

Ombrogenous Peat Swamps and Recommended Uses in Tropical Areas

1. Background

1.1. Formation of ombrogenous peat swamps

Formation of ombrogenous peat is a geogenic process that results in the accumulation of plant debris in an environment that slows down the natural breakdown of the organic materials. The retarded breakdown is caused by a prolonged flooding in those coastal lowlands that are subject to a Tropical Rain Forest climate. In Indonesia the ombrogenous peatlands are mostly formed on the inward edge of the mangroves. They are usually dome-shaped and several meters thick overlying the mangrove mineral soil; the whole sequence taking several thousand years.

Periods with rising sea levels promote the formation of very deep peat layers up to 20 meters thickness with the alluvial soil far below present sea levels. Peat domes younger than 3000 years do have the alluvial soil at about present mean sea level. Not all peat dome soils are overlying this alluvial/marine subsoil. Sometimes old deposits are found of poor whitish, very acid sandy to clayey soils below the peat soil.

The initial rate of vegetation growth and peat build-up is rapid, since the alluvial mangrove soils are nutrient-rich. As the peat accumulates, it builds up above the level of the nutrients in the alluvial soils that are accessible for the plant roots. In that case the mineral supply to the vegetation completely depends on the minerals in the rainwater and the available nutrients of the decaying vegetation in the surface layer. Therefore, as the swamp ages and the peat layer thickens, nutrients become increasingly scarce, the tree growth and litter production are reduced and growth of the whole formation slows down.

The inner parts of the peat dome areas usually are flatly shaped, but are the highest in elevation. They are very poorly drained with water levels at or slightly above surface level for most of the year. Vegetation is poor with a slow stunted growth of trees. It is an open savannah-like “padang paya” forest with trees not exceeding 10-15 meter in length, but mostly much lower. On the edges of the peat dome the drainage conditions are usually better and the soil more compact, resulting in a more vigorous growth of the virgin peat forest. The natural slopes along the edges of the peat dome could be relatively steep with slope rates of 2-4 meter/km. Despite these relatively high slope rates, also on the edges of the peat dome the ground water level never drops here more than 40 cm below surface under natural conditions.

1.2 Nutrients in Peat swamps

The nutrient contents in the ombrogenous peat swamps may vary, although all ombrogenous peat soils classify as low or very low in fertility. The original virgin forest (with no tree cuttings) shows the highest levels with especially the phosphorus and potassium levels relatively high in comparison with the reclaimed peat dome areas. In these reclaimed areas P and K nutrient levels may become critical by tree extraction and by decomposition and leaching of the surfaces layers. Other minerals that become scarce after reclamation are copper, zinc, borium, sodium and calcium.

In addition, the high concentrations of hydrogen ions (caused by the low pH of these peat soils at levels of pH 3.0-4.0) means that toxic components damaging the plant growth become more soluble. Toxic levels of manganese, iron, aluminium, phenols and tannins are common in the acid peat soils.

A special problem in the nutrient supply of reclaimed peat soils is related to the forming of hydrophobic peat surfaces in areas with annual crop cultivation. By direct exposure to sun light during cultivation the peat soil becomes irreversible dry in the surface layer and will change into dry pellets. (=hydrophobic peat soil, that means no biological activity is possible anymore and nutrient supply stops for these dry peat pellets). Direct sun-light exposure may raise temperatures in the peat surface layer to more than 70 degrees Celsius in peat soils and will cause this irreversible drying. Adding mineral soil, sand or volcanic ash to the surface will prevent this increase of the soil temperature by sunlight, but in practice is excessive expensive.

1.3 Hydrological effects in peat swamps

Often is mentioned in literature the sponge working of the peat domes. These peat domes are higher situated than the surrounding lands that means a natural flow of excess water can be expected. From observations it appears these outflows from the peat domes may extend far into the dry season. However these observations also prove that only the surface layers are subject to significant water flow and this flow depends mainly on the availability of surface water on the flat inner part of the peat domes. As soon the water drops below surface here the flows from the peat dome will be strongly reduced.

Drainage of peat soils is essential to enable agricultural development (including oil palm). However drainage of peat domes will cause subsidence of the peat surface. The soils become firmer as result of compaction and decomposition of the drained surface layer which is reflected by higher bulk density values, a higher bearing capacity and a reduced total spore space.

Subsidence and the rate of subsidence are major factors in assessing the sustainable drainage potential of ombrogenous peat swamps. When peat surface levels drop below average water level in adjoining canals no drainage is possible anymore and sustainable agriculture development will be impossible.

1.4 The CO₂ Emissions in drained peat swamps.

When peat swamps are drained for development purposes then there will be a yearly subsidence caused by oxidation of the organic matter. This oxidation will cause CO₂ emissions that will contribute to the yearly worldwide total amount of CO₂ emissions of fossil fuels. A drained peat land will release about 50-100 tons/year/ha of CO₂ emissions. It is estimated that in the whole of SE Asia about 7 million ha of ombrogenous peat lands are drained now. In that case the drained peat lands used for agriculture in SE Asia will contribute to about 0.35-0.7 gigaton CO₂/year, or about 5-10% of the total yearly worldwide CO₂ emissions. These estimates include burning of peat lands during extreme dry years and are based on many years of monitoring in the drained peat lands.

2. Assessing Land Qualities of peat soils to determine Suitability

Because so many ombrogenous peat lands are deforested now and also drained for agricultural purposes it is highly recommended to assess its sustainable use for the various agricultural and forestry options for development. For that reason we have to assess the relevant Land Qualities to determine the Suitability.

2.1. The Nutrient content

The nutrient content of the peat soils is an important land quality that determines its potentials. It is often expressed in the total ash content and its contents of minerals per volume of soil. The ash content is determined by burning at 600 °C of peat samples collected from a depth of 0-20 cm and measure its weight per volume of soil. These samples are obtained using soil sample rings of fixed volume. All ombrogenous peat soils belong to the fertility classes Low and Very Low.

Table 1. Ash content and fertility expressed in kg/ha for the layer 0-20 cm

<i>Fertility class of peat soil</i>	<i>Total ash content (0-20cm)</i>
High fertility	>60,000 kg/hectare
Medium fertility	20,000-60,000 kg/hectare
Low fertility	10,000-20,000 kg/hectare and P ₂ O ₅ >400 kg/ha
Very low fertility	<10,000 kg/hectare and/or P ₂ O ₅ <400 kg/ha

The fertility level of ombrogenous peat soils can be improved by adding fertilizers. For tree crops like oil palm often copper and borium is added in the first two years after planting. Zinc, phosphate and potassium is added during the continuing growth period of the tree at regular intervals. Lodging of the oil palm tree caused by subsidence is prevented by planting in 50 cm deep plant holes.

Other tree crops like sago and pulp wood normally only require applications of minerals that compensate for the extracted minerals of the harvested trunks.

Annual crops (including horticultural crops) are not recommended for peat soils with a Low to Very Low Fertility because they are most susceptible to the formation of hydrophobic peat. Only when high applications of minerals to the peat surface, like clay soil, sand or volcanic ash, are economically viable, annual crops should be recommended. These mineral applications will increase the specific heat capacity of the ombrogenous peat that will decrease the hazards for the formation of hydrophobic peat by direct sunlight exposure. Applications of about 40 tons of soil/ha are required to be sustainable for annual cropping. Farmers at subsistence level often burn the hydrophobic peat combined with remnants of crops and weeds and add the formed ashes to the plant holes. (like for maize). It means in practice that for the Low and Very Low Fertility peat soils only crops that permanently cover the surface, like tree crops, will be recommended.

2.2. The Drainage Potential

Without a potential for drainage there will be no sustainable development for Agriculture or Forestry on the ombrogenous peat soils. Soil compaction together with drainage of the surface peat layers is needed to increase availability of the nutrients. This will cause subsidence and the yearly rate of subsidence depends on the depth of drainage below surface and the amount of soil compaction. The mechanical compaction of the surface peat layers is recommended during the initial reclamation before planting the trees. By using the drainage system, oxidation of the organic matter will increase the subsidence rate.

2.2.1. The Subsidence Rate

To determine the drainage potential, first an estimate has to be made of the expected soil compaction and total subsidence. This depends on the land use and the required drainage depth for each crop. Table 2 shows the required drainage depth and the total subsidence 10, 20 and 40 years after reclamation, related to the land use. These subsidence rates are estimates based on actual measurements in Indonesia and Malaysia.

Table 2. Total subsidence 10 , 20 and 40 years after reclamation

Land Use	Required drainage depth below surface	Initial mechanical peat soil compaction	Total subsidence including soil compaction after 10 years	Total subsidence including soil compaction after 20 years	Total subsidence including soil compaction after 40 years
Oil Palm	70 cm	40 cm	120 cm	200 cm	350 cm
Pulp Wood/ Sago	50 cm	20 cm	90 cm	140 cm	220 cm
Slow growing forestry	30 cm	0 cm	10 cm	20 cm	35 cm

Note: In case the peat layer is less in thickness than the indicated total subsidence then the total subsidence will be equal to the peat thickness.

2.2.2 Assessing the drainage potential by computer modeling

The drainage potential of the ombrogenous peat soils depends on gravity drainage towards the adjoining rivers. A minimal water level slope in the drainage system is required of about 20 cm/km canal length to enable sufficient drainage potential. By continued subsidence peat lands may lose their potential for gravity drainage. Pump drainage is not an option for Tropical peat soils as the costs for pumping of excess water are too high in Tropical Rain Forest Climates. Measurements of the actual topographical levels, including the depth to the mineral subsoil, are required to determine the drainage potential. These measurements should include the topographical levels of the water levels in the adjoining river during the peak of the wet season. By modeling (Duflow) the drainage canal lay-out and its connection to the adjoining river, the actual drainage potential can be determined. The modeling should be created for the different land uses

and its required groundwater level and should use the hydrological measurements and the expected daily rainfall, during the rainy season.

Because the actual drainage potential might not be sustainable for the future the Duflow modeling should be repeated based on the expected subsidence of the peat layers at respectively 10 years, 20 years and 40 years after reclamation. This Duflow modeling will provide the best estimates for the sustainability of the present or proposed land use on the ombrogenous peat domes.

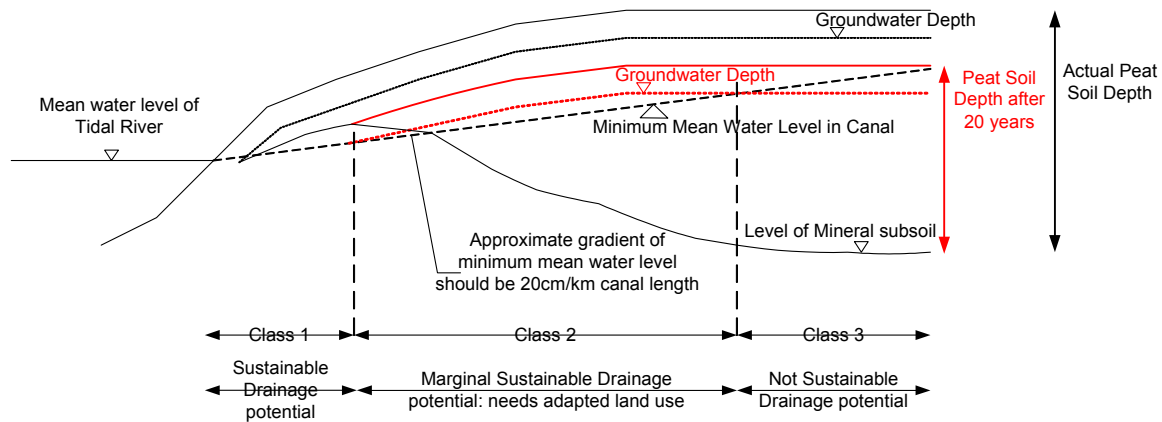
2.2.3. Identifying marginal drainable peat areas

During field surveys it might be necessary to locate the marginal drainable peat areas using field data only. These marginal drainable areas will require additional Duflow modeling to assess their potentials. To identify marginal drainable areas and to separate them from areas without drainage problems the assessment of collected field data are recommended. Three land qualities are proposed to use for this purpose: 1) the assessment of the Potential Drainage Depth (for definition; see below), 2) the assessment of the Tidal Range and 3) the Mean Water Level. The latter two hydrological/ land qualities should be determined during the wet season in the adjoining river. Still for final evaluation a Duflow modeling would be required, complete with a canal lay-out modeling.

Areas without drainage problems will have a positive Potential Drainage Depth combined with a Tidal Range of more than 2.5 m in the adjoining river. Table 3: Drainage potentials and recommended land uses, presents also the limits that indicate the marginal drainable areas requiring more detailed investigations including the Duflow computer modeling. Also ombrogenous peat domes with a tidal range of less than 2.5 m in the adjoining river are considered marginal drainable areas that may have drainage problems, certainly when tree crops such as oil palm are grown.

Definition: The Potential Drainage Depth is defined as the topographical level of the bottom of the peat layer above the minimum mean water level in the adjoining canal.

Example to assess sustainability of drainage potential in Peat Soils



Definition: The Actual Drainage Depth is the actual topographical level above the mean water level in the adjoining canal. *) See note below)

Table 3: Drainage potentials and recommended land uses.

Recommended Land use	Potential Drainage Depth above Mean Water level in adjoining river Tidal Range >2.5 m	Actual Drainage Depth above Mean Water Level in adjoining river, Tidal Range >2.5 m. Not yet Reclaimed Area	Actual Drainage Depth above Mean Water Level in adjoining river, Tidal Range >2.5 m. Reclaimed Area	Tidal Range in adjoining river <2.5 m
Oil Palm	>80 cm	>3.1 m	>2.5 m	Not sustainable
Pulp wood/sago	40-80 cm	>1.6	>1.2 m	Needs Duflow modeling
Slow growing Forestry option	Always Sustainable	Always Sustainable	Always Sustainable	Always Sustainable

Note: Land Uses that do not meet these criteria require a Duflow modeling for a final recommendation.

The recommendations for the Actual Drainage Depth are only valid for 10 years Pulp Wood/Sago cultivation and 20 years Oil palm cultivation. For estimates of prolonged land uses a Duflow modeling is recommended. The Potential Drainage Depth gives an indication of permanent sustainability.

*) Note: Minimum mean water level in adjoining canal is the mean water level during maximum drainage conditions by use of the water control infrastructure in the adjoining main canal.

3. Water Management

3.1. Recommended Groundwater Levels

Plantations of tree crops, including the slow growing Forestry option need groundwater levels below surface to be successful. This recommended depth of groundwater levels depends on the planted crop.

- ❑ Oil palm plantations require a groundwater level of 60-80 cm below surface. During high rainfall only for less than 2 days higher groundwater levels are permitted.
- ❑ The pulp wood and sago plantations require a groundwater level of 40-60 cm below surface. During high rainfall periods shallower groundwater levels should not exist more than 5 days.
- ❑ Slow growing forestry option require a groundwater level of 20-40 cm below surface. During high rainfall periods shallower groundwater levels should not exist more than 10 days.

The deeper the groundwater layer will be maintained below surface, the faster the subsidence will proceed. It is assumed that a constant groundwater level at 20-40 cm below surface will prevent subsidence almost completely; certainly in the slow growing forestry option.

3.2. The Water Control System

3.2.1. The ditches

Ditches are recommended at a spacing of 50 m apart for all plantation options. The depth of the ditches depend on the crop that is planted:

- ❑ For oil palm the required depth of the ditch is about 100 cm
- ❑ For pulp wood/sago the required depth is about 80 cm
- ❑ For slow growing forestry option the required depth is about 50 cm.

About 10-15 years after reclamation the ditch spacing should be reduced, caused by the reduced permeability of the soil after prolonged subsidence. The recommended spacing will be then about 25 meter with the same ditch depths as recommended above.

In old plantations the recommended ditch spacing might be reduced to 12.5 m. The ditches in ombrogenous peat soils need frequent cleaning as the loose, highly permeable peat soil of the ombrogenous peat soil easily flows into the ditch. After the mechanical peat soil compaction directly after reclamation and the prolonged subsidence the surface soils become more compact and ditches stay longer clean at the required depth. In practice at least twice a year cleaning of the ditches is required for the first 10 years after reclamation.

3.2.2. The structures

Structures are difficult to construct in peat soils caused by the continued subsidence that will cause collapse of all constructed structures. For that reason overflows are recommended build from soil-filled bags and protected by plastic sheets and wooden poles. This type of structures require regular maintenance.

Because ombrogenous peat domes show considerable slope along the edges there is a need of many overflow structures along the slope to control water levels at the required groundwater depth inside the plantations.

In the dry season the overflow structures will be kept at a high level to prevent drop of groundwater level. During the wet season the overflow level should be considerable lower to enable sufficient drainage during high rainfall. This will cause that during the wet season frequent adaptations of the overflow level of the structures might be required when wet periods are followed by dry periods.

4. Recommendation

Applying the assessment of the proper Land Qualities for sustainable use of the deforested Tropical Peat Lands might reduce its present contribution to the world wide CO₂ emissions considerably. This Land Quality assessment would also contribute to the Regional Development Plans by the Government for many coastal areas in Sumatra, Kalimantan and Irian Jaya

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