. The soils in the Klau-Bungor Association are classified as Typic Paleudults, with Bungor containing slightly more clay and being located on the steeper slopes. Several of the fields sampled in Kgs. Pian and Pasu were on the lower terraces of the Krau River and experienced periodic river overflow. These soils belong to the Telemong Series. They were very silty (35 to 45%), contained 10% or less coarse sand and had high CEC (12 to 22 $cmol_c\ kg^{-1}$), with most exchange sites being occupied by Ca. Finally, two soils mapped in the Steepland Association resembled the gray shale of the Kuala Brang Series (Oxic Dystropept) and contained high total Mg (>2000 ppm) and total P (>1000 ppm), whereas clay content remained relatively low (12 to 14% in topsoil).

With regard to soil limitations for rubber growth, the six fields located on lower river terrace had occasional flooding caused by river overflow. Three of these soils also showed problems with past uprooting and two had seriously limiting textures (clay + silt > 80%). It is hypothesized that the uprooting in these soils may have been due to a periodically high water table, even though this limitation was not detected in the field. Three fields in the hilly terrain had seriously limiting slopes (>30%), one of which also had shallow depth. Overall, total C and N were seriously limiting for all samples at one or both depths, and available P and exchangeable bases were very seriously limiting for these soils. CEC tended to be sufficient for the riverine and gray shale soils, although Ca occupied most exchange sites and exchangeable K and Mg were very low.

Kampung Penderas

Generally, the patterns seen with the 19 soils of Penderas mirrored those of the other villages along the Krau River. On both the slopes and the alluvial terraces, we detected coarse quartz grains in the subsoil, which were probably either remnants of weathered granite or alluvium. Several foothill soils contained laterized ferruginous shale below 30 cm. These areas mapped to the Klau Bungor Association. Four hillslope soils were presumed to belong to the gray shale

TABLE 4

Identified soil series within each region and corresponding parent material, characteristics, and limitations to rubber

Region soil series	N of fields	Parent material	Topography/ geomorphic position	Predominant characteristics	Soil limitation[a] (number of fields with serious or very serious limitation)						
					Flood	Slope	Depth	Texture	Total P	CEC	Other
Krau River Valley											
Telemong	12	Recent riverine alluvium	Low river terrace; nearly flat	Coarse sand <10% Silt >30 % Clay >30% CEC: 10–22 $cmol_c\ kg^{-1}$ Prone to flooding.	8	0	0	7 clayey	7	0	–
Klau	7	Older granitic alluvium	High river terrace; nearly flat or undulating	Quartz grains throughout Slightly gravelly CL-C In association with Bungor Series	0	0	2 firm/ clayey soils	0	7	5	Moderate drainage conditions; possibly Mn deficiency
Bungor	15	Shale/quartzite conglomerate	Hills above high river terrace; rolling or undulating	Quartz grains and laterized shale pieces common in subsoil In association with Klau Series	0	3	2 firm/ clayey soils	2 clayey	14	7	Moderate drainage conditions
Serdang	2	Quartzite conglomerate	Lower rolling slopes of granite/ quartzite ridges	Coarse sand > 40% Low silt + clay < 30%	0	0	0	2 sandy	2	2	Susceptible to erosion
Kuala Brang	5	Gray shale and quartzite	Backslopes of rolling hills	Tot. Mg: 1000–2500 ppm Tot. Mn: 600–1800 ppm Tot. P: 600–1000 ppm Laterized shale in subsoil.	0	2	2 steep slope/ clayey soil	3 clayey	0	0	Possible toxicity – Mg >2000 ppm Mn >1500 ppm Co > 40 ppm

continued

TABLE 4—*Continued*

Identified soil series within each region and corresponding parent material, characteristics, and limitations to rubber

Region soil series	N of fields	Parent material	Topography/ geomorphic position	Predominant characteristics	Soil limitation[a] (number of fields with serious or very serious limitation)						
					Flood	Slope	Depth	Texture	Total P	CEC	Other
Mendoi-Seboi											
Serdang	7	Sandstone/ quartzite conglomerate	Foothills and steep slopes of sandstone/ quartzite ridge	Coarse sand > 40% Silt+clay < 30% CEC < 8 $cmol_c\ kg^{-1}$ Al < 3.5%	1	0	1	6 sandy	7	7	Loose consistence; Possible toxicity–all soils with Ni > 100
Jempol	2	Trachyandesitic tuffs	Backslopes of rolling hills	Tot. Mg: 1000–2500 ppm Tot. Mn: 600–1800 ppm Tot. P 600–1000 ppm	0	0	1 slope	0	0	0	
Segamat	5	Andesitic lava or tuffs	Footslopes/ terraces of rolling hills	Tot. sand >65% Tot. P: 300–600 ppm Tot. Mn: 500–700 ppm Tot. Mg 800–1400	0	0	0	3 sandy	3	3	Loose consistence; Possible toxicity–all soils with Ni > 100
Rekoh											
Rengam	4	Granite	Slopes and hill terraces of rolling terrain	Silt < 15% Coarse sand > 40% Silt+clay < 50%) CEC < 10 $cmol_c\ kg^{-1}$	1	0	3 slope/ shallow	3 sandy	4	4	Loose consistence
Jerangau	3	Hornblende granite/ granodiorite	Slopes and hill terraces of rolling terrain	Silt < 10% Fine sand < 20% Silt+clay > 50% CEC > 10 $cmol_c\ kg^{-1}$	0	0	1 clayey	0	3	0	

[a]C, N, available P, exchangeable Mg and K were seriously or very seriously limiting at one or both sampling depths in every soil.

Kuala Brang Series, with silty clay textures high total Mg, Mn, and total P levels. Five soils were formed from recent alluvium (Telemong Series).

Serious soil limitations in Penderas were related to uprooting (10 soils) and excessive (>70%) silt plus clay content (4 soils) and flooding (2 soils). No soil had more than one serious physical limitation. Available P and exchangeable K and Mg were deficient for nearly all samples at both depths; however, CEC tended to be sufficient for most fields. Ca levels were raised enough to be seriously limiting for two soils, one of which had a high pH that was seriously limiting as well.

Kampung Paya Mendoi

The seven soils of Mendoi were formed from sandstones and quartz pebble conglomerates, with some volcanics and volcaniclastics. The sandstone-derived soils were Typic Paleudults (Serdang Series), whereas the volcanic-derived soils were Tropeptic Haplorthoxes (Segamat or Jempol Series). Textures for both parent materials were loamy sand to sandy loam, with 70 to 80% sand at each sampling depth. Soil structures were granular to subangular blocky, and consistence was loose to friable. As expected, the sandstone-derived soils were less active than the volcanic soils (CEC < 6 cmol kg^{-1} vs 9 to 16 cmol kg^{-1}) and were more acidic (pH < 4.3 vs pH > 4.8). The volcanic soils contained higher levels of exchangeable Ca, Mg, and total P. All of the soils of Mendoi had potentially toxic Ni (topsoil mean = 193 ppm) and very low Al (<2%), which are characteristics of serpentinitic soils. According to a Malaysian Minerals and Geoscience Department geologic map (Thani, 1988), this area also contains basalt conglomerates, which when weathered, can give rise to serpintinite. Ni levels in the Kg. Paya Mendoi sample, however, are much lower than those of a true serpentinitic soil (Sungei Mas Series), which has Ni levels above 2000 ppm (Min, 1967).

None of the fields of Paya Mendoi had uprooting or flooding, and the only soil on a steep slope had been terraced by RISDA. However, the sandy texture and loose consistence of these soils posed serious to very serious limitations for nearly all fields due to excessive drainage and the inability to retain nutrients. Available nutrients were limiting in all of the sandstone-derived soils, whereas CEC was not limiting for only the volcanic soils sampled. Only one soil had sufficient levels of available Mg, but this soil also had a seriously limiting pH (5.3) and excessive Ca (>5 $cmol_c$ kg^{-1}).

Kampung Seboi

The seven soils of Seboi are very similar to those of Mendoi, as they were derived from the same formation of sandstones and volcanics. Most rubber fields in Seboi were located on footslopes or backslopes, the steepest of which had been terraced by RISDA. Seboi soils were slightly less sandy than Mendoi soils yet tended to be quite variable texturally. Textures of the sandstone soils (mapped as Serdang Series) were loamy sand to clay loam, whereas those for the volcanic soils (Jempol Series) were loam, silty clay loam, and clay. The patterns seen in the previous village with volcanic-derived soils showing higher total P, Mg, and Mn held in Seboi. And as seen in Mendoi, Ni levels were elevated and potentially toxic (>125 ppm) and Al was depressed (<3.5%) for the sandstone-derived soils and for one of the volcanic soils.

Rubber suitability ratings were low (2) for texture (total sand >70%) on four sandstone-derived soils. Periodic flooding was a serious limitation for one soil located along a mountain stream. Three of the seven fields had problems with past uprooting, and all soils had exposed stones or boulders, which indicated that erosion is likely a problem in this area. All nutrients and base cations were seriously limiting at both depths in the sandy soils, yet CEC was sufficiently high in the volcanic soils. One volcanic soil had seriously limiting levels of Ca (>3 $cmol_c$ kg^{-1}).

Kampung Paya Rekoh

The soils of Paya Rekoh are underlain by granite or granodiorite and do not contain the shales, volcanics, or sandstones detected in the soils of other villages. Textural classes ranged from clay loam to clay, although there was one soil that was loamy sand. Structures of these soils were granular to subangular blocky structure, and consistence was loose to firm consistence. Most soils had very little silt (<12%) and a large component of coarse sand (40 to 60%). The soils formed on granite were very low in both total and exchangeable cations (CEC <7 cmol kg^{-1}) and are mapped as the Rengam Series. Those formed from granodiorite were slightly more active (CEC = 10 to 12 cmol kg^{-1}) and are mapped as the Jerangau series. Soils in the

Rengam-Jerangau Association are classified as Typic Paleudults.

Four of the six rubber fields had past uprooting, and one hill soil was shallow (45 cm to hardpan). Two soils exhibited excessive sand contents that were limiting to rubber productivity, one of which was comprised of 83% sand (60% coarse sand, 23% fine sand). This soil had no structure and loose consistence. According to the field respondent, the field flooded for three months of the year. The result of this flooding was a grayish loamy soil, a low content of clay (<9%), total C (<0.16%), total N (<0.05%), and base cations (total Mg < 35 ppm; CEC < 4 cmol kg^{-1}). Nickel content, however, was quite high (>160 ppm), more than double the mean of the other six fields (74 ppm). Available nutrients and base cations were very seriously limiting for all soils, with the exception of CEC, which was not limiting for soils in the Jerangau Series.

Regional and Geomorphologic Trends

Based on the analysis of the village-level data, there are instances of both within-village heterogeneity and clear regional trends that must be explored. To unravel these similarities and differences, we used qualitative and quantitative descriptions from reconnaissance surveys of rubber-planted soils in the northwest region of Pahang (Min, 1967; Pushparajah & Amin, 1977) to match each soil in our sample to the soil series it most resembled. The characteristics compared were geomorphic position, slope, parent material, total P, Mg, Mn, Ni, Co, Al, coarse sand, fine sand, silt, and clay fractions. Once soils were classified in this way, we re-analyzed the properties and limitations grouped by soil series within region. Table 4 illustrates the trends and variation in certain characteristics that can be traced to similarities and differences in parent material and geomorphology both within and across regions.

The rubber productivity limitations that appear in Table 4 relate strongly to region, parent material, and geomorphic position. For example, the Telemong Series was most susceptible to flooding, due to its location on the low river terrace. This soil had a very clayey-silty texture and a high CEC, with exchange sites being occupied mainly by Ca. The low total P status was the result of inherently low P in the alluvium.

The soils located on unterraced steep slopes were subject to topsoil erosion and nutrient loss as well as to uprooting. Uprooting is a function of strong winds combined with an undeveloped root system. In our sample, uprooting seemed to be a problem in those soils that were found on steep slopes, floodplains, and or that contained high (although not limiting) amounts of clay.

Texture was the most common physical limitation encountered in our sample and took the form of both excessive clay and excessive sand. Besides the river terrace soils, several of the shale-derived soils on the rolling hills above the Krau River Valley also contained >70% clay + silt. Nine of the 14 soils in Mendoi-Seboi and nearly half of the soils in Rekoh were >70% sand. Although excessive clay inhibits root growth, drainage, and soil workability, extreme sand leads to excessive drainage, water stress, and strong leaching of nutrients.

In general, nutrient status was poor for all soils. Due to the humid tropical climate of Malaysia, leaching eluviates essential nutrients from the soil depths at which the greatest concentration of *Hevea* roots are found (0 to 50 cm), to depths where they become unavailable. Several soils showed extremely high levels of Mg, Mn, Ni, and Co. Potential Ni toxicity was found in the high sand content soils of Mendoi and Seboi (Serdang and Segamat Series), whereas high Mn, Mg, and Co was found in the steep soils on gray shale (Kuala Brang Series). It is likely that these were inherited from the parent material, and further investigations should be made into whether these and excessive levels of other micronutrients may be inhibiting rubber productivity for these soils.

Potential Strategies for Mitigating Soil Limitations

For those fields that had seasonal inundation caused by river overflow, installation of drains would not be effective because the river would be the logical low-lying outlet. However, for flooding that is due to rain, drains may be a feasible, albeit expensive, option. If poor infiltration during the rainy season is the problem, drains are not necessary and the best remedy would be the establishment of a cover crop to improve the internal drainage, aggregation, and aeration of a heavy-textured soil (Pushparajah & Yew, 1977). Cover crops can also be helpful for reducing soil erosion and nutrient loss on sloped fields. Slopes >16%, however, should be terraced in order to avoid serious topsoil loss and soil shallowing (Pushparajah & Yew, 1977).

With regard to soil texture, best management practices should take into account texture-related limitations (poor infiltration, uprooting, heavy nutrient leaching) as well as the texture-related response to the management strategy. For example, if uprooting due to excessive clay or sand is a problem, managers should plant specialized light crown clones so that tree losses are minimized during heavy winds. For nutrient-deficient soils with sandy textures, a low rate, high frequency fertilization schedule should be used (Pushparajah & Yew, 1977). The establishment of a ground cover in either clayey or sandy soils can improve water infiltration and moisture retention, decrease bulk density, and promote sustained soil fertility (Pushparajah et al., 1977).

Adequate nutrition can dramatically improve rubber yields (up to 22% in some cases, Ooi, 1976), and provisions for increasing and maintaining soil fertility are essential for maximizing productivity. Estate managers commonly use chemical fertilizers to minimize inherent nutrient deficiencies and to support sustained rubber yields (Ooi, 1976). Discriminatory fertilizer use is essential, however, as nutrient imbalances can easily result from over- or under-application of a nutrient, or from using the wrong type of fertilizer (Pushparajah et al., 1977). Furthermore, since rubber in Malaysia is grown on soils with diverse chemical and physical properties, its responses to fertilizers vary by soil type, and training is crucial for maximizing returns of fertilizer usage (Pushparajah & Yew, 1977). For areas where soil type is unknown and/or for smallholders who are untrained and/or cash-constrained, soil nutrient levels can be maintained or improved by planting ground covers. Grasses or herbaceous covers maintain moderate soil nutrients, while leguminous covers are the most effective and least expensive method for enriching and maintaining soil N, P, K, Mg, and organic matter !(Pushparajah et al., 1977; Pushparajah & Yew, 1977).

Potential Relationship Between Soil Type and Yield

An unbiased measurement of yield from each rubber field was beyond the scope of this study. However, past research in Peninsular Malaysia has related some soil series to rubber yields on estates (Chan et al., 1975). In general, with all other factors held constant, the most productive soils are Haplorthoxes (Segamat and Jempol). Among the Paleudults, Reganam, Jerangau, and Bungor tended to be more productive than Serdang. The Dystropepts (Kuala Brang) are least productive. None of these soils are discouraged for rubber growth, and yields can be improved on all soils with appropriate management.

CONCLUSIONS

Building on previous research efforts to quantify important soil properties for rubber performance in Malaysia, this study has extended a soil suitability classification system for rubber growth to evaluate the soils of the *Jah Hut* group of indigenous rubber smallholders. The rating system was deemed particularly useful once the soils were grouped by region, geomorphic position, and soil type because patterns were detected with respect to soil/land characteristic and rubber limitation. In practice, this level of assessment is much more practical than field-level analyses, which are time and capital intensive, and potentially more effective than village-level analyses, which can ignore intravillage heterogeneity. We offer this region-level breakdown of soil types and their respective soil limitations as a method by which government and RISDA officials can maximize the returns of their investments in these smallholders. This information can assist with recommendations of appropriate soil specific technologies and techniques for currently tapped rubber and can also inform future planting and management decisions on replanted or newly cleared fields. The main challenge for the future is to enable continuous rubber production on currently cropped land without the threat of soil degradation or encroachment onto undeveloped fragile lands (e.g., steeplands or forest). Any actions taken to improve the suitability of these soils have the potential to not only increase future productivity but also future income and quality of life.

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