SAGO PALM 2: 21–30 (1994)

Sago Palm Growing on Tropical Peat Soil in Sarawak, with Special Reference to Copper and Zinc

Chihiro Yamaguchi, Masanori Okazaki and Takayuki Kaneko[1]

Tokyo University of Agriculture and Technology, Fuchu, Tokyo, 183 Japan
[1] Kyoto University, Kamigamo Experimental Station, Forestry Research Station, Kita-ku, Kyoto, 603 Japan

Abstract About 20 thousand ha of land are devoted to sago cultivation in Sarawak. Sixty percent of sago palm in Sarawak is grown on peat soils, and 33% is grown on alluvial soils. Copper (Cu) deficiency has been recognized and is thought to cause many severe disorders of plants on tropical peat soils, but it has not appeared in sago palms, so the sago palm is expected to be a potential food and industrial export crop utilizing the marginal land resource of deep peat soil. The abundance and distribution of Cu and zinc (Zn) in tropical peatlands, the relationship between sago palm growth and Cu and Zn content in the sago palm, and the evaluation of sago palm plantation as sustainable land use for tropical peat soil are discussed.

Copper and Zn concentrations distributed in soil and aquatic environments in tropical peatland were low, ranging from nd to 25.1 μg/gCu and from 6.83 μg/L to 32.4 μg/gZn. Despite low Cu and Zn contents in peat soils and water, Cu and Zn deficiency did not appear in sago palm tissue, although Cu content was low in tissue taken from sago palms growing on deep peat soil. The sago palms on deep peat soils grew more slowly than those on shallow peat soils and alluvial soils. The preliminary input and output study of Cu and Zn showed that Zn tended to be lost from tropical peatland under sago palm cultivation. Sago palm cultivation without appropriate planning would not qualify for sustainable land use in tropical peatland.

Key words: Copper, Sago palm, Sustainable land use, Tropical peat soil, Zinc

サラワク州における熱帯泥炭土壌に生育するサゴヤシの生長
—銅，亜鉛を指標として—

山口千尋・岡崎正規・金子隆之[1]

東京農工大学農学部　〒183 東京都府中市幸町 3-5-8
[1] 京都大学農学部付属演習林上賀茂試験地　〒603 京都市北区上賀茂本山

要　約　現在，マレーシアのサラワク州では2万 ha のサゴヤシ栽培地がありその約 60% が Oya-Dalat, Mukah 地区に分布し，大規模なプランテーションも行われつつある．この地域のサゴヤシ栽培地のうち約 60% が泥炭土壌である．このような熱帯泥炭は，oligotrophic peat であり，微量元素の含有率が著しく低く，特に銅は有機物と強い錯体を形成しやすいために，植物への有効性が低く，作物に欠乏症が発生しやすい．しかし，サゴヤシには銅の欠乏症が発生しにくいことから，このような泥炭土壌で栽培できる作物の一つとして期待されている．サゴヤシは生育立地によって生長が異なることが知られているが，その生育環境中に，あるいは植物体中にどの位の濃度の銅，亜鉛が分布しているか，また，それらが植物の生長と生育段階にどのように関係しているかを明らかにし，熱帯泥炭土壌におけるサゴヤシの持続生産の可能性を探ることを目的に研究を行った．

熱帯泥炭地域における土壌および水環境中の銅と亜鉛の濃度は非常に低く，特に銅は低濃度であった．それにもかか

わらず，サゴヤシ中の銅と亜鉛の濃度は沖積土壌で生育した作物体中の銅，亜鉛濃度とほぼ同じ程度で，Deep peat soil で生育したサゴヤシ中の銅濃度以外は欠乏症が発現するとみられる濃度を超えていた．異なる泥炭土壌に生育したサゴヤシの生長を比較してみると，Deep peat soil で生育したサゴヤシは shallow peat soil で生育したサゴヤシよりも生育が遅く，幹にデンプンを蓄積するようになるまでに時間がかかることが明らかになった．

サゴヤシを収穫し系外へ搬出すること，地下水位を低下させることによる泥炭の分解に伴って微量元素が流失することなど，サゴヤシ栽培地域の微量元素の循環を考慮すると，銅は降水からの付加が流出量を上まわるため系内に蓄積する傾向がみられるが，亜鉛は系内へ付加される亜鉛に比べ，系外へ失われていく亜鉛が多いため，施肥などによって亜鉛が付加されない限り，亜鉛は土壌中から失われていく傾向にあることが示された．このようなことから無計画なサゴヤシ栽培は持続的なサゴヤシ生産を保証しないといえる．

キーワード: 亜鉛，サゴヤシ，持続可能性，銅，熱帯泥炭土壌

Introduction

About 20 thousand ha of land are devoted to sago cultivation in Sarawak, and about 60% of these are in Mukah and Dalat Districts. Sixty-two percent of sago palm in Sarawak is grown on peat soils and 33% on alluvial soil (Tie et al. 1991). Within the peat soil group, deep peat soils with more than 150 cm of organic soil materials occupy about 58% of the sago areas and shallow peat soils with 50–150 cm of soil organic materials occupy 20.9% of the sago areas around Oya-Dalat District (Tie et al. 1991). Peat soils distributed in Mukah and Dalat Districts are classified as oligotrophic or mesotrophic based on soil nutrient contents. Major nutritional element and minor element contents in peat soils are low compared with other soils. Copper (Cu) and zinc (Zn) in boreal peat soils are present in the complexes with organic matter (Stevenson and Ardakani 1972). The amounts of Cu and Zn available to plants were governed by equilibria involving specifically adsorbed forms and organically bound fraction (Liang et al. 1991). Copper deficiency has been recognized and associated with many severe disorders of plants on tropical peat soils. It has not appeared in sago palms, so the sago palm is expected to be a potential food and industrial export crop utilizing marginal land resources of deep peat soil. The sago palm plantation on deep peat soils in Mukah was established to produce sago starch by the Land Custody and Development Authority (LCDA); the plantation has 7,700 ha.

The objectives of this study are to determine the abundance and distribution of Cu and Zn in tropical peatlands, to clarify the relationship between growth of sago palm and Cu and Zn content in sago palm, and to evaluate sago palm plantation as a form of sustainable land use for tropical peat.

Materials and Methods

Study areas

The relationship between growth rate and nutrient status of the sago palm was studied in Dalat, Sarawak, Malaysia, from 1992 to 1993. To establish the scientific background for sago estate management, the government of Sarawak started a sago palm study in the Sungai Talau Deep Peat Experimental Station, where cultivation practices for sago palm are tested (Schuiling et al. 1992). Sungai Talau Peat Research Station is located in the coastal area of Dalat, about 11 km from Dalat Town, Sarawak, where the thornless variety of sago known as *Metroxylon sagu* was planted (Fig. 1). The research station has an area of about 225 ha, of which some 50 ha had been opened up before 1992. Mean annual rainfall and mean annual temperature at Sibu, which is 60 km from Sungai Talau Peat Research Station, are 3194 mm and 26.3°C, respectively (Okazaki 1992a).

Histosols at the world classification level are classified according to an FAO and UNESCO soil classification system (FAO and UNESCO 1988), based on the content of organic soil materials: soils having 40 cm or more of organic materials either extending down from the surface or cumulatively within the upper 80 cm of the soil. In this study, however, soils having 5–150 cm of organic soil materials with nonsulfidic clays are called shallow peat soil, whereas

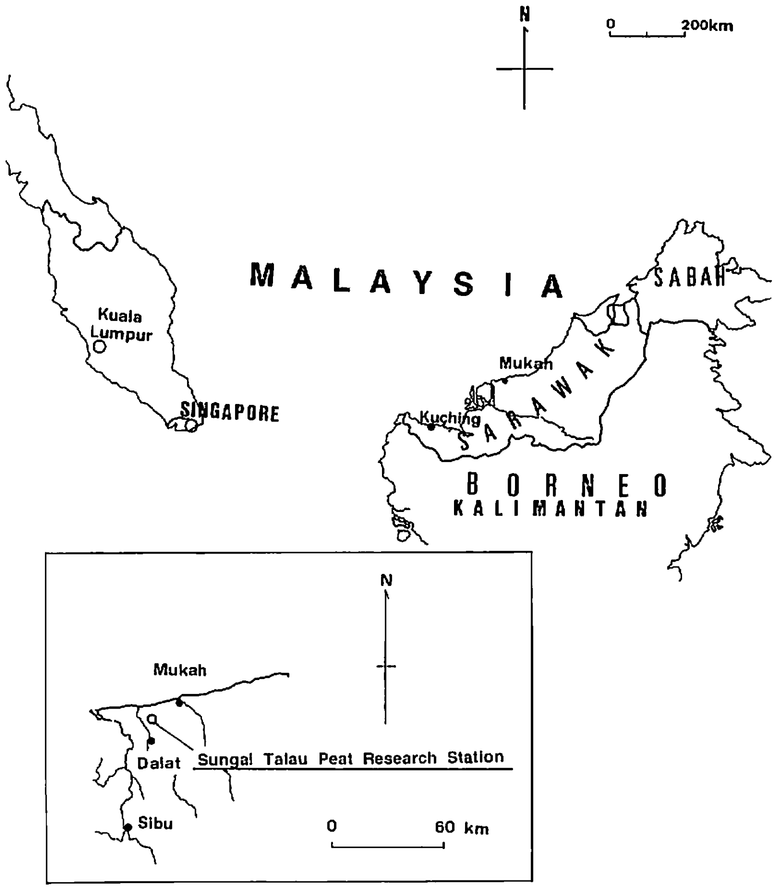

Fig. 1 Map of the study area.

soils having more than 150 cm of organic soil materials are called deep peat soil. In the Oya-Dalat area, 1,340 ha (21%) of sago-growing soils are shallow peat soils and alluvial soils, and deep peat soils form the main habitat for sago palm, accounting for 3,714 ha (58%) of sago-growing soils (Tie et al. 1991).

Water and soil analysis

A rainfall collector was installed in an open field of Sungai Talau Peat Research Station. Rain water samples were collected by funnels with 22 cm diameter at 2 sites. The water samples from peatland were collected from the edge of the ditches in Sungai Talau Peat Research Station. Soil solution samples from deep peat soil were taken at Sungai Talau Peat Research Station. They were taken from 10 to 60 cm at every 10 cm depth using soil solution extractors equipped with porous ceramic cups applying a suction of 80 kPa (Wagner 1962).

The concentrations of Cu and Zn in water samples were determined by Atomic Absorption Spectrophotometry (AAS) (Shimadzu A-670) after the concentration of water samples with HNO_3 on a hot plate.

The soil samples were taken at 4 sampling sites. Deep peat soil (Dystric Histosol) samples were taken from a cultivated field that had been fallowed for a few years at Sungai Talau Peat Research Station. Sampling was carried out down to 80 cm at every 20 cm depth. Deep peat soil was also sampled from tropical swamp forest at Dalat. Shallow peat soil with heavy clayey alluvium in the subsurface horizon (Dystric Histosol) was taken from a small farm in the western marginal area of Sungai Talau Peat Research Station. Alluvial soil (Eutric Fluvisol) was taken from Kp. Teh, 1 km northwest of Sungai Talau Peat Research Station. The sampling was done down to 80 cm at every 20 cm depth. The total amounts of Cu and Zn in the soil samples were determined by AAS after acid digestion method using HNO_3, $HClO_4$ and H_2SO_4 (Yamazaki 1986). Five grams of air-dried soil sample was placed in a glass beaker. After addition of 1 ml of concentrated H_2SO_4, 5 ml of concentrated HNO_3 and 20 ml of concentrated $HClO_4$, the mixture was heated on a hot plate at low temperature until the dense fume of $HClO_4$ had subsided to dryness. The residue was dissolved into 30 ml of 1 M HCl. The acidic solution was decanted and brought up to a final volume of 250 ml with re-distilled water. Dissolved metals were concentrated using a solvent extraction scheme (Takeuchi 1986) and determined by AAS.

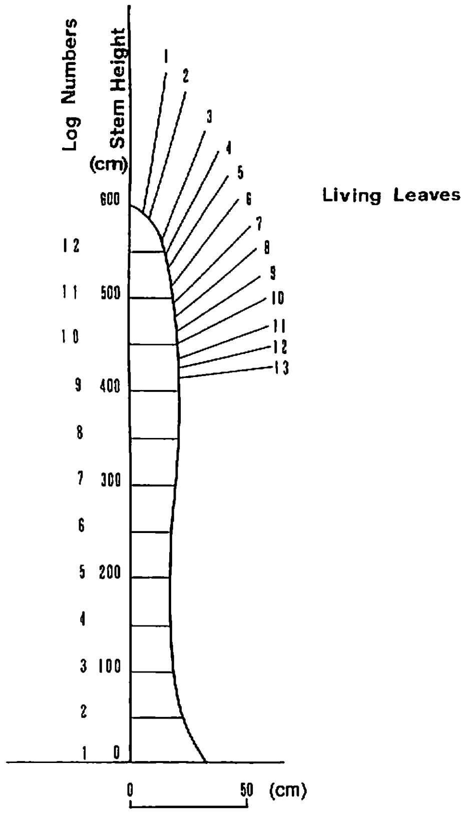

Fig. 2 Model of sampling procedure for sago palm.
Leaf and log samples were collected as follows:
Growing on alluvial soil Leaf Number 3, 8, 13
Log Number 2, 4, 7
Growing on deep peat soil Leaf Number 2, 7, 11
Log Number 2, 4, 9

Sago palm tissue analysis

Copper and Zn concentrations in different parts of the sago palms in relation to soil types were studied. Leaf and pith samples were collected from sago palms which were approximately 8 years old, growing on alluvial soils at Kp. Teh and deep peat soils at Sungai Talau Peat Research Station. Sim and Ahmed (1991) reported that the middle segment appeared to have the average nutrient concentration of the base and tip segments and that there was no significant difference in leaf nutrient concentrations due to frond age, which were numbered 3, 4, and 5. Leaf and log samples were collected referring to a modified procedure proposed by Sim and Ahmed (1991) (Fig. 2). The fully-opened frond which was the youngest was counted as 1, the next as 2 and so on. The fronds were taken from upper, middle, and lower parts of trunk of 8 years old sago palms (Fig. 2). A frond was cut into 3 equal segments, upper, middle, and lower, and leaflets were collected from the 3 parts. Midribs from each segment were removed. Pith samples of sago palms were also collected from 3 parts of the trunk cut off by a chainsaw in 50 cm sections at upper, middle, and lower levels. Each fresh sample was weighed and rinsed with distilled water, dried overnight at 60°C, weighed and ground to pass through a stainless sieve with 474 μm openings, and analyzed. Copper and Zn concentrations in the extract of acid digested plant ash were determined by AAS.

Growth study of sago palm

Growth of sago palms on shallow peat soils, alluvial soils, and deep peat soils was measured, related to several growth factors, and compared between 1992 and 1993 data. The total carbon and total ni-

Table 1 Cu and Zu in soil and water sampled from Dalta Sarawak, Malaysia

Water	pH	C (*mg*/L) mean (range)		Cu (μg/L) mean (range)	Zn (μg/L) mean (range)
Precipitation	5.75 (5.7–5.8)	1.67 (0.68–2.66)		1.18	7.36 (6.83–7.88)
Water from peatland	4.52 (4.1–5.3)	55.4 (39.7–62.9)		1.65	23.6
Soil Solution	5.27 (4.9–6.0)	42.7 (38.2–53.2)		8.21 (nd–28.7)	35.8 (16.5–77.0)
Soil	**pH (H_2O)**	**C (% DM) mean (range)**	**N (% DM) mean (range)**	**Cu (μg/gDM) mean (range)**	**Zn (μg/gDM) mean (range)**
Deep peat soil a	3.64 (3.48–3.88)	64.9 (61.2–67.3)	1.58 (1.28–1.97)	3.31 (3.06–3.61)	7.46 (6.25–9.16)
Shallow peat soil	3.21 (2.91–3.61)	31.7 (4.25–53.3)	0.91 (0.31–1.58)	18.7 (10.6–25.1)	16.3 (9.91–32.4)
Alluvial soil	3.60 (3.48–3.83)	15.9 (15.2–16.9)	0.82 (0.81–0.84)	7.70 (6.90–8.97)	15.8 (15.4–16.6)
Deep peat soil b	3.05 (2.99–3.48)	55.8 (53.5–58.2)	2.19 (1.74–2.55)	2.35 (2.11–2.63)	13.5 (7.68–19.3)

Mean values for soil samples taken from surface soil to 80 cm depth.
a: from sago palm field in Sungai Talau Peat Reseach Station.
b: from natural forest in Sungai Talau Peat Reseatch Station.
Soil pH (H_2O) was measured using 1:5 of soil and water ratio.

trogen contents in soil and sago palm tissue were determined by dry combustion method (Higashi 1986). The standard was prepared by hippuric acid, and the contents of C and N were determined by a CN analyzer (Yanagimoto MT500).

Results and Discussion

Distribution of Cu and Zn in tropical peatland

Table 1 shows low pH, high carbon concentration, and low concentration of nitrogen, Cu, and Zn in water and soil samples from tropical peatland. The concentrations of dissolved organic carbon (DOC) in the ditch water were much higher than those in rain water. The mean value of DOC in the ditch water was 55.4 $mgCL^{-1}$, ranging from 39.7 to 62.9 $mgCL^{-1}$. From the results of Hekkinen (1990), it is evident that the DOC concentrations in the river water from boreal peatland were high because of decomposition of soil organic matters in peat soils. Yonebayashi (1992) reported that most of the copper in tropical peat soil occurred as non-extractable and strongly chelated forms. Organic substances and/or carbon under natural tropical lowland forest would be lost by the process of mineralization, accelerated further by drying effects due to high temperature. This suggests that the transformation of Cu is associated with the Cu organically bound to a more soluble form through the decomposition of peat soils after reclamation.

Copper and Zn concentrations in water and soil samples are also presented in Table 1. Mean copper concentration in rain water samples was lower than the mean zinc concentration. Copper and Zn concentrations in peatland water ranged from nd to 1.65 $\mu gCuL^{-1}$ and from 11.0 to 23.60 $\mu gZnL^{-1}$, indicating higher concentration levels than the values in Malaysian peatland water (Okazaki 1992b).

The concentrations of Cu and Zn in soil solutions varied from nd to 28.65 $\mu gCuL^{-1}$ and from 16.52 to 76.97 $\mu gZnL^{-1}$. Soil solutions taken from 10 cm depth exhibited the highest concentration of Cu and Zn, and the concentrations of Cu and Zn gradually decrease in profile.

In deep peat soils, the mean values of Cu and Zn concentrations were 3.31 μgg^{-1} and 7.46 μgg^{-1}, respectively (Table 1). The mean concentrations of Cu and Zn in shallow peat soils were 18.69 and 16.27 μgg^{-1} for 0–80 cm depth, which were higher than the mean values of deep peat soil samples. These facts seem to show that shallow peat soils with 0–22 cm of peat horizon are affected by underlying alluvial soil. Since the medians of Cu and Zn in various mineral soils in the world are 20 μgCug^{-1} and 50 μgZng^{-1} (Bowen 1979), mean concentrations of Cu and Zn in deep peat soil in Dalat area are quite low. Tropical peat soils show considerably lower nutrient contents than peat soils in boreal areas. Alluvial soil contained about 2.3 times higher Cu concentrations than deep peat soils did.

Copper and zinc concentrations in sago palm on different soil types

Copper and Zn concentrations in lamina from sago fronds and in logs growing on alluvial and deep peat soil are presented in Fig. 3. Copper concentrations in the leaflet segments of sago palm growing on alluvial soil tended to be higher at the lower segment than at either the upper or middle segment except for the middle frond. Comparing the living fronds with dead fronds, Cu concentration decreased with an increase in frond age. Within the leaflet segments, higher Cu concentrations were shown in lower segments. In contrast to the former results, higher Cu concentrations were found in the upper parts of the log. There were significant differences in Cu concentrations of sago palm on different soil types. Frond and log samples collected from sago palms growing on deep peat soil had lower Cu concentrations than those on alluvial soil.

Zinc concentration in the leaflet segments tended to be slightly higher at the upper segments of sago palm growing on alluvial soil and a little higher at the lower segments of palm growing on deep peat soil than other segments. Zinc concentration in the living and dead fronds showed a tendency similar to Cu concentration except for the upper frond growing on alluvial soil.

The relation between Cu and Zn in sago palms on the 2 different type of soils is shown in Fig. 3. There were significant differences between the concentrations of Cu and Zn in the part of the fronds and lamina samples of fronds growing on alluvial soil.

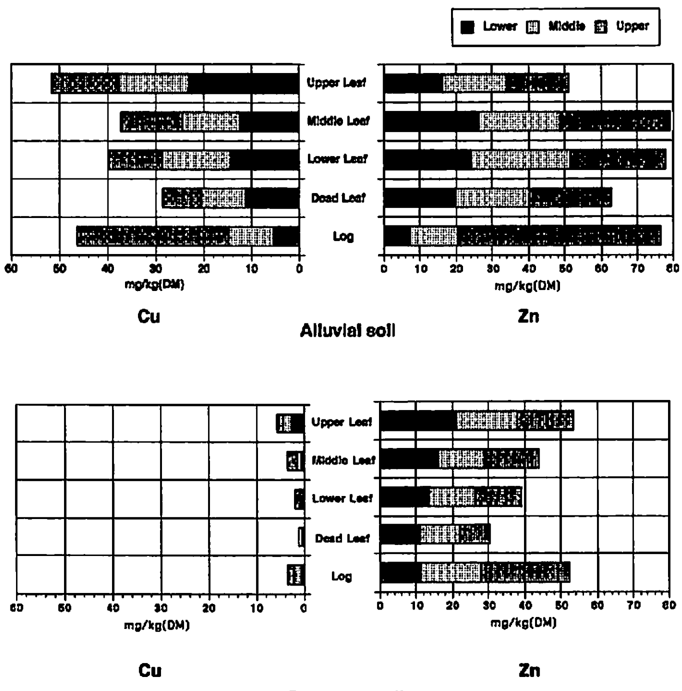

Fig. 3 Distribution of total copper and zinc in sago palm on alluvial soil and deep peat soil in Mukah, Sarawak, Malaysia.

Leaf and log samples collected from sago palms growing on deep peat soil had lower Cu and Zn contents (especially Cu) than in samples from sago palms growing on alluvial soil. In the pith, Cu and Zn concentrations tended to be higher at the upper part of the sago log than at either the lower or middle part. Sim and Ahmed (1991), who had studied the trace element contents in sago palm at Sg. Talau in Mukah District, Sibu Division, Sarawak, reported that there were no large variations in leaf concentrations of sago palm on different soil types. The deficiency level of Cu in plants is known to be less than 2 μgg^{-1}, which is likely to be inadequate for most of the plants. The deficiency of Zn in plants also has been recognized as 10 to 20 μgg^{-1} on a dry matter basis (Pendias and Pendias 1984). Despite the low Cu and Zn contents in peat soils analyzed in this study, Cu and Zn deficiency in sago palm tissues did not appear except in Cu content of tissues taken from sago palms growing on deep peat soil.

Copper and zinc status of sago palm as growth factor

Leaf and pith nutrient variations of sago palm on different soil types are presented in Fig. 4. Fresh leaf and log weights of sago palm growing on deep peat soil were 1.3–1.4 times heavier than those growing on alluvial soil. Dry pith of sago palm growing on deep peat soil, however, was 2.8 times lighter than that of growing on alluvial soil, indicating that the sago palm growing on deep peat soil had high water content. There is no large difference between carbon and nitrogen status in sago leaf and pith on the two soils. However, Cu content on a dry

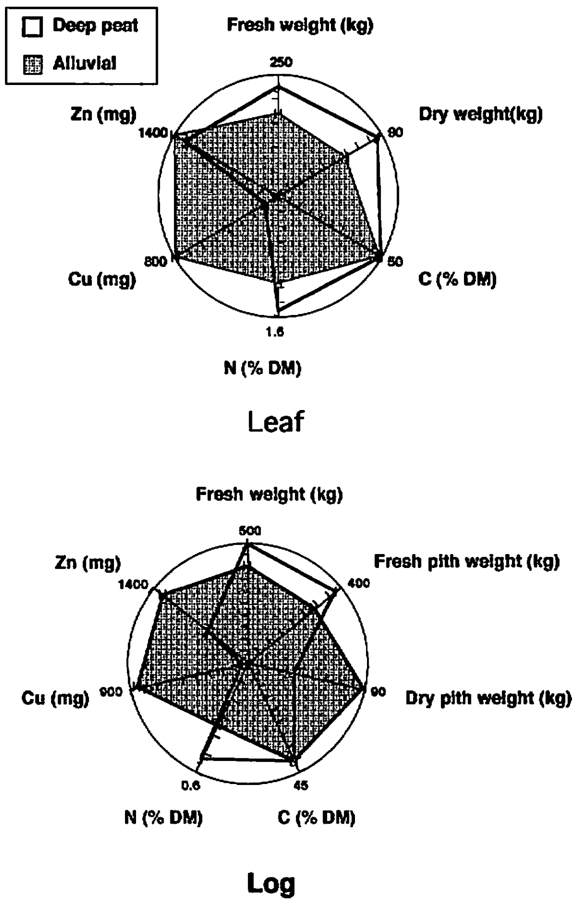

Fig. 4 Growth factor variations in sago palm growing on different soil types.

matter basis in both leaf and log of the sago palm growing on deep peat soil were much lower than those of the sago palm growing on alluvial soil. On the other hand, Zn content did not show any large variation in sago palms on the 2 different types of soils, although the sago palms growing on deep peat soil and on alluvial soil might be recognized at slightly different growth stages. Low Cu content is one of the reasons for the suppression of sago growth on deep peat soil because Cu proteins are essential for electron transfer and oxidase activity (Parker 1981).

Growth study in the field

The state of trunk-formation can be judged by counting the number of leaves and lengths and widths of leaflets. Starch contents of trunks can be assessed by the girth and height (Flach and Schuiling 1991). Growth of sago palms on shallow peat soils and deep peat soils at Sungai Talau Peat Research Station were determined by comparing stem height and diameter at the sago palm ground level between 1992 and 1993 (Fig. 5). The sago palms on shallow peat soil are growing more rapidly than those on deep peat soils. Figure 5 suggests that the trunks of sago palm on deep peat soil grow in height for 7 or 8 years, after which it begins to thicken to store the starch. On the other hand, the sago palms growing on shallow peat soil have already thickened by the age of 6 or 7. It is speculated that the sago palms on shallow peat soils accumulate starch at an earlier growth stage than those on deep peat soils. The low Cu status of sago palms growing on deep peat soil was caused by high content of strongly-bound Cu (Yonebayashi et al. 1991), which was not usually available to sago palms. The low mean values of Cu and Zn concentrations and Cu and Zn forms in deep peat soils are important growth factors which suppress the vegetative growth of the sago palm.

Sustainable land use for tropical peat soil

Sago palm plantation as a means of sustainable land use for tropical peat soil was evaluated from the viewpoint of Cu and Zn concentrations and Cu and Zn forms distributed in the sago palm environment. Copper concentration increased and Zn concentration decreased after reclamation of deep peat soil, as was shown by comparing natural forest soil (deep peat soil b) with sago palm field (deep peat soil a) in Sungai Talau Peat Research Station (Table 1). Trace elements associated with organic matters tended to be lost through mineralization of tropical peat soil. Assuming the inputs of Cu and Zn derived from 3000 mm/yr of precipitation multiplied by 1.18 μgCu/L and 7.36 μgZn/L of the precipitation

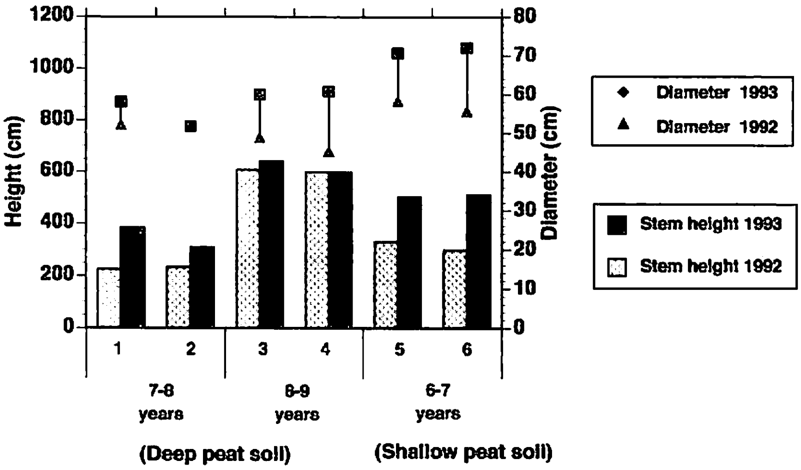

Fig. 5 Comparison of stem height and diameter at ground level of sago palms between 1992 and 1993.

concentrations, and the outputs of Cu and Zn calculated from 1,400 mm/yr (Scott 1985) of the net precipitation multiplied by 1.65 μgCu/L and 23.6 μgZn/L of the ditch water from peatland plus harvesting amounts of 2.95 gCu/ha/yr and 37.8 gZn/ha/yr in 10 years' sago palm, the balance indicates the accumulation of 9.37 gCu/ha/yr and the loss of 146.5 gZn/ha/yr from deep peat soil. Tie et al. (1991) reported that sago palm can be grown successfully on peat soils (including deep peat soils). However, from these results, sago palm cultivation without any management planning is unsuitable as sustainable land use for tropical peat soil. High and continuous sago palm production requires either returning the refuse of starch extraction to the field or fertilizer application (Flach and Schuiling 1991), as well as maintaining a high water table to mitigate the decomposition of tropical peat soil as base management of sago palm.

Conclusions

Copper and Zn concentrations (especially Cu) were low in soil and aquatic environments in tropical peat lands. The sago palms on deep peat soils grew more slowly than those on shallow peat soils or on alluvial soils. The preliminary input and output study of Cu and Zn showed that Cu tended to accumulate and Zn tended to be lost from a tropical peatland area under sago palm cultivation. Cultivation without appropriate plannings will not assure sustainable land use in tropical peat land.

Acknowledgement

This study was supported in part by the Grant-in-Aid No 04041089 as an overseas research project of the Ministry of Education, Science and Culture, Japan. The authors wish to express our thanks to Mr. John Foh Shoon and Mr. Hilary Lai, Department of Agriculture, Sarawak, Malaysia, for their assistance.

Reference

Bowen, H.J.M. 1979 Trace Elements in Biochemistry. Academic Press. (London and New York) pp. 241.

FAO and Unesco 1988 Soil Map of the World. World Soil Resources Report 60, FAO (Rome) pp. 119.

Flach, M. and D. L. Schuiling 1991 Growth and Yield of Sago Palms in Relation to Their Nutritional Needs. In Towards Greater Advancement of The Sago Industry In The '90s. Kuching, Sarawak, Malaysia. (Proc. of the 4th International Sago Symposium, August 6–9, 1990) pp. 103–110.

Hekkinen, K. 1990 Nature of dissolved organic matter in the drainage basin of a boreal humic river in northern Finland. J. Environ. Qual. 19: 649–657.

Higashi, T. 1986 Organic carbon, A dry combustion methods., In Standard Analysis and Measurement of Soil, (Committee of Standard Analysis and Measurement of Soil ed.) Hakuyusha (Tokyo) pp. 77–86.

Liang, J., J.W.B. Stewart, and R. E. Karamanos 1991 Distribution and plant availability of soil copper fractions in Saskatchewan. Can. J. Soil Sci. 71: 89–99.

Okazaki, M. 1992a Sampling sites and sample soils descriptions and general characteristics, In Coastal Lowland Ecosystems in Southern Thailand and Malaysia., (Kyuma, K., P. Vijarnson, and Z. Aini. ed.) Kyoto University. (Kyoto) pp. 55–86.

Okazaki, M. 1992b Abundance and distribution of copper and zinc in tropical peatland water. In Coastal Lowland Ecosystems in Southern Thailand and Malaysia. (Kyuma, K., P. Vijarnson, and Z. Aini. ed.) Kyoto University. (Kyoto) pp. 203–204.

Parker, A. J. 1981 Introduction: The chemistry of copper. In Copper in Soils and Plants (J. F. Loneragan, A. D. Robson, and R.D. Graham ed.) Academic Press (Australia) pp. 1–22.

Pendias, A. K. and H. Pendias 1984 Trace Elements in Soils and Plants. CRC (Florida) pp. 315.

Schuiling, D. L., J. F. Shoon and M. Flach 1992 Exploitation and natural variability of the sago palm (*Metroxylon sagu Rottb*). Department of Agronomy, Section Tropical Crop Science, Wageningen Agricultural University. (Wageningen) pp. 82.

Scott, I. M. 1985 The Soils of Central Sarawak Lowlands, East Malaysia. Soils Division, Research Branch, (Department of Agriculture. Sarawak ed.) Vol. 1. Department of Agriculture. (Sarawak) pp. 13.

Sim, E. S. and M. I. Ahmed 1991 Leaf nutrient variations in sago palms. In Towards Greater Advancement of the Sago Industry in the '90s. (Kuching, Sarawak, Malaysia) (Proc. of the 4th International Sago Symposium, August 6–9, 1990) pp. 94–102.

Stevenson, F. J. and M. S. Ardakani 1972 Organic matter reactions involving micronutrients in soils., In Micronutrients in Agriculture. (J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay ed.) Soil Sci. Soc. Am. (Madison, Wis.) pp. 79–115.

Takeuchi, M. 1986 Zinc, In Standard Analysis and Measurement of Soil, (Committee of Standard Analysis and Measurement of Soil. ed.) Hakuyusha (Tokyo) pp. 191–196.

Tie, Y. L., K. S. Loi, and E. T. Lim 1991 The geographical distribution of sago (*Metroxylon spp.*) and the dominant sago-growing soils in Sarawak. In Towards Greater Advancement of The Sago Industry In The '90s. (Kuching, Sarawak, Malaysia) (Proc. of the 4th International Sago Symposium, August 6–9, 1990) pp. 36–45.

Wagner, G. H. 1962 Use of porous ceramic cups to sample soil water within the profile. Soil Sci. 94: 379–386.

Yamazaki, S. 1986 Procedure for Acid decomposition, In Standard Analysis and Measurement of Soil, (Committee of Standard Analysis and Measurement of Soil. ed.) Hakuyusha (Tokyo) pp. 174–177.

Yonebayashi, K., M. Okazaki, K. Kyuma, Y. Takai, A. B. Zahari, P. Jiraval and V. Pisoot 1991 Chemical decomposition of tropical peat, In Tropical Peat. Proceeding of International Symposium on Tropical Peatland. (Kuching, Sarawak, Malaysia) pp. 158–168.

Yonebayashi, K. 1992 Distribution of heavy metals among different bonding forms in tropical peat soils, In Coastal Lowland Ecosystems in Southern Thailand and Malaysia, (Kyuma, K., P. Vijarnson, and Z. Aini. ed.) Kyoto University. (Kyoto) pp. 219–232.