Land & Water Management in Peat Swamp Lands of Indonesia

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Abstract

Deep peat soils in Indonesia are mostly ombrogenous peat dome soils of the fibric/hemic type with a low to very low fertility. Presently they are reclaimed or seriously disturbed over large areas. Beside a loss of nature and wild life it also causes large emissions of CO_2 by oxidation of the peat with a significant contribution to the Greenhouse effect. Drainage of peat soils causes subsidence. This means that there might be no sustainable drainage potential anymore after a number of years. In natural conditions there is interflow from the central dome towards the edges of the peat dome, which keeps water levels high. After construction of canals excess deep drainage can be prevented by implementing dams in the canals with by-passes. Besides conservation of the central peat dome stays essential for sufficient interflow during the dry season. Computer modeling of the flows, including interflow, can assess the effect of subsidence to the drainage potential. An adapted land use, conservation from the central peat dome and better water management can reduce the subsidence and CO_2 emissions by up to 80%. Figures of land use, drainage depth and subsidence are given in this paper. The paper offers also an alternative method to determine CO_2 emissions from oxidation of fossil peat, based on Driessen and Soepraptohardjo (Bogor,1974). The often used CO_2 gas flux measurements with closed chambers are not accurate in assessing the CO_2 emissions by oxidation of fossil peat. The PEAT-CO_2 discussion also requires a Nation Wide investigation of the already reclaimed/drained areas and computer modeling to assess its limits of drainage potentials after subsidence.

Keywords: *ombrogenous peat swamp lands, land & water management, land use, subsidence, drainage potential, interflow, computer modeling, CO2 emissions.*

Introduction

Based on the Nation Wide Study of Coastal and near-Coastal Swamplands (Nedeco-Euroconsult-BIEC, 1984) there are in the coastal zones of Indonesia about 9 million ha of mineral/peaty soils and relatively shallow peat soils (less than 2 m of peat soil). Further there are about 16 million ha of deep peat soils of more than 2 m thickness. Reclamation and Development of both types of soils is very environmental sensitive. However they are presently reclaimed already on a large scale. This means that first of all there is an urgent need for better protection and management of the identified remaining conservation areas. But also there is a need for a clear management policy to sustain and improve the existing development as much as possible by the introduction of the proper technologies. Failures to sustain and improve the existing development will only increase the pressure on the Conservation Areas in the Swamps, mainly caused by a need for income, resulting in illegal logging and new land clearing. This paper will concentrate on the recommended management of mainly deep peat lands that are already reclaimed. It will look at the water management requirements for these peat soils and its limitations.

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Also an insight will be given to the expected CO2 emissions that contribute to Greenhouse effect in the atmosphere.

Background

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. Measurements of average peat depth increase per year shows a rise of 1.8 mm/year for the ombrogenous peat domes in the last 5000 years. This is based on C_{14} age determinations and the peat depth. (Driessen and Subagio, 1974).

Periods with rising sea levels promote the formation of very deep peat layers up to 20 meters thickness with the marine/alluvial mineral soil far below present sea levels. 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 height, 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 1-4 m/1000 m. The rate of slope depends on the peat characteristics. Fibric peat will have higher permeability and a flatter slope and Hemic/Sapric peat soil will have lower permeability with steeper slopes.

Nutrients in Peat swamps

The nutrient contents in the ombrogenous peat swamps may vary, although all ombrogenous peat dome soils classify as low or very low in fertility. (See Table1) 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, aluminum, phenols and tannins are common in the acid peat soils.

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

Fertility class of peat soil	Total ash content (0-20cm)
High fertility	>60,000 kg/hectare
Medium fertility	20,000-60,000 kg/hectare
Low fertility	10,000-20,000 kg/hectare and/or P_2O_5>400 kg/ha
Very low fertility	<10,000 kg/hectare and/or P_2O_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. Planting in 50 cm deep plant holes prevents lodging of the oil palm tree, caused by subsidence.

Other tree crops like sago and pulpwood normally require regular applications of minerals that compensate for the extracted minerals of the harvested trunks.

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 subsurface flow, called interflow, of excess water can be expected towards the lower areas. The result will be that on the peat dome and its edges, the ground water level never drops more than 40 cm below surface under natural conditions.

Drainage of peat soils is essential to enable agricultural development (mainly oil palm and pulpwood). 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. This fact is the main limitation factor in sustainability of ombrogenous peat soil development

Methods

The Drainage Potential

Without a potential for drainage there will be no sustainable development 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. The assessment of the Drainage Potential will require a detailed topographical survey of the hydro-topography of the Peat Dome. This should include of the depth of the peat until the bottom mineral layer.

Definition: The Drainage Potential is defined as the actual topographical level minus the needed groundwater depth of the crop above the calculated potential minimum water level in the adjoining canal to sustain sufficient gravity drainage.

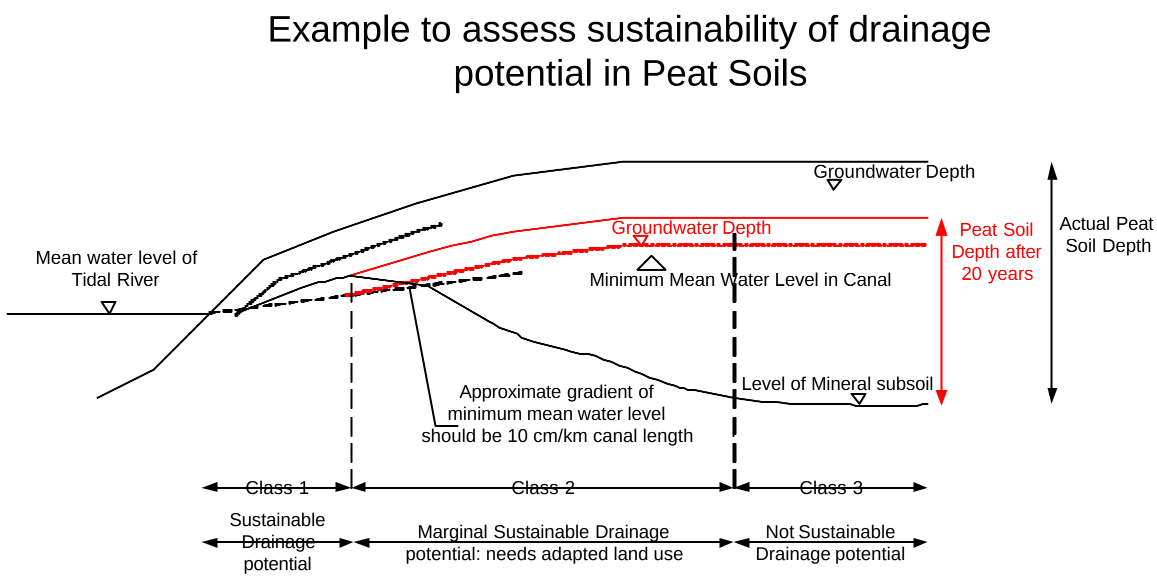
Assessing the drainage potential by computer modeling

By continued subsidence most deep 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. By modeling (/Balance/Duflow/Modflow) the drainage canal lay-out and its connection to the adjoining river, the actual drainage potential can be determined. The needed calculated drainage quantity should include the excess rainwater from the canal catchment area and an estimate of the interflow from the central peat dome towards the drained border area. The interflow could have also a major impact at the lower part of the slope from the central dome and will cause flooding in extreme rainfall conditions.

For this reason monitoring for at least 1 month during the peak of rainy season is required. That should include rainfall, estimates of evaporation, groundwater levels, topography levels at border central peat dome and along the slope towards the adjoining rivers, size of the central peat dome, flow volumes in outlets of the primary canals bordering the central peat dome.

The measurements for rainfall, evaporation, flow volumes in canals and groundwater levels are also required during the dry season. In that way the effect of the interflow effect from the central peat dome during the dry season could also be modeled.

Figure 1: Assessing Drainage Potentials.



Because the actual drainage potential might not be sustainable for the future the Balance/Duflow/Modflow 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 computer modeling will provide the best estimates for the sustainability of the present or proposed land use on the ombrogenous peat domes.

A rough estimate of the potential minimum water level in adjoining canal after subsidence is possible by assuming a minimum needed slope of 10-cm/1000 m. along the canal, starting from the mean water level in the adjoining river.

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	40-60 cm	20 cm	50 cm	75 cm	125 cm
Adapted 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. Adapted Forestry means tree plantations that are adapted to shallow groundwater levels. The expected subsidence assumes an optimum water management system that can keep the groundwater levels at the required depth.

Alternative CO2 emission assessments

In most cases CO2 emissions that contribute to the Greenhouse effect are determined by using gas flux measurements with closed chamber method. This method needs alternative CO2 emission determinations for comparison. The reason is that the gas flux measurements cannot separate the fossil peat CO2 emissions from the green matter CO2 cycle in a forest. While only the CO2 emissions from fossil peat will contribute to the greenhouse effect. Ombrogenous peat domes are mainly fibric peat in most cases with a bulk density of about 0.1 g/cm3. Further drainage and subsidence in the fibric peat of the ombrogenous peat domes will have an estimated compaction rate of 60% and an oxidation rate of 40% in the first 10-20 years. Besides fibric peat consist for about 50% in weight of Carbon (C). This means that per cm of subsidence there is 0.4 cm oxidation of fossil peat. This is equal to 0.4*0.1=0.04 g/cm2 surface. The 0.04 g/cm2 fibric peat consist of about 0.02 g/cm2 Carbon, which equals 44/12*0.02= 0.073 g/cm2 CO2 or an emission of $0.073*10^8/10^6$=7.3 ton CO2/ha for each cm subsidence.

Driessen and Soepraptohardjo (Bogor,1974) used a method that determined the percentages of compaction and oxidation, based on bulk density measurements before and after subsidence and the total amount of subsidence in that period. For recently reclaimed peat soils the compression will be most likely the major contributor to the subsidence. With time the mineralization will be most likely become a more important contributor to the subsidence. The total weight of mineralization/ oxidation per unit of surface will provide the total loss of fossil peat, expressed in the total weight of CO_2 production. The method will determine the total amount of mineralization/oxidation of fossil peat (V_{min} *BD_1) and the total amount of compression (V_{comp}*BD_1) that contributes to the subsidence.

$V_{min} * BD_1 = (V_1 \text{ x } BD_1) - (V_{rest} \text{ x } BD_2)$

$V_{comp} * BD_1 = V_{rest} \text{ x } (BD_2 - BD_1)$

1) V_{min} = volume of the mineralized peat that caused subsidence(cm3)
2) V_{comp}= volume of the peat that contributed to subsidence by compaction(cm3)
3) V_{rest} = volume of peat after subsidence until deepest groundwater level during test(cm3)
4) V_1 = volume of peat before subsidence until deepest groundwater level during test(cm3)
5) BD_1= average bulk density of the peat until deepest groundwater level during test, measured before subsidence (g/cm3)
6) BD_2= average bulk density of the peat until deepest groundwater level during test, measured after subsidence (g/cm3)

These measurements are subject to variations in the soil pits, multiple samples have to be collected for each layer of 15-20 cm thickness. However the total amount of subsidence can be accurately determined in the dip wells.

The amount of mineralization/oxidation in comparison of the amount of compression will than the base to calculate the total CO_2 emission per ha during the subsidence measurement period.

Water Management

Recommended Groundwater Levels

Plantations of tree crops, including the adapted 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 10 days.

- Adapted forestry option require a groundwater level of 20-40 cm below surface. During high rainfall periods shallower groundwater levels should not exist more than 20 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.

The Water Control System

The ditches

Ditch spacing and ditch depth should to be adapted to the drainage requirements for the plantation type:

- For oil palm the required depth of the ditch is about 100 cm with a spacing of 50 m
- For pulp wood/sago the required depth is about 80 cm with a spacing of 100 m
- For adapted forestry option the required depth is about 50 cm with spacing of 100 m.

About 15-20 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 m. for oil palm with the same ditch depths as recommended above.
In old plantations the recommended ditch spacing for oil palm might be reduced to 12.5 m. Also for the other plantation types the ditch spacing might be reduced with 50-75% when they become older. 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.

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 and should be made in the smaller canals e.g. tertiary canals.

Because ombrogenous peat domes show considerable slope along the edges The main canals perpendicular to the river should have dams with by-passes for sufficient drainage potential during high rainfall periods. Each dam should allow a drop of water levels in the main canal of not more than 50 cm. That means that on a slope of 1 m/1000 m the main canal should have a dam each 500 m. The by-passes should allow a maximum drop of 50 cm upstream/downstream of the dam. The overflows in the by-passes are usually wide dams, with each by-pass at a different overflow level. Compacted peat is used for the overflow dam. On the steeper peat dome slopes water level drops of up to 1 m for each dam might be possible as also the permeability of the peat soil will be less in the field.

Figure 2: Canal system in pulp wood plantation on 5-10 m deep peat in Kampar region. Note the dams with the by-passes.

The main dam in the canal should be made also from compacted peat and about 10-12 m in width. This width is needed to prevent side-and underflow in the not very stable compacted peat. It means also that these dams should be made and maintained by excavators (not manually). It means also that the presence of maintenance roads along the canals is essential to operate and maintain a reclaimed deep peat area.

Maintaining high water levels during the dry season

In the dry season the areas on the slope of the peat dome might have large drops of groundwater levels, resulting in sever levels of subsidence. This can be easily solved when the central dome will not be drained and developed. The interflow from the central dome will in that case supply sufficient water to the areas on the peat dome slope to keep water leve ls high. The peat dome will work then as a real sponge.

The CO_2 Emissions in drained peat swamps

When peat swamps are drained for development purposes then there will be a yearly subsidence caused by compaction of the upper soil and oxidation of the organic matter above the groundwater level. The 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 with groundwater levels below 70 cm from surface or deeper. It is estimated that in the whole of Indonesia about 10 million ha of ombrogenous peat lands are drained now, mostly below 60 cm from surface. In that case the drained peat lands used for mainly tree crop plantations and industrial forest plantations in SE Asia will contribute to about 500-1000 Mt CO2/year, or about 1.7-3.4% of the total yearly worldwide CO2 emissions of fossil fuels.

As can be seen from the adapted land uses and its subsidence rates, the total level of CO2 emissions can be reduced from 50-100 tons CO2/year/ha to 12-15 tons CO2/year/ha.

3. 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 of fossil fuels considerably. This Land Quality assessment would also contribute to the Regional Development Plans by the Government for many coastal areas in Sumatra, Kalimantan and Papua.

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Maps of the Nation Wide Study van be found and downloaded on the Tidal Lowlands website (right click on the required map and use Save target as…
http://www.tidal-lowlands.org/rawa/
User name: tamu
Password: banyuasin