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THE RELATIONSHIP BETWEEN PEAT SOIL CHARACTERISTICS AND THE GROWTH OF SAGO PALM (*Metroxylon sagu*)

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Abstract Intensive development on the vast peatlands of Sarawak has been planned for sago cultivation. Nevertheless, a number of unanticipated problems in large-scale sago cultivation have been highlighted − one of which is the trunking ability of sago palms. This study attempts at examining the relationship between the physical and chemical properties of peat against the growth pattern of sago palms. For this purpose, soil samples, water table data and palm growth were studied and analyzed at both trunking and non-trunking blocks on the Dalat Sago Plantation. The results revealed that the soils in the trunking blocks invariably contained higher levels of ash (minerals) and nutrients (nitrogen, phosphorus and potassium) needed to support the normal growth and trunking of palms. These mineral and nutrient contents were found to decrease from the periphery to the center of a peat dome. The productivity of cultivated palms was also compared with the degree of peat humification. No significant correlation was observed for these variables. The prevailing deficiency of nutrients in the soils of the non-trunking block suggests that supplementary nutrient input would be imperative.
Key words: *sago palm, Sarawak, shallow peat, deep peat, productivity*

泥炭土壌の性質とサゴヤシ(*Metroxylon sagu*)の生育との関係

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サラワクの広大な泥炭地の集約的な開発がサゴヤシ栽培のために計画されてきた．しかし，多くの予期せぬ問題が大規模サゴヤシ栽培地で見つかってきた．その１つはサゴヤシの幹立ちである．そこで，この研究では泥炭地の物理的，化学的性質とサゴヤシの生育状況との関係を調べることを目的とした．土壌サンプル，地下水位，サゴヤシの生育に関するデータを集め，Dalatプランテーションの幹形成地帯と非形成地帯とで比較分析した．その結果から，幹形成地帯の土壌では，サゴヤシの通常の生育及び幹立ちに必要な高レベルの灰分（塩基分）と養分（窒素，リン酸，カリウム）が含まれていた．これらの塩基，養分含量は泥炭地帯の周辺部から中心に向かって減少することがわかった．栽培されたサゴヤシの生産性が泥炭の腐植化度との関連で調べられたが，有意な関係は認められなかった．幹非形成地帯の土壌では養分が不足しているので，補足的な養分の供給が絶対に必要であることが推察された．
キーワード：サゴヤシ，Sarawak，層の薄い泥炭土，層の厚い泥炭土，生産性

Introduction

Sarawak has the largest share of peatland of any state in Malaysia, approximately 1.6 million hectares or 13% of the state's land in Sarawak. It has been identified as an important land source for agriculture. To date, approximately 535, 000 hectares (about 32% of the total peatland in Sarawak) has been converted into agricultural land. The cultivation of Sago palm is one of the most intensive agricultural developments taking place on peatland. It is the fourth-largest agricultural export earner, bringing in RM 23.15 million in export earnings in 1993 (Department of Agriculture, 1994). An estimated 19,720 hectares of sago palms are in Sarawak (Tie *et al.,* 1990), and 62% of this land is located in peat soils. Traditionally, sago is grown in Sarawak as a smallholder crop. The increasing population has stimulated the expansion of sago cultivation. Both the government and private sectors have invested heavily in the agricultural potential of the vast peatlands of Sarawak for sago cultivation. The government has established two large-scale sago plantations in Mukah and Dalat. Larger areas are planned for sago cultivation in the future. Nevertheless, the eventual development of sago plantations has brought to light many unanticipated problems. One is the trunking ability of sago palms. After 10 years of cultivation, no trunk formation was observed, particularly for sago palms cultivated in deep peat. The objectives of this study were to compare the physical and chemical properties of peat soils and the growth pattern of trunking and non-trunking sago palms.

Materials and Methods

Study area

The study was carried out at the Dalat Sago Plantation, Sarawak, Malaysia. The gross area of the Dalat Sago Plantation is 6,676 hectares (Figure 1). This study was conducted in Block 1 and Block 7 where the sago palms were first planted in November, 1993. An average of 176 and 224 palms per hectare were planted on Blocks 1 and Block 7, respectively (Land Custody and Development Authority, 2004). Generally, the study site is situated on a flat and low-lying area, consists of organic soil of the Anderson Family (moderately deep peat soil with 1-3 m). Figure 2 is a survey of the peat depth on the Dalat Sago Plantation (Melling, 2000).

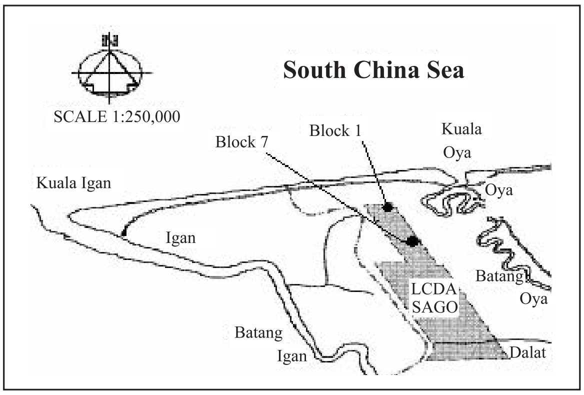

Figure 1: The study site (Craun Research Sdn. Bhd., 2003)

Block 1 is an area of shallow peat area with a thickness < 150 cm, and Block 7 is an area with moderately deep peat area with a thickness of 150-300 cm. The distinctive difference of these two blocks was the growth of sago palms. Sago palms cultivated on Block 1 were healthy with well-formed trunks, while those on Block 7 were stunted and had a high rate of

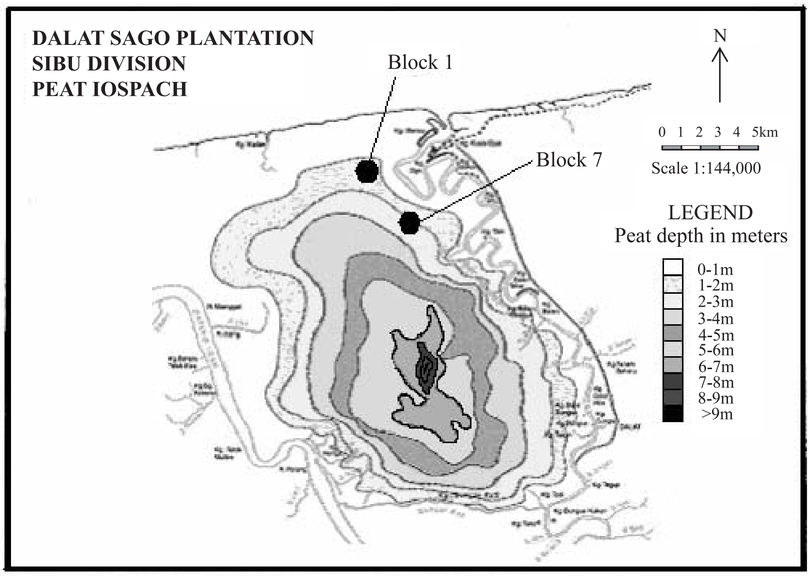

Figure 2: Peat depth at the Dalat Sago Plantation (Melling, 2000)

mortality. Fifteen plots were selected randomly from each block for soil and plant growth analyses. Each plot was identified as a circular area surrounding the randomly selected palm with a radius of 2.0 m from the trunk.

Soil analyses

Two soil samples were collected from each plot (at a distance of approximately 2.0 m apart from the trunk and within the canopy of the palms). The soils was sampled according to depth, 0-15 cm and 15-30 cm. For the soil samples collected from a defined depth, a composite sample was prepared and subjected to physical and chemical characterization in three replications. The bulk density, total ash content, degree of humification, rubbed fiber content, pH, nutrient content and cation exchange capacity were determined. The bulk density was determined using the core method (Black & Kartse, 1986) and the total ash content was expressed on an oven-dry weight basis and determined by the combustion of samples at 800℃ for 2 hours (Anon, 1992). The degree of humification was reported according to the Von Post Scale (Ekono, 1981) and the value of E_4/E_6. The rubbed fiber content (RFC) was determined using the syringe procedure to provide a measure of the degree of decomposition. In highly decomposed organic material, fibers are nearly absent. Fibers of moderately decomposed organic material however, may be largely preserved but they are easily broken down by rubbing (Mckenzie, 1974). The available phosphorus in soil was extracted using the Bray II solution (0.03 M NH4F/ 0.1 M HCl) and determined by the molybdate blue method (Bray and Kurtz, 1945). Nitrogen was analyzed with the Kjeldahl digestion procedure. The cation exchange capacity was determined by leaching the soil with ammonium acetate (Malaysian Standard MS 679, 1980), and the total amount of potassium was determined by igniting the air-dried peat sample at 550℃ for 1 hour and digested the ignited sample with concentrated HCl prior to analysis with an Atomic Absorption Spectrometer (Day *et al.,* 1974). The water table was measured at two points within each experimental plot throughout the study. The soils were augered to a depth of approximately 1 m and the water table was measured from the surface using a measuring tape.

Extraction of humic acids

Humic acids were extracted according to the method described by the International Humic Substances Society, 1983 with modifications. Approximately 1.00 g of air-dried peat soils were mixed with 10 ml of 0.5 M NaOH and shaken overnight. The mixture was centrifuged at 6,000 rpm for 15 minutes and the supernatant was separated from the precipitates. Hydrochloric acids (6 M) were added to the supernatant to attain pH 1-2 and allowed to stand overnight. The humic acids were precipitated and separated from the fulvic acids by means of centrifugation. The humic acids were washed with distilled water, centrifuged and freeze-dried.

UV-VIS spectroscopic analysis

Approximately 5 mg of humic acid samples were dissolved in 25 ml of a 0.05 M $NaHCO_3$ solution. The absorbance of the samples at 465 and 665 nm was recorded.

Plant growth

The growth status of a sago palm was measured by its average diameter at breast height or at the base of the trunk, average tree height, number of suckers and length of the longest fronds. Palms of the same age were compared to minimize variability. Nine-year-old sago palms were selected randomly from Blocks 1 and 7.

Statistical analysis

Analysis of Variance (ANOVA) at the 95% confidence level was employed to study any significant difference between the characteristics of peat soils from Blocks 1 and 7.

Table 1: Morphological characteristics of sago palms at Blocks 1 and 7

Growth performance	Block 1	Block 7	Shallow peat (Yamaguchi *et al.*, 1997)	Deep peat (Yamaguchi *et al.*, 1997)
Diameter at breast height, cm	53.4 ± 2.7		63.7	58.8
Height, m	15.4 ± 1.5	4.3 ± 1.1	17.4	13.5
Number of suckers	8.0 ± 2.4	4.0 ± 1.5	Na*	Na*
Length of longest frond, m	6.8 ± 0.5	2.4 ± 0.7	9.3	9.0

* Not available, n= 15

Results and Discussion

Morphological characteristics of sago palms

Table 1 shows the average morphological characteristics of sago palm cultivated on Blocks 1 and 7. The sago palms in Block 1 clearly showed better growth than those in Block 7. Yamaguchi *et al*. (1997) studied the growth of sago palms on deep and shallow peat at Sungai Talau Peat Research Station, Sarawak, and determined that sago plants grew better in shallow peat. The data of palm growth reported by Yamaguchi *et al*. (1997) in Table 1 did not indicate any problem regarding trunking ability. The issue of trunking ability was raised in a study by Sumida *et al* (2002). In their study, the palms at Sungai Talau Peat Research Station were found to grow well, with an average palm height of 10 m and a diameter of 40 cm; however, those at the Mukah Sago Plantation grew poorly, with a palm height of 2 m and no trunk. The better growth of sago palms at the Sungai Talau Peat Station was attributed to the presence of minerals in the soils at depths of less than 20 cm. The difference in the morphological characteristics of sago palms cultivated on Blocks 1 and 7 could have been influenced by the soil factors as suggested by Sumida *et al*. (2002).

Physical & chemical properties of soil

Table 2 summarizes the properties of peat soil in relation to depth. Soils from both blocks indicated an acidic environment with a low bulk density, which may be a limiting factor for the growth of sago palms. According to Benito et al. (2002), sago palms in peat soils grew more slowly and showed a lower production than palms grown in mineral-rich soils due to the physical and chemical constraints of peat soils, such as low bulk density, high acidity and low N, P, K, Ca, Zn and Cu levels.

The water tables for Blocks 1 and 7 were 20-30 cm and 40-50 cm, respectively. The measurements were obtained in April, when rainfall is rather frequent. The data suggested that the water table was managed in accordance with the recommended water table level of 20-50 cm (Teck *et al.,* 2001; Flach & Schuiling, 1990; Jong, 2001). A significant difference was

Table 2: Mean values for soil properties according to depth

Physical & chemical characteristics	Trunking (Block 1) 0-15cm	Non-trunking (Block 7) 0-15cm	p value	Trunking (Block 1) 15-30cm	Non-trunking (Block 7) 15-30cm	p value
pH	2.9-3.7	3.0-3.6	0.46	3.3-3.7	3.2-3.7	0.02
Bulk density, g cm^{-3}	0.11 ± 0.04	0.15 ± 0.03	0.30	0.12 ± 0.07	0.11 ± 0.03	0.01
Total ash content, g kg^{-1}	231.0 ± 160.0	33.0 ± 8.0	5.8×10^{-5}	245.0 ± 158.0	38.0 ± 17.0	2.7×10^{-5}
Rubbed fiber content, g kg^{-1}	206.0 ± 48.0	140.0 ± 27.0	2.0×10^{-4}	218.0 ± 67.0	173.0 ± 56.0	0.07
Cation exchange capacity, meq $100g^{-1}$	81.1 ± 11.8	71.8 ± 11.8	0.04	79.5 ± 13.6	79.3 ± 13.4	0.96
Total nitrogen, g kg^{-1}	23.0 ± 3.3	3.6 ± 1.9	5.8×10^{-18}	28.0 ± 7.6	3.8 ± 2.2	3.1×10^{-12}
Available phosphorus, mg kg^{-1}	48.8 ± 13.9	15.7 ± 13.7	1.0×10^{-6}	45.3 ± 12.4	24.6 ± 10.9	4.0×10^{-5}
Total potassium, mg kg^{-1}	102.8 ± 10.9	43.6 ± 24.4	2.6×10^{-9}	100.2 ± 34.5	48.5 ± 12.0	7.3×10^{-6}
Degree of humification	H3 - H4	H4 - H7	-	H4 - H5	H5 - H6	-
Water table	20 - 30cm	40 - 50cm	-	20 - 30cm	40 - 50cm	-

n = 45

consistently observed in ash content and nutrient content between Blocks 1 and 7 ($p < 0.05$). The ash content in Block 1 was relatively high. Usually, the ash content of tropical peat soil is less than 10 % (Wong, 1991). However, the value of ash content can be higher due to a waterlogged condition (Tie & Kueh, 1979). The poorer ash content in Block 7 probably has resulted in retardation of the growth of sago palms. According to Tie (1982), peat soils with a low ash content are extremely low in available nutrients, which imposes a serious limitation on crop production.

Table 3 is a summary of the estimation of nutrient content per hectare (ha) for the upper 15-cm horizon in Blocks 1 and 7. A 15-cm horizon was considered, as Driessen (1978) reported that most of the nutrient elements in tropical peat accumulate in the top 25 cm where a dense root mat is formed. The subsurface layer commonly contains fewer minerals. Apparently, the nutrient content in Block 1 was higher than that in Block 7.

Table 3: Nutrient content (kg) of soil per hectare (ha)

	Total nitrogen, kg/ha	**Available phosphorus, kg/ha**	**Total potassium, kg/ha**
Trunking (Block 1)	3,795	805	1,696
Non-trunking (Block 7)	810	353	981

Table 4 shows the total estimated annual uptake of nutrients in the trunks and leaves of a sago palm cluster before harvesting (Jong & Flach, 1995). According to the study, a sago palm requires an input of 5.2 kg N, 1.1 kg P, and 6.7 kg K before the first harvest. If 100 clusters were established per ha, the nutrients taken up the sago palms would be estimated to be 520 kg N, 110 kg P and 670 kg K (Jong & Flach, 1995). The guidelines suggested that a 9-year-old palm would require a continuous supply of 2.1 kg N, 0.5 kg P and 3.6 kg K to reach maturity at the end of 12 years. The anticipated nutrient requirement for sago palms in Blocks 1 and 7 can be computed. Sago palms in Block 1 (176 clusters) would require an additional 370 kg N, 83 kg P and 634 kg K before the first harvest. However, palms in Block 7 (224 clusters) would demand a nutrient supply of 470 kg N, 105 kg P and 806 kg K. The nutrient reserve in the non-trunking block (Block 7), summarized in Table 3, might be insufficient to support the formation of a trunk.

Nutrient deficiency is common in peat soils (Rankine & Fairhust, 1999). Phosphorus, for example, is usually fixed on iron and aluminium in an acidic environment; therefore, it is unavailable for plant uptake (Rankine & Fairhust, 1999). Nitrogen, however, is commonly found to be higher than other elements in tropical woody peat, ranging from 2,000 to 4,000 kg/ha in the upper 20-cm horizon; however,

Table 4: Total estimated annual uptake of nutrients in the trunks and leaves of a sago palm cluster (Jong & Flach,1995)

Time from planting (yrs)	**Nitrogen (kg)**		**Phosphorus (kg)**		**Potassium (kg)**	
0-1	0.03		0.01		0.02	
1-2	0.06		0.01		0.03	
2-3	0.19		0.03		0.10	
3-4	0.31		0.05		0.17	
4-5	0.36		0.06		0.20	
5-6	0.47		0.09		0.45	
6-7	0.48		0.09		0.54	
7-8	0.53		0.11		0.67	
8-9	0.64		0.13		0.92	
9-10	0.65		0.14		1.01	
10-11	0.69	2.14	0.15	0.47	1.15	3.56
11-12	0.80		0.18		1.40	
Total	**5.20**		**1.10**		**6.70**	

less than 3 % is available (Driessen, 1978). The study of nutrient deficiency in sago palms is, in fact, not well established. No study was documented on the trunking ability of sago palms in relation to nutrient deficiency. Therefore, the characteristics of nutrient deficiency in oil palms are employed to explain the trunking ability of sago palms in the present study because of their similar characteristics when grown in peat soils. In the study of oil palm, phosphorus deficiency was reported to result in the decrease of frond length, bunch size, and, in particular, trunk diameter. Imbalances in other elements such as potassium, nitrogen and zinc were also revealed to contribute to the reduction of stem diameter (Ramirez *et al.,* 2002). Therefore, the results obtained suggest that the failure of mature sago palms in Block 7, accompanied by the lack of trunk formation, could be associated with nutrient deficiency, primarily phosphorus, nitrogen and potassium in the deeper peat in Block 7. Block 7 is located closer to the peat dome, whereas Block 1 is at the periphery (shallower part) of the peat basin. According to the present results, the edges of the peat dome were relatively rich in nutrient, whereas the center was nutrient-poor. This ocurrs because, when the peat rises above the surrounding land, the flow of lateral water seeping into the upper layers is prevented. The influx of nutrients at the center of a peat dome depends exclusively on the precipitation; therefore contain fewer nutrients (Andriesse, 1988). Tie (1990) also reported a generally decreasing trend from the periphery to the center of a peat dome in Sarawak for most of the nutrient elements, especially Ca, P, Fe, and Cu.

Nutrient deficiency is critical in areas of deep peat. One study has shown that the vertical rooting system of sago palms growing in deep peat was 2.5 to 8.6 times greater than that in palms in mineral soils to allow for exploitation of a larger volume of soil materials (Kueh *et al.*, 1987). In addition to the nutrient content, the mineral content was also found to be richer at the periphery of the peat dome than at the center. Therefore, it was primarily concluded that peat soil at the periphery of peat dome is chemically more suitable for agricultural purposes. In addition to having higher ash content and nutrient availability, it allows the roots of vegetation to penetrate into the substrata of mineral deposits, which are within 50 cm of the supplementary nutrients and anchorage in Block 1. Nevertheless, repeated harvest in this area may result in the depletion of nutrients. In the absence of nutrient replenishment, the crops will be subjected to nutrient deficiency and, therefore, the growth will be constrained and show stem tapering.

Degree of humification

The productivity of cultivation on peat may be hindered by peat maturity, which is reflected by the degree of humification. In Sarawak, most of the peat soils are characterized by an irregular complex of poorly decomposed woody materials (Andriesse, 1988). This feature could appear to be a major yield constraint. According to the Von Post Scale, soils from Blocks 1 and 7 were categorized as moderately humified with humification values of H4 – H5 and H5 – H6, respectively. The degree of humification was also evaluated with the ratio of absorbance at 465 and 665 nm, which is commonly described as E_4/E_6. Absorbance at 465 nm expresses the presence of humic acids formed in the initial stage of humification, and absorbance at 665 nm indicates the presence of humic acids formed in well-humified organic matter (Debska *et al.,* 2002). Therefore, the high ratio of E_4/E_6 reflects a lower degree of humification. The E_4/E_6 of the trunking and the non-trunking blocks was at an average of 8.30 and 7.55, respectively. Statistical analysis revealed no significant difference in the degree of humification. Tie & Lim (1991) reported that the classification of peat into various degree of decomposition (i.e. fibric, hemic, and sapric) is not suitable for woody tropical peat. Most tropical peat does not show differentiation in terms of the degree of decomposition unless it has been drained for a long time. Nevertheless, it is generally concluded that the peat soils were not well humified in comparison to those reported in the literature (Melling 2000, Andriesse, 1988).

Very often, the degree of decomposition is associated with the bulk density and the RFC. Soil taxonomy suggested that soil of varying degrees of decomposition namely fibric, hemic and sapric soil, in increasing order of decomposition degree, exhibits a bulk density of < 0.1 g cm^{-3}, 0.07-0.18 g cm^{-3} and > 0.2 g cm^{-3}, respectively (Soil Survey Staff, 1975). The results of bulk density obtained in this study demonstrated that the soils were moderately decomposed. In terms of the RFC, fibric materials are characterized as having > 40 % RFC and classified as class 1 to 4 on the Von Post Scale; hemic materials have an RFC ranging from 10 to 40 % and are classified as class 5 to 6 on the Von Post Scale; and sapric materials have an RFC content of < 10 % and are classified as class 7 and above on the Von Post Scale (Soil Classification Working Group, 1998). According to this classification, the results corroborated that the peat soils were moderately humified.

Conclusion

The nature of peat is very important in determining the productivity of crops. It appears that impoverishment of nutrients is significant in deep peat. Shallow peat however is more suitable for cultivation because of the underlying mineral deposits and richer nutrient reserve. Cultivation in deep peat may require fertilizer application to replenish the nutrients in the soil and weeding to minimize the competition for nutrients. The management of fertilizer application may require extensive research, since studies by Siong (1995) did not reveal any significant growth response based on the rate of frond production, palm girth and rate of palm height, when the effects of applied N,P, K fertilizer on the growth of sago palms were examined.

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