Chapter 5
Peatland and Peatland Forest in Brunei Darussalam

Shigeo Kobayashi

Abstract Peatlands, stored with abundant organic matter, become a source of the greenhouse effect gases emissions such as carbon dioxide and methane generated by decomposition of organic matter since such lands have not been properly utilized. Rehabilitation of degraded peatlands has, nevertheless, hardly been attempted. This paper aims to clarify peatland properties of (1) peatland forest, (2) climate and water conditions, (3) physical properties, (4) chemical properties, (5) possibility of utilization of peat as organic compost, and (6) peat land-use changes in peatland of Brunei Darussalam. Natural peatland was distributed by mixed Dipterocarp forest, Alan (*Shorea albida*) Batu, Alan Bunga, Alan Padang, and Padang Paya. The typical peat of Brunei Darussalam was identified as the Oligotrophic Tropofibrists (Histsols-Fibrists) based on the physical and chemical properties of peat. Especially, carbon storage of the peat swamp forest ecosystems was indicated the maximum 1700 Ct/ha/m. Peat of Brunei Darussalam was also shown the possibility of organic compost, but the problems were pointed out its difficulties of natural regeneration after harvesting and the surface sink-age.

Keywords Alan (*Shorea albida*) forests • Physical properties of peat • Chemical properties of peat • Carbon storage • Compost utilization

5.1 Introduction

The Ramseur convention treaty on wetland conservation was concluded as an international treaty in 1971. According to this treaty, the wetland forests in the tropics have, however, been experiencing drastic land-use transformations for easy access and utilization, which, together with tropical forest decline, has also been a focal point of global environmental issues. Southeast Asia in particular has a very

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wide area of wetlands in which peatland forest, mangrove, and freshwater wetland forests are distributed in 22.2 million ha (Whitmore 1984; Kobayashi 1988; Yamada 1984; Page et al. 1999).

In tropical peatland, which most emit the greenhouse effect gases due to land use change, attempts have never been made to revitalize local society in favor of a land use which urges global-warming prevention (e.g., peatland forest rehabilitation). Therefore, this paper propose to adequately develop multi-purpose land use for agriculture (wet rice, coconut, etc.), forestry, fishery (shrimps and crabs) and the like, taking into consideration of conservation of very fragile tropical peatland ecosystem, and to build a sustainable management system.

This paper aims to clarify (1) climate condition of peatland/forest (indicating as peatland and peatland forest), (2) characteristics of peatland forest, (3) physical and chemical properties of peatland, (4) peatland use changes. This paper results obtained mainly from the permanent plots of peatland/forests at Alan Padang, A. Bunga and A. Batu (Alan: *Shorea albida*) forest in Belait, Seria and Sungai Mao, Brunei Darussalam.

5.2 Characteristics of Peatland Forest

Peatland/forest seems that the round water level is different between sites with a developed root system and sites with an underdeveloped root system (Kobayashi 1997b; Shimamura 2004). If a root system develops, the A_0 horizon is formed on the root above the peat horizon. Otherwise, A_0 accumulates directly on the peat horizon. Root systems with A_0 horizons show a high variation in water tension and become easily dry. An A_0 horizon in peat is generally not thick and the peat horizon is constantly saturated. Water tension in peatland creates severe habitat whereby the peat horizon is easily flooded and the root systems are easily dried out. It seems generally for severe habitat for seedling establishment. Tropical peatland forest is one of the most important area for the land utilization in insular Asia, although peatlands are widely distributed in Asia of 22.2 million ha compared with 5.2 million ha in America and 3.5 million ha in Africa (Kyuma et al. 1986). About 18.2 million ha of peat exist in insular Asia. On the other hand, peatland forests are distributed 90,884 ha in Brunei Darussalam. These forests dominantly consist of pure *Shorea albida* (Alan) stands classified into three forest types such as Alan Batu, Alan Bunga, Alan Padang (Anderson 1964; Stoneman 1997).

There are typical four forest types such as Mixed Dipterocarp forest, Tropical heath forest, Peatland forest, and tropical mountain forest where are occupied 95 % of area except mountain forest and others. The structures and soil profiles of each three major different forest types are the peatland forest, the heath forest and the mixed Dipterocarp forest in Brunei (Figs. 5.1 and 5.2).

The study site of mixed Dipterocarp forest was located in Andulau Forest Reserve about 5 km from Sungai Liang. Acrisols (red and yellow podzolic) soil composed of thin A0 and A horizon was distributed. The dominant species in this

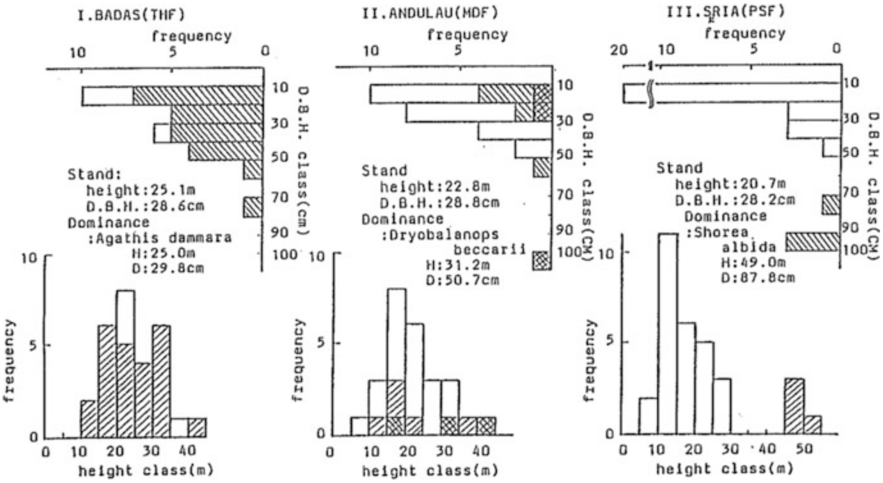

Fig. 5.1 Typical three types of forest structures in Brunei: (I) BADAS (THF): Tropical Heath Forest dominated by *Agathis dammara*, (II) ANDULAU (MDF): Mixed Dipterocarp Forest dominated by *Dryobalanos beccarii*, (III) SRIA (PSF): Peat Swamp Forest dominated by *Shorea albida* (Kobayashi 1988)

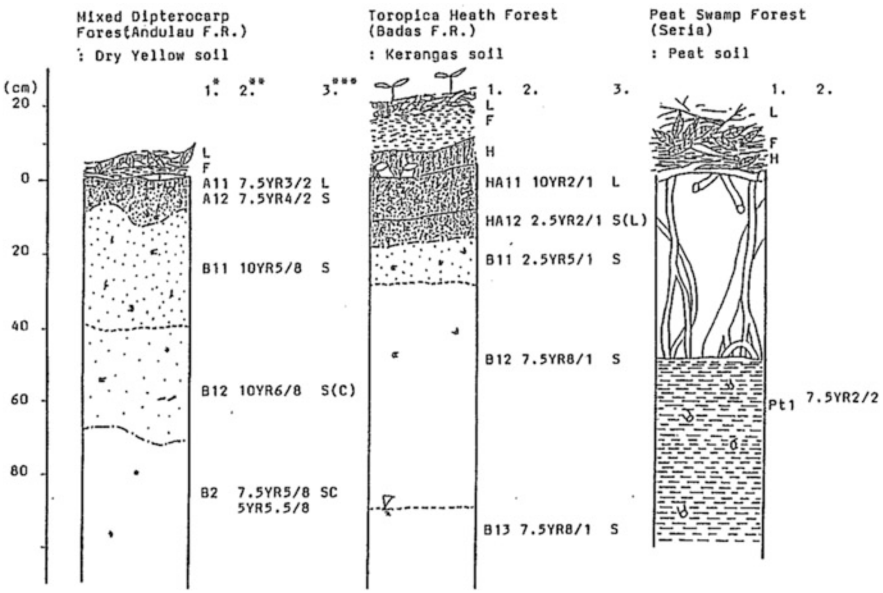

Fig. 5.2 Soil profiles of each forest type (Kobayashi 1988)

forest ware *Dryobalanops beccarii*, *Shorea beccariana* and *Shorea quadrinervis*. The stand was shown an average of 28.8 m in height, an average of 28.8 cm in D.B.H. and 50 % of trees belonged to *Dipterocarpacea*. The study site of tropical heath forest was located in Badas Forest Reserve about 10 km from Lumut. The soil was classified into Arenosols (Kerangas soil). Thick organic matter was accumulated and topsoil was mixed with undecomposed humus and white silica sand. This forest represented a pure stand of *Agathis dammara*. The average height of stand was 25.1 m and the D.B.H. was 28.6 cm. The dominant *Agathis dammara* comprised every size class and covers approximately 90 % of this site. The study site of peatland forest was located in Peat Swamp Forest Reserve 3 km from Seria. Peat swamp was characterized by peaty soil consisting of a thick peat horizon. Root systems were developing above the peat horizon near huge trees and height about 70 cm between the A0 horizon and peat horizon. This space was appeared to influence of the dominated *Shorea albida* regeneration. This peatland forest was mainly dominated by *Shorea albida* and characterized with an average of 22.7 m in height, an average of 28.2 cm in D.B.H. and about 100/ha in density. The comparison among these three forest types, the peatland forest dominated by *Shorea albida* and the heath forest dominated by *Agathis dammara* were less biodiversity caused by environmental condition instead of the rich biodiversity of tropical forests.

5.2.1 Structure of Peatland Forest

On specified different forests types were observed from outside of peat dome to center such as the mixed peatland forest dominated by *Dryobalanops rappa*, Alan Batu, Alan Bunga, Alan Padang and Padang Paya forests. Among of these forests, Alan forests occupied wide area and *S. albida* as monoculture stand is very peculiar in tropical rain forests associated with its phenological characteristics and site condition of peatland. Different Alan forest types are characterized on their heights and ground water levels. On the seedling establishment and regeneration process, although *S. albida* blossomed in February, 1986 in Brunei and Sarawak, the seedling population of *S. albida* almost disappeared from the forest floor 2 years after. The main factors of mortality were considered to be the shortage of light intensity (less than 700 lux) and the water condition of the habitat which becomes easily dry on days without rainfall on the root system and becomes flooded after continual rainfall on the peat horizon. It is also appeared on the point of demography that the energy allocation pattern to root weight of *S. albida* seedlings indicates less than 20 % compared with *Shorea laxa* and *Shorea angustifolia* more than 30 %. Peat land utilization must be taking into account of fragile ecosystem of *S. albida* forest on its regeneration process (Kobayashi 2000).

Shorea albida which established pure stand, had been harvesting like a clear cutting without plantation. The natural regeneration is the most difficult in this stand because of long period of *S. albida* flowering, lack of mother trees and the

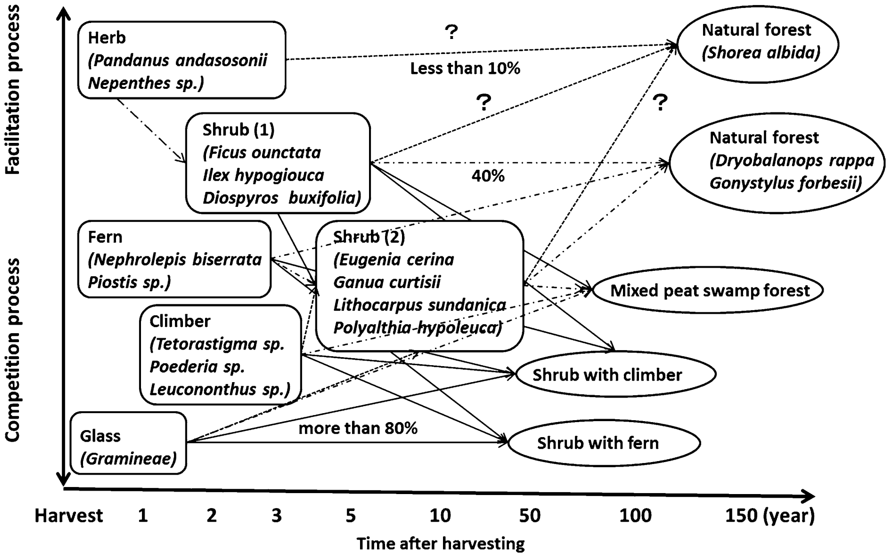

Fig. 5.3 Secondary succession after Shorea albida harvesting. The Parenthesis shows indicated species

extremely severe environment which were structure of peat profile, physical and chemical properties of peat (Matsune et al. 1994; Kuusipalo et al. 1996). Therefore, the clarification on the initial phase of vegetation recovery at the harvested site will be suggested as the feature forest rehabilitation activities at peat swamp areas. As the results of survey, vigorous vegetation recovery was recorded for 46 months after harvesting. Among of recovered species, *Pandanus andersonii* and *Nephrolepis biserrata* reproduced vigorously and established their dominances. The number of species increased according to the time lapse after harvesting. Sixty-seven species/100 m^2 were observed for 46 months after harvesting. However, an average of 30 species was surveyed in the natural Alan forest. Species composition was changing according to time. Natural regeneration of by original *Dipterocarp* species was very poor and only three species were observed such as *D. rappa*, *Shorea inaquilatealis* and *S. albida*. Nevertheless, the former dominant *S. albida* was recorded at only 1 plot among 16 plots (density: 3.1/ha). The *S. albida* forest will be taken over by different forest types. Therefore, initial vegetation recovery was classified into Shrub, Herb, Fern and Climber types (Fig. 5.3). Shrub and Herb types are considered the facilitation process and Fern and Climber types are the competition process during secondary succession according to species changes, although *S. albida* forest is not expected to re-establish (Kobayashi 2004). This perspective is recognized coupled with natural regeneration by Dipterocarp species and Ramin is very poor. The *S. albida* forest will be taken over different forest types which are expected low value resources.

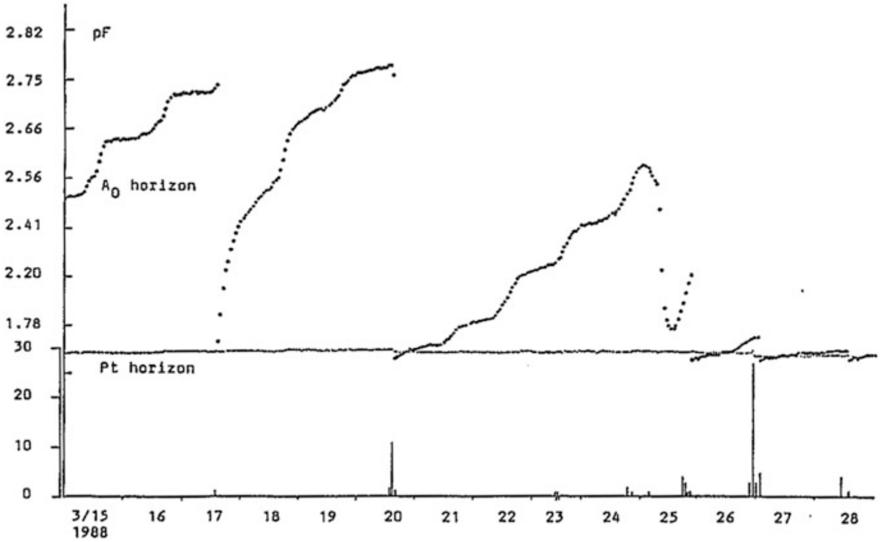

Fig. 5.4 Peat water condition related with horizon and rainfall. If no rain, surface will be dried (Kobayashi 1988)

5.2.2 Environment Conditions of Peatland

Peatland forest seems that the ground water level is different between sites with a developed root system and sites with an underdeveloped root system (Fig. 5.2). If a root system develops, the A_0 horizon is formed on the root above the peat horizon. Otherwise, A_0 accumulates directly on the peat horizon. Root systems with A_0 horizons show a high variation in water tension and become easily dry (Fig. 5.4). An A_0 horizon in peat is generally not thick and the peat horizon is constantly saturated (pF: about 1.5). Water tension in peat swamp creates severe habitat whereby the peat horizon is easily flooded and the root systems are easily dried out. It seems generally for severe habitat for seedling establishment (Burslem 1996; Gunatilleke et al. 1996). Each study recorded a maximum temperature of approximately 30 °C and a minimum temperature of 22 °C in same month when peat water tension was measured. The daily variation of each study site was synchronized. The daily range was less than 5 °C at each site. Tropical heath forest recorded comparatively high daily variations and peatland forest recorded the lowest average temperature for air temperature (Kobayashi 1997a; Takahashi and Yoneta 1997). Soil temperature remained constant at an average of approximately 26 °C for each site according to same month. The highest average of soil temperature was indicated in tropical heath forest and the lowest average of soil temperature was recorded in peatland forest. The daily variation of soil temperature in mixed *Dipterocarp* forest was comparatively higher than other types of forests. Soil temperature at peatland forest was relatively constant due to the thick A_0 horizon and saturated water condition.

5.3 Physical Properties of Peat

Physical properties of peat was analyzed and shown in Table 5.1. Peats were characterized to appear high hydraulic conductivity, low bulk density, high total porosity, and low specific gravity (Kobayashi et al. 1989). Hydraulic conductivity of peats decreased from Alan Padang to Alan Batu, but moisture content of fresh peats increased from Alan Padang to Alan Baru affected by ground water levels. Composition of solid, liquid and gaseous phases in peats indicated large differences depend on Alan forest types. Rate of gaseous phase indicated the largest in peat at Alan Padang, the smallest at Alan Batu. Rate of liquid phase indicated the smallest at Alan Padang and the largest at Alan Batu conversely. Gaseous and liquid phases were characterized each peats which were also affected ground water level. Therefore, these differences of gaseous and liquid phases were one of the characteristics of peats in Alan forests. Composition of fine and coarse porosities also indicated differences among peats at each Alan forest types. Their total porosity

Table 5.1 Physical properties of peats at Alan Padang, Alan Bunga and Alan Batu Forests (Kobayashi et al. 1989; Kobayashi 2012)

Plot	Alan Padang			Alan Bunga			Alan Butu		
Horizon	Pt1	Pt2	Pt3	Pt1	Pt2	Pt3	Pt1	Pt2	Pt3
Depth (cm)	0−12	2−34	34−	0−8	8−26	26−	0−5	5−24	24−
Hydroaulic conductivity (cc/min.)	977	1118	126	382	207	295	197	21	7
Bulk density (g/cc)	0.112	0.122	0.074	0.153	0.147	0.079	0.113	0.152	0.098
Porosity (%) coarse	56.2	56.0	64.4	55.3	29.7	47.3	30.6	15.6	34.6
Fine	29.5	35.7	29.0	33.6	58.6	45.9	59.4	73.2	57.3
Total	85.7	91.7	93.4	88.9	88.3	93.2	90.0	88.8	91.9
Water maximum (%)	58.5	59.8	57.4	52.5	80.2	74.0	78.7	87.9	94.3
Air minimum (%)	27.2	31.9	36.0	36.4	8.1	19.2	11.3	0.9	−2.4
Moisture content (%)	36.9	42.2	37.6	36.5	68.4	61.4	71.8	84.5	95.5
Specific gravity	1.50	1.53	1.49	1.53	1.47	1.55	1.51	1.45	1.40
Saturated water/dry peat (%)	566.8	490.4	784.3	347.9	555.8	951.8	715.2	582.0	972.2
Ground water level (cm)	74			56			24		

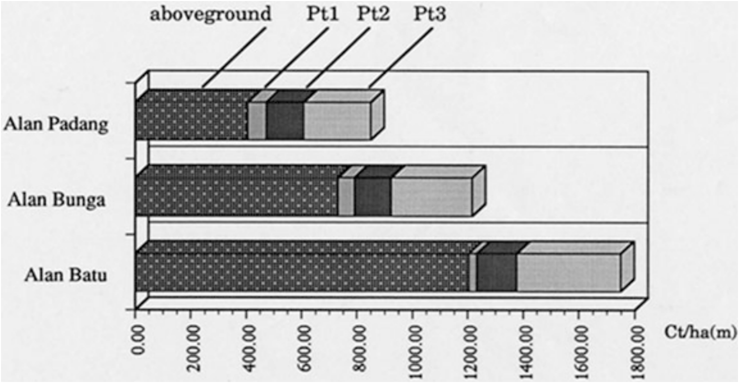

Fig. 5.5 Carbon storage of *Shorea albid*a forest ecosystem: the above-ground biomass was estimated and the under-ground carbon storage was estimated by depth of 1 m (Deepest peat was over 10 m)

were similar and more than 80 %, but the peat at Alan Padang showed much coarse porosity, the peat at Alan Batu had much fine porosity and the peat at Alan Bunga was medium.

The USDA Soil taxonomy (1990) classifieds fibric material using the criteria that its bulk density is less than 0.1 g/cc and that saturated water content based on dry peat weight is 850–3000 %. The bulk density of sapric material is more 0.2 g/cc while saturated water content was less than 450 %. Hemic material is classified by medium values of bulk density and saturated water content between Fibric. Although each horizon of peat at three Alan forest types was classified according to the above mentioned criterion, fibric materials were distributed within all Pt3 horizons. The peats of Alan forest were Tropofibrsts due to the key horizon of peat classification occurring on subsurface tiers (USDA Soil Taxonomy was changed in 2010, but Author used to apply the old Taxonomy because of the taxonomy must be synchronized the former taxonomy).

A problem exists concerning the utilization of peat which tends to sink down from the surface during dehydration and decomposition. Results from the experiment using the 400 cc cylinder showed the peat of Alan Batu underwent a 6.0 mm surface sinkage during a 40 % loss of water (Fig. 5.5). Other peats also displayed a surface sinkage but at different ratios. The volume of peats also decreased with thisprocess.

5.4 Chemical Properties of Peat

Chemical properties of peats did not indicate exceptional differences without for ash contents and cation exchangeable capacity at three Alan forests types (Table 5.2). Differences of ash contents and cation exchangeable capacity were related to different ratios of mineral soil and hemic substance. The characteristic aspects of

Table 5.2 Chemical properties of peat at Alan Padang, Alan Bunga and Alan Batu Forests (Kobayashi et al. 1989; Kobayashi 2012)

					Inorganic nitrogen			Exchangeable cation			
					NH_4	NO_3	C.E.C	Ca^{2+}	Mg^{2+}	K^+	Na^+
		pH		Ash (%)	mg/100 g dry soil		me/100 g dry soil	me/100 g dry soil			
Alan Pagang	Pt1	3.35	(3.30)	1.2	(9.52)	(0.00)	243	0.00	7.76	1.47	0.28
	Pt2	3.53	(3.29)	2.1	(7.47)	(0.14)	283	0.00	6.81	0.75	0.29
	Pt3	4.35	(3.20)	21.3	(8.57)	(0.00)	273	0.00	4.51	0.96	0.34
	Pt4	4.74	(3.58)	0.3	(5.55)	(0.00)	245	0.00	2.87	0.45	0.17
Alan Bunga	Pt1	3.32	(3.24)	1.6	(5.87)	(0.00)	316	0.76	8.56	1.22	0.42
	Pt2	3.47	(3.28)	1.7	(1.84)	(0.31)	361	0.00	5.57	0.71	0.33
	Pt3	3.56	(3.51)	1.0	(9.86)	(0.58)	250	0.00	5.13	0.52	0.41
	Pt4	3.50	(3.69)	0.6	(9.71)	(0.29)	266	0.00	3.29	0.40	0.33
Alan Butu	Pt1	3.25	(3.34)	2.9	(8.56)	(0.00)	301	2.27	7.86	1.05	0.44
	Pt2	3.35	(3.45)	6.6	(1.61)	(0.00)	225	0.00	3.00	0.38	0.28
	Pt3	3.29	(3.47)	0.8	(2.47)	(0.00)	309	0.00	2.60	0.29	0.27
Top soil of arboretum		4.66		90.8	(4.40)	(0.00)	87	0.00	4.33	1.09	0.00

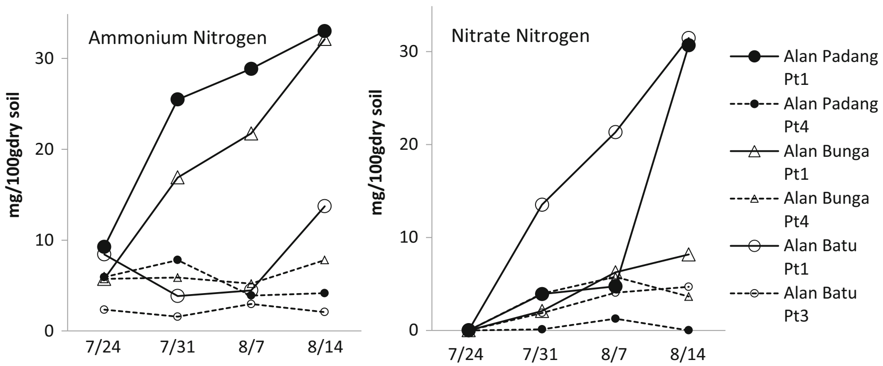

Fig. 5.6 Process of decomposition of peat under the analysis of ammonium nitrogen and nitro gate nitrogen (Kobayashi 1988, 2012)

Brunei peats revealed that the pH level dominated between 3.5 and 3.2 in fresh peats. It also indicated strong acidity with cation exchangeable capacity being more than 220 mm equivalent per 100 g dry peat while the exchangeable cations content was extremely low. Among exchangeable cations, the content of calcium and potassium in this study were low and the peats showed strong acidity. Therefore, peats of Alan forests were classified oligotrophic. Although peats indicated strong acidity, there was no evidence of sulfidic acidity, which was tested by SO_4 using Merckoquant test papers (Yonebayashi et al. 1997). Carbon stocks of Alan forest ecosystems were from 750 to 1700 Ct/ha/m at the center site to the marginal site of peat dome (Fig. 5.6). Aboveground carbon stocks of Alan forests were 300–1150 Ct/ha and underground carbon stocks of Alan forests were about 500 Ct/h/m which strongly affected depth of peat. If the depth of peat is 2.5 m, underground carbon stocks will be 1250 Ct/ha more than its aboveground carbon stocks.

The decomposition process of peat was examined by mineralization of nitrogen which showed different ratios and processes depending upon the horizons at Alan forest types. Generally, surface peats were easily decomposed and the deepest horizons sometimes indicated immobilization after 2 weeks in an incubation (Fig. 5.7). Ammonification was identified on surface peats of Alan Padang and Alan Bunga. Nitrification was also found on the peat surface of Alan Batu. It is therefore concluded that the decomposition ratio and process were affected by acidity, organic materials and water contents. In spite of different water contents and organic materials, peats displayed the possibility of decomposition and the future utilization of peats as compost. Nitrogen mineralization in peats showed different ratios and processes depending on the horizons and Alan forest types. Generally, surfaced peats were easily decomposed and the deepest horizons indicated immobilization after 2 weeks in the incubation. Ammonification was identified on surface peats of Alan Padang and Alan Bunga and nitrification was also found on the peat surface of Alan Batu. It is therefore concluded that the decomposition ratio and process

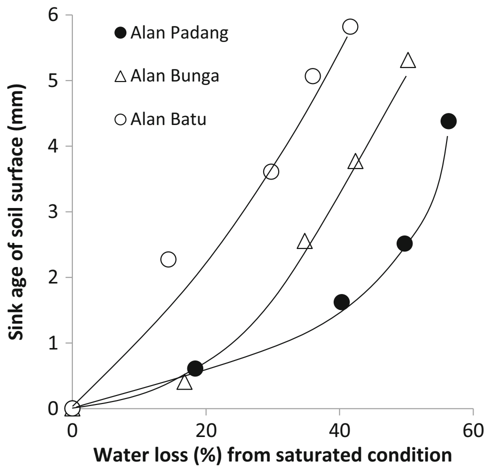

Fig. 5.7 Sink age of surface level of peat during the dehydration (Kobayashi et al. 1989; Kobayashi 2012)

affected by acidity, organic materials and water contents. Instead of different water contents and organic materials, peats displayed the possibility of decomposition and the future utilization of peats as compost.

5.5 Examination of Possibility of Utilization of Peat as Organic Compost

Tropical peat was studied for utilization of compost compared with common materials such as sawdust, litter and grass (Kobayashi 1994). The original peat of chemical properties indicates lower cation contents and a strong acidic pH value of 3.5. The water content is 500 % indicating the peat was oversaturated. It's necessary to be controlled and created the compost under 70 % of water content and pH7.0 of acidic condition for making the compost (Fujita 1987). When the lime was added to the peat to neutralize the pH and water content tried to be maintained 70 % at calorific fermentation was stimulated which was indicated to increase the temperature (Fig. 5.8). After treatment, the fermented was occurred, and chemical properties were changed (Table 5.3) after 68 days. Chemical properties of the compost before and after were changed that the amount of inorganic nitrogen and exchangeable cations increased in the peat compost through calorific fermentation. A final test of compost quality was conducted using the bioassay method and a fast growing plants, the tropical tomato (Table 5.4). Potting soil consisted of a 1:1 ratio of each material and topsoil. Grass and sawdust composts were sowed a sufficient growth of tomato seedlings two after sowing. Among of characteristics of tomato seedlings, increment of height and biomass displayed excellent growth occurred on grass and sawdust composts. According to these two composts, leaf litter and peat composts showed good tomato growth without topsoil. It will be necessary to

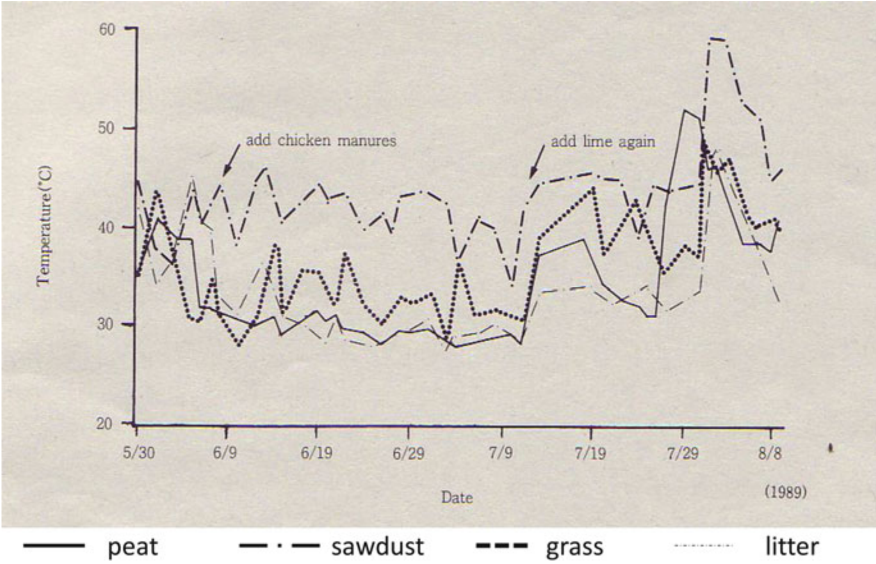

Fig. 5.8 Changes of temperature of compost in composts during pilling process (Kobayashi 1994)

check the matured peat compost for nutrients, because tomato showed third growth rate and peat did not ferment sufficiently in this study. There was no evidence of chlorosis in the tomato seedlings, because of leaf color was greenish (7.5 GY, 4/4.5–4/6). In addition, impediments to tomato growth such as root decay by post fermentation, did not occur.

Although, the peat had the potential to become compost, some problems were encountered therefore first of all, the *Shorea albida* forests have very unique structures and are scientifically important among tropical rain forests because only one species is dominated and consists of pure forest on the peat swamp. Secondly, drying and decomposition case, the peat will become to shrink and subside. Third, the structure of peat layers indicated complex layers alternating between peat and clay, the latter which usually contains Pyrite and transforms into sulfate after oxidation. Therefore, tropical peat must be carefully considered for use as compost.

5.6 Peatland Use Changes

It's rarely reported to clarify the unevenness environment of peatland forest on the process of litter decomposition (Shimamura 2004). Litter decomposition parameter (standard error) was 0.8910 (0.0410), 0.916(0.0603), 0.760(0.0394) in mound, flat and gap, respectively. It showed the highest value at flat area and the lowest at gap. We also clarified the environment changes according to land use changes from peat swamp forest to cultivation land, rubber plantation, coconut plantation and

Table 5.3 Changes of chemical properties after piling of compost (Kobayashi et al. 1989)

	Peat		Sawdust		Litter		Grass		Chicken	
	Before[a]	After[b]	Before	After	Before	After	Before	After	Manures	Topsoil
pH	3.56	6.82	4.95	8.34	5.39	7.64	6.64	7.53	7.31	4.66
Inorganic nitrogen										
MH_4-N	22.1	846.0	5.2	476.4	56.8	885.6	35.2	396.5	995.1	4.4
NO_3-N	1.1	466.2	0.0	37.3	0.0	148.4	0.0	165.6	56.9	0.0 (mg/100 g) dry-soil)
Total	23.2	1212.2	5.2	513.7	56.8	1034.0	35.2	562.1	1051.0	4.4
Cation exchangeable capacity	224	182	117	151	161	291	189	193	–	87 (me/100 g dry-soil)
Ca^{2+}	0.00	22.97	0.00	11.74	3.52	17.93	6.13	25.47	17.37	0.00
Mg^{2+}	1.70	5.22	1.32	3.75	3.46	4.06	3.55	4.94	21.74	4.33 (me/100 g dry-soil)
K^+	1.09	29.00	1.18	25.22	4.20	24.61	16.66	30.12	68.08	1.09
Na^+	0.00	7.51	0.00	5.36	0.52	6.15	3.89	6.49	16.22	0.00
Ash %	31.2	51.8	2.3	21.2	13.3	24.3	23.7	60.2	45.7	91.1

[a]Composting material air-dry
[b]Two months after piling, adding chicken manure and sulfate ammonium and lime

Table 5.4 Bio-assey of composts quality using tomato seedling after 2 weeks sowing (Kobayashi et al. 1989)

	Height	Stem fiameter	Leave no.	Biomass	Root weight*	Leafe color	Growth condition
Peat	7.6	1.3	4.4	12.5	1.2	7.5GY 4/4.5–4/6	Good
Sawdust	9.4	1.8	5.1	17.1	1.3	7.5YG 4/4.5–5/5.5	Very good
Litter	8.1	1.5	4.9	15	1.8	7.5YGY 4/4.5–4.5/5	Good
Grass	9.6	1.7	5.5	17.9	1.6	7.5YG 4/4.5–4.5/55	Very good
Topsoil	3	0.7	3.5	3.6	1	7.5YG 4/4.5–5/5	Bad
(unit)	cm	mm		mg	mg		

*dry weight (mg)

paddy. It showed lower air and underground temperatures and stronger acidity than agriculture fields. The environmental changes of land use changes from peatland forest indicated to accelerate the peat decomposition. Carbon decreasing rate by peat decomposition was estimated 0.053 Ct/ha/year from the peatland to coconut plantation (Kobayashi 2007).

After land use changes, surface temperature increased, moisture of peat became dry and mild acidic. Then the peat changed from fabric peat to mesic peat and to sapric peat. After changing, peat completely decomposed. Annual organic matter accumulation in peatland was 1.25 Ct/ha/year. We have also estimated the accumulation of peat and organic matter 5.7 t/ha/year. As the 50 % of peat and organic matter annual decomposition rate. We have gotten the less than 0.26 Ct/ha/year at Teluk Meranti and 0.15 Ct/ha/year under the conversion of land utilization from forest to Coconut plantation.

The tropical peatland/forest ecosystem will be contended the most organic matters where will be faced on the frontier of the development of land use change, even though it's the most carbon storage ecosystem (Kobayashi 2007; Gunawan 2012). Therefore, this peatland with the unique forest types must be taken account to conserve for future original forest and to global warming issues.

References

Anderson JAR (1964) The structure and development of the peat swamps of Sarawak and Brunei. J Trop Geogr 18:7–16

Burslem DFRP (1996) Differential response to nutrients, shade and drought among tree seedlings of lowland tropical forest in Singapore. In: Swaine MD (ed) The ecology of tropical forest tree seedlings, vol 17, MAB. The Parthenon Publishing Group, Paris, pp 211–244

Fujita K (1987) Manures made of livestock excreta and their application to the nursery. TARQ 21:129–133

Gunatilleke CVS, Perera GAD, Ashton PMS, Ashton PS, Gunatilleke IAUN (1996) Seedling growth of Shorea section Doona (Dipterocarpaceae) in soils from topographically different sites of Sinharaja rain forest in Sri Lanka. In: Swaine MD (ed) The ecology of tropical forest tree seedlings, vol 17, MAB. The Parthenon Publishing Group, Paris, pp 245–265

Gunawan H (2012) Rehabilitation of degraded peat swamp forest for the promotion of ecosystem services and rural livelihoods in Giam Siak Kecil-Bukit Batu Biosphere Reserve, Riau, Indonesia. Ph.D. Thesis. Kyoto University, Kyoto

Kobayashi S (1988) The maintenance and effective use of forest resources in Negara Brunei Darussalam. Forest Research Note in Brunei Darussalam. RNB-11, p 175

Kobayashi S (1994) Effects of harvesting impacts and rehabilitation of tropical rain forest. Journal of Plant Research 107:99–106

Kobayashi S (1997a) Site conditions of peat swamp forest and vegetation recovery process after harvesting in Seria, Brunei Darussalam. International Workshop on Environmental Management of Wetland Ecosystem in South East Asia. Abstracts. JSPS, Palangka Raya, p 29

Kobayashi S (1997b) Rehabilitation of a logged-over peat swamp forest (*Shorea albida*) in Brunei Darussalam. International Workshop on the Management of Secondary Forests in Indonesia. Abstracts. CIFOR/USAID, Bogor, pp 10–11

Kobayashi S (2000) Initial phase of secondary succession in the exploited peat swamp forest (*Shorea albida*) at Sungai Damit, Belat in Brunei Darussalam. In Proceedings of the International Symposium on Tropical Peat lands, Hokkaido University, pp 205–214

Kobayashi S (2004) Landscape rehabilitation of degraded tropical forest ecosystems-case study of the CIFOR/Japan project in Indonesia and Peru. For Ecol Manag 201:13–22

Kobayashi S (2007) Study on the option of land resources management and the empowerment for local community in the lowland swamp forest in Southeast Asia. Summary report of research results under the GERF. Ministry of Environment, Japan, pp 60–72

Kobayashi S (2012) Chapter 4: Tropical peat swamp forest ecosystem and REDD+. In: Kawai S (ed) Reclamation of tropical biomass society. Kyoto University Publication, Kyoto, pp 193–215, in Japanese

Kobayashi S, Ochiai Y, Jily R, Wahid R (1989) Interim report on the utilization of peat resources in Brunei Darussalam. Forest research note in Brunei Darussalam. RNB 31:1–37

Kuusipalo J, Jafarsidik Y, Adjers G, Tumelo K (1996) Population dynamics of tree seedlings in a mixed dipterocarp rainforest before and after logging and crown liberation. Forest Ecology and Management 81:85–94

Kyuma K et al. (TARQ) (1986) Lowland swamp in South East Asia. Norin-Tokei, p 301 (in Japanese)

Matsune K, Kojima K, Tange T, Yagi H, Soda R, Kobayashi N, Sasaki S (1994) Growth responses of Dipterocarp seedlings to various light conditions in the field. In Proceedings of International Workshop BIO-REFOR, Yogyakarta, pp 78–80

Page SE, Rieley JO, Shotyk OW, Weiss D (1999) Interdependence of peat and vegetation in a tropical peat swamp forests. Philos Trans Roy Soc Lond B 354:1885–1897

Shimamura T (2004) Plant species coexistence controlled by organic matter dynamics in the tropical peat swamp forest in Riau, East Sumatra, Indonesia. Ph.D. Thesis. Kyoto University, Kyoto

Stoneman R (1997) Ecological studies in the Badas peat swamps, Brunei Darussalam. In: Rieley JO, Page SE (eds) Biodiversity and sustainability of tropical peatlands. Samara Publishing, Cardigan, pp 221–230

Takahashi HH, Yoneta Y (1997) Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan Indonesia. In: Rieley JO, Page SE (eds) Biodiversity and sustainability of tropical Peatlands. Samara Publishing, Cardigan, pp 179–187

USDA (1990) Keys to soil taxonomy, p 422

Whitmore TC (1984) Tropical rain forests of the Far East, 2nd edn. Clarendon, Oxford, p 352

Yamada I (1984) Lowland swamp forests in Southeast Asia, 4. Peat swamp forests. Res SE Asia 22:214–233

Yonebayashi K, Okazaki M, Kaneko N, Funakawa S (1997) Tropical peatland soil ecosystems in Southeast Asia: their characterisation and sustainable utilization. In: Rieley JO, Page SE (eds) Biodiversity and sustainability of tropical peatlands. Samara Publishing, Cardigan, pp 103–111