SAGO PALM 10: 55–63 (2003)

Chemical properties of tropical peat soils and peat soil solutions in sago palm plantation

Masayuki Kawahigashi[1], Hiroaki Sumida[1], Kazuhiko Yamamoto[1], Haruo Tanaka[2] and Chihiro Kumada[3]

[1] College of Bioresource Science, Nihon University, 1866 Kameino, Fujisawa, Kanagawa 252–8510, Japan
[2] Faculty of Agriculture, Tokyo University of Agriculture and Technology 3–5–8 Saiwaicho, Fuchu, Tokyo 183–8510, Japan
[3] Research Institute of Environmental Science, Tamagawa University, 6–1–1 Tamagawagakuen, Machida, Tokyo 194–0041, Japan

Abstract Chemical properties of tropical peat soils and soil solutions under sago palm plantation in Sarawak, Malaysia were discussed. Strong acidic soil reactions and high contents of organic matter were observed in most of soil samples. Chemical properties were obviously different between deep peat soils (DPS) and a shallow peat soil (SPS). Chemical properties in DPS changed with depth. Electric conductivity, ash contents and total nitrogen contents tended to decrease with increasing soil depth, whereas humification degree of peat soils tended to increase with increasing soil depth. Bulk density of surface layer was about 0.1 Mg m^{-3} except for SPS and shrinkage of peat soil causing land subsidence have not occurred by land reclamation for sago plantation.

Dissolved organic carbon, electric conductivity and acidity in soil solutions decreased with increasing soil depth. There was a significant positive relationship between dissolved organic carbon and acidity. Principal components of acidity might originate from various organic acids. Proportions of cations in soil solutions to those in soils were different due to their positive valences. Higher proportions of monovalent cations were in soil solutions compared to divalent cations. Fe content in soil solution was very low and high proportion of Fe was organic bound form.

Physico-chemical properties of soils and soil solutions clearly represented the process of peat accumulation and soil formation condition. There was not clear relationship in deep peat soils between sago growth and chemical properties in soils and soil solutions.

Key words: sago palm, deep peat soil, shallow peat soil, soil solution, humification

サゴヤシプランテーションにおける熱帯泥炭土壌と泥炭土壌溶液の理化学性

川東正幸[1]・隅田裕明[1]・山本一彦[1]・田中治夫[2]・山口千尋[3]

[1] 日本大学生物資源科学部　〒252–8510　神奈川県藤沢市亀井野 1866
[2] 東京農工大学農学部　〒183–8509　東京都府中市幸町 3–5–8
[3] 玉川大学学術研究所　〒194–8610　東京都町田市玉川学園 6–1–1

要約　マレーシア，サラワク州のサゴヤシプランテーションにおいて開墾年度の異なる熱帯泥炭地で土壌および土壌溶液を深さに基づいて採取し，その理化学性を検討した．泥炭土壌の理化学性は泥炭層が深い土壌（DPS）と浅い土壌（SPS）との間で顕著に異なった．DPS では多くの理化学性が深さに応じて変動した．電気伝導度，灰分および全窒素量は表層で高い値を示し，深さに応じて減少する傾向が認められた．一方，泥炭中の有機物の腐植化は深さの増加に

伴い高くなる傾向が認められた．また，DPS では表層土壌の仮比重は約 0.1 M gm^{-3} の低い値を示し，開墾に伴う泥炭の分解による土地の圧密化を受けていないと判断された．

土壌溶液の pH も土壌同様に強酸性を示した．溶存有機態炭素，電気伝導度および酸度は土壌溶液の採取層位が深くなるほど減少する傾向を示した．また，全有機態炭素と酸度の間には有意な相関関係が認められ，酸度の主体が種々の有機酸であることを推測した．土壌溶液中の各陽イオン濃度の土壌中の全量に対する割合はイオンの荷電によって異なり，1 価の陽イオンは 2 価の陽イオンに比べて土壌溶液中の割合が高かった．土壌溶液中の鉄含量は極めて低く，土壌中の鉄は有機物結合態の割合が高かった．

土壌の理化学性は泥炭の集積過程および生成環境を反映していた．鉱質土壌を有する SPS を除くと，サゴヤシの生育概況と土壌および土壌溶液の理化学性との間に明瞭な関係は認められなかった．

キーワード　サゴヤシ, 厚層熱帯泥炭土壌, 浅層熱帯泥炭土壌, 土壌溶液, 腐植化

Introduction

Tropical peat soils originated from woody plant debris extensively distribute around coastal area in Southeast Asia. Most of them are strongly acidic and are oligotrophic peat according to the classification by Anderson (1964). Tropical peat lands are not suitable for most of crops because of strongly acidic and their oligotrophic nutritional condition. However, the vast lands have been developed on a large scale for plantation of some crops growing on an adverse soil condition. Sago palm (*Meteroxylon sagu* L.) forest in Sarawak, Malaysia is one of the large scale plantations in tropical peat lands (Jong and Flach 1995). Sago growth status on peat soils depend on depth of peat soil layers and fertility of mineral soils below peat soil layers (Yamaguchi 1996). Micro and macro nutrient supply is one of limiting factors for sago growth. Sustained growth of sago palm on deep peat land requires fertilizer application and nutrient supply by decomposition peat itself (Kyuma 1984, Kueh 1995).

The study on the influence of development of peat swamp forests on physical properties of peat soils causing land subsidence and on chemical properties for plant nutrition is important for conservation of tropical peat lands and its sustainable management. In this study, soils and soil solutions collected from tropical peat soils under sago plantation with different sago growth condition, different reclamation and plantation year. Physico-chemical properties of the soils and the soil solutions discussed according to soil depth, management history and sago growth status.

Materials and Methods

Study sites

Experimental plots were selected according to sago

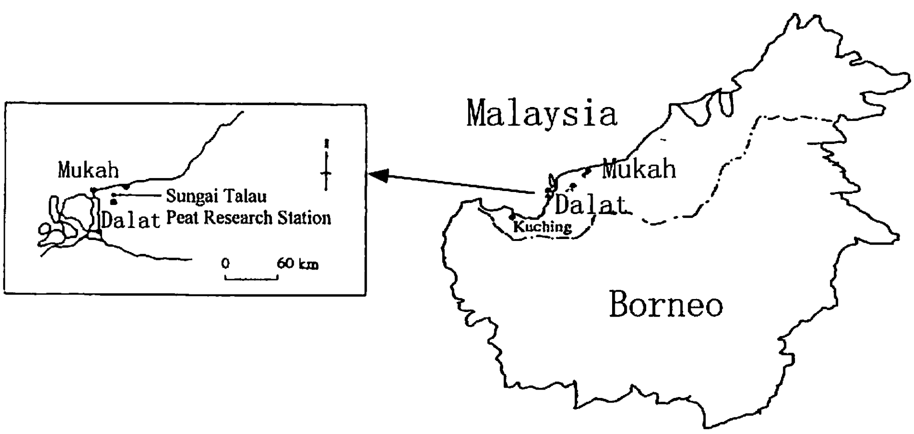

Fig. 1 Location of experimental plot

Table 1 Soil Profile discriptions

M-1 Date of soil survey: 26, August, 1999
Reclamation year (Sago planting year): 1987 (1991)
Vegetation (Local name): Sago palm, Pakis, Plaik, Teruntun
Ground water table (cm): 65

Horizon	Depth (cm)	Soil color
H1	0–30	5YR 2/4 very dark reddish brown
H2	30–65	5YR 2/3 very dark reddish brown
H3	65–	5YR 2/1.5 brownish blak

M-2 Date of soil survey: 26, August, 1999
Reclamation year (Sago planting year): 1987 (1991)
Vegetation (Local name): Sago palm, Pakis, Plaik, Teruntun
Ground water table (cm): 53

Horizon	Depth (cm)	Soil color
H1	0–25	5YR 2/4 very dark reddish brown
H2	25–53	5YR 2/3.5 very dark reddish brown
H3	53–	5YR 2/3 very dark reddish brown

M-3 Date of soil survey: 26, August, 1999
Reclamation year (Sago planting year): 1991 (1992)
Vegetation (Local name): Sago palm, Pakis, Pelaik, Serai, Lemidin, Ubah, Orchid, Rengit, Teruntun
Ground water table (cm): 25

Horizon	Depth (cm)	Soil color
H1	0–10	2.5YR 2/3 very dark reddish brown
H2	10–20	2.5YR 2/2.5 very dark reddish brown
H3	20–	2.5YR 2/3 very dark reddish brown

M-4 Date of soil survey: 26, August, 1999
Reclamation year (Sago planting year): 1991 (1991)
Vegetation (Local name): Sago palm, Pakis, Pelaik, Serai,
Ground water table (cm): 20

Horizon	Depth (cm)	Soil color
H1	0–20	5YR 2/4 very dark reddish brown
H2	20–25	2.5YR 2/4 very dark reddish brown
H3	25–30	2.5YR 2/4 very dark reddish brown
H4	30–40	2.5YR 2/4 very dark reddish brown

T-1 Date of soil survey: 30, August, 1999
Reclamation year (Sago planting year): 1985 (1985)
Vegetation (Local name): Sago palm, Pakis
Ground water table (cm): 30

	Horizon	Depth (cm)	Soil color	soil texture and mottling
	H1	0–10	5YR 2/3 very dark reddish brown	
	H2	10–30	5YR 2/2.5 very dark reddish brown	
	H3	30–40	5YR 2/3 very dark reddish brown	
	H4	40–50	5YR 2/3.5 very dark reddish brown	
	H5	50–60	5YR 2/3.5 very dark reddish brown	
T-2	Date of soil survey: 30, August, 1999 Reclamation year (Sago planting year): 1985 (1985) Vegetation (Local name): Sago palm, Pakis Ground water table (cm): 30			
	Horizon	Depth (cm)	Soil color	soil texture and mottling
	H1	0–18	5YR 2/4 very dark reddish brown	
	Cg1	18–30	10YR 4/2 Grayish yellow brown	SiCL; few cloudy mottling
	Cg2	30–42	10YR 3/2.5 dark brownish black	L; few cloudy mottling
	Cgj	42–	2.5Y 5/2 Dark gray yellow	HC; few tubular and cloudy mottling

growth and reclamation year for sago plantation in the Sungai Talau Peat Research Station (STPRS) and in LCDA (Land Custody Development Authority) sago plantation in Mukah, Sarawak, Malaysia (Fig. 1). Soil survey was conducted at two plots (T-1 and T-2) in STPRS and at four plots (M-1 to 4) in Mukah sago plantation. Sago growth was better in T-plots than in M-plots. Heights of sago palms in T-plots were approximately 10 m and those in M-plots were approximately 2 m. Trunk formation was not observed in M-plots. Sago palms in T-plots formed trunks with approximately 40 cm diameter at breast height. Only T-2 plot was shallow peat land with mineral soil layers below 18 cm. Reclamation and planting year in each experimental plot was different (Table 1). T-plots were reclaimed in 1985. M-1, 2 and M-3, 4 were reclaimed in 1987 and 1991, respectively. An approximate 0.25 kg of chemical fertilizer (N:P:K = 12:12:17) was applied to a sago palm at every experimental plots in May and November since 1996.

Analytical methods

Sample preparation. It passed about two weeks until sample preparation since soil samples were collected. The fresh soil samples were centrifuged at 3,000 rpm for 20 min and divided into precipitates and supernatants. The precipitates were freeze-dried and were prepared for chemical analyses of peat soils by sieving through 2 mm mesh. After the measurement of pH and electric conductivity of the supernatants by pH and electric conductivity meter, the supernatants were prepared for soil solutions by filtrating through 0.45 μm membrane filters. The soil solutions were stored in refrigerator under 4°C and immediately used for each analysis.

Peat soils. Soil pH was measured in water and in 0.01 M $CaCl_2$ with dry soil weight to solution volume ratio of 3:50 by a glass electrode (Karam 1993). Electric conductivity was measured in water with dry soil weight to water volume ratio of 3:50 by an electric conductivity meter. Total carbon and nitrogen contents were determined by the NC analyzer (Sumigraph NC-80). Ash contents were calculated from differences in weights of peat soil samples before and after combustion in muffle at 550°C for four hours (Tsutsuki 1996). Humification degrees were calculated from absorption at 550 nm of humic solution extracted from air-dried peat soils with 0.025 M $Na_4P_2O_7$ (Kaila 1956). The values of $\Delta\log K$ of the solutions calculated from ratios of absorptions at 400 nm to those at 600 nm were also calculated for a humification indicator (Kumada 1987). Contents of Fe dissolved in 0.1 M $Na_4P_2O_7$ were measured by atomic absorption spectrophotometry (AAS) as Fe binding with organic matter. The total elemental analysis of Fe, Ca, Mg, K and Na in peat soils was measured by AAS after digestion of peat soils with HNO_3, $HClO_4$ and HF (Desjardins 1978). Bulk densities of soils upper than underground water level were determined using a 100 mL stainless core.

Soil solutions. Contents of Na, K, Mg, Ca and Fe were measured by AAS. Contents of Cl^-, NO_3^-, and SO_4^{2-} were measured by ion-chromatography with Shimpack IC column (Shimadzu) using tris-amino methane buffer (pH 4.6) as a mobile phase. Dissolved organic carbons (DOC) were measured by total organic carbon analyzer (TOC-5000, Shimadzu). Aliquots of soil solutions were titrated to pH 8.3 using 0.01 M NaOH for determination of acidity.

Results and discussion

Soil profiles

Brief descriptions of soil profiles were shown in Table 1. Soil horizons were mainly divided based on the degree of decomposition judging from von Post grade (Japanese Society of Pedology, 1997). Ground water level was deeper in M-1 and M-2 than the other plots. Change in ground water level between April and October in deep peat area was about 19 cm in depth (Anderson 1964). Deeper trenches for drainage were dug in M-1 and M-2. Soil color was very similar in organic soil layers. Mottling was observed in mineral layers under a histic horizon in T-2, especially, mottling derived from iron oxides was observed in Cg horizons in T-2.

Physico-chemical properties of peat soils

Chemical properties of all of peat soil samples were shown in Table 2. Soil pH was lower in $CaCl_2$ than in H_2O, which ranged from 2.56 to 3.75 and from 3.83 to 4.49, respectively. Both pH values tended to increase with increasing soil depth. Most of physico-chemical properties distinguished T-2, which possess mineral layers below 18 cm, from the other soils. T-2 shows lower electric conductivity, carbon and nitrogen contents, and higher ash contents and bulk densities than the other soils. Except for T-2, phisico-chemical properties of soils changed with soil depth. Electric conductivity values decreased with increasing soil depth and ranged from 0.11 to 0.36 dS m^{-1}. Ash contents ranged from 7.4 to 26.3 g kg^{-1} and decreased with increasing soil depth. Peat decomposition in upper layers could concern with high ash content in surface layers. Carbon contents were greater than 500 g kg^{-1}. Nitrogen contents ranged from 1.7 to 30.5 g kg^{-1} and shows decreasing trends with increasing soil depth. The ratio of carbon content to nitrogen content was increased with increasing soil depth. This indicates that low decomposed plant residues were more abundant in the upper layers. Bulk density ranged from 0.08 to 0.14 Mg m^{-3}. These bulk densities were lower than those of peat soils for farmyard drained well after reclamation (Drieseen and Spepraptohardjo, 1974; cited from Kyuma 1984). Proceeding of compactness by drainage after reclamation could be constrained in sago plantations sampled in this study.

Contents of Ca, Mg, K, Na, and Fe in soils were shown in Table 2. Most of base cations were exchangeable forms in tropical peat soils (Funakawa, 1998). Elementary contents that determined by the total elemental analysis could be potential contents for plant available forms in tropical deep peat soils. Although T-2 soil contains extremely higher amount of Fe, K and Na than the other soils, content of Ca in T-2 soil is lowest of all the soils. M-4 soil also contains a small amount of Ca below 10 cm depth. In the other soils, contents of Ca were higher than contents of the other elements. Contents of Ca positively correlated with ash contents ($r = 0.844^{***}$, $P < 0.001$) and pH values ($r = 0.875^{***}$, $P < 0.001$). The abundance of Ca in these soils might depend on peat decomposition at the upper layers. Except for T-2, contents of Fe were ranged from 0.4 to 1.9 g kg^{-1}. Contents of Fe extracted by 0.1 M $Na_4P_2O_7$ (Fe*p*) occupied over 30% of total content of Fe, except for some organic layers in M-4 and mineral layers in T-2. This might indicate that most of Fe bound to humic substances in peat soils.

Except for T-2, humification degree tends to increase with increasing soil depth (Fig. 2). Humifi-

Table 2 Physico-chemical properties of soils

depth	pH (H_2O)	pH ($CaCl_2$)	EC	Total carbon	Total nitrogen	C/N	Ash	K	Mg	Ca	Na	Bulk density
cm			dS m^{-1}	g kg^{-1}			g kg^{-1}	g kg^{-1}				Mg m^{-3}
M-1												
0–10	4.49	3.30	0.29	616.1	30.5	20.2	24.9	0.55	0.95	2.73	0.14	0.11
10–20	4.39	3.18	0.23	639.2	29.8	21.5	23.7	0.33	0.84	2.39	0.12	0.09
20–30	4.39	3.19	0.17	643.8	28.6	22.5	15.7	0.12	0.92	2.09	0.13	
30–40	4.25	3.06	0.17	657.5	28.1	23.4	19.2	0.11	1.07	2.24	0.15	0.09
40–50	4.29	3.04	0.14	649.1	22.5	28.9	16.6	0.07	1.08	2.16	0.18	
50–60	4.34	3.04	0.13	673.9	22.2	30.3	14.6	0.11	1.15	2.43	0.19	
M-2												
0–10	4.01	2.86	0.23	548.9	15.7	34.9	15.0	0.16	2.13	1.65	0.15	0.14
10–20	4.01	2.89	0.19	580.3	16.5	35.2	14.4	0.11	1.79	1.67	0.16	
20–30	4.08	2.93	0.15	556.7	13.7	40.7	14.5	0.13	1.35	1.66	0.16	
30–40	4.10	2.91	0.14	599.3	14.9	40.3	16.5	0.05	1.02	1.51	0.14	0.08
40–50	4.15	2.96	0.13	536.7	13.3	40.4	9.9	0.03	0.73	1.44	0.12	
M-3												
0–10	4.33	3.19	0.36	560.6	20.4	27.5	23.2	0.89	1.35	3.83	0.19	0.10
10–20	4.36	3.07	0.14	596.7	21.3	28.1	14.4	0.25	1.17	2.44	0.15	
20–30	4.26	2.97	0.12	572.6	17.6	32.6	13.9	0.12	0.98	2.12	0.17	
M-4												
0–10	4.03	2.84	0.28	615.6	16.5	37.3	14.2	0.90	1.84	1.48	0.19	0.10
10–20	3.83	2.61	0.23	574.6	14.3	40.1	6.1	0.44	1.65	0.41	0.19	
20–25	3.87	2.56	0.20	531.0	10.9	48.8	7.1	0.21	1.28	0.28	0.18	
25–30	3.86	2.62	0.20	600.1	15.8	37.9	7.7	0.19	1.13	0.24	0.21	
30–40	3.92	2.65	0.18	588.9	16.2	36.3	4.1	0.14	1.10	0.36	0.14	
40–50	3.96	2.65	0.14	582.6	15.0	39.0	5.5	0.06	1.15	0.62	0.13	
T-1												
0–10	4.19	2.94	0.21	548.5	23.7	23.2	26.3	0.25	0.81	2.45	0.27	0.11
10–20	4.07	2.93	0.21	575.7	21.4	26.9	21.5	0.18	0.80	2.37	0.21	
20–30	4.12	2.83	0.13	589.5	17.1	34.5	12.9	0.08	0.73	1.86	0.19	
30–40	4.00	2.79	0.11	630.6	10.2	61.7	10.3	0.04	0.75	2.15	0.16	
40–50	3.99	2.79	0.11	629.8	9.8	64.0	9.0	0.03	0.65	1.38	0.11	
50–60	3.85	2.77	0.11	632.5	12.7	50.0	7.4	0.04	0.72	0.90	0.11	
T-2												
0–10	4.32	3.23	0.10	243.5	7.7	31.7	578.7	10.30	1.59	0.21	1.09	0.40
10–18	4.30	3.26	0.09	190.2	5.6	34.0	676.0	12.21	2.01	0.18	1.38	
18–30	4.44	3.58	0.07	84.1	2.0	43.0	833.5	15.57	3.05	0.08	1.88	0.52
30–42	4.28	3.51	0.07	74.0	4.8	15.5	844.4	18.77	3.98	0.06	1.87	0.57
42–	4.44	3.75	0.12	59.6	1.7	34.2	868.5	20.24	4.81	0.05	2.21	0.48

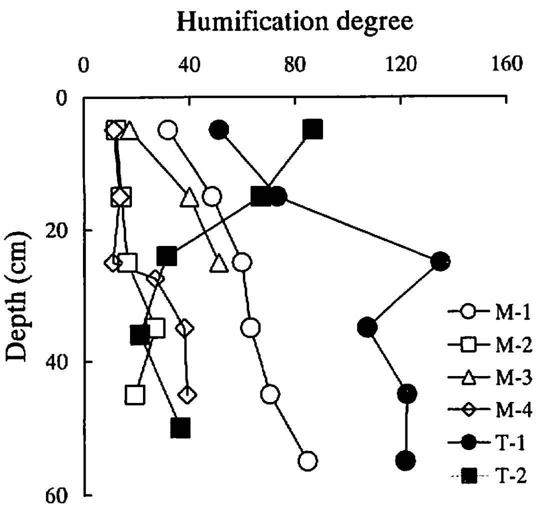

Fig. 2 Humification degree with depth

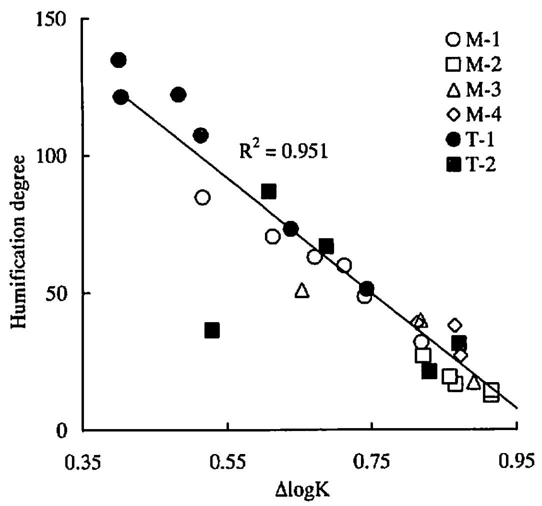

Fig. 3 Relationship between humification degree and ΔlogK

cation and decomposition of peat more progressed in the older peat in deeper layers. Driessen (1978; cited from Kyuma 1984) estimated an accumulation rate of tropical deep peat at about 0.5 mm/year. Enormous time passed for peat accumulation of several tens centimeters according to his estimation. Humification rate was very slow and humification degree might be influenced by pedogenesis condition such as oxidation-reduction potential, accumulation rate of plant residues. The difference in humification degree in each depth might reflect pedogenesis condition at that time. There is a significant linear relationship between humification degree and ΔlogK (Fig. 3). Humification process might progress in similar way at each site.

Although chemical properties of peat soils changed with soil depth, they did not depend on lapse of time after reclamation. The effects of reclamation on physico-chemical properties of peat soils were expected because of peat decomposition brought by land dryness after reclamation. Peat soils in this study area were not promptly decomposed, and physico-chemical properties and supply of nutritional elements of peat soils could be constrained. Low values of bulk density would indicate the constraints of peat decomposition. The differences in humification degree in surface layers, which were higher in older land for sago plantation, might depend on reclamation years.

Chemical properties of soil solutions

Table 3 shows concentrations of cations (Ca, Mg, K, Na and Fe) and anions (Cl^-, NO_3^- and SO_4^{2-}), concentrations of DOC, pH, electric conductivity and acidity. Soil solution pH at every site was lower than soil pH in H_2O and was higher than soil pH in 0.01 M $CaCl_2$. DOC at every site shows the decrease trend with increasing soil depth. Electric conductivity and acidity decreased with increasing soil depth, except for T-2. Again except for T-2, there are significant relationships between DOC and acidity ($r = 0.679$***, $P < 0.001$). The higher values of DOC, acidity and electric conductivity might depend on higher decomposition rate of peat in upper layers by peat drying. In DPS, dissolved organic matters such as low molecular weight organic acids might largely contribute to acidity and might influence cation behavior in soil solutions by retaining them on acidic functional groups. Cations were uniformly distributed in the profile of M-1 and M-2. On the other hand, cations concentrated in upper layers in M-3, M-4 and T-1. The higher concentration in upper layers might depend on remaining of fertilizer. Divalent cations in soil solutions were a hundredth to fiftieth parts of those cations in soils. Monovalent cations highly distributed in soil solutions as well as

Table 3 Chemical properties and ionic composision of soil solutions

depth	(cm)	Cl^-	NO_3^-	SO_4^{2-}	Na^+ (g m^{-3})	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+} (× 10^3 g m^{-3})	pH	EC (dS m^{-1})	DOC (g m^{-3})	Acidity (dmol$_c$ m^3)
M-1	10–20	24.4	1.2	10.2	3.7	2.2	1.9	1.2	10.6	4.37	0.32	111.0	2.26
	20–30	17.2	1.2	4.5	3.2	4.2	1.5	1.4	8.5	4.03	0.17	61.0	1.31
	30–40	30.5	1.3	2.6	3.6	2.9	2.3	2.3	10.2	3.84	0.17	55.1	1.23
	40–50	22.2	1.0	2.3	4.6	2.9	2.1	1.8	7.1	3.98	0.15	55.7	1.05
	50–60	17.3	1.3	1.6	3.5	3.5	1.8	1.5	8.0	3.95	0.14	51.5	1.02
M-2	0–10	19.9	4.6	6.6	—	—	—	—	9.8	3.63	0.22	203.7	—
	10–20	11.9	2.2	2.5	4.3	1.3	1.6	3.1	23.8	3.66	0.17	142.5	1.54
	20–30	11.9	1.3	0.0	3.4	1.9	1.5	1.8	13.4	3.82	0.13	111.1	1.26
	30–40	8.4	1.6	0.0	4.2	2.2	1.5	1.6	15.1	3.91	0.11	80.6	1.13
	40–50	5.5	1.5	0.0	2.7	1.8	1.2	1.0	35.6	4.03	0.09	66.4	0.86
M-3	0–10	95.7	1.4	7.3	8.5	30.4	7.2	4.1	27.3	3.91	0.44	126.3	2.22
	10–20	9.7	1.3	6.1	3.1	3.1	1.5	0.8	3.6	4.11	0.12	48.3	1.06
	20–30	5.5	1.3	1.9	2.9	1.8	1.1	0.7	3.7	4.18	0.08	33.2	0.94
M-4	0–10	30.8	1.4	2.2	2.8	19.1	1.4	2.2	9.4	3.72	0.26	49.4	1.60
	10–20	23.7	1.0	1.2	4.2	4.6	1.2	1.6	22.1	3.52	0.21	28.6	1.26
	20–25	26.7	1.0	1.9	3.4	3.6	0.7	1.5	15.3	3.45	0.21	25.2	1.21
	25–30	37.0	0.9	0.7	3.6	5.1	0.5	2.0	30.4	3.46	0.23	21.6	1.09
	30–40	19.3	1.1	1.2	3.0	3.1	0.5	1.2	31.7	3.64	0.16	22.8	0.97
	40–50	10.7	0.9	8.7	2.0	1.5	0.9	3.7	73.3	3.82	0.10	36.5	0.99
T-1	0–10	32.4	1.5	1.4	8.6	3.2	2.2	1.3	11.6	3.81	0.21	59.9	1.40
	10–20	17.9	1.3	2.9	4.6	2.1	2.2	1.2	5.3	3.83	0.16	50.1	1.21
	20–30	5.9	1.2	4.9	3.1	0.6	1.5	0.7	8.6	3.86	0.09	36.7	0.83
	30–40	6.0	1.2	3.2	3.1	0.4	1.4	0.7	6.5	3.87	0.09	41.7	0.94
	40–50	4.1	1.0	2.6	2.6	0.2	1.3	0.7	2.3	3.85	0.08	44.9	0.89
	50–60	2.8	1.0	2.5	2.5	0.2	0.7	0.6	6.3	3.88	0.08	48.5	0.95
T-2	0–10	9.9	2.0	58.7	3.4	2.7	0.6	0.5	5.7	4.08	0.24	171.2	1.44
	10–18	14.0	2.0	44.3	2.8	1.2	0.7	0.6	5.9	3.97	0.22	71.2	1.15
	18–30	6.1	1.8	49.5	2.5	0.4	0.6	1.1	5.5	4.07	0.20	24.9	1.07
	30–42	7.3	2.1	63.8	3.0	0.5	1.2	2.0	10.4	3.95	0.28	23.3	1.23
	42–	5.4	2.0	199.6	26.6	0.5	2.0	9.1	8.2	4.04	0.68	11.1	1.80

in soils (Fig. 4). Divalent cations retained as available forms in soil solid phases and monovalent cations might be easily lost from soil systems.

Sulfate concentration was extremely high in soil solutions from T-2. Sulfate was considerably generated in C horizons, in which mottling originated from iron oxides were observed, in T-2 under comparatively oxidative condition. Could oxidation progress in T-2, acid sulfate soil might appear under sago palm forest around T-2.

In conclusion, most of chemical properties of soils and soil solutions were changed with soil depth. The differences in the chemical properties with soil depth might reflect the process of peat accumulation and soil formation condition such as aquatic condition, vegetation, plant nutritional condition and so on.

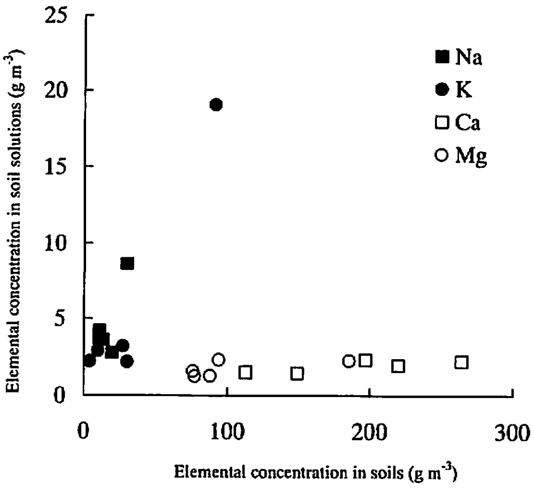

Fig. 4 Relationships between elemental concentration in soil and soil solution

Differences in sago growth status in deep peat soils were not clear. Peat soils in lower layers in T-1, in which better sago growth observed, showed higher ratios of carbon content to nitrogen content than those of the other peat soils obtained from deep peat area. The high ratio in T-1 might be brought by mineralization of organic nitrogen in peat decomposition process. Continuous supply of nutritional nitrogen from peat soils might contribute to better sago growth in T-1. Kakuda (2000) pointed out the effect of mineralized nitrogen supply on the basis of unit volume of soil on sago growth. Mineralization of peat soil might largely influence nutritional condition for sago palm.

References

Anderson, J.A.R. 1964 The structure and development of peat swamps of Sarawak and Brunei. J. Trop. Geor. 18: 7–16.

Desjardins, J.G. 1978 Determination of total major and minor elements (other than C, N, P and S) *In*: Manual on soil sampling and methods of analysis, (McKeague ed.) Can. Soc. Soil Sci. (Ottawa) 140–141.

Funakawa, S., Yonebayashi, K., Jong, F.S., and Chai, O.K. 1995 Nutritional environment of tropical peat soils in view of soil solution composition, *In*: Environmental rehabilitation of tropical peat land: sustainable land use and soil ecosystems in peat land (Koyo Yonebayashi and Lim Chin Pang ed). Hakuto Print Co. Ltd., (Kyoto) 65–75.

Japanese Society of Pedology 1997 Soil survey for peat soils *In*: Soil survey handbook (T., Hamazaki ed.) Hakuyusha (Tokyo) 108.

Jong, F.S. and Flach, M. 1995 The sustainability of sago palm (*Meteroxylon Sagu*) cultivation on deep peat in Sarawak, *In*: Environmental rehabilitation of tropical peat land: sustainable land use and soil ecosystems in peat land (Koyo Yonebayashi and Lim Chin Pang ed.) Hakuto Print Co. Ltd. (Kyoto) 95–109.

Kaila A. 1956 Determination of the degree of humification in peat samples. J. Agric. Sci. Finl. 28: 18–35.

Kakuda, K., Ando, H., Yoshida, T., Yamamoto, Y., Nitta, Y., Ehara, H., Goto, Y., and Puruwandto, B.H. 2000 Soil characteristics in sago palm grown area. Factors associated with fate of inorganic nitrogen in soil. Sago Palm 8: 9–16.

Karam A., 1993 Chemical properties of organic soils In Soil Sampling and Methods of Analysis. (Carter ed.) Lewis Publishers (Boca Raton) 459–471.

Kueh, H.S. 1995 The NPK requirement of the sago palm (*Meteroxylon Sagu* Rottb) on an undrained deep peat soil in Sarawak. *In*: Environmental rehabilitation of tropical peat land: sustainable land use and soil ecosystems in peat land (Koyo Yonebayashi and Lim Chin Pang ed.) Hakuto Print Co. Ltd. Kyoto131–139.

Kumada K. 1987 Studies on the optical properties of humic acids In Chemistry of soil organic matter. (Kumada, ed.) Elsevier (Tokyo) 18–22.

Kyuma, K. 1984 Distribution and properties of lowland soils in tropics, especially in south-east Asia. (in Japanese) *In*: Acidic soils and its agricultural utilization — present status and future scope of acidic soils in tropics-(A. Tanaka ed.), Nippon dojyo hiryo gakkai, Hakuyusha (Tokyo) 101–142.

Tsutsuki K and Kondo, R. 1997 The composition of phenolic CuO-NaOH oxidation products of peat as affected by change in vegetation and the drying tendency in peatland. Jpn. J. Soil Sci. Plant. Nutr. 68: 536–543 (in Japanese with English abstract).

Yamaguchi C., Watanabe, T. and Moromachi, S. 1996 Sago plantation for sustainable agriculture in tropical lowland areas. *In*: Sago study (Okazaki ed.) Tokyo University of Agriculture and Technology (Tokyo) 147–175.