AN EXAMINATION OF THE CORRELATION BETWEEN PEAT SOIL CHARACTERISTICS AND THE GROWTH OF SAGO PALM (*METROXYLON SAGU*)

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ABSTRACT

Sarawak has about 1.6 million hectares of peatland and this represents 13% of the state's total land area. Peatlands, in particular the coastal peatlands of Sarawak are very important for agricultural and other land use. Approximately 535,000 ha or about 32% of the total peatland in Sarawak have been converted to oil palm, forest plantation, sago, paddy, pineapple and tapioca plantation. Peat soils are usually waterlogged with very low pH and lack of nutrient contents. Due to these inherent characteristics, they are only suitable for crops with shallow rooting and fibrous root system. Sago palm (*Metroxylon sagu*) is one of the most intensive agricultural developments on peat. The uniqueness of this plant is its capability to tolerate high acidity and flooding condition in the peat swamps. Because of its natural adaptation, the State government has invested a great deal of money to tap its economic potential on peat. However, the eventual development has brought to light many unanticipated problems, one of which is the trunking ability of the sago palms. In this context, a study was carried out at the Dalat Sago Plantation, in Mukah Division to compare the physical and -chemical properties of peat in relation to the growth pattern of trunking and non-trunking sago palms. The parameters selected for this study were pH, bulk density, degree of humification, soil depth, total ash content, rubbed fibre content, total nitrogen, total potassium, available phosphorus and CEC. The plant growth parameters measured were palm height, dbh, number of suckers and length of the longest frond. The study showed that both the physical and chemical properties differ with peat depth. Better peat properties were found in the trunking plantation plot. For example higher concentration of nutrients (N, P and K) and ash contents were measured in the trunking plot. Further study is nevertheless recommended to determine the relationship between the soil characteristics and the pattern of sago growth and yield.

ABSTRAK

Sarawak mempunyai kawasan tanah gambut lebih kurang 1.6 juta hektar dan jumlah ini meliputi 13% daripada keseluruhan kawasan negeri ini. Sumber ini amat penting untuk sektor pertanian dan juga guna tanah yang lain, terutama sekali bagi kawasan gambut di persisiran. Lebih kurang 535,000 ha atau 32% kawasan tanah gambut di Sarawak telah ditebus guna untuk pertanian khususnya untuk penanaman kelapa sawit, hutan ladang, sagu, padi, nanas dan juga ubi kayu. Tanah gambut biasanya sentiasa ditenggelami air dan mempunyai nilai pH yang sangat rendah and kurang sumber nutrien dalam tanah. Dengan sifat yang sedemikian, hanya tanaman yang mempunyai sistem akar yang pendek dan berserat sesuai ditanam. Pokok sagu (*Metroxylon sagu*) adalah satu daripada tanaman yang giat diusahakan di tanah gambut. Keunikan tanaman ini adalah kebolehannya untuk hidup dalam keadaan keasidan yang tinggi dan juga ditenggelami air di kawasan gambut. Cara mengadaptasi yang semulajadi ini telah menarik minat pihak kerajaan negeri untuk melabur sejumlah besar untuk meneroka potensi ekonomi tanaman tersebut pada tanah gambut. Walaubagaimanapun, usaha ini mengundang pelbagai masalah dan antaranya ialah kebolehan tanaman sagu ini untuk membesar dengan sihat. Sehubungan dengan masalah ini, satu kajian telah dijalankan di Ladang Sagu Dalat, di Daerah Mukah. Fokus utama kajian ini adalah untuk mengenalpasti, menilai dan membandingkan unsur-unsur fizikal-kimia tanah gambut dengan corak pertumbuhan pokok sagu untuk dua keadaan yang berbeza, pertumbuhan yang sempurna dan juga pertumbuhan yang terbantut. Parameter yang dipilih untuk kajian ini adalah pH, ketumpatan pukal, darjah pereputan, kedalaman tanah, jumlah kandungan abu, kandungan serat gosok, jumlah nitrogen, jumlah kalium, fosforus tersedia dan juga kapasiti pertukaran kation. Untuk kajian berkaitan kadar pertumbuhan pokok, parameter yang dipilih adalah seperti tinggi pokok, diameter pada paras dada, bilangan anak pokok dan panjang dahan yang terpanjang. Hasil kajian menunjukkan bahawa kedua-dua ciri fizikal dan kimia tanah gambut meningkat mengikut pertambahan kedalaman tanah. Walaubagaimanapun, tanah gambut di Blok 1 (pertumbuhan sempurna) menunjukkan ciri-ciri yang lebih baik. Blok 1 mempunyai kandungan nutrien (N, P dan K) dan kandungan abu dalam tanah gambut yang tinggi. Penyelidikan susulan pada masa hadapan amatlah diperlukan untuk mengetahui hubungkait antara ciri-ciri tanah gambut dengan pertumbuhan pokok sagu dan hasil tuaian.

CHAPTER 1

INTRODUCTION

1.1 The status of peat land utilisation in Sarawak

Sarawak has about 1.6 million hectares of peatland and this represents 13% of the state's total land area (Murtedza & Jamaludin, 2003). It was identified as an important land resource for agriculture and other land use in the state. According to Melling (1999), approximately 535,000 hectares or about 32% of the total peatland in Sarawak have been converted to agricultural land. Most of these converted lands have been used for oil palm, forest plantation, sago, paddy, pineapple and tapioca.

Most of the peat soils of Sarawak are found in the coastal lowlands. They are usually waterlogged with very low pH and nutrient content. Due to these inherent characteristics, they are only suitable for crops with shallow rooting and fibrous root system such as oil palm, sago, and pineapple.

1.2 Importance of Sago palm to Sarawak

Sago palm (*Metroxylon sagu)* plantation is one of the most extensive agricultural developments on peat lands. The uniqueness of this plant is its capability to tolerate high acidity and flooded condition in the peat swamps (Jong, 1995). Because of its natural adaptation, the State government have invested a great deal of money to tap its economic potential on peat lands.

Twelve years ago the estimated area under sago cultivation in Sarawak was 19,720 hectares (Tie & Lim, 1991). The five major areas in which sago had been intensively cultivated are Oya-Dalat, Mukah, Pusa-Saratok, Igan and Balingian. The cultivation of sago was mainly on the smallholding basis with average size of 5.03 hectares (Chew *et al.*, 1998). Their productivity was undetermined as the yield fluctuated. Chew *et al.* (1998) found the average growth density of 14 palms/hectare, while Kueh, *et al.* (1991) reported a growth density of 102 palms/hectare. Harun (1995) and the Department of Agriculture, Sarawak (1996) recorded 90 palms/hectare and 70 palms/hectare, respectively.

Although sago cultivation is dominated by smallholders, it generates promising revenue to the state. Currently, the export of sago is ranked the fourth biggest agricultural revenue earner for Sarawak, after oil palm, pepper and cocoa. In 1993, the crop brought in RM 23.15 million in export earnings. Sago cultivation in Sarawak has a great potential to expand due the large acreage of peatland. Furthermore, the increasing population has stimulated the expansion sago cultivation in order to cater for the demand.

Government of Sarawak has initiated several efforts to increase the production of sago in the state. The government has established two large-scale sago plantations in Mukah and Dalat. A state agency, Land Custody and Development Authority (LCDA) was appointed to manage these plantations. Millions of ringgit was invested to provide modern equipments and new scientific agricultural technologies to ensure the success of the sago industry. Following that, a research unit, Crop Research and Development Unit (CRAUN), was established to undertake intensive research and development on sago to support and accelerate its development (Jong, 1995). Nevertheless, the eventual development has brought to light many unanticipated problems; one of which is the trunking ability of the sago palms. The other problem hindering the development of sago palm cultivation is the long maturity period of 10 to 15 years (Jong, 1995).

1.3 Objectives

The objective of this study is to identify, evaluate and compare the physical and chemical properties of peat in relation to the growth pattern of trunking and non-trunking sago palms.

CHAPTER 2

LITERATURE REVIEW

2.1 Physical Properties of Peat Soils

Peat soil is generally reddish brown to black in colour. It consists of high amount of organic materials, which has low potential for agriculture (Andriesse, 1988). The organic materials consist of woody materials such as partly decomposed leaves, branches, twigs and tree trunks. Other than the colour, the physical properties of peat can be identified, among others, by the degree of humification, bulk density, total ash content, porosity, rubbed fibre content, water holding properties and its hydrology.

a) *Degree of Humification*

Peat consists of three distinct layers that are distinguished by its level of humification. They are sapric (well decomposed), hemic (moderately decomposed) and fibric (slightly decomposed). The thickness of these three layers varies depending on the water table and cultivation practices (Teck *et al.*, 1998). Tie (1988) reported that the sapric layer normally extends to a depth of 110-120 cm. In the virgin peat dome, sapric materials may be absent and the depth of hemic layer can be less than 20 cm (Ambak & Melling, 2000). The Von Post Scale, ranging from H1 (least humified) to H10 (most humified) can be used for the characterisation of humification (Table 2.1).

Table 2.1: The Von Post Scale for Humification

Classification	Fibre Content	Von Post Class
Fibric	Over 66 %	H1 to H3
Hemic	33-66 %	H4 to H6
Sapric	Less than 33 %	H7 to H10

Source : Melling, 2000

b) *Bulk density*

One of the most important features of peat is the bulk density. Bulk density is the ratio of the mass of solids to the total or bulk volume (Soil Survey Laboratory Staff, 1995). Peat usually has a very low bulk density. Its average bulk density values range from 0.05 to 0.40 g/cm^3 (Ismail, 1984) or about 0.1 g/cc (Tie & Lim, 1991). This feature is influenced by the degree of humification and ash content. Compaction due to subsidence of decomposed material and high level of ash content will increase the bulk density. Organic soil materials with high ash content can have bulk density values up to 0.2 g/cc or more (Tie & Lim, 1991). Bulk density could also be increased due to drainage, which result in consolidation and subsidence of soil.

c) *Total Ash Content*

Generally, peat has high organic content due to the presence of plant residues such as leaves, branches, tree trunks and other wood fragments. The ash content which is a measure of the mineral content is usually less than 10% (Wong, 1991). A 10% ash content limit has been used to differentiate some organic soils at series level (Tie, 1982). However, the value of ash content can be higher due to waterlogged condition (Tie & Kueh, 1979). The increase in the ash or mineral content will improve soil fertility.

d) Rubbed Fibre Content

Plant materials such as branches, leaves, wood fragments and roots contribute to rubbed fibre content. Fibre is defined as a fragment or piece of plant tissue, excluding live roots, that is large enough to be retained on a 100-mesh sieve (McKinzie, 1974). According to Lynn *et al.* (1974), rubbed fibre content is used to characterize the degree of decomposition for comparison with other properties. In natural state, dying plants, falling leaves, broken branches will replenish the rubbed fibre content of peat. Removal of these residues will decrease the fibre content. Decrease in rubbed fibre content affects the bulk density and subsidence after drainage (McKinzie, 1974).

2.2 Chemical Properties of Peat Soils

Chemical properties are normally represented by pH, exchangeable cation, electrical conductivity (EC), soil organic carbon, nutrient contents (N, P and K) and cation exchange capacity (CEC).

a) pH

Peat soils are acidic with pH ranging from 3.0 to 4.5. According to Andriesse (1988), the low pH is due to the presence of organic compound, the exchangeable hydrogen and aluminium, iron sulphide and other oxidizable sulphur compounds. The acidity of soil influences the growth of agricultural crops therefore liming is essential for most crops (Tie & Kueh, 1979).

b) Nutrient content (N, P and K)

Nitrogen (N), phosphorus (P) and potassium (K) are essential elements in soils for plant growth. Peat in Sarawak contains more than 1% of total nitrogen (Tie & Kueh, 1979). Although the N content in peat is rather high, its availability for plant uptake is low (Ambak & Melling, 2000). This is due to the formation of stable lipoproteins (Wee, 2001).

Phosphorus is an essential element for plant growth. The range of available phosphorus for Anderson Family is from the trace level to 304 ppm (Wee, 2001). The available phosphorus usually decreases with the increase of peat depth.

c) *Cation Exchange Capacity (CEC)*

Cation Exchange Capacity (CEC) is defined as the sum of exchangeable cations that can be absorbed by the soil (Brady, 1990). Generally, peat has high value of CEC. According to Tie and Lim (1991), CEC of organic soils are usually in the range of 50-100 cmol/kg. CEC is highly pH dependent due to the strong association of hydrogen ion with the functional group in acid materials which prohibit cations exchange (Andriesse, 1988). Increased humification is generally associated with increase in CEC while higher ash content usually means a lower CEC (Tie & Lim, 1991).

2.3 Sago Growth on Peat

Sago palm is a hydrophilic plant which makes it having some similar characteristics to oil palm (Melling, 2000). With this unique feature, sago palm is able to sustain under flooded condition. On prolonged waterlogging, roots of sago palm undergo morphological adaptation with the production of pneumathodes to ensure sufficient supply of oxygen to the roots (Melling, 2000). According to Kueh *et al.* (1987) none or minimal drainage is needed for sago plantation. Sago palm grows well in shallow swamps where there is a regular flow of fresh water, such as inlet zones of swamp margins and where the water table is below the surface outside the flooding seasons (Paijmans, 1979).

Although sago palm requires minimal drainage and fertilizer application, there are several challenges in cultivating sago palm on peat. Sago stands become permanently stunted in transitions to deep herbaceous swamp, in brackish environments and on sites where the water table temporarily sinks deep enough to cause drought stress (Paijmans, 1979). Therefore, drainage is needed to make these waterlogged swamps suitable for agriculture use (Wosten & Ritzema, 2001). Insufficient water table will result or affects other physical and chemical properties of peat soils. The suitable water table for oil palm cultivation is suggested to be 50cm, while for sago cultivation is 25cm below soil surface (Wosten & Ritzema, 2001).

The suitability of peat for crop cultivation depends on its characteristics and properties. Sago palm is tolerant to low pH, high Al, Fe and Mn in the soil as well as heavy impervious clays (Ishizuka *et al.*, 1995). According to Flach (1977), full sunshine, a soil pH of 4 or higher and regular but not continuous flooded conditions provide an ideal ecological niche for optimal growth of sago palm. However, the perfect soil pH could not guarantee the success of sago cultivation on a particular site. Other factors that relates to soil properties also influence the growth of sago palm.

Sago palm grows well in peat swamps unlike other crops. However, sago palms mature faster when grown on mineral soils, which take 8 to 10 years (Johnson & Raymond, 1956) compared to those cultivated on peat that usually requires 12 to 15 years (Tie *et al.*, 1987). The annual trunk production on deep peat is estimated at 15 to 20 trunks per hectare while on mineral soils are estimated at 25 to 40 trunks per hectare.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the study area

Dalat Sago Plantation

The study site lies between latitudes 2° 40′ N and 2° 48′ N, and longitudes 111° 49′ E and 111° 55′ E (Figure 3.1).

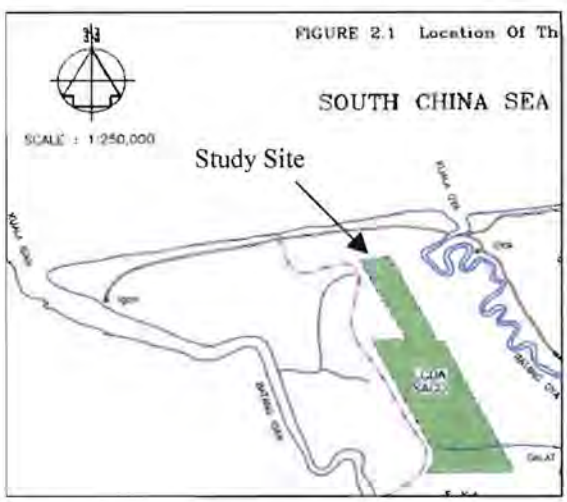
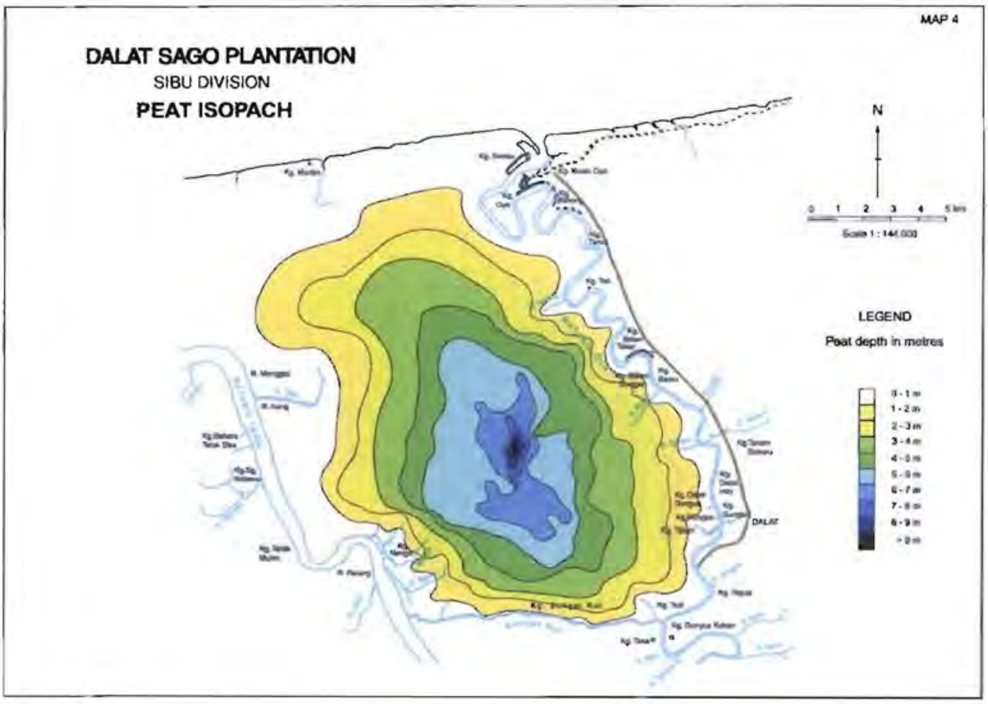


Figure 3.1: Location of Dalat Sago Plantation

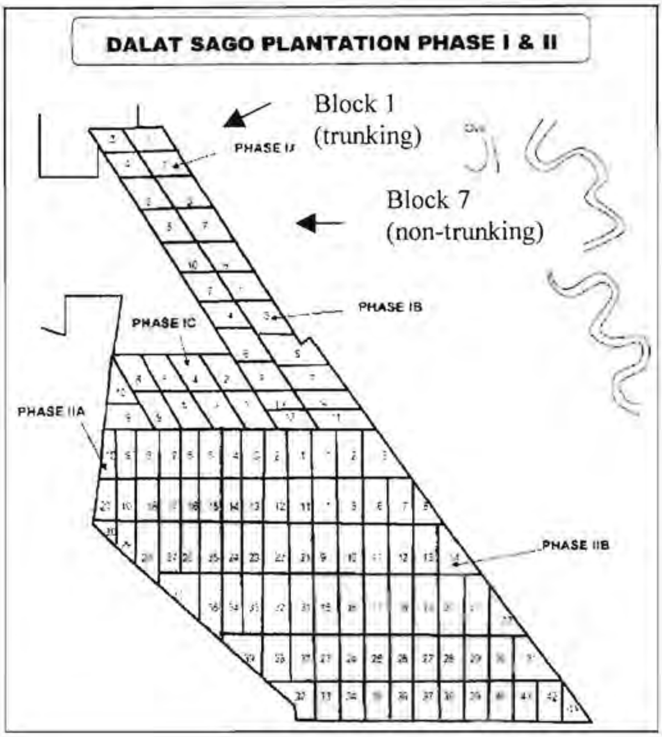
The gross area for Dalat Sago Plantation is 6,676 hectares, which comprises two phases, Phase I and Phase II with areas 1,729 hectares and 4,947 hectares, respectively. Generally the study site is situated on a flat and low-lying area, which consists of organic soil of the Anderson Family. Anderson Series is locally defined as deep Organic or Peat Soils with more than 150 cm of peat depth. Like all coastal peat swamps in Sarawak, the study area has a dome-shaped morphology, i.e. with a slight rise in ground elevation, in the order of 1-8 metres, from the periphery to the centre of the peat dome. Figure 3.2 shows the survey of peat depth of the study site (Melling, 2000).



Source : Melling, 2000

Figure 3.2: Peat depth of Dalat Sago Plantation

Experimental blocks were selected according to sago growth, trunking (Block 1) and non-trunking (Block 7) as illustrated in Figure 3.3. The reclamation year for both sites was in 1994.



(Source: CRSB, 2003)

Figure 3.3: Experimental blocks of the study

3.2 Soil Analyses

Fifteen plots were selected randomly at each site. For each plot, soil samples at two depths (0-15cm and 15-30cm) were collected. The soil samples were subjected to physical and chemical analyses. This included determination of the bulk density, pH, rubbed fibre content, ash content, degree of humification, CEC and nutrient content.

3.21 Physical Properties

a) Degree of Humification

Degree of humification was determined by squeezing the soil samples and categorising it based on the Von Post Scale, ranging from H1 to H10 as follows:

The Von Post Scale of humification

H1 Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.

H2 Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.

H3 Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.

H4 Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.

H5 Moderately decomposed pear which when squeezed, releases very muddy water with a very small amount of amorphous granular pear escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.

H6 Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.

H7 Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one half of the peat escapes between fingers. The water, if any is released, is very dark and almost pasty.

H8 Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.

H9 Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste.

H10 Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

UV analysis was also performed at wavelength 400, 465, 600 and 665nm for characterizing the degree of humification.

b) Bulk Density

Bulk density is commonly used to convert data from weight to volume basis, to determine the coefficient of linear extensibility, to estimate saturated hydraulic conductivity and to identify compacted horizons. A PVC cylinder was pressed into the soil and was removed. The moist sample weight was recorded. The sample was then dried in an oven at 110°C and weighed. The bulk density was calculated as follow:

$$Db = \frac{ODW - CW}{CV}$$

Where,

Db = bulk density in g cm^{-3}
ODW = oven-dry weight in g
CW = empty core weight in g
CV = core volume in cm^3

c) Total Ash Content

The soil sample was dried overnight at 110°C and weighed after cooling. Sample was then placed in the furnace at 800°C for 2 hours. Sample was weighed after cooling. The ratio of soil sample weights at 800°C and 110°C is the fraction of mineral content.

d) Rubbed Fibre Content (RFC)

RFC was determined by rubbing the soil sample between thumb and fingers under stream of tap water on 100-mesh sieve. The volume of sample was measured in half-syringe.

3.22 Chemical Properties

a) pH

The soil pH was measured with a pH meter on a suspension of soil in water in a ratio of 2 : 5 (Chin, 2000).

b) Soil Nitrogen

The Kjeldahl digestion method was employed to determine the nitrogen content. In this method the combined nitrogen in the soil organic matter was converted to ammonium ion by digestion in concentrated sulphuric acid and in the presence of selenium-sodium sulphate catalyst mixture. The digest was made alkaline and the ammonia was distilled off into a buffer or acid solution and was titrated (Chin, 2000).

c) Available Phosphorus in Soils

The soil was extracted with Bray II solution (0.03 M NH_4F and 0.1 M HCl), and the P in the extract was determined by molybdate blue method. UV analysis then was carried out at the absorbance at wavelength 660 nm to determine the concentration of available P in the soil (Chin, 2000).

d) Potassium in Soils

The peat soil sample was first ignited at 550° C for 1 hour. The ignited sample was then boiled with concentrated HCl and the K in the extract is determined using AAS (Atomic Absorption Spectrophotometry),(Chin, 2000).

e) Cation Exchange Capacity (CEC)

Cation exchange capacity was determined by leaching the soil with ammonium acetate and then determining the amount of ammonium ions retained by the soil (Chin, 2000).

3.3 Plant Growth

The growth status was based on the morphological characteristics such as palm height, diameter at breast height, number of suckers and length of the longest frond.

3.4 Water Table

Water table was measured using a measuring tape from ground level to the water level inside the sample plot hole.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The study area is situated at Phase I: Block 1 and Block 7. Both areas were reclaimed and cultivated with sago palms in 1994. The sago palms were planted with triangular 7.5 m spacing with approximately 205 palms per hectare (Kueh *et al.*, 1991). The gross area for Block 1 is approximately 50 ha and 68 ha for Block 7. Each block was planted with more than 10,000 palms. The distinctive difference of these blocks is the crop growth. Sago palm of Block 1 was very healthy (Plate 4.1 while those at Block 7 (Plate 4.2) were stunted. After 9 years of cultivation, the formation of trunk was not observed for palms at Block 7 and the mortality rate is high.

Plate 4.1 Healthy condition of sago palms in Block 1

Plate 4.2 Stunted sago palm in the field

The morphological characteristic of peat for Dalat Sago Plantation is dome-shaped as illustrated in Figure 2. Block 1 is considered as shallow peat area with peat depth of 1 - 2 m, while Block 7 is deep peat area with depth of 3 – 4 m.

Plate 4.3 The bushy condition in the field which creates problem during field survey.

The water table at Block 1 was 20 – 30 cm and water table at Block 7 was 40 – 50 cm. Proper water table is important for development projects on peat. Once the water table falls below the ground level, oxidation and mineralisation will take place (Tan, 2001). Teck *et al.* (1998) recommended water table of 20 – 30 cm for sago plantation. Flach & Schuiling (1991) however suggested water level of 40 – 50 cm for optimum growth of sago. With reference to the water level suggested, the water table management at Dalat Sago Plantation was adequate for healthy growth of sago palms. The variation of water table might due to the peat morphology of the study area whereby Block 1 is situated at the periphery of the peat area (shallower peat) while Block 7 is nearer to the centre of the dome.

4.2 Morphological characteristics of sago palms

Table 4.1: Morphological characteristics of sago palms at Dalat Sago Plantation.

Plant Morphology	Block 1 (Trunking)[1]	Block 7 (Non-trunking)[2]
Palm height (m)	15.4	4.3
Diameter at breast height Dbh (cm)	53.4	0
Number of suckers	7.6	3.9
Frond length (m)	6.8	2.4

[1]Average value of 15 samples.

[2]Average value of 15 samples.

Generally, the growth of sago palms at Block 1 was better than those at Block 7. The growth of sago palm was reported to be slower on deep peat than on shallow peat (Yamaguchi *et al.* 1997). The palms grow well on shallow swamp where there is a regular flow of fresh water (Paijmans, 1979). Jong and Flach (1995) reported that trunk volume of palms under intensive cultivation on deep peat was 37 % smaller than those grown on mineral soils. Although sago palms were cultivated successfully on deep peat, palm maturity period is longer. Sago palms grew on deep peat would only mature after 13 years (Yamaguchi *et al.*, 1997). Nevertheless, Kueh *et al.,* 1991 reported that sago palms growing on deep peat could have trunks, which were 24 % longer.

The result showed that the trunking block has higher number of suckers compared to non-trunking block. The average density of trunking block and non-trunking block was 7.6 and 3.9, respectively. The density was determined by counting the individual suckers grown in a clump of a mother palm. The average frond length of trunking block was 6.8 m while for the stunted palm at the non-trunking block was 2.4 m. According to Yamaguchi *et al.* (1997), sago palms on shallow peat had significantly longer fronds than those on deep peat soil and the canopy was well developed by 9 years after planting the suckers.

4.3 Soil Properties

Table 4.2: Average physical-chemical properties of soils at Dalat Sago Plantation

Property	Block 1 (Trunking)[1]		Block 7 (Non-trunking)[2]	
	0 – 15 cm	15 – 30 cm	0 – 15 cm	15 – 30 cm
Physical				
Bulk Density (g/cm^3)	0.11	0.15	0.12	0.11
Degree of Humification	H3 – H4	H4 –H5	H4 – H5	H5 – H6
Rubbed Fibre Content (%)	20.6	21.8	14.0	17.3
Total Ash Content (%)	23.1	24.5	3.3	3.8
Chemical				
pH	3.4	3.5	3.3	3.4
Total N (%)	2.32	2.76	0.36	0.38
Total K (ppm)	103	100	44	49
Available P (ppm)	49	45	16	25
Cation Exchange Capacity (cmol/kg)	81	80	72	79

[1]Average value of 15 samples.

[2]Average value of 15 samples.

Generally, peat soils of the study area were very low in pH and bulk density. Soil pH for both areas was very acidic ranging from 3.3 to 3.5. Bulk density however ranged from 0.11-0.15 g/cm^3. The properties of peat soils were summarized in Table 1. However, nutrient contents and ash content for Block 1 and Block 7 were significantly different.

Tropical peatlands are not suitable for most of the crops because of strongly acidic and their oligotrophic nutritional condition (Kawahigashi *et al.*, 2003). With these properties, it is very hard for inland crop plants to grow well on the soil. The high acidity of peat is mainly caused by the high content of organic acids (Adi Jaya *et al.*, 2002). Nevertheless, sago palms appear to be well adapted to undrained, acidic peat soils condition which are not recommended for other crops (Lim *et al.* 1992). Its effective root system could be one of the factors that encourage the capability of sago palms to adapt to the natural condition of peat. Kueh *et al.* (1987) studied the vertical rooting system of sago palms growing on deep peat and found that they had 2.5-8.6 times more roots than palms on mineral soils. A much denser and extensive rooting system is developed to allow exploitation to a larger volume of soil materials (Tie *et al.*, 1987).

The nutrient analysis revealed that Block 7 was nutrient deficient. This could also be one of the factors for the observed non-trunking growth in Block 7. Sago palms can be classified as hardy species whereby it requires little maintenance and additional fertilizers are not essential. However, severe deficiency in P could results in gradual decrease in stem diameter over a period of time (Ramirez *et al.*, 2002).

The ash content of trunking block was higher compared to non-trunking block. The ash content of organic soils, which are more decomposed, and/or subject to flooding is usually higher (Tie & Lim, 1991). Block 1 is situated at the edge of the peat area, which is very shallow and prone to flooding. The elevated level of mineral content in this area should thus improve the soil fertility. Peat soils with less than 10 % ash are probably never flooded and crops growing on such soils generally fail to produce harvest (Tie and Lim, 1991).

The productivity of crops is also determined by the peat thickness. According to soil survey of Melling (2000), Block 1 has a peat depth of 1 – 2 m and Block 7 has a peat depth of 3 – 4 m. Tie *et al.* (1987) found that sago can be grown satisfactorily on deep peat, although they take a longer time to reach maturity and the starch content per unit volume of pith is slightly lower. However, growth rate of sago palm differs depending on the thickness of the peat layer and on the soil types beneath it (Yamaguchi *et al.*, 1997).

Growth rates of sago palms are significantly higher on shallow peat in terms of trunk diameter, palm height and frond length than on deep peat.

4.4 Humification

The sapric-hemic-fibric profile morphology is necessary for cultivation of crops. Sapric and hemic layers function as a provider for rooting medium and anchorage for the plants (Mutalib *et al.*, 1992). The peat is drained to encourage decomposition and to enhance consolidation and compaction of the broken down organic materials resulting in the formation of sapric and hemic layers.

The major factors governing the rate of humification are moisture, temperature, pH, depth, aeration and cultivation (Melling, 2000). In agriculture, the level of humification relates to nutrients availability. Low humification stage result in low availability of nutrients due to high C : N ratio (Melling, 2000). Therefore, cultivation on poorly humified peat will lead to improper growth of crops.

Based on the Von Post Scale, the humification degree of non-trunking block (Block 7) was higher compared to the trunking block (Block 1). However, classification of humification degree based on the coefficient values of Δ log K (Δ log K = log A_{400}- log A_{600}) showed no significant different between trunking block and non-trunking block. Trunking block and non-trunking block has an average Δ log K of 0.87 and 0.88, respectively. On the basis of the Δ log K, the humic acids are divided into three groups (Kumada, 1987).

Type A : Humic acids of high degree if humification of which values of Δ log K is up to 0.6.

Type B : Intermediate level of humification of which values of Δ log K values between 0.6 and 0.8.

Type R_p : Low humification level of which values of Δ log K values within the range of 0.8 and 1.1.

Results revealed that the peat soil of both study areas were poorly humified.

CHAPTER 5

CONCLUSIONS

Peatland was identified as important land resource for agriculture and other land use in the state, especially for the coastal peatland. Sago palm (*Metroxylon sagu)* is one of the most intensive agricultural developments on peat lands. The uniqueness of this plant is its capability to tolerate high acidity and flooding condition in the peat swamps. Because of its natural adaptation, the State government had invested a great deal of money to tap the economic potential on peatlands.

Sago palm is relatively simple to cultivate, requires less maintenance and it is well adapted to low nutrient contents in soil. As sago planting is intensified, there are obviously constraints affecting the sago growth. At the moment, sago palms grown by small holders are found to be generally more productive than the yield reported in the large-scale plantation. . Several studies have been carried out to overcome these problems, but there are no clear answers that could relate the unsatisfactory growth in certain peat areas.

The results obtained in this study indicated that both the physical and chemical properties of peat differ as the peat depth increases. Block 1 (trunking block) has peat of better properties for cultivation purposes compared to Block 7 (non-trunking block). The nutrient contents (N, P and K), essential for healthy growth of sago palms were higher in Block 1. Also, the high ash content measured in Block 1 is indicative of high concentration of available minerals for good plant growth.

There are other growth determining variables not addressed in this study. These include crops maintenance and fertilization programme. Cultivated palms without fertilizer supplement and maintenance could not be expected to produce good yield.

It is recommended that further investigation on the relationship between soil characteristics and sago growth be carried out in order to better understand the optimum agronomic practices for the cultivation of sago palm on deep peat.

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