Part 3
Agriculture and Environment

Proceedings of the International Symposium on
TROPICAL PEATLANDS
Bogor, Indonesia, 22-23 November 1999
Hokkaido University & Indonesian Institute of Sciences
pp. 101-107 (2000)

Biological Clean-up of Biomass Wastes Using Sawdust as an Artificial Soil Matrix

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Abstract

Biomass wastes such as garbage, human excrement, and cattle manure will decompose and separate into water and carbon dioxide in garbage automatic decompose-extinguisher (GADE), bio toilet (BT) and livestock manure fermented (LF) systems, respectively. All the systems contain sawdust an artificial soil matrix and the waste is converted to organic fertilizer rich in N, P, and K or soil conditioner. Establishment of a forestry, agriculture, and fishery biomass wastes recycling system (FAFBRCS) is discussed.

Key words: garbage, sawdust, artificial soil, compost, aerobic bacteria, biomass wastes

1. Introduction

Sustainable development in our society depends on three basic ideas:

1) The limited resources of field and forest, river and sea be used as efficiently as possible,
2) biomass wastes not be discarded but recaptured in the form of usable resources, and
3) these usable recaptured resources be returned to the production sites of biomass.

This paper introduces an approach to realize these ideas so as to lessen the environmental distress this century has brought to our society.

2. Utilization of Unutilized Resources

The primary unutilized resources of the forest industry are sawdust and bark. These are usually incinerated, and while there may be no great crime in using biomass as fuel; the preferred use for such biofiber is as matrix: an artificial soil matrix. This artificial soil matrix can convert food related wastes (garbage), human excrement, and livestock manure into a multipurpose resource.

The benefits of the use of the artificial soil matrix are derived from the characteristics of sawdust as a matrix:

1) high porosity, 2) high void volume ratio, 3) high water and air retention, 4) high drainage, 5) high bacterial tolerance, 6) low apparent density, and 7) biodegradability.

Characteristics 1)-4) create an ideal environment for aerobic bacteria to thrive, decompose, and separate garbage into carbon dioxide and water without generating odor. After several months the process produce a compost rich in N, P, and K.

High bacterial tolerance of woody material allows us to use the sawdust as an artificial soil matrix for a long period in the GADE, BT, and LMF machines and low apparent density of sawdust saves energy when mixing the matrix.

The key characteristic, however, is the essential biodegradability of the sawdust, which makes it the ideal ingredient for establishing a biomass waste recycling system.

2.1 Recovering Food Waste

The recovery of food waste is effected using a GADE (garbage automatic decomposer-extinguisher) system, that is, the high rate composting of food wastes using sawdust biofiber as an artificial soil matrix.

Two types of GADE machines are differentiated. The one is for room temperature conditions and the other is for thermophilic conditions.

2.1.1 Composting in room temperatures

This GADE machine is for family of four to five. The compost machine uses a rotor to turnover, distribute, and intervally constantly aerate the daily food waste load deposited among the sawdust. Food waste is reduced entirely to water and carbon dioxide by the action of soil bacteria in room temperature conditions, leaving fumins and minerals. After several months of operation, the sawdust has been converted into N, P, and K enriched compost.

2.1.2 Composting in high temperatures

This GADE machine is for institutional food waste management. A rotor churns a sawdust, rice bran, or oat bran matrix in a heated tub (80°C) with variable moisture content, allowing for bioconversion of the wastes by thermophilic bacteria for every day. The partially-cured compost can be used as feed (the bran-based product is ideal for chicken farming).

When sawdust is used in this GADE machine as a matrix, a user can operate the machinecontinuously for two to three months and the compost formed are utilized as partially-cured organic fertilizer.

In both machines, in order to provide a rich environment for the aerobic microbe activity and multiplication, it is best to use a sawdust in which moisture content and temperature can be easily controlled.

2.1.3 The significance of the introduction of the GADE system

The wide spread introduction of the GADE systems using a bacteria seeded organic matrix to decompose food waste, and the further development of a forest, agriculture and fishery biomass recycling system (FAFBRCS), through which the biomass can be returned to natural ecosystems, would be of great environmental significance, as outlined in the following five categories:

(i) ***The use of the GADE system would;***

1) decrease the stress of keeping smelly waste inside the kitchen,
2) relieve municipalities of the necessity of collecting food waste,
3) enable source-separated collection of other fractions of municipal solid waste,
4) decrease the air pollution associated with waste incineration, and the soil and ground water pollution associated with landfills,
5) lessen the need for new incinerators,
6) relieve citizen protest against the construction of incinerators, and
7) have an educational effect on the consciousness of environmental hygiene and resource recovery.

(ii) ***The effective use of sawdust would;***
1) add value to food and certain urban industrial waste,
2) contribute to the vitality of the forest industry through use of sawdust, bark, street tree trimmings, and forest thinning, and
3) promote managed forestry on land either removed from agricultural production through crop quotas or for environmental reasons, not forgetting urban forests.

(iii) ***The introduction of the GADE system would;***
1) promote the establishment of the requisite production, transport, and service sectors,
2) stimulate the refurbishing of kitchens, and
3) convert householders into, not just consumers but also producers, bring about a change in the recycling system.

(iv) ***Thermophilic composting would;***
1) enable the conversion of food waste into livestock feed,
2) decrease the odor from livestock manure, contribute to livestock health, and improve meat quality, and
3) create a means for the recovery of manure for the same livestock to use as a stable fertilizer.

(v) ***The use of GADE compost would;***
1) provide fertilizer municipal parks and roadside green spaces, and improve crop quality in rural regions,
2) be a source of organic fertilizer, work against the damage caused by burn-and-slash agriculture in tropical regions,
3) prevent soil depletion caused by the intensive farming of cassava, kenaf and fast-growing hybrid plantation trees, and
4) create new business chance such as mushroom farming using the N. P, and K enriched sawdust as cultivation bed and molding factory making seedling-pots for agriculture and forestry use.

In summary, municipal food waste, certain industrial waste, and forest and agricultural waste may all be streamed together via the FAFBRCS system to produce a new and environmentally-friendly resource.

2.2 Recovery of Human Waste
Human waste can also be regarded as resources the same as agricultural waste. The spread of the flush toilet has reached the point where sewage treatment of this waste water has become prohibitively expensive. A re-evaluation of the costs and benefits of the various biosolids treatment systems is in order, and the biotoilet should be included in such a consideration.

2.2.1 The wastefulness of the flush toilets
The benefits of the flush toilet are low odor and quick and hygienic removal of waste. However, problems of flush toilets are:

1) the cost of toilet stools and cisterns, 2) the cost of water supply and sewage

piping, 3) the cost of sewage treatment plants construction, 4) the cost of sawege treatment, 5) odors emanating from the toilets and sewage treatment facilities, 6) massive use of clean water, 7) the necessity for disposal of sewage sludge, and 8) possible pollution of water by discharge of water containing water soluble organic and inorganic materials.

2.2.2 The revolution of the forest products toilet

In the biotoilet (BT), the tile septic tank and its attendant plop, are replaced by a composting chamber filled with sawdust. After use of the toilet, the pushing of a button activates a turning screw, and the sawdust is immediately and slowly turned over. The biosolids are incorporated without sound or odor into the artificial soil matrix of by sawdust.

Unlike the copious amount of water used in the flush toilet, any excrement in the biotoilet is cleaned off, when necessary, with a small amount of water through a water jet. After half a year of use, the product becomes a loose, handlable, easily-used compost.

(i) ***Experience of a culture shock***

After the first use of the biotoilet, you are instantly ashamed of all of the water you have wasted so far in using the flush toilets. It is a kind of a culture shock.

The need of the water barrier in the current flush toilet to prevent the rising of sewer gas leads to the situation where the toilet must be frequently flushed if you wish to avoid living with the smell of your own waste.

In contrast, the biotoilet seat is just as simple a hole found with the septic tank toilet. But owing to the action of an exhaust cylinder fitted into the composting chamber, warm air from the composting material is circulated outside, and no odor rises into the toilet room. Of course, no odor has been generated during the operation of the biotoilet.

In addition, food wastes can be disposed of in a BT, obviating the necessity for a separate GADE machine such as “MAM” or “BIOSELF” for food wastes in the kitchen.

(ii) ***Characteristics of biotoilets***

Characteristics of biotoilet are superior to those of flush toilet for the following reasons:

1) odor free, 2) no flush water use, 3) relatively cheap, 4) conversion of human wastes into valuable recyclates, 5) less the burden on conventional sewage treatment plants, 6) capable of treating any organic solid wastes including food related waste (garbage) and toilet papers, 7) environmentally-friendly, and 8) effective in emergencies.

(iii) ***Types of biotoilets***

Types of biotoilets are classified into two categories. The first ones are biotoilets for human beings and the second ones are biotoilets for animals.

A) Biotoilets for humans: 1) Domestic fixed biotoilets: for household use, 2) Public fixed biotoilets: in schools, hospitals, stations, airports, parks, etc., 3) Public tranferable biotoilets: for emergencies, big events, recreation areas, hiking courses or lodges in the mountains, in parks, etc. For handicapped people using wheelchairs. 4) Chair style portable biotoilets: can be set up inside a bed room for people who need help getting to and from the toilet room in hospital or at home.

B) Biotoilets for animals: 1) Pet biotoilets: for cats and dogs. 2) Large scale biotoilets: for livestock manure (See section 2.3).

(iv) *Biotoilets for the 21st century*

The biotoilet is suitable for rural towns considering the implementation of flush toilets, cottage and resort areas (removal of biosolid compost bears no resemblance to the stink of the conventional vacuuming of septic tanks), and any area that has forest resources close at hand. In particular, suburban developments recently converted from farmland are best served by the biotoilet. As the trend of returning to rural areas accelerates, rural residents will no longer be ashamed of not having a flush toilet; rather, they will be proud to be able to have a biotoilet.

With changing times comes changing attitudes. The eco-biotoilet is representative of the in-region recycling, environmental protection, efficient energy use, and low pollution life style we all wish to see in the 21st century.

(v) *Starting point for changing our life style*

Although flush toilet system is a symbol of the civilization of our modern life, the system has several problems for achieving sustainable development of our society. We need to pay attention to the wastefulness of the system and to seek for new ways.

1) Even human wastes should be regarded as precious resources, which must not be disposed after dilution. 2) Instead of wasteful flush toilets, environmentally-friendly biotoilets should be accepted in to our daily lives. 3) The basic principle of the biotoilet is the same as that of the GADE system; they depend on the physical and chemical properties of woody material, sawdust, which acts as an artificial soil matrix in both the systems. 4) Rate of decomposition of human waste is faster than that of garbage because of the large number of bacteria derived from human wastes. 5) Promote the biotoilet as the most advanced toilet in the sense of modernization. 6) Local governments should stock biotoilets to use when there is a natural disaster such as Hanshin-Awaji earthquake. 7) In national parks, mountain sites, and sight seeing resorts, biotoilets seem to be the most appropriate because they harmonize with nature. 8) Acceptance of biotoilets may be the starting point for changing our life style in the 21st century and achieving sustainable development for our society. 9) Solar and wind energy should be used in future as the power for the operation of biotoilets set outdoor.

2.3 Processing of Livestock Manure

The processing of livestock manure has become a crisis topic worldwide. But a livestock biotoilet would have to be radically different in design from the one serving the household.

For example, a cow produces forty times more waste than a human. A hundred-head dairy herd would therefore produce the equivalent of 4,000 people, or 1,000 households, or 1,000 biotoilets.

2.3.1 Heating, vacuum evaporation, fermentation and drying apparatus

The first trick is dewatering the slurry; a mixture of manure and water. A process has been developed that combines vacuum dehydration, heated fermentation, and drying of the fermented materials. The development of this single-vessel machine was designed for the management of brewery dregs, sugar beet pulp, *tofu* sludge, and fisheries waste (CK, C-Luck Co. Ltd.). It came about as an extension of the initial successful development of technology for the treatment of such slurry state food waste after congealing with coagulants.

The machine is also ideal for the treatment of the slurry of livestock manure. Though a little expensive, considering the environmental impact of the conventional management of livestock manure, it is well worth the investment.

2.3.2 Livestock manure fermenter

Sawdust functions as an artificial soil matrix in the GADE and BT systems because of its special characteristics as described in section 2. When sawdust is used in a cattle shed as litter, it should be used in the same way as used in the GADE and BT systems until it loses its special characteristics through deterioration.

A larger amount of sawdust is used as litter in a cattle shed than usual, and after the moisture content of the sawdust matrix become 70-80%, the sawdust is removed automatically and moved by a conveyor belt to a livestock manure fermenter (LMF). During the biodegradation process of the manure in the LMF, temperature of the sawdust matrix increases more than 60°C and kills ordinary bacteria including *Escerichia coli.*

After the manure degrades in the sawdust matrix in the LMF, the sawdust, which is now bacteria free, is reused again in the cattle shed as litter. The process is repeated until the characteristics of the sawdust have changed and it can no longer function as an artificial soil matrix.

3. Conclusions

(1) Instead of separately managing perish-able food waste, non-perishable sawdust, and biomass wastes from forest and field, sawdust should be used as an artificial soil like matrix to convert food waste and other low-structure biomass into a valuable fertilizer or soil conditioner resource.

(2) The conventional “mixed/centralized/large scale” management of municipal waste is critically flawed. A switch to “source separated/decentralized/low volume” management of foodwaste would enable recovery and recycling of garbage without odor generation.

(3) The introduction of GADE processing would be a critical element in the further implementation of the FAFBRCS, biomass recovery system, with all of the accompanying benefits.

(4) The end of the era of the flush toilet is near. The resource recovery eco-biotoilet era is about to come. This toilet is particularly well suited to areas nearby forests and farmland.

(5) The sheer volume of livestock manure is beyond the capacity of GADE machines, even when using coagulants. Instead, a novel vacuum dehydration/heated composting/drying in-vessel system can be used for this tremendous biomass management problem.

(6) LMF system seems to be more reasonable from a cost performance in view point of than conventional solid/liquid separation treatment.

4. Papers Related

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Proceedings of the International Symposium on
TROPICAL PEATLANDS
Bogor, Indonesia, 22-23 November 1999
Hokkaido University & Indonesian Institute of Sciences
pp. 109-117 (2000)

Whole Aspect on Nature and Management of Peat Swamp Forest in Thailand

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Abstract

The total area of peat swamp in Thailand currently comprises about 64,555 ha, of which 48% (30,969 ha) is found in Narathiwat province along the east coast of Thai peninsula near the Malaysian border. The secondary forest covers mostly the remaining peat swamp area (86%) in Thailand. The extensive primary peat swamp forest remaine almost all in Toe-Deang peat swamp forest in Narathiwat province (8,403 ha), and only 629 ha is scattered into three other areas. (Chukwamdee *et.al.*, 1999).

Since the primary peat swamp forest in Thailand remainle too small, it is absolutely vital that this valuable nature resource should be conserved carefully and appropriately because peat swamp forest reserve huge amount carbon and water, and conserve biological diversity including very rare species existed in only peat swamp. Such conservation should be managed by reliable information from more basic science such as peat swamp forest ecosystem, silviculture technique of rehabilitation, and more applied technique such as local knowledge and field experiment including forest fire control and wise utilization of peat resource. Therefore, in current paper, whole aspect on nature and management of peat swamp forest in Thailand is described owing to the research result and conservation experience during past almost 10 years.

Keyword: peat swamp forest, reforestation, rehabilitation, forest fire, biological diversity

Introduction

Thai people call peat swamp forest as Pa Phru. However, it's just become well-known since about ten years ago because of very small area in Thailand that is about 0.13% of the country or about 0.48 % of the whole forest. Because recognized the peat swamp forest give a lot of benefits of nature resource to the people who inhabit the surrounding area, and have most important role on environment conservation such as carbon and water storage which are more conspicuous than the other kind of forests. By these reasons, Thai people and government are now getting interests in the peat swamp forest.

Distribution of Peat Swamp in Thailand

Almost all of peat swamp forest in Thailand are distribution in the southern part (63,982 ha) and southeast coast (537 ha) where are found in Narathiwat, Nakhonsi Thammarat, Chumphon, Surat Thanee, Songkla, Pattani, Yala, Trang, Phuttalung, Phuket, Krabi, Trat and Rayong provinces (Table 1). Most of peat swamp area (86%) is the 8,403 ha and 629 ha secondary forest. The primary peat swamp forest area are about 9,032 ha (14%) of which located in Toe-Deang peat swamp forest, Narathiwat province and in other peat swamp forest such as Bacho peat swamp forest (575 ha), Narathiwat Ban Dan peat swamp forest (5 ha), Trang and Kuntulee peat swamp forest, Surat thanee (48 ha), respectively. (Chukwamdee *et al.* 1999) The age of peat in Toe-Deang peat swamp at 1-2 m deep level is about 700-1,000 years old. (Sinskul, 1998)

Table 1. Distribution of peat swamp forest in Thailand

Region	Province	Secondary forest (ha)	Primary forest (ha)	Total (ha)	Remark
Southern part					
	Narathiwat	21,992	8,978	30,970	Toedaeng 8,403 ha
	Nakhonsi Thammarat	18,946	-	18,946	Bachoe 575 ha
	Chumphon	3,285	-	3,285	
	Surat Thanee	1,542	48	1,590	
	Songkla	4,829	-	4,829	
	Pattani	1,205	-	1,205	
	Yala	190	-	190	
	Trang	86	6	92	
	Phuttalung	2,768	-	2,768	
	Phuket	63	-	63	
	Krabi	47	-	47	
	Total	54,951	9,032	63,982	
South east coast					
	Trat	453	-	453	
	Rayong	120	-	120	
	Total	573	-	573	
Grand Total		55,523	9,032	64,555	

Source : Jirasak *et al.* 1999

Flora in Peat Swamp Forest

The floristic composition of peat swamp forest is extremely complicated, consisting of 124 families and 470 species of which 109 families and 437 species of flowering plants, and 15 families and 33 species of ferns (Phengkai *et al*., 1991). Tree species growing in peat swamp have adapted themselves to survive in waterlogged ecosystem, for which they make short taproots and wide spread roots, including lateral roots, pneumatophores and many split roots. Dominance tree species in primary peat swamp forest are *Syzygium pyrifolium, Ganua motleyana, Campnosperma coriaceum, Macaranga pruinosa, Calophyllum teysmannii, Neesia malayana, Endiandra macrophylla, Syzygium obatum, Sterculia bicolor, Stermonurus secumdiflorus, Syzygium muelleri,* and *Baccaurea bracteata* (Bunyavajchwin, 1995; Hara *et al*., 1995). Dominance tree species in secondary peat swamp forest are *Melaleuca cajuputi* and *Macaranga pruinosa*.

Fauna in Peat Swamp Forest

Wild fauna of amphibians, reptiles, birds and mammal listed in peat swamp forest are 17 species, 50 species, 196 species, and 62 species, respectively. Following wild fauna in Thailand were firstly discovered in peat swamp forest; Dayak fruit bat *(Dayacopterus spadiceus)*, red-cheeked flying squirrel *(Hylopetes lepidus)*, singapore rat *(Rattus annandalei)*, rufous tailed shama *(Copsychus pyrropygus)*, Malaysia blue fly-catcher *(Cyornis turcosa)*, rough-sided frog *(Rana glandulosa),* and Malayan brown snake *(Xenelaphis hexagonatus)*. Other rare and endangered fluna are flat-headed cat (*Felis planiceps*), otter civet *(Cynogale bennetti),* and grey-headed fish-eagle *(Ichthyophaga ichthyaetus)*. These 3 species have been found only in the peat swamp forest (Pitayakajorwate *et al*., 1997).

Macrofungi in Peat Swamp

The macrofungi of at least 67 species are found in peat swamp, which are classified into 1 Myxomycota, 6 Ascomycota, and 60 Basidiomycota. The commonnest genera are *Ganoderma, Phellinus, Microporus, Termitomyces, Lentinus, Marasmius, Marasmiellis,* and *Pycnoporus* (Chalermpongse *et al*., 1998).

Soil in Peat Swamp Forest

Most of peat soils are consisted of the woody materials that contain high of amount lignin. The peat layer in Thailand is typically 0-3.8 m thick, although that is more than 20 m in Poland (Paprocka and Podstolski, 1996). The peat soil have characteristics of very low bulk density, high organic carbon content, extremely wide C/N ratio, extremely acidic, and high CEC, but very low in exchangeable cations, zinc and copper (Pisoot, 1999). The soil in peat swamp is not suitable for agriculture (G.M.T. Coorperation, 1994).

Water Condition in Peat Swamp Forest.

In peat swamp forest, pH of the water is different among soil types that the water run through. Normally, the pH value of water inside primary peat swamp forest is almost the same as that outside primary peat swamp forest. However, pH decrease is observed after water pass through the area without peat covered, because sub soil under peat in Thailand is consisted of (potential) acid sulfate soil. Generally, the dept of water in peat swamp area is about 10-40 cm above ground, and fluctuate seasonally owing to periodical dry and wet seasons. During long dry period, as water level decrease down to 2 cm under ground level, fire damage become very severe in peat swamp during dry season.

Causes of the Damage of Peat Swamp in Thailand

Once peat swamp dry up by the over drainage of water from inside peat swamp areas, forest fire break out frequently (Suzuki and Hara, 1995). In some areas, peat layers are all destroyed by the repeated burning, resulting in devastated lands that are not suitable for growing field crops. Utilization of peat swamp forest for agricultural purposes can be found in some areas, but not much when compared to other types of forest. Moreover, deforestation and intruding of human community causes also the loss of peat swamp.

Plant Succession of Peat Swamp Forest after Destruction by Forest Fire

After the land was burned for 3-5 months, 3 types of peat land were identified as; 1) *Melaleuca cajuputi* regrowth area, 2) *Macaranga* spp. regrowth area, and 3) no tree regrowth area. After burning, *Melaleuca cajuputi* become the major pioneer species because this species only have a benefit to seed dispersion system by fire fruits of this species open by high temperature occurred during fire, and the seeds are dispersed to the ground (Tange *et al*., 1995). However, in some area *Macaranga* spp. become dominants species. Since *Macaranga* spp. are rarely found in these area before fire damage, seeds disperse system of *Macaranga* spp. after fire should be studied in future. No tree regrowth area may be understood by as seed dispersion of pioneer species. When the peat land is burned again, it is easily covered with *Melaleuca cajuputi* because of benefit ability of seeds dispersion. Thus as *Melaleuca cajuputi* a become pure stand in most of the deforested peat swamp area, and can be found everywhere in, the people have been misunderstanding that peat swamp forest is as *Melalueca* forest

Thus, if the succession of deforested (mainly fire damaged) peat swamp area occurs naturally, as *Melalueca cajuputi* will covered all most of the areas, reforestation is required for recovery of original peat swamp forest. In another outstanding evidence in peat swamp forest damaged by fire, native palms spp. have very strong tolerance to fire, and easily recover the growth. Therefore, native palms spp., especially sago palm are useful as barrier for fire protection.

Reforestation in disturbed peat swamp area

Royal Forest Department (RFD), Ministry of Agriculture, and Cooperative are the organizations that are taking care of reforestation in Thailand. During 102 years since RFD was established, 640 ha of peat swamp areas have been reforested. This amount of areas is quite small compared to other types of forest, because of lacking of scientific data, lacking of seedling management techniques, including, and costing for investment in this type of forest compared to other types of forest. However, techniques on reforestation in peat swamp areas have been developed during the past about 10 years are as follows.

1. The promising species for rehabilitation

The experimental results on rehabilitating trials for peat swamp species at Royal Pikulthong Project, Narathiwat were as follows. 1) Of 15 species at age 3 years in the 1988 plot, growth of *Acacia mangium* was the best, but all these trees died at 5.5 years (Table 2). 2) Of 13 species at age 5.5 years, *Ganua motleyana* showed the highest survival rate (90 %), *Melaleuca cajuputi* showed the fastest growth by the indicators of

Table 2. Survival percentage and growth characteristics of each plant species in 1988 at Toe-Daeng peat swamp

No	Species	Growth characteristic																	
		Survival (%)		Stem diameter (cm) at 10 cm above ground			Tree height (m)			Stem biomass*		Branch biomass*		Leaf biomass*		Stem volume*	
		5.5 yr.	9 yr.	3 yr.	5.5 yr.	9 yr.	3 yr.	5.5 yr.	9 yr.	kg/ tree	t/ha	kg/ tree	t/ha	kg/ tree	t/ha	$1000m^3$/ tree	m^3/ ha
1	*Macaranga*	48	48	3.0	5.5	8.4	1.7	2.4	3.9	1.7	2.91	0.92	1.71	0.48	0.81	4.20	6.94
2	*Syzygium py.*	82	82	2.2	4.0	9.3	1.4	2.2	4.6	1.0	2.07	1.47	3.23	0.65	1.42	1.59	3.47
3	*Ganua*	90	88	1.8	4.0	7.2	1.2	2.0	3.4	0.3	0.59	0.06	0.13	0.05	0.11	0.78	1.76
4	*Sterculia*	85	84	2.6	6.3	9.6	1.6	2.6	3.7	0.6	1.16	0.08	0.17	0.04	0.08	1.84	3.93
5	*Stemonurus*	72	72	2.3	4.0	6.9	1.2	1.6	2.8	0.3	0.49	0.68	1.22	0.08	0.15	0.73	1.34
6	*Dialium*	76	76	2.1	3.4	5.3	1.4	2.5	3.8	0.9	1.82	0.16	0.31	0.15	0.3	1.30	2.54
7	*Fagraea*	61	47	3.3	5.4	6.4	2.0	3.5	3.7	1.2	1.89	1.23	1.93	0.21	0.33	2.42	3.81
8	*Melaleuca*	88	83	6.0	12.5	15.8	2.5	6.4	8.7	5.9	12.87	2.25	4.90	1.22	2.65	17.36	37.9
9	*Syzygium ob.*	83	81	3.7	7.8	9.1	2.2	4.6	5.8	4.2	8.72	4.80	9.86	1.52	3.14	7.17	14.8
10	*Polyalthia*	23	22	1.2	2.2	3.8	0.6	1.0	1.6	0.1	0.03	0.01	0.01	0.01	0.01	0.15	0.08
11	*Baccaurea*	87	87	3.7	7.0	8.1	1.5	3.1	1.6	1.7	3.66	1.08	2.33	0.26	0.57	3.11	6.68
12	*Horsfieldia*	80	79	2.4	5.4	8.7	1.4	1.8	3.5	0.5	0.96	0.07	0.13	0.09	0.19	1.12	2.23
13	*Vatica*	49	49	1.8	4.0	6.2	1.5	2.4	3.3	0.7	1.00	0.27	0.38	0.13	0.18	1.50	2.12

* estimated at 5.5 years after planting

average diameter 10 cm above ground (12.5 cm), tree height (6.4 m), and stem yield (12.9 ton/ha) (Table 2). *Syzygium oblatum* showed the highest yield in same of stem, branch and leaf (21.7 ton/ha). 3) Of 15 species at age 4 years in 1993 plot, *Alstonia spathulata* had the highest growth (13.1 cm), *Calophyllum teysmannii* had highest height (3.4 m), and *Ixora grandifolia* and *Alstonia spathulata* had the similar highest survival rate (97 %) (Table 3).

Table 3. Survival percentage and growth characteristics of each species planted in 1993 at Toe-Deang Peat Swamp

No.	Species	at 1 year old			at 2 years old			at 3 years old			at 4 years old		
		Survival (%)	Growth*		Survival (%)	Growth*		Survival (%)	Growth*		Survival (%)	Growth*	
			D10 (cm)	Ht (m)		D10 (cm)	Ht (m)		D10 (cm)	Ht (m)		D10 (cm)	Ht (m)
1	*Cinnamomum*	82	1.8	0.9	79	3.1	1.3	78	4.2	1.5	78	5.6	1.8
2	*Alstonia*	97	4.0	1.2	97	6.7	1.7	97	10.6	2.0	97	13.1	2.5
3	*Ixora*	96	1.5	0.8	97	2.6	1.4	97	3.2	1.9	97	4.2	2.0
4	*Polyalthia*	90	1.1	0.6	69	1.5	0.8	79	1.8	1.0	76	2.4	1.1
5	*Mangifera*	90	1.1	0.5	81	1.7	0.8	81	2.3	1.0	81	3.0	1.1
6	*Calophyllum*	95	1.4	0.9	94	2.5	1.7	94	3.6	2.6	94	4.9	3.4
7	*Neesia*	75	1.4	0.4	69	2.4	0.9	67	3.1	1.3	67	4.1	1.4
8	*Persea*	63	0.7	0.5	47	1.4	0.8	29	1.5	1.0	28	2.0	1.2
9	*Dacryodes*	35	0.7	0.4	29	1.3	0.7	22	1.9	0.9	22	3.0	1.5
10	*Sandoricum*	81	1.4	0.9	79	2.4	1.4	78	3.4	1.9	78	4.3	2.5
11	*Litsea*	79	1.3	0.8	72	2.3	1.2	69	2.9	1.6	71	3.9	1.9
12	*Campnosperma*	90	2.1	0.3	88	3.9	0.9	88	5.9	1.3	88	7.5	1.7
13	*Garcinia*	63	0.9	0.6	61	1.1	0.9	58	1.5	1.2	53	1.9	1.3
14	*Aglaia*	79	0.9	0.4	56	1.3	0.6	32	1.7	0.9	26	2.5	1.2
15	*Olea*	89	1.4	0.5	81	1.5	0.9	75	2.1	1.2	75	3.0	1.6

*D10 indicates stem diameter at 10 cm above ground, and Ht indicates tree height

The growth rate of individual species was not constant (Fig. 1). For example, growth rate (estimated by tree height) of *Calophyllum teysmannii* increased after one year, that of *Cinnamomum rhynchophyllum* decreased after one year, and that of *Dagryodes incurvata* increased suddenly after 3 years.

2. Techniques for planting

The mound effect on tree growth was examined among 5 species, because most of trees are growing well in natural mounded condition in peat swamp. Five species were planted in mounded plot (50 cm height from ground, 70-90 cm round) and unmounded (ordinal ground level) plot. After 3 years, all species grew better in mounded plot than in unmounded plot because of presumably appropriate oxygen supply and less weeds growth at first years (Fig 2). As tree growth estimated by tree height was improved almost two times in mounded plot of *Syzygium* species compared to unmounded plot, these species require the mound construction for rehabilitation. However, as the cost for mound construction is expensive, further study on the costs and benefits of mound construction is required for large area of rehabilitation.

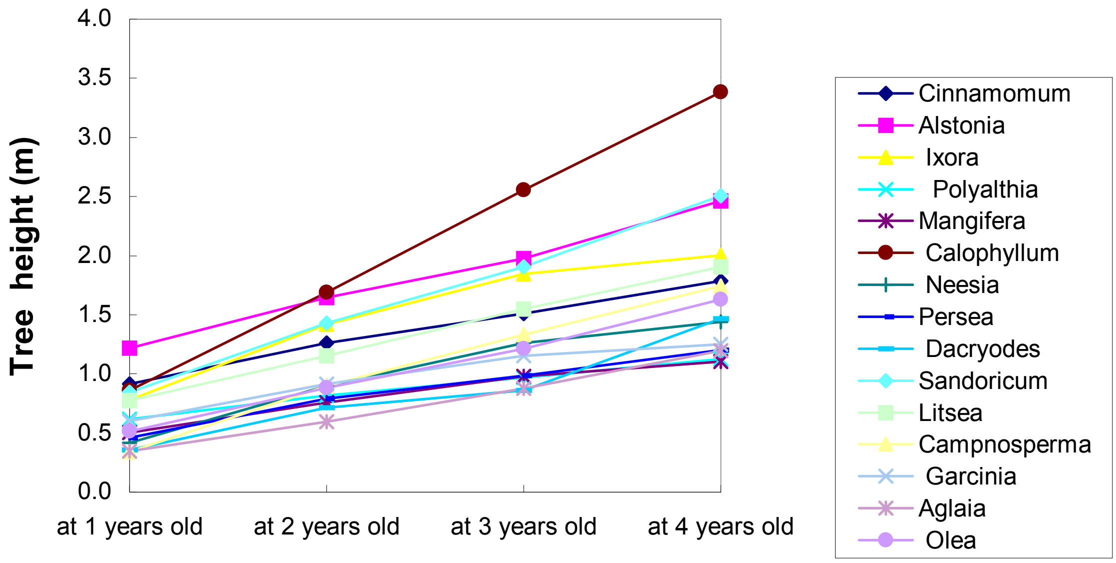

Fig. 1. Changes of average tree height (m) of each species planted in 1993 at To-Deng peat swamp

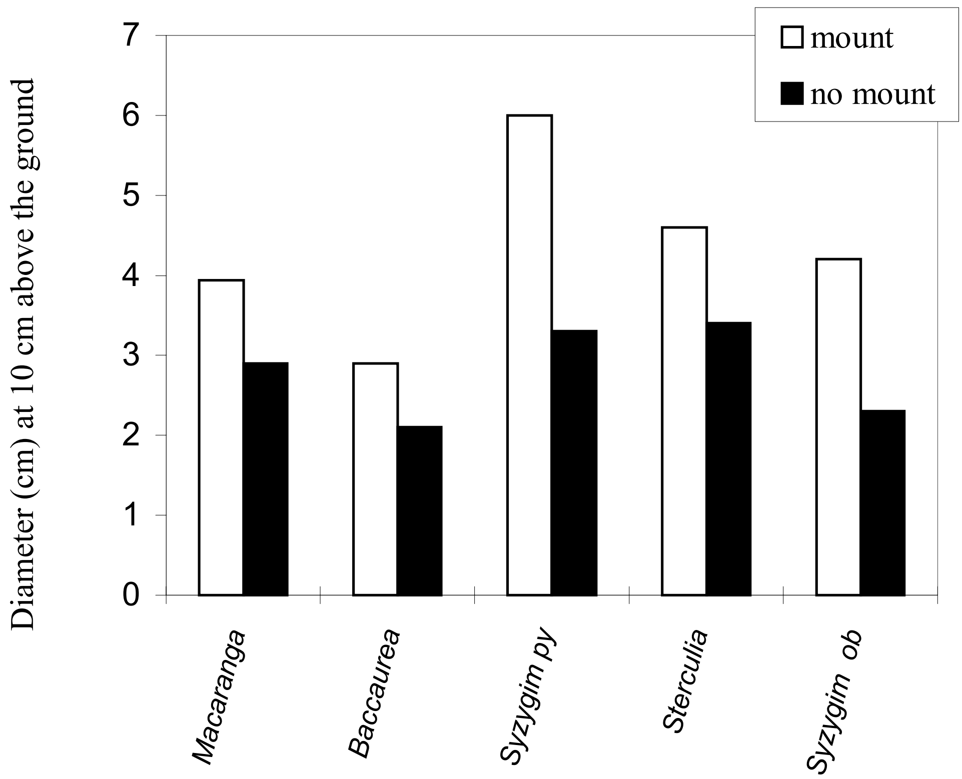

Fig. 2. Effect of mound construction on diameter at 10 cm above ground (cm) of 5 species at 3 years old

Soil improvement by effect on diameter and tree height of 5 trees species applying organic fertilizer, chemical fertilizer and liming showed no significant effect on diameter and tree height of 5 trees species.

By weeding, the growth and biomass of *Macaranga pruinosa* was improved through the increase of stem diameter, stem biomass and branch biomass, but survival percentage, tree height, and width of crown were not effected by weeding. Monthly weeding caused to higher productivity that diameter, stem biomass and branch biomass, were improved around 2, 4 and 6 times greater in weeding than in non weeding (Nuyim, 1997).

Wise choice of tree species is crucial for success in reforestation (Chareon *et al.,* 1979). Optimum species should be matched to the site and the objectives of planting. Consequently the most promising species so far tested for rehabilitation of degraded peatland are *Syzygium oblatum, Syzygium pyrifolium, Sterculia bicolor, Calophyllum teysmannii, Alstonia spathalata,* and *Sandoricum beccarianum. Melaleuca cajuputi* is also a promising species for woodlot in community forest. The mound construction in planting helps the seedling growth for especially *Syzygium* species.

Management of Peat Swamp Forest

1. Forest fire and its control

It was said whether the peat swamp forest in Thailand or peat swamp in the world would be left for the next generation to see or to study. To conserve the peat swamp forest, forest fire is the major factor. Once forest fire occur in dried peat swamp area, adjacent areas are burned down in a spreading fire. In this condition, it is difficult to extinguish completely by even human power or use of any kind of machines. Making a deep ditch using big tractor to reach the level of underground water is one way to protect the fire broaden to neighboring area, and also water pump namely ”Look Ped” is suitable to stop the beginning of fire. However, incredible amount of water is required to fill up the burned peat layer to extinguish the fire completely. In 1998,Toe Deang peat swamp forest was burned continuously from May to June because of a severe drought in this year. By this fire, about 2,374 ha of forest was destroyed. This was the biggest fire damage of peat swamp forestry in Thailand ever happened. Finally, artificial rain fall from helicopter completely ceased fire of which project was supported by His Majesty King Phumipol.

2. Making of forest zone

Peat swamp area should be divided into some zone according to vegetation, and geographic topography, and natural resource utilization. For instance, peat swamp forest at Narathiwat province are consisted of 3 zones, 1) **preservation zone** which is restricted against people use, and is used for scientific studies only, 2) **conservation zone** which is allowed for necessary utilization and is rahabilitated as much as possible, and 3) **development zone** which can be used for sustainable agriculture and agroforestry.

3. Declaration as National Park or Wildlife Sanctuary

Based on very strict law of National Forest and Wildlife Sanctuary, under supporting and managing by the full-time officer or worker, the conservation or protection of pear swamp forest is bound in duty.

4. Effective utilization of natural resources

Peat swamp forest is rich in natural resources such as starch from sago palm, fruit of *Eloiodoxa* spp.*, Lygodium* spp., honey, and timber use of *Melaleuca* tree, 50 cm. Utilization and management of this kind of forest should be considered by the principle of Maximum Sustainable Yield with minimum environmental disturbance.The reforest area in peat land should be managed by planting some cultivation crops such as oil palm, rice, pineapple, and so on, otherwise reforest area will be extinct by frequent fire.

5. Research activity, nature study, public announcement and tourism

Several researches in peat swamp forest are still required because of very few academic back ground in past. To realize and appreciate an importance of peat swamp forest on what it has many functions in nature, public services are also very important, which for example are the construction of footpath into the forest, making the media such as panels pamphlets to distribute the knowledge on peat swamp forest, or information to tourists. Princess Sirindhorn Peat Swamp Forest Research and Nature Study Center under the Royal Pikunthong Development Project is the only one center for doing these kinds to activity in Thailand.

Acknowledgement

Special thanks go to Mr. Smit Bunsermsuk from RFD for improving the English and commenting on the text of this paper.

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Proceedings of the International Symposium on
TROPICAL PEATLANDS
Bogor, Indonesia, 22-23 November 1999
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pp. 119-134 (2000)

Management Practices for Sustainable Cultivation of Crop Plants on Tropical Peatland

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Abstract

Most of the tropical peatland is found in Southeast Asia where it occupies some 20 million hectares, mainly concentrated around the Sunda Flat of Malaysia and Indonesia. It is part of the important rain forest ecosystem which is very sensitive and very fragile. Due to vast human development, some of these areas had been inevitably converted to agriculture, industrial and settlement sites. Utilisation of peatland for agriculture pose a lot of problems. Progressive drainage is a prerequisite for peatland development for agriculture. However, upon drainage the peat shrink and subsides and thus to sustain its usage in the long run will be difficult to accomplish. Therefore in order to sustain its utilisation for agricuture, a proper management practices need to be adopted and practiced. This paper highlights some of the important management practices for crop cultivation on tropical peatland with special reference to the Malaysian experience.

Introduction

Peatland, peat or muck is a common term referring to organic soils that has been defined as Histosol according to Soil Taxonomy (Soil Survey Staff, 1975). In the tropics, tropical peatland formed part of the important rain forest ecosystem. About 80% of the tropical peatland are found in the coastal lowlands of Southeast Asian region (Driesen, 1978) where it occupies some 21 million hectares, mainly concentrated around the Sunda Flat of Malaysia and Indonesia (Dent, 1986). This peatland in its natural state is swampy and is one of the most fragile and sensitive ecosystems that support various unique flora and fauna of the tropics. Malaysia has approximately 2.7 million hectares of peatland of which 1 million hectares are distributed in Peninsular Malaysia and another 1.7 million hectares in East Malaysia. Due to vast human development and shortage of customary agriculture land, utilization of marginal soils, particularly the peatland, is on the increase, especially for agriculture, horticultural uses and human settlement.

The proper and efficient utilisation of these lands for agriculture would contribute significantly towards a long-term economic growth of the country. On the other hand, if its utilisation is not well managed, its economic usefulness would be short lived and the country may loose one of its most valuable resources. This is because the tropical peatland is a marginal and fragile soil and it is a non-renewable resource. Progressive drainage is a prerequisite for peatland development for agriculture. However, upon drainage the peat shrinks and subsides and thus to sustain its usage in the long run will be difficult to accomplish. Therefore in order to sustain its utilisation for agriculture, a proper management practices need to be adopted and advocated. This paper highlights some of the important management practices for sustainable crop cultivation on tropical peatland with special reference to the Malaysian experience.

The understanding of the specific properties and behaviour of the peat is very important to prevent excessive and rapid exhaustion of the peat natural fertility. The peatland environmental importance, role and functions need to be well recognised when reclaiming for any agricultural development.

Peatland Characteristics

Among the important inherent characteristics of the Malaysian peatland are the presence of a dense mass of woody materials, usually water-logged in its natural state, shrinkage and subsidence upon drainage, irreversible drying if excessively drained, extreme acidity and low fertility status. Agricultural development on this peatland is mainly restricted by those problems associated with the inherent characteristics.

Physical properties

The Malaysian peat is generally reddish brown to very dark brown in colour depending on the stage of decomposition. It was estimated that the Malaysian peat is made up of more than 50 % of semi-decomposed stumps and logs (Coulter, 1950). Recent studies by Yonebayashi *et al.* (1992) further confirmed this estimate.

It has a high moisture content and water holding capacity of 15-30 times of their dry weight (Tay, 1969). The high water content results in high buoyancy and high pore volume leading to low bulk density and low bearing capacity. Its average bulk density values ranges from 0.05 to 0.40 g/cm^3 (Driessen and Rochimah 1976; Ismail, 1984) and the particle density ranges from 1.4 to 1.8 g/cm^3 depending on the mineral constituents of the peat. Thus, the total porosity ranges from 75 to 95% on volume basis. Coupled with variable depths of the peat materials, they restrict the use of machinery and impose limitation to the types of crops that can be grown. Top-heavy tree crops, such as oil palm, rubber and coconut trees tend to lean and fall over as a result of poor root anchorage on deep peat areas. Even the hole-in-hole planting of the oilpalm is not entirely satisfactory as the problem of lodging and root exposure and damage is still prevalent (Singh *et al.*, 1986).

The ash content is usually less than 10% (Wong, 1991; Melling, 1997) showing a very high content of organic matter. This is indicated by a loss of ignition value exceeding 90% (Melling, 1997). Excessive drainage of the peat will cause a transformation of its colloids resulting in it having the properties of irreversible drying. Subsequently, the peat soils may loose their available water after four to five weeks of continuous drying. Thus, it is very susceptible to burning. On intensively cultivated areas, water availability in the top soil is critically low. Studies by Salmah (1992) suggest that the wilting point (15 bar) of a typical peat soil is almost equivalent to 5 bar suction. As such, shallow rooted crops need to be regularly irrigated in the dry season.

The common soil profile morphology of Malaysian peat consists of three distinct layers differentiated by its level of humification. They are the sapric, hemic and fibric as it goes down the soil profile. The thickness of these three layers varies depending on the water table and cultivation practices (Melling *et al.*, 1998). Some augerings had shown that the sapric material could extend down to a depth of 110–120 cm (Tie, 1988; Melling *et al.*, 1998). In the virgin peat dome, sapric materials may be absent, and the hemic layer can be less than 20 cm. The sapric-hemic-fibric sequence can also be reversed as the mineral substratum is approached. The occurrence of vacant layers within the top 50cm of a virgin peat profile is quite high. Thus the rate of subsidence will varies depending on the sequence and thickness of the three layers of the peat profile.

The peat soils are very dynamic. This is because the peat will undergo subsidence and oxidation upon drainage. Initially, it involves principally the loss of buoyancy and compaction of the organic column under its own weight. The compaction results in the changes in the hydropedological parameters like the hydraulic conductivity, bulk density, pore volume and moisture content. The subsequent dominant process that may last for decades is the oxidation and shrinkage. The rate of subsidence varies strongly depending on the peat profile morphology, peat composition, peat depth, depth of drainage and land use. Due to the differential rate of subsidence upon drainage, the microrelief of the peat surfaces becomes hummocky. A subsidence of 60 cm has been recorded for a drained deep peat (water table level of 75–100cm below the surface) in the first two years after reclamation followed by a rate of 6 cm per annum (Tie and Kueh, 1979). On this basis, a subsidence of approximately 200cm can be expected for the first 25 years after reclamation.

The peatland in their natural state plays an important role in the hydrological cycle whereby it acts like an aquifer by absorbing and storing water during the wet seasons and slowly releases it to the surrounding environment through streams and rivers or underground seepage during drier periods. The dense and close canopy of the forest further enhance the humidity of the atmosphere, cools the surrounding air and ultimately stabilizes the climate of the region. Thus virgin peatland is an important catchment area (Boelter, 1966).

The peat are generally classified as the ombrogenous peat (rainfed) and therefore poor in nutrients (oligotrophic). They are generally dome-shaped. The surface convexity becomes more pronounced with distance from the sea.

Chemical properties

The thickness of the organic horizon, the nature of the subsoil and the frequency of flooding (Tie and Kueh, 1979) influence the chemical composition of the peat. This means that the older and thicker the organic horizon, the more impoverished are the surface layers. If the soil is regularly flooded, it has a higher amount of mineral content and is more fertile. A typical chemical characteristic of the Malaysian peat is as shown in Table 1.

The peat soils usually have very low mineral content with organic matter content more than 90%. It is very acidic in nature with a pH generally below 4.0 (Wong, 1991). With the occurrence of organic acids such as phenolic compound monomers which are known to be detrimental to crop growth (Tadano *et al*., 1991), the lime requirement of these soils for the cultivation of dryland crops is normally high. These soils have a high CEC of 40–143 cmol kg^{-1}). Thus these soils are strongly buffered. However, the high CEC is not due to the presence of Na, K, Ca or Mg but because of the presence of exchangeable H^+. The peat has very low amounts of exchangeable bases causing them to have low percentage base saturation. The N content of peat is rather high but its availability for plant uptake is rather low.

The high C:N ratio coupled with the low pH results in low mineralisation of the peat. The electrical conductivity values are generally less than 1 mmhos/cm but may go up to more than 4 mmhos/cm in some areas near to the sea. Micronutrients, particularly Cu, and Zn are very deficient. Boron is also among the most deficient micronutrient in the Malaysian peat (Ambak *et al*. 1991 and Ambak and Tadano, 1991)

Table1. Typical chemical characteristics of a Malaysian peat[1].

Property	Topsoil (0-25 cm)	Subsoil (50-100 cm)
pH (H_2O)	3.7	3.8
Organic Carbon (%)	41.1	43.8
Total N (%)	1.58	1.25
Exch. Ca (me/100 g)	5.68	4.02
Exch. Mg (me/100 g)	4.55	4.19
Exch. K (me/100 g)	0.41	0.18
Exch. Na (me/100 g)	0.65	0.65
CEC (me/100 g)	70.8	66.4
Available P (ppm)	79	9
Total P (ppm)	401	149
Total Ca (ppm)	1468	457
Total Mg (ppm)	526	373
Total K (ppm)	283	143
Available Cu (ppm)	0.14	0.16
Available Zn (ppm)	0.96	0.52
Available Mn (ppm)	5	2
Available Fe (ppm)	10	2

[1]Anderson series
Source : Melling, *et al*. (1999)

Peatland Utilisation

According to available statistics as reported by Abdul Jamil *et al*. (1989) and Melling *et al*. (1999), approximately 868,375 ha of peat are under cultivation, representing 32 % of the total peat area in Malaysia (Table 2). Out of this, about 313,600 ha, are being utilised for agriculture in Peninsular Malaysia and 554,775 ha in the state of Sarawak.

Oilpalm, at present, is the most important crop being grown on the peatland (Table 3). It is the principle crop for plantation establishment as it is proven to be relatively profitable. A well managed oil palms growing on drained peat often has better yield than those planted on upland soils. In the state of Sarawak, the area planted with oilpalm is more than double those planted in Peninsular Malaysia.

Sago is being planted on a large scale only in the state of Sarawak since it is traditionally a staple source of starch for the people of Sarawak. Rubber and coconut are traditionally planted by smalholders as cash crops especially during the post war period when these commodities fetched a high price. However, coconut is not grown on a large scale on the peatland in Sarawak. Except for oilpalm and sago, other crops such as coconut, padi, pineapple and mixed horticulture crops (including vegetables and field crops) are being much more planted in Peninsular Malaysia than in Sarawak. Fruit trees are also being grown on the peatland especially on the shallow peat. Those that have potential on peat includes rambutan, jack fruit, papaya and 'ciku'. Other perennials that have potential are dwarf coconut, tea, mulberry and breadfruit.

Table 2. Peatland developed for agriculture in Malaysia.

Region	State /Division	Total area (ha)	Area developed for agriculture (ha)	% Peat area developed for agriculture
Peninsular Malaysia[1]				
	Johore	298,500	145,900	49
	Pahang	282,500	17,100	6
	Selangor	194,300	59,900	31
	Perak	107,500	69,700	65
	Terengganu	88,000	13,900	16
	Kelantan	7,400	2,100	28
	Negeri Sembilan	6,300	5,000	79
	Total	984,500	313,600	32
Sarawak[2]				
	Sibu	502,466	269,571	54
	Sri Aman	340,374	50,836	15
	Miri	314,585	66,114	21
	Samarahan	205,479	50,836	25
	Sarikei	172,353	61,112	35
	Bintulu	168,733	47,591	28
	Limbang	34,730	8,715	25
	Kuching	26,827	n.a	-
	Total	1,765,547	554,775	31
	Grand Total	2,750,047	868,375	32

Source: [1]Abdul Jamil *et al*. (1989) n.a = not available
[2]Melling *et al*. (1999)

Table 3 The utilisation of peatland for agriculture in Peninsular Malaysia and Sarawak

Type of crops	Peninsular Malaysia[1] (ha)	Sarawak[2] (ha)	Total area (ha)
Oil Palm	146,730	330,669	477,399
Sago	-	64,229	64,229
Rubber	98,143	23,000	121,143
Coconut	29,701	-	29,701
Padi	15,013	2,000	17,013
Pineapples	14,690	1,895	16,585
Mixed horticulture	5,810	908	6,718
Miscellaneous	7,425	369	7,794
Total	317,512	423,070	740,582

Source : [1]Abdul Jamil *et al*. (1989)
[2]Melling *et al*. (1999)

Sustainable Management Practices

In the true sense of the word, sustainable agriculture may not be appropriately used for peatland utilisation as the land will shrink and subside once it is developed for agriculture. Nevertheless, it may be construed to mean prolonging the life span of the peatland by minimising its rate of subsidence by adopting appropriate water, soil and crop management strategies.

Water Management

Water management is the most important and critical factor for crop growth and production on peatland. It not only lowers the water levels but also has significant influence on the crop management, peat subsidence and irreversible drying of the peat. Inefficient water management in times of limited water supply or excess is one of the main yield limiting factors. Therefore a good water management system requires a good functional drainage system.

1. Drainage and drainability

Drainage is a prerequisite for any agriculture utilization on peat. Without drainage establishment of dryland crops is difficult, as the Malaysian peatland is formed in lowland basins whereby water table is normally high and fluctuate according to rainfall. Drainage is therefore an important aspect of water management for agricultural development on peatland. Drainage network for agriculture on peatland should be able to lower the water table as well as to evacuate the water from rainstorm that could cause flooding. This is important to prevent damage to agricultural crops, as most of them cannot withstand prolonged flooding. The drainage network therefore, should be able to drain the flood water within this time limit, failing which could result in yield reduction or even dying of the crops. The drainage system should consist of a network of interconnected field, collection and main drains. The intensity varies with the nature of the soil and rainfall. The drainage system need to be designed to cater for its unusually high rainfall which can be as high as 4,000-5,000 mm per year to minimize the effects of flash floods. These rainfalls are not equally distributed over the year. There are seasonal wet and dry seasons. Hence, the drainage system needs to be designed to cater for these variations.

The drainage system should consist of shallow drains and narrower spacing instead of deep drains with large spacing (Ritzema *et al*, 1998), so that it would be easier to build the water level control structure across the drain. To further regulate the water table and to prevent the ingress of tidal river water, which in many instances is brackish, water gates are constructed at the discharge end of the main drains. Regular and proper maintenance of the drains is essential if they are to continue to function efficiently. Desilting needs to be done. Weeds are major problems. If they are left unchecked, can choke the system, adversely affecting the capacity and flow. Therefore frequent rounds of degrassing is required to keep them under control.

A drainage system can hardly be expected to perform both the tasks of removing floodwater and conserving water at the same time, particularly in peat soil area. Other water conservation methods such as mulching, rain-harvesting and temporary detention storage should be considered.

The consequence of drainage is that it bleeds the peat swamp the very medium that is its basis of existence. This will trigger the inevitable process of irreversible subsidence, which is a hard-to-overcome constraint of developing and utilizing of the peatland for agriculture development (Andriesse 1988). Thus it is important that the peatland should not be over-drained. Over drainage will increase the rate of subsidence and the occurrence of flooding, the reduction of the water holding capacity, an increase in the occurrence of acid-sulphate soils, forest fire, irreversible drying, pest and termite attack, nutrient imbalance and decrease the crops yield. All these phenomena will have an adverse effect on the sustainable utilization of the peat soil for agriculture and thus significantly shortens the economic usefulness of the land.

In planning the drainage system of the peatland, it is also important to consider the drainability potential of the selected area that can be sustained. In this context, sustainable drainability refers to gravity drainage, which can only be possible and economical, if the mineral subsoil level is above the mean water level of the nearest water body into which the drainage water is discharged. This is because the ground surface is still above this level even after all the peat has disappeared through decomposition. Therefore gravity drainage can be sustained almost indefinitely. But it becomes more difficult and uneconomical or even impossible to have gravity drainage if the peat is below the mean water level. Gravity drainage also becomes even more difficult if they are situated further away from the water bodies because an additional hydraulic head of at least 20cm per kilometre has to be allowed for. When this happens, the area will become waterlogged and development of the area will have to be abandoned unless very expensive measures such as bunding and pumping are resorted to.

2. Water-table control

As drainage is important, maintaining constant groundwater levels within the optimal range for crop production is also as important. The ground water levels should be maintained as high as possible using appropriate water level control structures. A series of weirs are constructed across the collection drain at strategic positions to maintain the required water levels and to be able to control the water levels at a higher level during periods of low rainfall, to prevent over drainage. The spacing depends on the type of land use and the thickness of the peat layer.

An example of a water management system, based on similar design principles can be found at United Plantations in Perak (Singh *et al*., 1986). In their oil palm plantations on peat soil, they have constructed a series of structures in the collector drains to control the water level in a block of 50ha. In the block, an intensive tertiary drainage system, with spacing of about 30m, maintains the ground water level depth at 0.6 to 0.9m below the soil surface.

The water table requirements differs according to the crop type. The optimal water table level varies on the depth of the root zone of each crop. It also has varied temporal requirements depending on the stage of crop growth as well as field activities such as tilling and harvesting. Ideally, water table should be designed about 20cm below the root zone of crops after taking into consideration the rate of capillary rise and capillary fringe in peat. These changes need to be accounted for adequately in order to achieve optimal production. For example, crops with shallow rooting zone of about 30cm will suffer from unnecessary moisture stress if grown in a field with mid-field drainage level designed at 90cm. Several optimum average water tables have been identified for best performance of some crops as shown in Table 4.

Dropping the watertable too low below the root zone due to subsidence would adversely affect the yield, particularly during the drier months. The slow vertical water conductance of the peat restricts the water recharge to the rooting zone of the crops by capillary rise, thus subjecting the crops to moisture stress. This requires that the watertable should be maintained at the highest possible water level consistent with the crops grown. During the dry season, the water table should be higher to curb the occurrence of peat fire.

Table 4. Water table requirements for crops grown on peat

Crops	Water table (cm)	References
Oil palm	50 – 75	Singh *et al.* (1986)
Pineapple	60 – 90	Tay (1980); Zahari *et al*. (1989)
Sago	20 – 40	Melling, *et al.* (1998)
Cassava	15 – 30	Tan and Ambak (1989); Zahari *et al*. (1989)
Groundnut	65 – 85	Ambak *et al*. (1992)
Soybean	25 – 45	Ambak *et al*. (*op cit*)
Maize	75	Ambak *et al.* (*op cit*)
Sweet potato	25	Ambak *et al*. (*op cit*)
Asparagus	25	Ambak *et al*. (*op cit*)
Vegetables	30 - 60	Leong and Ambak (1987)

The choice of crops grown on a particular peat basin is very important. This choice dictates the required drainage depth. It is unwise to develop one part of the same swamp for deep rooting crops demanding a water table depth of 75 cm (e.g. oil palm), if on the neighbouring estate, attempts are being made to keep the water table levels at 30 cm (e.g. Sago). Hence, this creates a conflict in water table requirements. The choice of crops in relation to the location of the water catchment area should also be well considered so as not to affect the role of the peat swamp as a source of water supply.

Pests such as rats (predominantly *Rattus tiomanicus*) and termites (*Coptotermes curvignatus*) can be reduced or prevented with high water table and good water management.

Maintaining the water table as high as possible will be able to encourage a rapid growth of *Nephrolepsis*, which acts as a cover crop so as not to expose the peat surfaces, and maintains a cooler surrounding. The exposed peat surfaces tend to form organic crusting and this will decrease infiltration and increase surface runoff causing an increase in peat erosion. Leguminous cover crops are not encourage because it will increase the rate of mineralisation of the peat, thus increasing the rate of subsidence.

Optimal fertilisers, pesticides and herbicides application can be well coordinated with good field water management. The peat developers and planters need to understand the impact of the application of these inputs with the varying moisture status to maximise crop development and productivity. Ensuring the appropriate water level has bearings on the correct application of inputs and minimising residuals.

3. Irrigation

When the water table can be controlled at the optimum level as required by specific crop, water management is not much a problem, except during early stage of crop establishment. The planting schedule then can be timed in such away that it coincides with the wet season.

If the water table cannot be controlled and is always deeper than the required depth, irrigation is necessary, especially for short term crops. This is important in order to supply water for crop growth as well as to prevent excessive drying of the top soil. Leafy vegetables grown on peat often showed mid-day wilting during hot weather condition. This could be attributed to the shallow soil profile that is occupied by the roots. Water uptake in peat does not follow the pattern found in mineral soil. Water availability in peat soil is limited to a water tension equivalent of only 5 bars (wilting point) compared to 15 bars for mineral soils (Lucas, 1982; Salmah, 1992). Thus water depletion in the peat profile as the plant transpire will be much faster than the corresponding mineral soils.

Different crops have different growth stages sensitive to water stress. Knowing the different stages would enable one to irrigate at the critical time so as to minimize water stress and optimize water usage. Lucas (1982) reported that the productivity of field crops grown on peat decreased markedly as the amount of available water falls below 30% of the total available water.

For planting of annuals, irrigation measures must be considered. The planting schedule and irrigation system required must take into consideration the amount of water available in the soil above the water table, amount of rainfall and distribution and evapotranspiration of the area. There must be appropriate control measures on the water supply sources for back irrigation particularly during the dry period.

4. Flooding

In order to minimize the occurrence of soil subsidence, the best approach is to flood the soil and adopt aquatic usage of the peatland such as planting hydrophilic (water-loving) or water-tolerant plants of economic importance, namely Chinese water chestnuts (*Eleocharis tuberosa*), Chinese spinach (*Amaranthus hybridus*), ‘kangkong’ (*Ipomoea aquatica*), water cress etc. In the Florida Everglades, when the soil is not cultivated, especially during the off-season, it is a common practice to flood the whole field (Synder *et al*., 1978).

Soil Management

In principle, peat is an excellent soil substrate for growing crops, because of its high amount of pores, which provide abundant oxygen supply for root growth above the fully water saturated zone. It has large moisture retention capacity and hence transplanted crops establish themselves much faster than on mineral soils. However, due to certain inherent negative characteristics such as high acidity, low in base saturation and poor in certain macro and micronutrients, peat soil is generally considered as a marginal soil. Thus, with appropriate soil management practices, it can be sustainably utilised for agriculture.

1. Burning

Open burning of any area is not an environmentally friendly practice and it should never be encouraged. However, when the peatland is initially cleared and developed from virgin jungles, the land surface is full of undecomposed woody debris which hinders immediate usage of the land for crop cultivation. The undecomposed woody mass need to be removed at least to plough depth before the soil can be utilized for agriculture (Md. Sharif *et al*., 1986). The use of machinery to clear these debris is difficult as the soil is soft and unworkable and thus requires intensive labour inputs. Therefore, initial burning seems to be unavoidable unless there is a technology that can transform these woody mass into a well decomposed materials in a relatively short time. Thereafter, the practice of burning by farmers to liberate nutrients as well as to sterilize the soil should not be advocated. This is to prevent the accelerated physical soil loss.

2. Liming

Farmers usually burn the soil, either along the planting rows or as a blanket burning before planting. Burning improved the soil pH up to 5.5 to 7, released available nutrients and partially sterilized the soil. Although the benefits is immediate, but the amount of soil loss is tremendous and therefore it is not a sustainable practice and burning as stated earlier should not be encouraged. The best alternative is to use liming materials such as calcium carbonate or wood ashes. Studies have shown that rubber wood ash is superior to oil bunch ash as a soil ameliorant for vegetable production on peat (Md. Sharif *et al*., 1986). In oil palm estate, oil palm bunch ash is being recommended as it contains high amount of potash (Yim *et al.,* 1984). However, difficulty in obtaining wood ashes limits its commercial application.

Liming is necessary for cultivation of dryland crops on peatland, except those acid tolerant crops such as pineapple and tapiocca. In general, about 2.5 tons/ha lime is required to bring the virgin peat pH of about 3.5 to about pH 4.0 (Joseph *et al*., 1974). Table 5 shows yield responses to varying amount of lime for several short term crops.

Table 5. Mean yield of some short term crops in relation to lime.

		Yield (tons/ha) at levels of hydrated lime			
Crop	Product	0	3.5	7.0	14.0
Tapioca	fresh tubers	43.45	54.26	48.36	42.73
Groundnut	dry seeds	0.404	0.891	1.285	1.041
Guinea grass	dry grass	10.92	15.91	17.74	19.33
Sweet potato	fresh tubers	9.33	19.65	20.75	24.57
Chilli	fresh chilli	0.082	0.392	0.606	0.625
Sorghum	dry seeds	0.867	1.509	1.986	2.294
Soil pH	-	3.6	3.8	4.1	4.3

Source: Joseph *et al.* (1974)

3. Nutrient Requirements

The problem of low fertility status of peat soil could be overcome through appropriate fertilizer application. Generally, N and K requirements are high for vegetables and field crops (Leong *et al.,* 1993). Calcium and magnesium requirements are adequately supplied through liming. For perennials, especially oil palm, potash is most deficient while nitrogen and phosphorus, the rate of fertilizer required is in the region of about 209, 8 and 220 kg/ha of N, P205 and K20, respectively, given in three split application at 3,6 and 9 months after planting.

There are indications that plant nutrients vary with the depth of water table. Phosphorus and potassium requirements are normally greater with a high water table probably as a result of restricted root development (Lucas, 1982). Tay (1980) observed that pineapple yield responses to potassium were influenced to a large extent by water table depths. Only at water table below 40 cm depth does increasing levels of potassium application leads to increase in pineapple yield. Fertilizer application in areas with extreme water table level, either too low or too high, was not beneficial to the crop.

Copper, boron and zinc deficiencies are common on Malaysian peatland. This is normally overcome through ground application as well as foliar sprays. In pineapple cultivation symptoms attributed to copper (green dieback) and zinc (crooked neck) have been reported (Joseph *et al*., 1974). This is normally over come through foliar application of about 5.6 kg/ha of copper sulphate, and zinc sulphate, respectively. The `peat yellow' found in oil palm (Turner and Bull, 1967) has been identified as being due to copper deficiency (Ng and Tan, 1974). This symptoms however, was effectively cured by spraying with zinc sulphate (Singh, 1983). In tapioca, copper deficiency, as shown by curled or cupped young leaves, was successfully and economically cured through ground application of about 13 kg/ha of copper sulphate (Chan and Ramli, 1986). Boron deficiency in papaya is normally overcome by spraying 0.25 % boric acid every 2 weeks for the first 3 months of planting followed by ground appplication of 5 gm borax/tree.

In the reclamation of peat, the felling of natural forest vegetation causes a substantial change in the nutrient content in the ecosystem due to interrupted cycling, release of nutrients from decomposition of organic materials and compaction of the drained surface soil (Dent, 1986). The degradation of the chemical properties of peat with land clearing has a detrimental effect on yields of crops grown on it. After a few years of cropping, yield of crop tend to drop sharply. For example, the average pineapple yield from eleven years old (74 ton/ha), at the Peninsular Pineapple Plantation in Simpang Renggam, Johore, is somewhat 25% higher than those from the 20-25 years old fields (59 ton/ha), although with similar fertilizer inputs (Tay *et al.,* 1987).

Thus, to ensure optimum and sustainable utilization of the peatland, adequate and appropriate applications of essential crop nutrients is very crucial.

4. Cultural Practices

Another important aspect to be considered under soil management practices in order to sustain the usage of peatland is the cultural practices commonly adopted for peat soils. Is it necessary to till the soil or to adopt minimum tillage approach? For growing vegetables and root crops such as sweet potatoes, is it necessary to plant them on raised beds? Is it necessary to clean the weeds throughout the entire field? Our limited experience on planting crops on peat revealed that minimum or no tillage practice normally is as good as tilling the soil. Thus, non tillage practice should be adopted since it not only reduce soil disturbance but it reduces the input cost. In the cultivation of sweet potatoes, it was observed that tuber yields was significantly higher with those planted without beds as compared to those planted on beds. Thus, making beds should not be a normal practice for planting sweet potatoes on the peatland, provided that the land is well drained and the water table is kept at optimum level.

Crop Management

With proper management, various types of field crops, pasture, vegetables, pineapple, banana and coffee could be successfully grown on the Malaysian peatland. The agronomic requirements such as planting distances, fertilizer levels and management procedures are well documented (Leong *et al.*, 1993).

1. Crop Suitability

Selection of suitable crops that adapt well on drained and undrained peat is important for successful utilization of peat soils for agriculture. Among the introduced crops, pineapple showed highest adaptability on drained peat (Tay and Wee, 1972). It adapts very well to the high acidity and low fertility nature of the Malaysian peatland.

Tapioca is another crop that perform well on peat soils. Its high tolerance to acidity requires little amount of lime (Chew, 1971; Joseph *et al*., 1974). The fibrous and loose nature of these soils encourage tuberization and facilitate harvesting. As such, yield as high as 50 tons/ha can be expected.

Oil palm has been found to be one of the perennial crops fairly suitable on medium to shallow peat. Yield as high as 13 tons/ha in the third year of planting was reported (Yim *et al.,* 1984). Rubber, coconut and coffee are the most popular crops among small farmers.

Sago adapts well and give good yields without any fertilizer input (Ahmad and Sim, 1975) on undraied / minimum drained peat. However, the crop takes a very long time (15 to 20 years) to mature. Rice is another crop that grows on undrained peat but very often having, the problem of sterility which produces empty husk (Driesen, 1978; Dent, 1986). Some fruit trees are found to grow well in native swamp forests of Sumatra and Kalimantan, namely, 'jambu air' (*Eugenia* spp.), wild species of mangosteen (*Garcinia* spp.), passion fruit (*Passiflora* spp.) and 'rambutan' (*Nephelium* spp.) (Anderson, 1976).

The search for suitable crops that can adapt well on drained and undrained peat with minimum soil amendments is continuously being sought. Some of the crops that show potential are jackfruit, guava, breadfruit (sukun), 'ciku' and papaya.

2. Cropping Practices

In order to reduce soil loss through biochemical oxidation, it is important that the soil surface should not be left barren. Some kind of vegetation such as grasses or legumes should be allowed to grow except at the planting hole. Similarly, clean weeding, particularly when dealing with perennial crops such as oil palm and coffee, should not be practiced. Some kind of leguminous creeper, *Canavalia maritima* can be grown satisfactorily with minimum inputs (Singh, 1986). It shows good tolerance to high acidity and establishing itself fairly quickly in the planting avenues.

Alternative approach to burning of crop residues as normally practiced in pineapple cultivation should be seriously looked into as burning is an environmentally unfriendly practice. Crop residues should be turned into composts and plough back into the soil. This practice not only give added nutrients but also helps to offset soil loss through subsidence.

Conclusion

Part of the peatland in Malaysia has been successfully reclaimed for agriculture. Various crops have been economically grown under suitable agronomic practices and proper water management. Efforts to overcome various agronomic problems through research have met with some success. This is particularly true with pineapple and some short term crops such as tapioca, maize, sweet potato and vegetables.

Maximize usage of the already developed peat rather than opening up more peat swamp forest should be emphasized. Developed peat areas in the integrated agriculture development projects (IADP) such as in the West Johore IADP and South-West Selangor IADP in Peninsular Malaysia, should be fully utilized for crop cultivation. Where peatland had been drained and developed for agriculture, measures to conserve it to the fullest should not be ignored. Even though the soil continue to shrink and subside at the onset of draining, the rate of soil loss can be slowed down

The sustainable utilisation of peat for agriculture development must be approach from a total management perspective. It should be well understood, however that, even with the best water management, subsidence cannot be arrested. It is the price one has to pay for the use of tropical peatlands. The irreversible process of subsidence can only be arrested through complete re-saturation of the peat. There should be continued efforts by everyone concerned to look for optimum ways of controlling the subsidence of peat especially by appropriate water management. Therefore, the sustainable utilisation of peat for agriculture development is actually to prolong the lifespan of the productivity of the peatland.

Acknowledgement

The authors wish to record their gratitude to Director General of MARDI and Director, Department of Agriculture, Sarawak for allowing this paper to be presented and to Dr. M. Osaki for the invitation and financial arrangements for the senior author to be present at this Symposium.

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Proceedings of the International Symposium on
TROPICAL PEATLANDS
Bogor, Indonesia, 22-23 November 1999
Hokkaido University & Indonesian Institute of Sciences
pp. 135-143 (2000)

Utilization of Inland Peat for Food Crop Commodity Development Requires High Input and is Detrimental to Peat Swamp Forest Ecosystem

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1. Background

The province of Central Kalimantan with an area of approximately 153,564 km^2, contains 2,651,724 ha (or around 17.3%) of peatland. Based on the geographical site and the influence of seawater overflow, peatland can be grouped into two types: **inland peat** (the type of peatland that is not influenced by the overflow of seawater), and **coastal peat** (the type of peat that is mainly influenced by seawater). Both of these types of peatland have their own characteristics. The inland peat is not only identified as thick peat reaching about more than 17 m, but also poor peat. This is due to the decomposition process within this type of peat which is at the level of fibric or hemic process. In addition, the support material beneath the peat is mainly quartz and granite.

In contrast, coastal peat is shallow peat of about 25–100 cm, having highly fertile soil. It is due to the enrichment caused naturally by the sea water sediment. Its maturity is usually sapric or hemic and the under layer materials are dominated by mineral tough soil.

Peat swamp forest is not only important as the habitat for flora and fauna having high economic values and rarely found, but it is also important as carbon storage. If vegetation on the peat layer is destroyed, the ecosystem will change accordingly, and at the same time will increase the concentration of CO_2 in the atmosphere.

Up to the present the government has executed development programmes, often without taking into account undeniable fact and past experiences. Every separate sector makes different plans and carries out their own programs in disintegrated ways, and underestimating every research findings. The successful experience in managing peat in Sumatera has been assumed to be a successful method and applicable to Central Kalimantan. The real fact that can be easily understood about this problem is that of the cases of agriculture within the area of ex-transmigration in Bereng Bengkel (Kalampangan). The farmers in this area have not been able to manage successfully their farming areas, except the area surround their resident areas (0.25 ha). In this way, a lot farming areas have now become unproductive. Factors that caused the failure of the transmigration program in Bereng Bengkel have not been identified by the government for further development planning, as well as the negative impact in the long run on the ecosystem in this area.

2. The Utilization of Peat Swamp Forest

In 1950s, the local Dayak community had intensively cultivated shallow peat both in the coastal and inland areas. Within the inland area (peat is locally called “LUWAU”), within the area of river banks or around the valley, which characterized by mineral clay, for natural raining-regulated rice field (Sawah tadah hujan). Where as within the tidal areas, the local community only traditionally cultivated rice farming around the river banks by establishing small canal for circulating the tidal water into the rice fields.

Before the establishment of big canals and the placement of the transmigrants within the tidal areas was implemented, Palingkau area has been identified as the leading rice producer for Central Kalimantan, but now instead of producing rice, Palingkau is importing rice from other areas.

In 1980s, the government started to utilize or conserve thick peat swamp areas within inland, which dominantly characterized by sand and granite, for agriculture. The examples of peat exploitation for agriculture through transmigration program are in the area of Kalampangan (Ex of Technical Executing Unit of Bereng Bengkel) Transbangdep Tahai, and the northern part of 1 million hectares of PLG project.

2.1 Kalampangan (Ex of Technical Executing Unit of Bereng Bengkel) and Transbangdep Tahai

2.1.1 Agriculture

a. Technology

Up to the present, the local farmers are still heavily relying on ash for fertilization, resulted from the burning of grass and wood waste. The burning process has been carried out consistently on the peat layer. Consequently, upper peat layer of about 20-30 cm has been seriously damaged. To help the crop grow well, it was estimated about 300–500 g of ash / plant needed in every plantation period. Without using ash, the local farmers would not be able to grow what so ever, except by utilizing other kind of fertilizer such as manure.

In 1984/1985 a true experiment was worked out on the utilization of peat by mixing it with mineral soil as much as 40 tonnes / ha and given along the plant lines. The mixture of peat with mineral soil, lime organic fertilizer and other micro-element showed a better result. However, there will always be problems to require mineral soil in great amount as the source of the mineral soil is limited, as well as the dug areas will resulted in environmental degradation.

b. Commodity

The leading commodity developed by the local farmers is mainly vegetable such as “sawi”, Salad, Cucumber and “Kangkung” where as the main “palawija” is maze (corn).

Generally the pattern of plantation is mono - culture type within a very limited scale, the farmers only cultivated the house yards as large as 0.25 ha. The size of the plots that have been utilized is usually as follows: For salad type of vegetation: 10.0 m × 1.0m. **Sawi**: 20.0 m × 15.0 m, cucumber: 25.0 m × 20.0 m, **Kangkung (hipomoea)**: 20.0 m × 15.0 m and for corn: 50.0 × 25.0 m. Most of the local farmers utilized the plots within those sizes, since these sizes are manageable when provided enough ash.

The revenue resulted from those practices was very little when the ash needed had to be bought. For example, to grow 125,000 corn crops, there should be about 37.5 tonnes/ha with the assumption that every corn consumes 300 g/plant. Whereas the price of ash in Palangka Raya is about Rp. 600 – Rp. 800/kg. If the ash within this area is sold on the price about Rp. 500/kg, the production cost will be as much as Rp.18,750,000 /ha. Based on the assumption that 75% of the crops will generate corn and out of this, only 30% of corn having good quality (28.25 corn/ha), so that the gross product that will be resulted and gained by the farmers is about Rp. 19,687,500/ha, by the assumption that the price of the corn is Rp. 700/corn. The low rate of assumption in this case, the assumption was based on the findings made by Limin (1992) by utilizing 4 tonne of dolomite ha, 21 tonnes /ha manure and 180 kg, of phosphate P_2O_5/ha, resulted in good quality corn of > 12 cm. This was only about 21,49-26.85%. Based on these figures, the net income would be smaller, if the need for nitrogen, phosphate, potassium, manure lime, pesticide, including cost for preparing the land, and maintenance until harvesting time. However the local farmers have never included those costs, mainly the costs of ash and the cost resulted from the utilization of manpower.

There are also constrains in developing plantation commodity. For example, coconut never would grow well outside the house yard. Where as rubber trees which were planted within the area of thick peat ranging from about 2.75-3.00 m. Those rubber trees when reaching the age of 12 years old, they could only reach varied dbh ranging from 11.0-54.0 cm, and there were only 11% of the rubber tree population reaching ≥ 40 cm, which satisfied the tapping criteria. The small amount of the rubber trees reaching tapping criteria denoted that rubber trees were hardly grow in the thick peat area.. In addition to the slow growth, the appearance of the tree trunk was very rough and stiff (Fig. 1). Sunarko (1996) asserted that the type of hybrid rubber trees which were sowed based on the seed, when reaching the age of 5–6 years, were generally 60% of the population could reach 40–45 cm of dbh.

2.1.2 Physical condition of the environment

Based on direct observation on the field and information attained from the local farmers, it was proven that the farming areas would get dry easily, especially when the intensity of rain was low. This was actually the effect of soil water level decrease as further effect of the establishment of the excessive drainage system. There has been a clear indication of this problem, in every dry season the land should be watered with a great amount of water since the land is badly dry.

The rate of soil surface subsidence has also been significant, it is ranging from 1.0–3.0 cm per annum and it is very much depend on the local hydrological condition. Based on the result of water level measurement n the field, it was found out that within the period of 18 years, the peat surface subsidence has reached 36 cm (Fig. 2). Limin (1998) asserted that as the result of over drainage system develop, water soil had been drastically decreased. This in turn had resulted in great change of temperature and humidity on the upper peat layer. This change caused the proliferation of kind and type of soil microorganism that might have contributed restructuring of organic matter, so that the land surface gradually lowered. It is also asserted that the decrease of soil level was also resulted from the process of continues leaching of peat layer by erosion (water or wind).

On the other hand, in a certain area where peat layer structure have been very much changed, there has been exchange of vegetation grow. Fig. 3 shows that a certain type of vegetation, "alang-alang" (*Imperata cylindrica*) is growing very well in the area. In addition, the areas of peat swamp forest, which have hydrological status changes, in fact were easily caught fire. The burnt peat layer was ranging from 10 -100 cm or even more. The depth of burnt peat layer was depending on the availability of the organic materials and the depth of the soil water level. (Fig. 4).

Fig. 1. Rubber (Planted 1987; 11,0 % Dbh ≥ 40 cm)

Fig. 2. Subsidence (36 cm for 18 years period)

Fig. 3. Vegetation change: Alang-alang (*Imperata cylindrica*) Growing well.

Fig. 4. Peat fire characteristics

As the effect of many hindrances and high cost of input and technology needed for growing vegetation as well as corn, up to present ± 80% (700 ha) of farming areas in Kalampangan has been unproductive.

2.1.3 Population

Based on the report of Transmigration Office of Central Kalimantan, the number of transmigrants in Transbangdep Tahai and Kalampangan until 1999 were 3,433 people, as presented in Table 1. It is important to note that the increase in the number of population within these areas has not been followed by the increase of housing facilities, this was due to the strict use of the areas, as farming areas. The decrease of the number f house holds in the area of Transbangdep Tahai, from 230 house holds to 176 house holds, was actually indicating that transmigration program within those areas was failed. This was due to the soil condition, it was poorer than those in Kalampangan areas. In addition, it is important to assert here that almost 80% of farmers in Kalampangan area have been working in many different sectors other than farming, such as daily public workers, illegal mining, and illegal logging and so on.

Table 1. The number of families in Bereng Bengkel and Tahai

Locations	Placement			Delivery			November 1999	
	Year	Families	Number of people	Year	Families	Number of people	Families	Number of people
Bereng Bengkel (Kalampangan)	1979/1980	500	2112	1985	487	2125	515	2415
Transbangdep (Tahai)	1991	230	800	1996	230	?	176	1018

Source : Transmigration Office of Central Kalimantan

2.1.4 Research findings of UNPAR staff

Based on the research finding of Limin (1998) on the residual effect of manure, dolomite, and phosphate on the thick peat in Kalampangan area. It was found out that the treatment by using manure, dolomite and phosphate in this area could only effective as long as 22 months. Within those periods, the area was planted sweet corn in first sequence, Chili in the second sequence, and then sweet corn in the third sequence. Chili was again planted in the fourth sequence, but it was fail. This was clearly denoting that the residue effect of those inputs was not effective any more. To know for sure about this case, half of each sequence above was given retreatment by inputting dolomite, manure, and phosphate. It was found out that Chili which were planted within the area that was re-input with those materials, could grow well, and productive. Where as those planted within the area without re-treatment, were all die. For further information on the problems of the utilization of thick peat for agriculture can be clearly seen through Figs. 5 and 6.

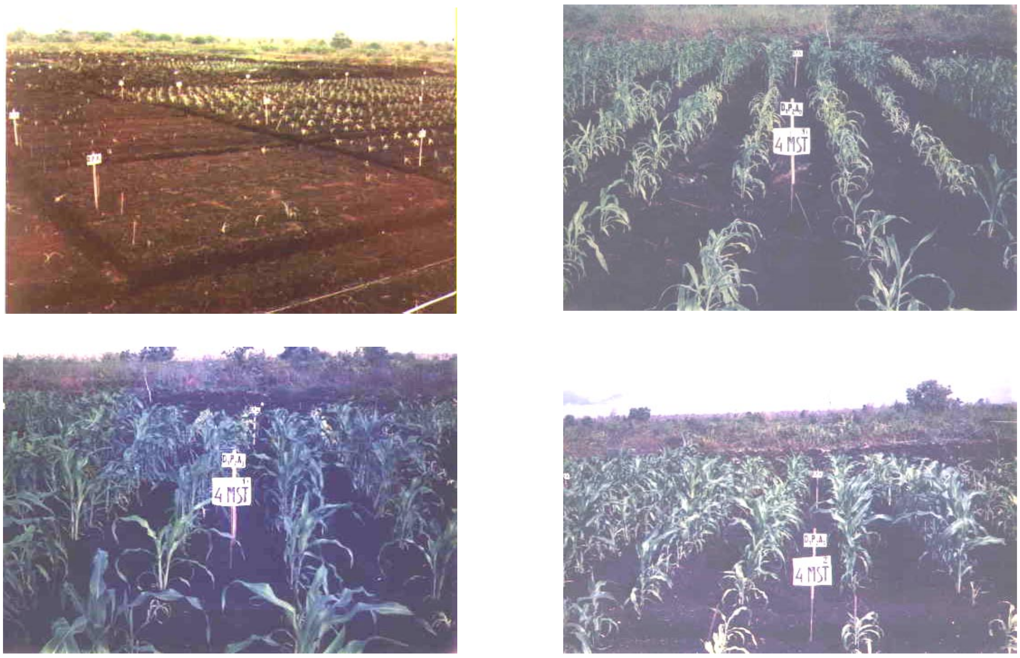

Fig. 5. Sweet corn plants were planted without lime and manure input.

Sequent IV (1st) residual effect

New treatment sequent IV (regrowing) on the right are plants planted using residual effect

Sequent IV (regrowing)

Sequent IV (regrowing)

Fig. 6. Chili plants replanted (re-treatment) with lime, manure and phosphate.

2.2 The Development of One Million Hectare

The opening of peat swamp forest area known as the One Million hectare Peat land Development Project (PLG), right from the beginning has brought about conflict. In the first meeting on PLG in December 1995 in Central Kalimantan, the writer has reminded the government to be careful in establishing the canals as what had been planed, because they would bring about problems. The problems would be **"The swampy areas could be dry and the dry areas could become swampy or wet or there would be areas having those two characteristics wet and dry"**. In addition, "it had been proven that thick peat areas would never be productive for rice cultivation, as well as for other crops and big scale plantation". The utilization of thick peat having more than 1 m deep, would gradually make the peat useless, as well as flora and fauna on the peat. The reformation of the peat layer would not happen in a very short time, as according to Rieley *et al*. (1996), the age of peat within the Sabangau catchment areas in Central Kalimantan within the depth of about 2–10 m, was about 960-9600 years.

2.2.1 The establishment of canals and their problems

The total length of canal has been completed up to the middle of 1998 was 2,008.7 km. This was covering 183.1km of the first primary canal, 620.5 km of the second primary canal, 241.1 km of support primary canal, 964 km of secondary and tertiary canals developed for irrigating 17,500 ha rice fields.

But later, the canal, which was established for irrigating the rice fields, could not be functioned due to the lack of water source from the upper stream of the Kahayan, Kapuas, and Barito rivers. However, if the idea of dumping the three rivers for water supply for irrigation, had been done, we could be sure, the new disaster would have happened, because there were many residences in the northern part of the area would be totally flooded. In fact, so far those canals have been effectively used for transporting logs resulted from illegal logging. In this case, instead of irrigating the rice fields, those canals have been effective used for illegal logging activities and they surely threatening the environmental sustainability. In addition, those canals would bring about two extreme conditions: extended drought and flood. Then these two conditions would support the exchange of vegetation. Further more, the potential danger of long dry season is land and forest fire. Based on the data on the spreading of hot spots in 1997, land and forest fire had always been started from the openly dry areas where there were many human activities.

2.2.2 The placement of transmigrants and its problems

There were 15,200 families or 62,379 people of transmigrants have been placed in the areas of Dadahup and Palingkau, and Lamunti. The problem was that in the 1998/1999 sowing period, there were about 30,000 ha rice fields destroyed by rat enemy. By manipulating this rat issue, the main cause of harvesting failure, the government could easily provide a big amount of budget, i. e. Rp. 52.1 billion for solving the rat problem. This was thought to be easy and simple as well as accurate. Of this budget Rp. 8.4 billion spent for buying 770 units of chainsaw and Rp. 12.4 billion spent for buying 309 tonnes of rat poison. In fact, both the chainsaw and the rat poison are of great threat to the environmental sustainability. Those chainsaws would facilitate illegal logging, where as rat poison would be able to destroy any bio-organism both those are living on land and in water including human beings within the area, especially those who use water for daily consumption. The government's policy on the above problem solving was very controversial, besides underestimating the substantial causes of the agricultural failure. This would even bring about other new complicated environmental problems. According to Limin *et al*. (1999), the causes of agricultural failure mentioned above was really contributed by many factors, among others were soil characteristics, hydrology aspect, as well as the qualification of the farmers themselves. Where as rat problem came later, consuming those poorly grew rice crops.

It was suggested to the government not to look at the partial causes of the agricultural problems in the area, as well as their problem solving. Rat attack was actually due to the extreme ecosystem change, as well as due to rat food chain destruction. For this reason, the government was suggested to carry out the rearrangement of land use, i.e. among others by placing transmigrants into the area where rice cultivation is feasible. In other words that peat areas having >50cm characterized by sand and granite underneath, and those areas which are having more than 100 cm peat, characterized by clay underneath, should be reforested with local trees, and followed by the closing of the canals. Furthermore those farmers who are not farmers by profession, should be returned to their former profession or should be returned back to their original places.

2.3 Coastal Areas

The development of coastal areas for agriculture by highly depend on the irrigation system, which chopped the whole area in such a destructive manner, in fact have not been able to bring about satisfactorily out comes. As the result of high "firit" content of the soil and poor hydrology system in managing the area, many transmigrants had abandoned their farming areas. Therefore, in many cases, the area of transmigration has become unproductive. The unproductive areas have not been well identified by the government. To underestimate and neglect those unproductive areas and letting those canals unfunctional, with out any effort for the best solution, is actually showing that the government consistency in maintaining extended poverty, and would surely resulted in ecosystem damage.

For example, within the area of Kapuas regency, Central Kalimantan, a costal area of about 31,976 ha (agricultural area) has been cleared off for 18,272 families (79.82 people) of transmigrant (the previous data of placement). If the whole of the area had been rowed with rice, the yield was estimated to be about 3.3–4.8 tonnes per ha (based on the report), so that, a sowing period would have produced 105,520.8–153,484.8 tonnes rice. Based on the rice need per capita that was estimated 120/Kg/anum, the rice need of the transmigrants was estimated to only 9,579.840 tonnes/anum. However, that on fact the rice need has been highly satisfied by importing rice from outside of the area. This has been again the clear indication that the agriculture area of transmigrants has been to many cases become unproductive.

3. Conclusion

(1) The utilization of thick inland peat for agriculture and plantation must be stopped, because it has been proven that it has facilitated environmental degradation, and required high input in many cases.
(2) Every peat areas which have been opened within the area of PLG as well as within the other areas should be reevaluated for appropriate use as follows:

(2.1) Peat areas which are having > 50 cm deep, and characterized by sand or granite underneath, and

(2.2) Peat areas which are having > 100cm deep, and characterized by mineral clay underneath, must be designated for conservation areas, i.e. by planting local highly economic value trees such as ***Jelutong, Gemor, Ramin, Meranti*** and so on.

(3) Every canal within the area of PLG must immediately be closed, mainly those crossing through peat areas of having > 100 cm deep.

(4) To let those wide canals open, going through the thick peat areas, would result in hydrology changes, soil surface subsidence and as well as vegetation change.

(5) The utilization of peat swamp forest should be specialized for the local commodity (including its fauna). In this way it is believed that the peat swamp forest will produce not only forest product with high economic value but also result in sustainable and well-balanced ecosystem.

(6) Being in the serious damage of ecosystem now, it would be better to work out the approach known as selling the wood without cutting the forest for the need of credit carbon/ carbon storage.

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Proceedings of the International Symposium on
TROPICAL PEATLANDS
Bogor, Indonesia, 22-23 November 1999
Hokkaido University & Indonesian Institute of Sciences
pp. 145-149 (2000)

Discussion on Rural Development of Peat Swamp Area of Central Kalimantan from Hydrological Aspect

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Abstract

Chaotic and disordered development practice is now undertaken on peat swamp area of lowland Central Kalimantan. The existing development plan seems to be quite absurd, because it does not reflect the situation and the nature of the area.

On this paper, the necessity of recognizing area's present condition, the land zoning principle, priority of development, etc., is discussed with special reference to the hydrological view points. In order to establish appropriate land use planning, it is essential to know present conditions of the area and the ability of its potential resources. The importance of establishing monitoring stations is also emphasized.

1. Introduction

Development on tropical peat swamp is now undertaken on many coastal areas of Southeast Asia. The pressure of exploitation is also getting very high in the coastal region of Central Kalimantan, Indonesia. It is well known that both boreal and tropical peatland are very sensitive landscape when the impact from human activity influences its system. Hydrological condition is the most influential factor to the peat land environment. But in case of Central Kalimantan, almost nothing has been taken in considering the conservation of the hydrological conditions of the peatland, and it means, on sustainable and environmentally tolerant peatland utilisation, too. In this paper, the brief buck ground of peatland development in both boreal peatland (Hokkaido) and tropical peatland (Central Kalimantan) are compared and discussed through the view point of land use and its history. Problems, keys and hints for more adequate development are mentioned.

2. Our Recent Experiment on Peatland Development in Hokkaido and Indonesia

Hokkaido is quite 'young' region in Japan. It means that it is young in development, which recently opened, compared to the other regions in Japan. It has agricultural history of only one century or so. But nowadays, Hokkaido, especially on lowland peatland areas, is completely 'developed', or 'consolidated' for agricultural production. The farmlands are settled systematically in rectangular shape, and fully equipped with roads, irrigation canals and drainage ditches. More or less, the area in natural condition is very limited. The hydrological conditions are artificially controlled. No part of agricultural area is wasted, or abandoned on large scale.

Same kind of neatly managed land use can be found in Java and Bali of Indonesia. The agricultural land use of these areas is so tidy and well managed by local people. These Japanese, Javanese, and Balinese farmers have something in common with the experiment on rice cultivation, or common way-of-thinking based on rice cultivation. They do not like 'disordered' land use form.

The very important fact is that all these results of development are not achieved at once, of cause. They are accumulated step by step spending through quite long time of span.

3. Failure of MRP and Condition of Lowland Central Kalimantan

Looking to the conditions of lowland area of Central Kalimantan, we found the situation is largely different from that of peatland area of Hokkaido, or from Java and Bali. As Limin *et al.* (1999) and many others already mentioned, Mega Rice Project (MRP), a tremendous huge project conducted and failed in the area of lowland Central Kalimantan. In case of MRP, it seems that no careful consideration was paid for peatland development, and the 'rice-cultivating people's way of thinking' was simply and directly adopted.

The development plan of MRP did not refer the natural conditions of the area, in spite of recommendation given by 'environmental impact assessment' team in 1997 and re-evaluation team in 1998. It seems that the plan was designed only on the desk, not in the field. The plan seems to put its goal to catch up with the agricultural style in Java or Bali, but the natural and social condition is far from its adaptable level. As a result of the project, chaotic and disordered development practice was undertaken in peat swamp area of Central Kalimantan.

The most apparent evidence of this is the canal system built by MRP. Its route is simply drawn on the desk, not referring to the topological and hydrological conditions of the site. We can find many canals that are dried up, or partly dammed up into several sections to avoid over-drainage when we fly over the area. It is obviously shown that those canals are functionally useless for irrigation or drainage purpose. These evidences also apparently show that the plan was drawn without considering the gradient of the water flow, which is most essential for canal design. The quite basic questions must be thrown to the planners; "Why did they draw such plan? Did they really intend the water to flow there? And, for what purpose they planned the canals?"

4. Land Use

There are three principles that are already agreed in agricultural group of Japan Society for the Promotion of Science (JSPS) program.

1. No need for new exploitation (or opening) of the forest.
2. Establishing the sustainable production system on the land that already opened for agriculture.
3. Restoring or rehabilitating the damaged forest and abandoned land.

From 1998, agricultural group of JSPS program started several researches on agricultural conditions of this area, visiting several villages and making interviews with local people. Many villages that we visited are transmigration villages, and almost all farmers possess 2 hectares of land and home yard. We found some of them are relatively in good situation. But according to the interview with them, it become apparent that many of them cannot fully utilise their 2 hectares farmland, mainly because of lack of labour. They do not have enough labour, cattle which they can use, and no machinery. Many of them only use 1 hectare or so. In the surroundings of the village and utilised farmlands, there is a vast area of abandoned lands, which once prepared for agricultural use, that we can still utilise without opening the forest.

I also want to point out that several villages are doing relatively fine in agriculture. Some of them are near to the city so that they can supply vegetables and fruits. They have good market. But not only with those in lucky situation, some other villages are doing several efforts to improve their agricultural conditions. We need to put more attention to those villages that are trying to get more opportunity. We need to encourage the existing farmers and villages to improve their ability of agriculture.

As already mentioned, there are quite vast lands still exist that are over-exploited. It means that, there is some extent of lands that once opened, but no one can utilise because of its natural condition. These lands mainly found in the dead end of the canal (*anjir*), interior land that is very far from the river. The soil is poor, and we commonly can found peat deposit.

Such abandoned or damaged land seems to be quite difficult for agricultural use, due to soil nutrient condition, drainage condition, and house hold conditions, etc. Such area should be concerned as the buffer between the developing area and the native forest. We need more discussion on land use of this buffer zone. To establish low-intense land use, like forest for fuel use, may be the one idea

Conservation of the forest is another important matter. Quite a large area was already opened for agricultural purpose. Large part of this area is still remained unused. So why we need to open another virgin land for development? So many researchers emphasise on the regional and global importance of tropical peat swamp forests. We also need to recognise that new exploitation is waste of nation’s resources. They are not only wasting land resources, water resources, or biological resources, but also wasting a lot of money and people’s tax.

5. Keys for Developing Lowland Central Kalimantan

First, it should be emphasised again that there are no needs for new exploitation of the forest. It should be conserved as one of the treasure of Indonesia, and we need to hand it over to our next generation.

Second, we must recognise that there is no sustainable use of tropical peat itself, as Rieley (1999) and many others already emphasis. We already found several places that the peat layer almost disappeared. All those area faced to the difficulty of agricultural production, and also the degradation of environment, such as water pollution. It is much better to exclude peatland from developing area, but when we need to deal with tropical peat, we should consider about the problem caused by the rapid disappearance of peat.

Third point is that the rice is not only the crop that should be considered to cultivate in this region. The way of thinking of rice-cultivating people such as Japanese, Javanese and Balinese must be omitted. Many other crops or agricultural form beside rice cultivation must be considered.

Fourth, we need to think deeply about the goal of development. The economical growth is not only the goal. The local people’s quality of life must be considered, too. There are no issue if the development effects the people’s way of life directly, but several evidences suggest that there are many problems exist on this matter.

The conservation of tropical peat swamp forest is not only the required answer in this area. Local people really need the development. It is quite difficult question to find out the answer, to find out the break through to the environmentally adaptable development.

We need to learn a lot of hints from the evidence of traditional land use style. Sumawinata (1992) mentioned the Banjarese people's practices on land use of lowland area. The principle is 1) to keep the drainage to the minimum, so as to depress the oxidation of pyritic sediments, 2) to employ traditional methods of swampland rice cultivation, and 3) to conserve secondary *Melaleuca* forest by shifting cultivation of rice with long-term planting and long-term fallowing periods. It is very important to learn from these traditional farming systems, because they should have been harmonised with the environment of this area for long time.

Learning from the history of development of this area is also significant. We already know that some areas near to the coast have more than fifty years of history of agricultural land use. More or less, there are many transmigration villages with more than ten years of history after its establishment. The local people there have a lot of experience and know-how on development and management of their land.

Learning from practices of leading farmers, or advance and energetic farmers of the area is also important. We meet many farmers who are trying to improve their farming. They suggest many things on land management and farming practices in the area. Many hints may be learned from the field.

6. Importance of Hydrological View Points

It is quite important to know how is the condition of groundwater (or surface water), its form and range of fluctuations, influence of the canal on the surroundings, etc. on peat land. The hydrological conditions play a basic role in movement of many substances, sustainability of peat itself, and agricultural productivity.

In 1998, with collaboration with the University of PalangkaRaya, hydrological monitoring stations on three sites in the area were established. One in the farmland, one in the abandoned shrub, and another in the forest. The purpose of measurement is to clarify the water balance on each land use, and to measure the speed of land subsidence. For this purpose, we set transect and benchmark on each site and conducting levelling survey. Transect was also settled to define the influence of drainage to the groundwater table. At each of these monitoring stations, we are measuring amount of rainfall, groundwater level, atmospheric temperature, and soil surface temperature. Each of them is measured continuously by using data logger.

Compare to the other monitoring factors such as biological study, monitoring of hydrological condition is quite simple, easy, and fast to detect. The influence of impact will appear immediately to the change in hydrological condition. Moreover, the hydrological study is essential for revealing the characteristics and nature of the peatland. Without any hydrological information and knowledge, any kind of conservation and/or development work could not be done. It is highly necessary to gain more information on hydrology and related interests on tropical peatland.

Acknowledgements

The author wish to thank Dr. Mitsuru Osaki of Hokkaido University, Dr. Supiandi Sabiham of Bogor Agricultural University (IPB), Ir. Mr. Suwido H. Limin, Ir. Mr. Adi Jaya, and Ir. Mr. Sehat Jaya of the University of Palangka Raya, Ir. Mr. Dedi Kusnadi

Kalsim, Dr. Suwarno and Ir. Mr. Untung Sudadi (IPB), and other members whom we work and discussed together during the field study in Central Kalimantan in 1998 and 1999.

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