MANAGING PEAT SOILS UNDER OIL PALM

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Introduction

Total oil palm area in Malaysia in 2007 is estimated to be 4,304,913 hectares. Currently, the country is the world's second leading producer of palm oil, after Indonesia. In 2007, the annual production was 15,824,000 tonnes of crude palm oil with export earnings of oil palm products estimated at RM 45.17 billion (MPOB, 2008). Sarawak has 664,612 hectares of oil palm plantations with an annual production of 7.8 million tonnes of fresh fruit bunches (FFB) (MPOB, 2008).

Suitable land for oil palm cultivation in Malaysia especially in Sarawak has become a scarce resource. For further development and contribution to the state's overall agricultural production, rural development and economic growth, it is necessary to expand into peat lands. In Malaysia, oil palm has been successfully planted on peat soils for two generations and into its third now. Development of oil palm plantations on peat land is therefore not m new. Oil palm is currently the most economical perennial crop for planting on peat soils as it gives the best return on investment when properly managed.

The main objective of the paper is to highlight the main agro-management practices for sustainable cultivation of oil palm on peat soils.

Classification and Distribution of Peat Soils in Malaysia

Peat is developed in large water-logged basins from dead natural vegetation under anaerobic condition where the rate of organic matter (OM) buildup is faster than the breakdown. It is defined as a soil that contains at least 65 % OM (<35 % mineral material), is at least 50 cm in depth and cover an area of at least 1 ha. Tropical lowland peat is acidic with pH of 3-4 and low in minerals with ash content generally less than 2 %. Tropical peat soil is commonly classified as a Hydric Tropohemists, dysic, isohyperthermic (Soil Taxonomy, 1992) although Troposaprists and Tropofibrists are also found. The definition of hydric connotes "to have a layer of water within the control section beneath the surface tier." Tropical peat is generally heterogeneous as it contains admixtures of fine and fibrous materials as well as woody fragments which had developed through time from the residues of trees and shrubs or other plants that occupy the forest floor of the swamp.

The dates of initiation of tropical peat swamps in Southeast Asia vary considerably between 9600 and 800 radiocarbon years BP although most of the ages fall after 6000 BP (Chapman, 2002). During this period, the rates of accumulation of peat showed marked periodicity being influenced by climate, sea level, topography and underlying substratum. Lately, human activity has also been associated with the negative rates particularly in the eighteenth and nineteenth centuries during British colonial occupation in Jamaica (Chapman, 2002). Similar event was likely in Southeast Asia as radiocarbon dating showed a drastic change in vegetation during the same period (Rieley et al., 2008). Thus, the notion that peat always accumulates is probably a misconception.

In Malaysia, most of the peat is found along the poorly drained coastal areas where the peat usually overlies marine alluvial clay or sandy deposits. There are 2.365 million ha of peat in the whole of Malaysia with 810,000 ha in Peninsular Malaysia, 86,000 ha in Sabah and 1.47 million ha in Sarawak (Table 1).

Table 1: Distribution of peat in Malaysia

State	**Approximate area under peat (ha)**
Johore	216,000
Pahang	285,000
Selangor	182,000
Perak	69,000
Terengganu	46,000
Kelantan	11,000
Negeri Sembilan	4,000
Sabah	86,000
Sarawak	1,466,000
Total	**2,365,000**

Peat Types, Peat Depth and Topography

Peat types in Sarawak

Upon alienation of the peat land for oil palm development, it is of utmost importance to determine the existing forest type or the original vegetation on the peat via the forest type map (Melling *et al*., 2007). Vegetation or forest types determine the type of peat formed which will influence both the biophysical and chemical characteristics of the peat. Biophysical characteristics play a significant role in both the method of land development and water management especially in Sarawak peatlands whereas the chemical characteristics determine the initial fertility of the soil.

There are six forest types across a peat basin in Sarawak although only three of them are dominant. They are Mixed peat swamp forest, Alan forest and Padang Alan forest. The main difference amongst them is the morphological structure of peat profile which directly influences both the physical and chemical properties of the peat such as the bulk density, porosity, woodiness, water holding capacity, chemical composition and hydraulic conductivity. Thus, an understanding of these peat types is essential towards the correct implementation of various operations e.g. destumping and peat compaction during land development to oil palm. This in turn will affect the cost of development.

Mixed peat swamp forest generally has the most decomposed peat profile which makes it the best peat type for oil palm development. Peat developed from Alan forest (esp. Alan Batu) is the woodiest and also has the most extensive inter-locking root system. The woody material composes of very hard wood. This inter-locking root system creates a vacant space predominantly within the top 100 cm which can range from 25 - 40 cm (Melling *et al*. 2007).

As observed in Loagan Bunut National Park, the Mixed peat swamp is located nearest to the river or lake, succeeded by Alan forest and Padang Alan forest, the last two being located at the peat dome (Figure 1). In this forest, water table was the lowest at the Padang Alan forest and the highest at the Mixed peat swamp forest as shown in Figure 2.

Figure 1: A cross-section of the 3 different forest types on peat at Loagan Bunut National Park.

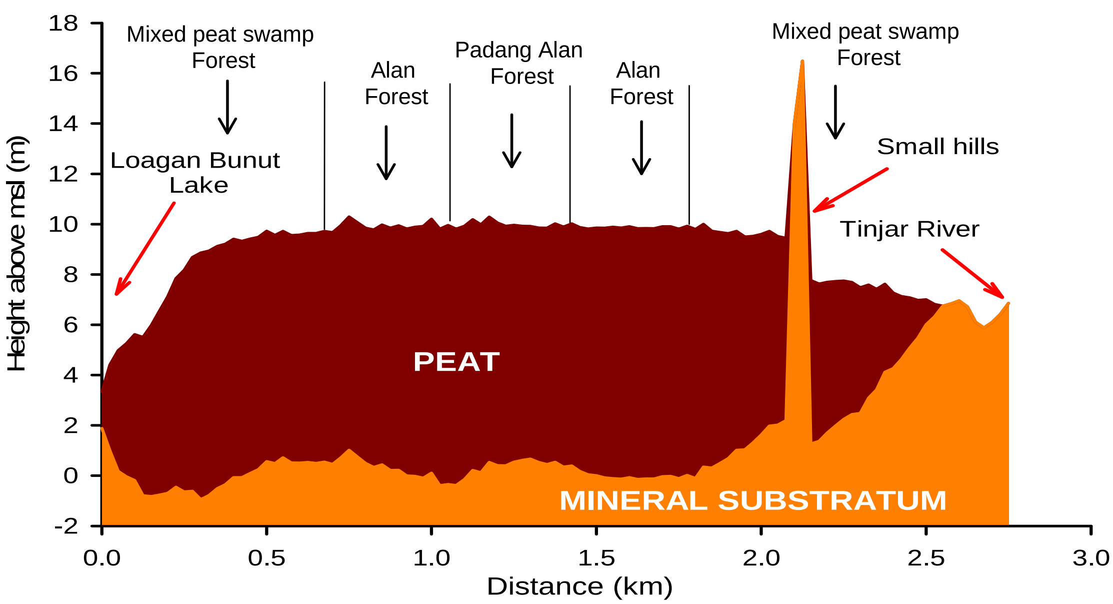
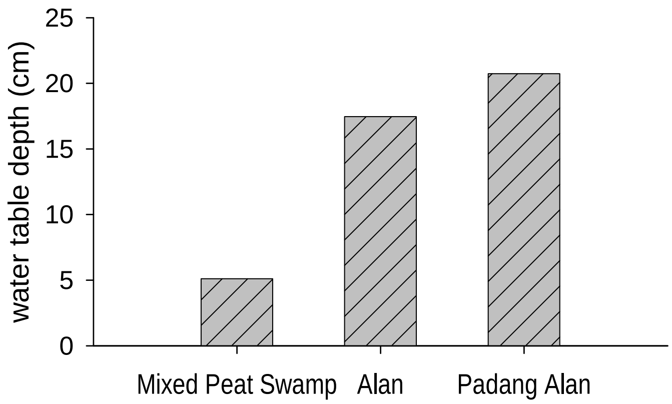


Figure 2: Watertable of the Mixed peat swamp, Alan and Padang alan forest



The different peat types will determine the hydraulic properties of the peat as shown in Table 2. At the same time, the hydrology of the peat will determine the types of vegetation or forest that will grow on it.

Table 2: Saturated hydraulic conductivity of peat

Site	Hydraulic conductivity, Ks (m/day)
Mixed Peat swamp	33.77
Alan forest,	59.06
Padang Alan,	32.76

Peat depth

It is important to determine the peat depth. Peat is considered shallow if it is less than 1.5 metres deep. The depth of peat is generally shallower near the coast and increases inwards, sometimes exceeding more than 20 m deep in Sarawak (Melling *et al*., 2006).

Tropical deep peat naturally exhibits some undesirable physical and chemical properties for optimum plant growth. Unlike shallow peat which is suitable for most crops such as sago and wet paddy, the constituents of deep peat is not homogenous and thus, there is a need for studying it in more detail and putting the necessary ameliorating measures in place before its conversion to oil palm. Besides its depth, it is also important to determine the mineral substratum i.e. whether sandy, clayey or potential acid sulphate soil. This affects the drainage scheme and the use of mineral substratum for road construction as discussed in later sections.

Topography

Topographical (Topo) survey is needed to assess the elevation of the peat surface in relation to the mean sea level and also to ascertain the water flow (direction). This is important for positioning the drainage layout plan. Since the peat surface will undergo continuous subsidence as long as drainage is taking place, the long-term drainability of the peat should be assessed between the mineral subsoil and the river water level, rather than the existing ground surface to prevent the area from being water-logged at a later stage and affects the oil palm growth and yield.

Physical and chemical characteristics of peat

As had been mentioned earlier, the vegetation or forest types determine the type of peat formed which will influence chemical characteristics of the peat as shown in Figures 3a - 3d, 4 and 5. In its natural state, peat soil has been generally recognized as having marginal to unsuitable agricultural capability because of its several serious limitations to crop growth. These include woodiness, high water table/flooding, very high porosity due to the very low bulk density, high acidity, low fertility, severe micronutrient deficiencies and nutrient imbalance. For example, the K content in peat is generally very low compared to its Mg and Ca contents (Table 3).

The low bulk density of peat poses restriction to mechanization and movement of heavy machineries such as the excavators during clearing and land preparation. Due to the very high porosity, leaching losses of applied fertilizers on peat are expected to be high.

Table 3: Chemical properties of the peat at both 0-25 cm and 25 -50 cm soil depths

Forest Type	**Mixed Peat Swamp**		**Alan**		**Padang Alan**	
Sampling depth (cm)	0-25	25-50	0-25	25-50	0-25	25-50
Soil pH	3.37	3.29	3.40	3.31	3.33	3.25
Pyrophosphate solubility index (PSI)	18.04	22.07	11.11	11.24	11.64	10.33
Loss of ignition (%)	96.45	95.93	97.32	97.94	96.52	96.67
Total C (%)	57.47	60.35	56.42	58.39	55.48	58.10
Total N (%)	1.94	1.60	1.90	1.69	1.83	1.69
C:N ratio	29.70	37.72	29.65	34.63	30.27	34.38
CEC ($cmol_c$ kg^{-1})	37.95	39.21	34.36	33.28	36.03	34.34
Base saturation (BS)	13.72	6.83	13.76	7.44	7.92	4.47
Available P (ppm)	157.79	52.71	125.42	30.52	95.17	30.56
Exch K (ppm)	0.38	0.12	0.73	0.32	0.52	0.21
Exch Ca (ppm)	1.47	0.75	0.82	0.57	0.72	0.57
Exch Mg (ppm)	2.82	1.37	2.50	0.88	1.15	0.33
Exch Na (ppm)	0.50	0.45	0.69	0.70	0.47	0.42
Extractable Fe (ppm)	15.02	11.06	11.74	12.96	6.10	6.10
Extractable Mn (ppm)	4.21	0.62	1.77	0.52	3.10	0.77
Extractable Cu (ppm)	3.19	4.13	1.77	2.77	3.13	2.19
Extractable Zn (ppm)	8.65	8.86	6.54	8.02	7.54	7.49
Extractable B (ppm)	0.95	0.85	0.93	1.01	1.11	1.30
Total P (ppm)	347.38	129.35	306.96	120.63	272.60	79.90
Total K (ppm)	55.33	19.94	116.81	73.06	68.05	30.50
Total Ca (ppm)	319.21	184.29	360.15	104.46	119.54	80.94
Total Mg (ppm)	266.13	91.00	232.10	44.17	60.69	1.56

Total Fe (ppm)	529.39	204.21	219.88	209.48	37.44	13.52
Total Mn (ppm)	0.00	0.00	0.04	0.88	1.15	0.00
Total Cu (ppm)	25.33	28.58	14.79	20.23	26.33	14.60
Total Zn (ppm)	36.38	34.69	31.50	33.40	33.23	30.81
Total B (ppm)	20.00	21.90	16.60	20.90	17.48	26.94

Source: Melling *et al* 2008

While drainage is important for oil palm cultivation, over-drainage should be strongly avoided as it increases the rate of subsidence, develops hyperacidity especially in potential acid sulphate areas and increases possibilities of peat fire. Excessive drainage of the peat will also cause the transformation of organic colloids resulting in them losing their adhesive characteristics and moisture retention (irreversible drying), typical of an organic matter. With improved knowledge of peat characteristics, development technology and agronomic practices, peat is now considered an important resource for the economic development in Sarawak especially for oil palm cultivation.

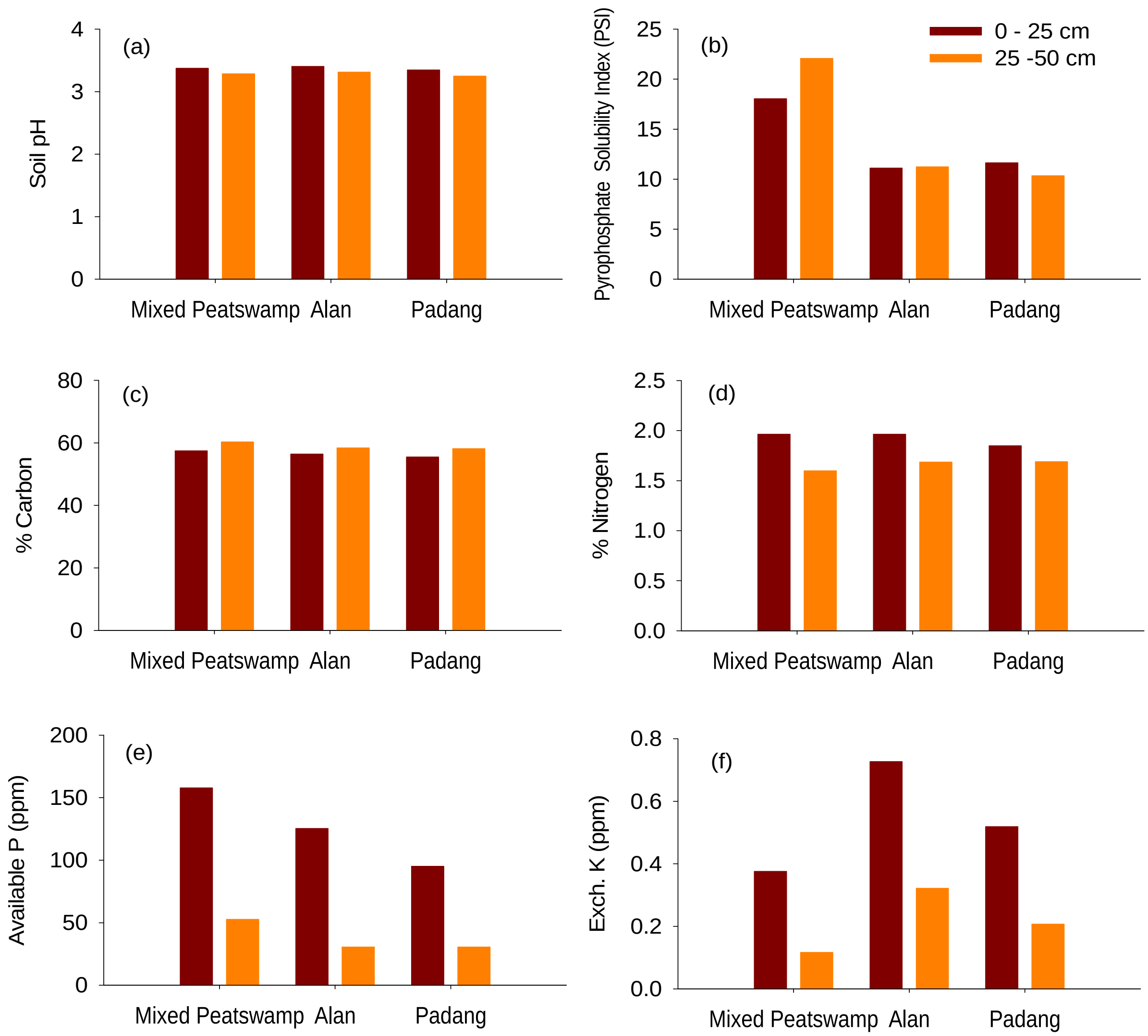


Figure 3a Soil chemical content of Mixed Peat Swamp, Alan and Padang Alan forest for soil pH (a); PSI (b); % C (c); % N (d); available P (e) and Exch. K (f)
Source: Melling *et al* 2008

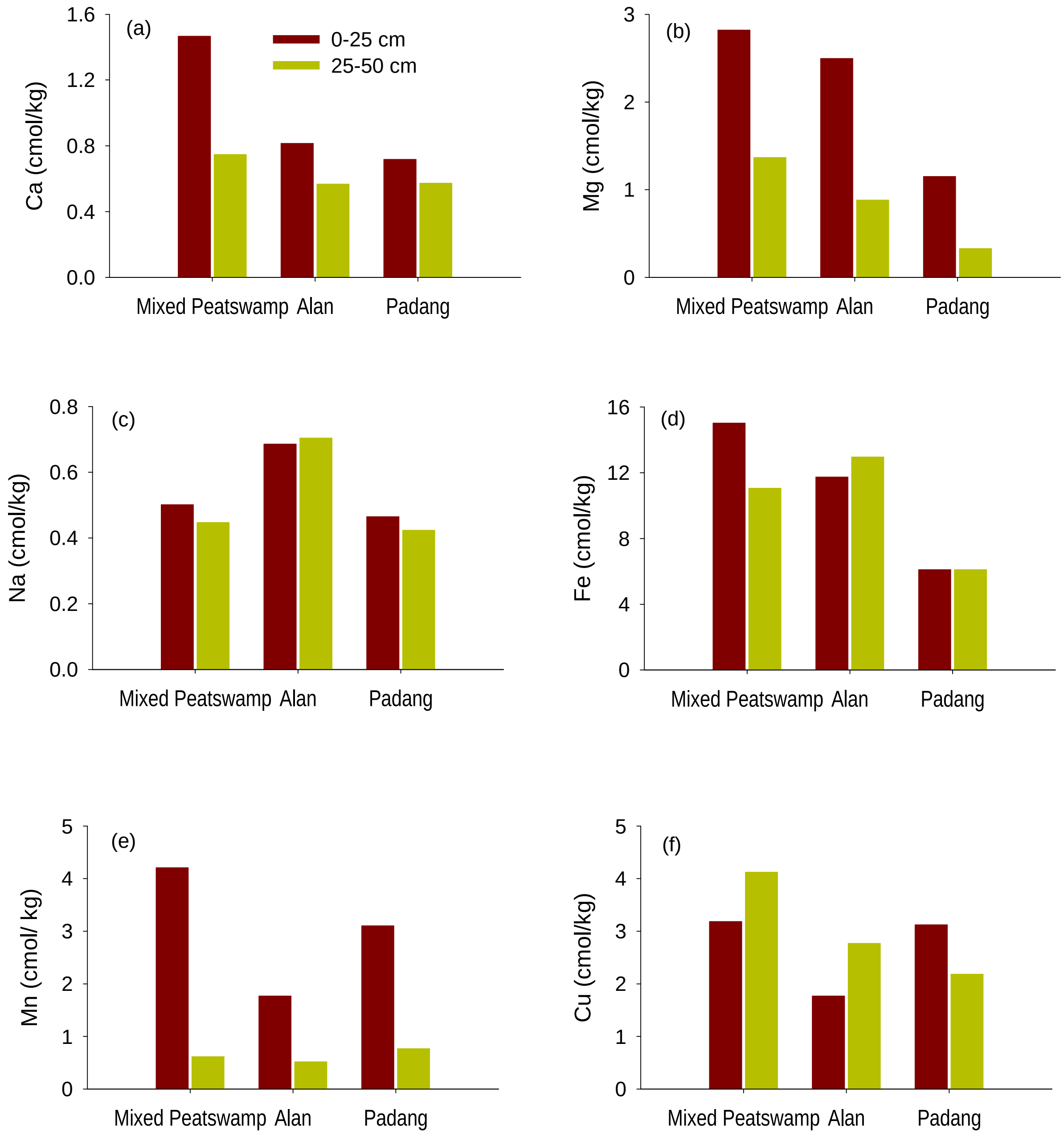


Figure 3b Soil chemical content of Mixed Peat Swamp, Alan and Padang Alan forest for Ca (a); Mg (b); Na (c); Fe (d); Mn (e) and Cu (f).
Source*:* Melling *et al* 2008

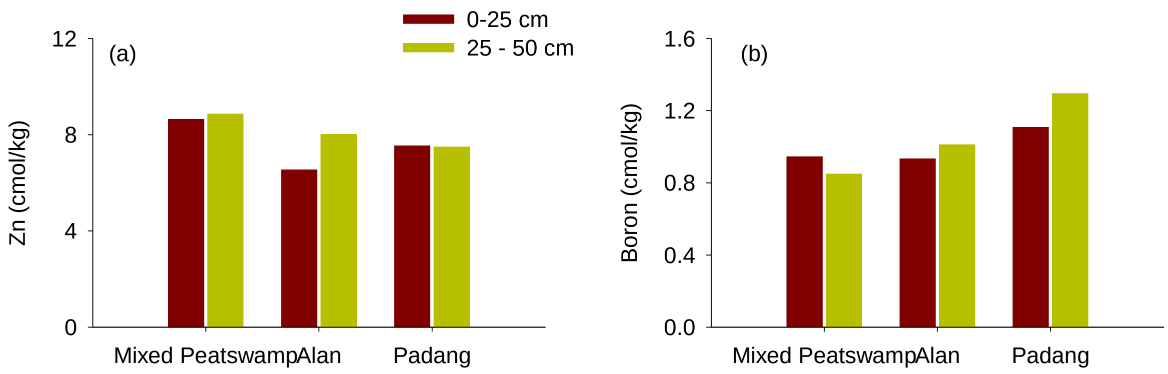
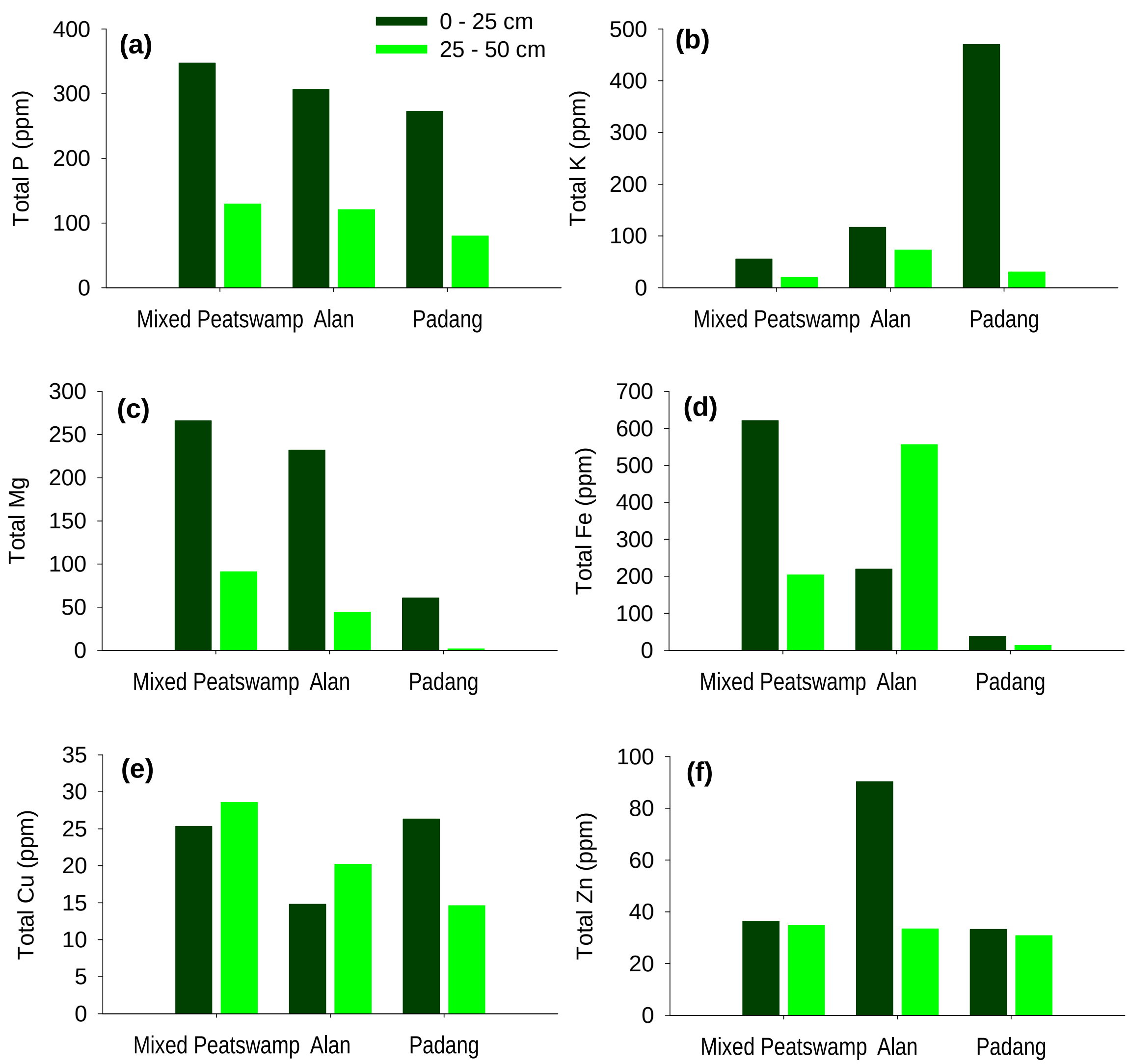


Figure 3c Soil chemical content of Mixed Peat Swamp, Alan and Padang Alan forest for Zn (a) and B (b).
Source*:* Melling *et al* 2008


(a)
Total P (ppm)
0 - 25 cm
25 - 50 cm
(b)
Total K (ppm)
(c)
Total Mg
(d)
Total Fe (ppm)
(e)
Total Cu (ppm)
(f)
Total Zn (ppm)
Mixed Peatswamp
Alan
Padang

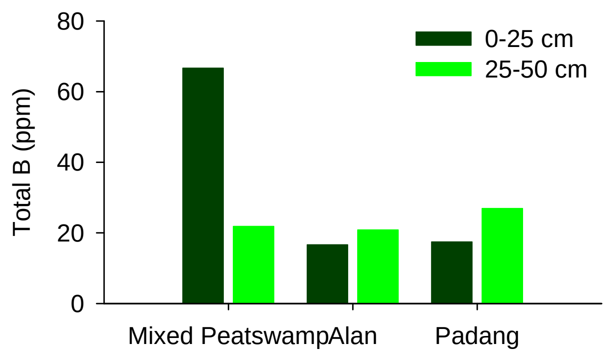

Total B (ppm)
0-25 cm
25-50 cm
Mixed Peatswamp
Alan
Padang

Figure 3d Soil chemical content of Mixed Peat Swamp, Alan and Padang Alan forest for Total P (a); Total K (b); Total Mg (c); Total Fe (d); Total Cu (e); Total Zn (f) and Total B (g)
***Source**:* Melling *et al* 2008

Cation and anion content of the peat soil

The cation and anion content of the peat soil at both 0-25 cm and 25-50 cm for Mixed Peat Swamp, Alan and Padang Alan forests are shown in **Table 4 and Figures 4 and 5.** Both the cations and anions level were usually much lower in the sub-surface of deep peat than in the upper 25 cm suggesting that the elements in the surface layer may be recycled whilst the remainder formed part of the organic matrix and were relatively unavailable for plants.

Table 4 Cation and anion content of the peat soil at both 0-25 cm and 25 -50 cm soil depths

Forest Type	**Mixed Peat Swamp**		**Alan**		**Padang Alan**	
Sampling depth (cm)	**0-25**	**25-50**	**0-25**	**25-50**	**0-25**	**25-50**
Sodium, Na^{+} (ppm)	69.89	64.90	66.62	82.28	62.92	96.87
Ammonium, NH_4^{+} (ppm)	37.05	26.79	35.91	26.31	29.60	21.61
Potassium, K^{+} (ppm)	4.64	2.21	15.38	5.85	13.33	6.84
Calcium, Ca^{2+} (ppm)	2.51	1.68	3.86	2.02	5.87	3.15
Magnesium, Mg^{2+} (ppm)	0.10	3.49	0.03	0.87	0.43	0.05
Fluoride, Fl^{-} (ppm)	0.90	1.24	1.10	1.03	1.08	0.98
Chloride, Cl^{-} (ppm)	34.90	32.67	46.08	40.07	33.58	30.94
Nitrite, NO_2^{-} (ppm)	0.02	0.03	1.24	0.06	0.07	0.02
Bromide, Br^{-} (ppm)	0.23	0.13	0.13	2.17	0.20	0.22
Nitrate, NO_3^{-} (ppm)	13.18	12.78	10.98	11.02	13.05	13.81
Phosphate, PO_4^{-} (ppm)	104.60	37.75	83.80	27.91	78.08	26.91

Sulphate, SO_4^{2-} (ppm)	22.58	19.75	19.10	18.07	20.94	17.47

Source: Melling *et al* 2008

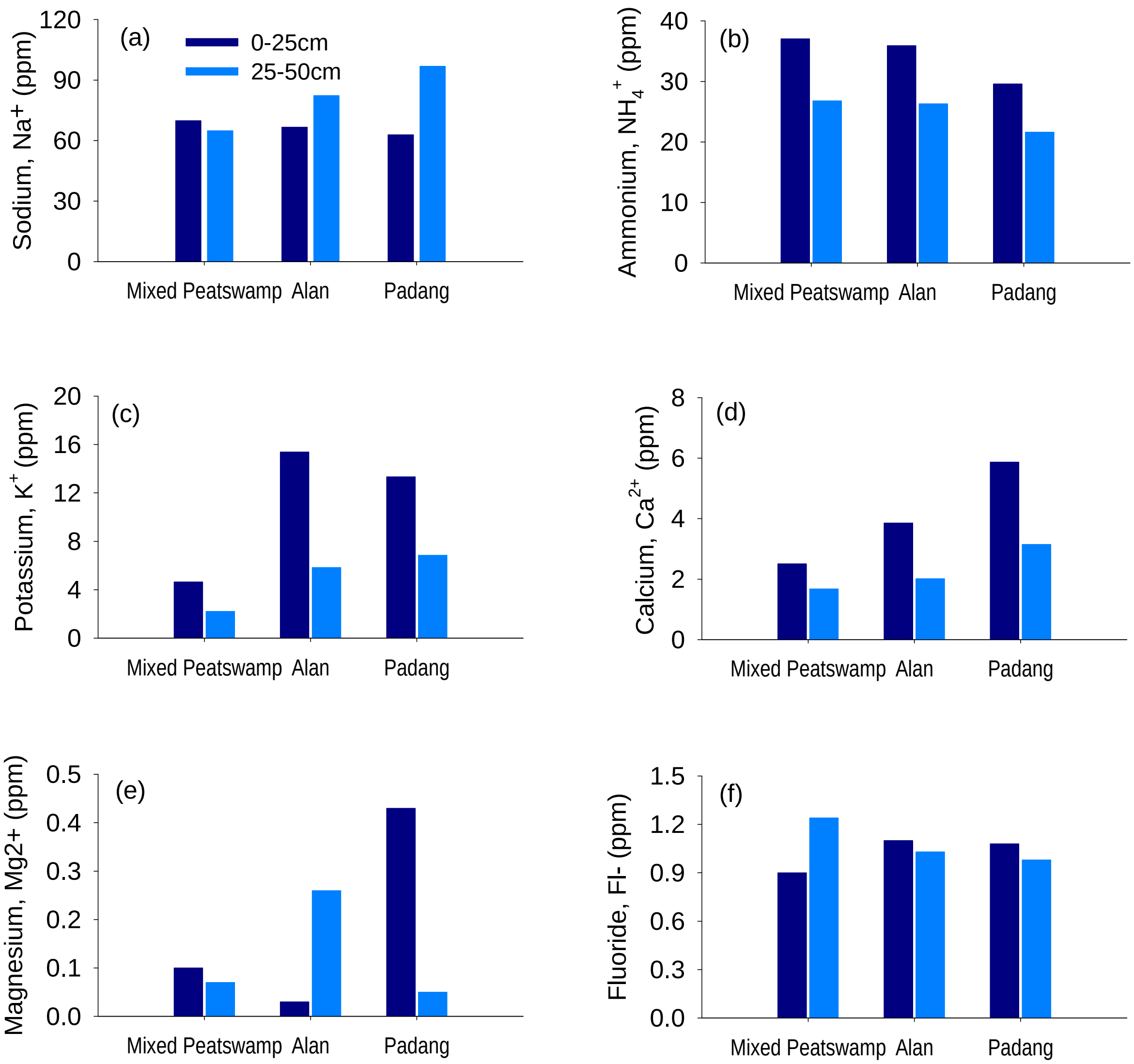


Figure 4 Anion content of the peat soil at Mixed Peat Swamp, Alan and Padang Alan forest for sodium (a); ammonium (b); potassium (c); calcium (d); magnesium (e) and fluoride (f).
Source: Melling *et al* 2008

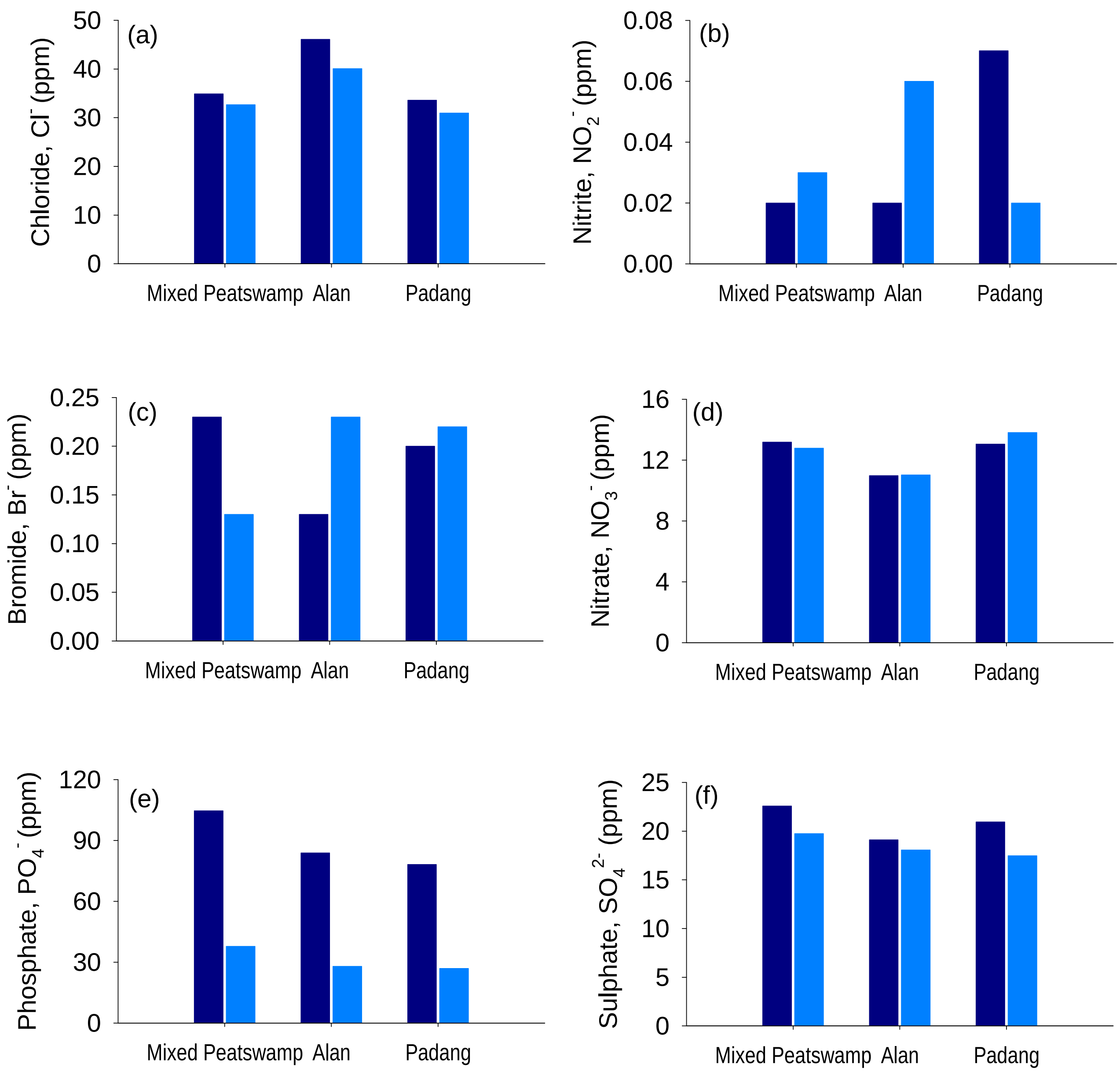


Figure 5 Cation content of peat soil at Mixed Peat Swamp, Alan and Padang Alan forest for Chloride (a); Nitrite (b); Bromide (c); Nitrate (d); Phosphate (e); and Sulphate (f)
Source: Melling *et al* 2008

Peat subsidence

An important effect of draining peat for oil palm cultivation is the subsidence of the peat surface. Subsidence is the result of consolidation and oxidation shrinkage of the peat soil after drainage improvement. This process is difficult to stop as long as the water table is below the peat surface. The lower the water table the faster is the subsidence, which is mainly caused by peat consolidation or water draw down rather than loss of carbon due to oxidation. Continuous lowering of the peat surface can cause some areas that can initially be gravity drained to become undrainable by gravity after some years of lowering the water table. This situation will be further aggravated by the rising mean sea level due to global warming.

Oxidation of peat which contributes partly to subsidence is essentially a slow composting process which is aerobic in nature i.e. requiring oxygen and aided by specific micro-organisms. For tropical peat with relatively high carbon content of about 45-50 %, over-drainage and high temperature may expedite the oxidation process. Maintaining a water table as high as practical and keeping a manageable ground cover on the peat surface especially *Nephrolepis biserrata* to reduce surface temperature will therefore help to minimize the rate of peat subsidence.

The rate of peat subsidence also depends on the porosity, woodiness, elevation, depth of the water table and vehicle movement. In areas where in-field mechanization is carried out, differential subsidence rates occur between the planted rows and mechanization paths, often resulting in "hanging palms" such as seen on mature oil palm plantations especially on Alan Batu peat type.

Peat profiles with thicker humified Sapric horizon generally have lower subsidence rate. In Riau, Sumatra where the peat is generally more humified than those in Sarawak, a lower subsidence rate of about 1.5 cm per year was measured under 10 year old palms, where a water table of 50-75 cm from the peat surface was maintained. On the very woody peat developed over Alan Batu forest in Sarawak where the Fibric horizon is often right up to the peat surface, a higher subsidence rate of 4-5 cm/year was estimated under 10 year old first generation palms. The adverse effects of peat subsidence on water control structures, road construction/maintainance, random leaning and fallen palms had been highlighted by Lim, 2007.

Peat subsidence is not noticeable unless it is measured using a vertical hollow iron pipe (also known as subsidence peg) of about 8 cm external diameter and coated with anti-rust paint on the external surface. Both ends of the subsidence peg are sealed before installation. The end that is inserted into the peat is conical in shape to facilitate installation. It is important to ensure that the subsidence peg is installed firmly onto the mineral substratum. Readings of peat subsidence should be taken at least at 3 monthly intervals. The water level at time of reading and daily rainfall are essential data to be recorded as well in order to explain the subsidence rate. Continuous long-term measurements from the time of drainage are useful for better understanding and more effective management of peat subsidence.

There have been some estimations of CO_2 emission from drained peat based on the high initial rate of peat subsidence. However, it is now a well known fact that this method of estimation of CO_2 emission is often grossly over-estimated the quantity of CO_2 emission from drained peat soils under oil palm cultivation. This has caused a lot of concern on the sustainability of oil palm cultivation on peat soils. This situation should be rectified over time with long-term measurements of greenhouse gas (GHG) emission on site using standard scientific techniques.

Infrastructure and agro-management requirements on peat

Prior to the conversion of peat swamps to oil palm, it is useful to examine the original vegetation on the peat by referring to the forest type map (Melling *et al*., 2007) as described in the preceding sections. A detailed development plan and infrastructure requirements are then formulated to minimize the escalating cost of cultivating oil palm on peat lands. The main agro-management practices that must be taken into consideration are:

i. Good standard of land preparation and correct lining of drains, roads, and planting rows.
ii. Adequate destumping for proper soil compaction especially along the planting rows in order to increase the bulk density of the peat for better anchorage and growth of the palms.
iii. Effective drainage and water management system including the right water control structures.
iv. Recommended agronomic practices (proper planting technique, well selected planting materials, integrated pest and disease management including weed control).
v. Balanced, adequate and timely fertilization.

Collection of rainfall data at site

Information on rainfall distribution is very important for successful water management of oil palm on peat. Long-term rainfall records would serve as a guideline for actions to be taken before the onset of both dry and wet seasons such as preparation for water retention/irrigation and better anticipation of flooding and its control.

Lim *et al*. (1994) mentioned that rainfall influences various estate operations such as the timing for land preparation and planting. The most probable monthly rainfall based on about 20 years of rainfall records instead of the mean rainfall should be calculated in order to increase the accuracy of predicting rainfall and to minimize risk.

Rainfall may vary with different peat swamps. This makes it very important for the rainfall data of each site to be collected so as to assist in better development of the peat swamp for oil palm cultivation. Some peat forest areas recorded lower yearly rainfall of between 2500 to 3500 mm, some are very high at about 5500 mm per annum. The fact is that when a large peat swamp forest has been felled for oil palm development, the rainfall pattern and hydrology may change over time. Our observation shows rainfall normally decrease if compared to the initial figure before development. The planning and development of an oil palm plantaion on peat need to take this factor into consideration.

Sequence of development works (land preparation) in the conversion of peat swamp forest to oil palm

Peat forest development is ecologically sensitive. In order to achieve high and sustainable oil palm yield on peat, good planning and correct sequence of development works are vital. The RSPO Criteria for Sustainable Palm Oil should also be taken into consideration.

Land clearing and preparation works in the developmental phase are normally contracted out to minimize the large capital expenditures for purchase of heavy equipment. Selection of contractors must be based on their successful work records and experience, possess adequate suitable machineries, receptive to new ideas and more importantly with good financial standing.

The zero-burning technique is currently practised for environmental reason. Open burning should be avoided as it will result in uneven subsidence of the peat surface that will lead to difficulties in soil compaction, mechanization and water management.

The usual sequence of works in the development of logged-over peat forests for oil palm cultivation are as follows:

Site selection

At present, only logged-over peat swamp forests can be developed into oil palm plantation in Malaysia. Once a peat swamp area has been offered for development, it is important to carry out a quick verification of the proposed project area using global positioning system (GPS). The main coordinates of the proposed project area should be checked and verified. This is important to prevent any land encroachment problem.

It is important to assess the topography and the drainability of the site especially for planning, development and management purposes. Thus, a drainability study is usually carried out before any large scale peat development for oil palm cultivation can take place effectively. This is because in many instances, the success of oil palm plantings on peat lands is dependent on whether the areas can be drained by gravity.

Long-term drainability of an area is in relation to the level of the substratum surface rather than the peat surface to the existing water level of the adjacent river courses. This is because the peat surface will continue to subside as long as it is drained. When drainage by gravity is not sustainable, the area will become water-logged and flooded. Under such situation, bunding and pumping will be required and these will add on to the development cost.

Suitable sites are those where the natural water table can be easily maintained at 50-75 cm from the peat surface and drainable by gravity during the rainy season when periodic floodings usually occur. A good source of road building material within the project area will be an added advantage to reduce cost of road construction and maintenance.

To be successful in planting oil palm on peat based on present technology and experience, it is suggested to avoid certain peat areas such as those with salinity problem, which are difficult or problematic to manage. Such areas are usually localised near to the sea or subjected to strong tidal influence. The limit of salinity tolerance for oil palm is about 4000 µmhos/cm. The affected areas will require strong bunds and installation of weirs with automatic flap-gates. This will invariably increase the development cost and the FFB yields can be expected to be lower. It is therefore best not to develop such areas (Lim, 2006).

In most peat areas, it is inevitable to have pockets of low-lying areas of about 5 to 20 ha which are prone to periodic floodings e.g. ex-river basins. It will be advisable to leave them unplanted as wetlands (e.g. to improve biodiversity within the estate). It will also avoid spending too much money and management time dealing with small pockets of unsuitable fields and diverting precious resources to them.

Once an area has been selected for oil palm planting, every effort must be made to prolong its economic life span. Peat should be considered as a precious soil resource that must be properly and sustainably managed because once it is destroyed, the damage is often irreversible.

Construction of the perimeter bund and perimeter Drain

Perimeter bund is constructed from the excavated material from the perimeter drain. It should be located just within the boundary of the project area. There must be an excess berm of 5 m wide between the perimeter bund and the perimeter drain for future maintenance work.

The perimeter bund should be at least 1.5 m wide, leveled and compacted on the top to allow for supervision using motorbikes. It should have a proper foundation. For bund stability, the bottom width should be about twice the top width. It should be about 50 cm higher than the normal flood level. To minimize bund erosion and breakage, the slope of the bund should be quickly vegetated when completed. Depth of the perimeter drain should be about 1 m deeper than the main drain, to facilitate drainage.

Establishment of the Raja Line and construction of main drains

The Raja Line is the governing line for all lining works in the development of a peat estate. It is normally established along the main flow gradient of the project area determined by a topo-survey.

Main drains are constructed first for removing excess water from the project area. They are aligned parallel to the Raja Line and are best spaced at 1 km apart. Main drains should be sufficient in size to dry up the area quickly for subsequent mechanical works. However over-drainage of the project area (with water level lower than 100 cm from the peat surface), should be avoided.

Felling and stacking

Broadtracked hydraulic excavators (770 mm or 950 mm wide track) are normally used for clearing, stacking and surface compaction. Mechanical felling and stacking should be carried out only in the designated area demarcated by the perimeter survey.

For areas subjected to strong tidal influence, it will be useful to leave a buffer zone of about 100-200 m of natural vegetation uncleared eg. mangrove tree species and Nipah palms, to reduce the tidal force against bund breakage. This will also help to increase the biodiversity around the oil palm plantations on peat. The clean-clear method should be used where all stumps should be uprooted and cavities filled. Removing as much as possible all partially buried stumps and protruding logs is important for facilitating the construction of the drainage system and for future mechanization. Furthermore planting seedlings close to tree stumps will affect root development, water and nutrient uptake, resulting in poor growth and yield of the affected palms.

Long and large logs (> than 15 cm diameter) should be cut to shorter lengths to ease the stacking job. The stacked rows should not be more than 3 m wide and 3 m high, to minimize shading and obstruction to the planted points .

The stacking rows are usually spaced at 1 to every 4 palm rows, in the middle of 2 field drains. With a planting density of 160 palms/ha, the spacing of the stacking rows is 29.6 m (centre to centre).

The stacked rows should be disconnected every 75 m as fire breaks and to serve as U-turns for machines to turn around. Remnants of the smaller woody materials (< 15 cm diameter) are to be placed in the middle of the future harvesting paths/mechanization paths for constructing elevated paths. Boundary stones should not be removed during land clearing. The Contractors to make good for any damage done to the boundary stones.

Lining and construction of roads, drainage system and bridges

Main drains and main roads are aligned parallel to the Raja Line and the collection drains and collection roads perpendicular to it.

Road systems

All weather main roads are essential for effective FFB evacuation and other estate operations. Main roads for regular heavy traffic normally spaced at 1 km apart should have strong foundation up to 1 m thick and 5.0 m wide, properly cambered and compacted.

No large logs should be buried under main roads for strengthening the foundation as when they decompose later, it will give rise to numerous cavities on the road surface that will require frequent repairs. Geotextile can be used as an underlying material to strengthen main roads but the cost is relatively high. Over-loading and speeding of transporting vehicles on main roads should be strictly prohibited to reduce maintenance cost. Where the main roads cross collection drains, proper bridges of hardwood need to be constructed.

Collection roads are best spaced at 300 m apart. Where possible the collection roads are to be in the E-W direction to facilitate more rapid drying of the road surface during rainy seasons. Collection roads are normally 4.0 m wide with 60 cm thick foundation. Where road material is limiting, narrower collection roads (3.0 m wide) are preferred to reduce costs. In this case, road side parking areas (about 3.0 width by 4.0 m length) are required at every 300 m intervals to avoid vehicles from the opposite direction. Collection roads should also be properly connected to the in-field mechanization paths or harvesting paths.

Drainage system

The drainage can operate most efficiently when planned with the help of a topo-survey at 50 m intervals. It is through the topo-survey that the location of main drainage outlets as well as drainage system is designed.

Collection drains, are normally aligned and constructed at 300 m apart, between collection roads which are also spaced at 300 m interval. This gives a carry distance of 150 m. With the main drain spacing of 1000 m (1 km), the block size is 30 ha.

Field drains (and stacking rows) are pegged perpendicular to the collection drains. They are best constructed at 1 to 4 palm rows or 29.6 m apart during land preparation but can be reduced later by not maintaining some of them. Reducing the intensity of field drains during land preparation with the view to increase them later when needed should be avoided as this will result later in higher cost, disturb the growing palms and other estate operations.

When constructing the field drains, it will be useful to place the spoil on the positions of the future harvesting paths or mechanization paths rather than close to the field drain edges, to avoid back-filling which will result in higher maintenance cost. It is important to ensure that all planting rows are at least 2 m from the edges of field drains and stacking rows.

All lining pegs should not be removed until the area is planted up.

Surface compaction

Pre-planting surface compaction from an initial bulk density of about 0.10 to about 0.20 gm/cm^3 esp. on the planting rows is done using tracked excavator. Compaction has several advantages. Other than increasing the soil bulk density, it increases the soil mass per volume, thus reducing the rate of fertilizer leaching. It also increases nutrient supply (more nutrient per unit peat volume) and help to reduce early palm leaning due to better root anchorage. Thus beneficial effects of pre-planting compaction will lead to significantly higher yields.

For effective compaction, it is very important to have a good destumping and also useful to first lower the water level in the field drains to about 90 cm. Normally 2 to 3 passes of the tracked excavator are necessary. Avoid rainy seasons when carrying out compaction. The front bucket of the excavator can also be used for compaction of areas not reachable by the tracks.

For some areas where the peat soils were initially very raw such as Alan areas, it is encouraged to do a re-compaction after the 1^{st} year planting and not after 3 years planting. This is to minimize the amount of damage to the roots.

Lining of planting points, planting technique and planting depth

Lining of the planting points are to be done after surface compaction. It is important to ensure that the planting points are as triangular as possible. With a density of 160 palms/ha, the planting points are spaced at 8.5 m along the planting rows. The interrow spacing is 7.4 m. It is important to ensure that they are not close to the stacking rows for easier management later.

Planting holes are usually constructed mechanically to simulate a "hole-in-hole" planting using a "hole puncher" attached to the front bucket of the excavator. With adequate compaction of the planting rows, a planting depth of about 15 cm from the peat surface to seedling bole is recommended. Shallow planting should be strictly avoided as this will lead to early palm leaning that will adversely affect yield.

Care and maintenance of field and palms

Legume cover

Legume cover is generally not recommended on peat as it does not establish well on periodically flooded fields. On non-flooded areas due to the low pH of the peat, N fixation is anticipated to be minimal. The thick organic litter from the legume may pose a fire hazard during dry season.

Shade tolerant *Mucuna bracteata* is sometime planted on both sides of the stacking rows to expedite decomposition of timber residues and reduce breeding sites of rhinoceros beetles. However due to its vigorous climbing habit on the palms, it may become a weed problem. Thus, unless sufficient workers (or contract workers) are available to form a special team to prevent *Mucuna bracteata* from smothering the palms, it should not be planted.

Mechanisation on peat

The relatively flat terrain of peat is advantageous for mechanisation especially in areas with labour shortage problem such as in Sarawak. However, the main constraint is the soft ground condition especially during rainy seasons and in areas with high water table. To facilitate in-field transport especially for FFB evacuation, elevated mechanisation paths of about 3.5 m width and 50 cm height with a slight camber can be constructed, on alternate palm rows during land preparation. Zero-burning is important as the residual woody materials less than 15 cm diameter are used to strengthen the elevated paths.

As the palms get older, work rate on the construction of elevated paths is slower due to interference by the growing fronds. For planted areas, construction of elevated paths should be carried out no longer than 182 months after field planting. In areas where there are insufficient woody materials, non-elevated but compacted paths of about 3 m width can be constructed on the existing harvesting paths. They are constructed by removing protruding stumps, filling surface cavities followed by one round of compaction using a track excavator. Path construction is usually carried out just before harvesting commences and must be well connected to the collection roads. Removal or chain-sawing of protruding stumps (especially those with sharp edges) on the mechanisation paths is important, as puncturing of low ground pressure (LGP) tyres and snapping of rubber tracks have been reported.

Fimbristylis acuminata, a common weed on peat areas with extensive surface root system should be encouraged or planted on peat roads or mechanisation paths to further strengthen the peat surface against rutting by moving vehicles.

A number of machines have been tested on both the elevated and non-elevated paths. With construction of elevated paths, mini-tractors and trailers with normal tyres can operate without much problem. On the non-elevated compacted paths, tracked carriers or mini-tractors and trailers with LGP tyres are more workable, especially during rainy seasons (Lim, 2003).

Water Management

<u>Drainage layout and water management system</u>

Effective water management is the key to high oil palm yield on peat. Too little or too much water in the palm rooting zone will adversely affect nutrient uptake and fresh fruit bunches (FFB) yields. Most palms' feeder roots are concentrated in the top 50 cm of the peat, therefore this zone must not be water-logged.

A good water management system for oil palm on deep peat is one that can effectively maintain a water level of 50-75 cm from the peat surface for as long as possible. It should be able to remove excess surface and sub-surface water quickly during wet seasons and retain water for as long as possible during dry spells. At this water level, the emission of greenhouse gases (CO_2 and CH_4) was reported to be lower compared to the forest ecosystem (Melling *et al*., 2005a; 2005b). The moist peat surface at this water level minimise the risk of accidental peat fire.

A system of boundary, main, collection and field drains with water control structures are used for drainage and effective water management. The usual drain dimensions and their spacings are given in Table 5.

Table 5: Drain dimensions and spacings on peat areas

	Spacing	Top width (m)	Depth (m)	Bottom width (m)
Field drain	1:4 palms rows	1.2	1.2	0.8
Collection drain	300 m	3.0	2.0	2.0
Main drain	1000 m	4.0	2.5	3.0
Perimeter drain (canal)	variable	6.0	3.0	4.0

Lining and construction of the main drains, collection drains and field drains must be according to the specifications especially the depth, for the efficiency of the drainage system.

Due to the rapid initial subsidence, simple stop-offs using in-situ residual logs or soil bags are installed in the initial years. Permanent water-gates and weirs at strategic locations along the main and collection drains are installed later when the subsidence rate is reduced. Automatic flap-gates are usually installed at main outlets which are subjected to tidal variations.

Drain maintenance must be carried out regularly or when required, to keep the drainage system working properly. Poor maintenance of the drainage system is often the main cause of flooding in estates on peat. Desilting to required depth is best carried out during dry weather.

Management of water level

For effective water management, it is important to determine the directions of water flow in the various parts of the estate. This is required to determine the strategic locations for installing stop-offs, water-gates and other water control structures. For more effective supervision and speedy actions, each estate on peat should have a detailed water management map indicating the directions of water flow, flood-prone fields, locations of water-gates, stop-offs, water-level gauges, bunds, etc.

Water level in peat can fluctuate rapidly especially during rainy or dry seasons. It is therefore important to carry out regular monitoring of water level. This can be done by installing gauges at strategic locations and at the entrances of collection drains behind each stop-off and numbered. Level should be set at zero on the planted peat surface. Negative value indicates water level below the peat surface and positive value indicates flood level. Readings should be taken daily to monitor changes in water level in relation to rainfalls. When the water level in a block is less than 25 cm from the peat surface, one has to start preparing for drainage and if it is more than 75 cm from the peat surface, the need will be for water retention.

It will be useful to have a full-time water management worker in each estate on peat for effective and timely control of water at optimum level. He is also responsible for operating the water-gates, regular checking of bund conditions and inspection of water control structures for damage, blockages, etc. During dry seasons this worker can also assist in fire patrol.

Fertilization

Next to water management, adequate and balanced fertilisation is vital for high oil palm productivity on peat. Due to the high porosity and infiltration rate of peat, minimising fertiliser leaching is important due to increasing fertilizer prices. This is especially important in areas with high and frequent rainfalls e.g. in Sarawak with 4000 to 5500 mm and 180 to 220 rain days per year. Under such circumstances, strict timing of fertiliser applications to avoid high rainfall periods is important to reduce leaching losses especially when applying boron and potassium fertilisers which are easily leachable in peat.

The fertilizer requirement of oil palm on peat may differ depending on the conditions of the peat where it is cultivated. Fertilizer programmes are designed based on the chemical properties of the peat and nutrient requirements for good growth and high yields based on fertilizer trials. Two aspects of fertilizing oil palm on peat are the high rates of potassium and he need to apply micronutrients copper, zinc and boron on a yearly basis. Due to labour shortage in Sarawak, controlled release fertilizer is often used in the first year at the time of planting which can provide essential nutrients for about 9 to 10 months

The low K content of peat will require higher dosage of K fertilizer. Nitrogen and phosphorus fertilizers are also needed but the amounts required for oil palm on peat has to be determined correctly as excessive amounts will adversely affect yield.

Requirement of phosphorus by palm is normally low to moderate. In some peat soils, oil palm shows no phosphorus response. Calcium and magnesium are usually not deficient in peat. However, since the pH is generally low, limestone dust or ground magnesium limestone at a rate of 1.5 to 2.5 kg per palm per year may be applied to decrease the acidity during the immature period (Lim, 2005a). When the palms come into maturity (normally 36 months after field planting), fertilizer recommendations are usually based on annual leaf analysis, trial results, yield performance and foliar deficiency symptoms.

Straight fertilisers (urea, muriate of potash, rock phosphate, borate, copper sulphate and zinc sulphate) are normally used on mature palms. High inputs of potassium (5 to 6 kg muriate of potash per palm per year), over 2-3 split-applications are needed for high yields on peat (Gurmit Singh, 1999; Manjit *et al*., 2004). It is important to time fertiliser applications during the drier seasons, to minimise losses due to leaching and periodic high water-tables. Where available, bunch ash application will be useful for mature palms at 5 to 6 kg per palm per application. Apart from supplying potassium, bunch ash will help to improve the peat pH.

Due to the escalating fertilizer prices, it is important for large companies with oil palm planting on peat to carry out more fertilizer trials to improve fertilizer use efficiency on the major peat types. An earlier trial indicated that application of Urea and MOP mixture in perforated plastic bags simulating a slow release effect, was able to reduce leaching losses (Lim *et a*l., 2003). At 2 bags per palm placed at about 2 m from the palm bole, they regulated fertilizer release for about 4-5 months. Supervision on the evenness of application using this fertilizer protection technique is more effective.

Due to the long carry distance and soggy ground condition during rainy days in peat estates, stringent supervision by all levels of the estate management is vital to achieve high efficiency in fertiliser application on peat.

Integrated pest and disease management on peat

With planting of oil palms on large contiguous areas of peat, a number of pests have adapted themselves to the woody and moist environment. If not properly controlled, pest outbreaks can occur, resulting in economic losses due to reduction in yield and stand. Considerable costs and management inputs will be required to control these pests during outbreak situations.

To be cost-effective and environment-friendly in the control of major pests, Integrated Pest Management (IPM) on peat should be adopted (Lim, 2005b). IPM is defined as a pest management system that utilises suitable techniques in a compatible manner and maintains the pest population at levels below those causing economic injury and crop losses. Good understanding of the pest biology and peat ecology is needed in making the correct choice of physical, cultural, chemical and biological control methods. It is important to look for weaknesses in the pest life cycles for targeting control.

In IPM, the amount of chemicals is reduced, to minimize the impact on beneficial and non-target organisms. Chemical treatments are only carried out by using selective pesticides at low rates and timely application to ensure minimum impact on the biodiversity and environment. The key success factor in IPM is early detection by regular census and speedy treatment. In this respect, all peat estates should have permanent pest census teams. With effective implementation of IPM, expenditures on pest control on deep peat can be greatly reduced.

Termite control

The termite species (*Coptotermes curvignathus*) is a very important pest of oil palms planted on peat, causing death to numerous palms if not properly controlled. Termite attacks on palms can be as early as just after planting and infestations of immature plantings could reach 8-9 % with 3-5 % dead palms per year if not quickly treated (Lim and Silek, 2001). On mature areas more than 50 % of the palms can be killed by termites before age of 10 years if not properly controlled. Negligence in termite control can lead to failure in a peat planting.

Termite control is perhaps the most important pest management work on peat estates. It should be stringently managed to minimize losing stand and yield. For effective termite control, monthly census on all palms is required. Infested palms should be treated immediately using fipronil (5.0% a.i.) at 2.5 ml / 5 litres water/ palm (Lim and Bit, 2001). Delayed treatment will result in death of the infested palm, when the meristematic region is consumed by the termites.

Tirathaba bunch moth control

There have been increasing incidences of severe damage on developing bunches by the caterpillars of the bunch moth (*Tirathaba rufivena*) on peat plantations in Sarawak and Riau in Sumatra. Poor sanitation e.g. leaving unharvested rotten bunches on the palms will attract infestations by the bunch moths.

The caterpillars of bunch moth are dark brown in colour and grow to a length of about 4 cm. They are hatched from eggs laid close to the stalks of fruit bunches, especially those which are rotten. The life cycle is short (about 1 month), therefore spread is very rapid on peat.

Once the caterpillars have infested a palm, inflorescences and developing bunches are also attacked. Infested bunches have non-glossy appearance and covered with frass. The distal ends of fruitlets are usually eaten superficially. Attacked bunches are lower in bunch weight. Abortion of bunches can happen, when the attack is severe. For immature areas, due to early bunch formation on peat, it will be beneficial to carry out ablation of young palms from 12 to 21 months after field planting at monthly intervals, to optimize palm growth and minimize infestations by the bunch moths due to unharvested rotten bunches.

Under high Tirathaba infestations, 2-weekly spraying of *Bacillus thuringiensis* based product (e.g. Dipel WP at 1 g/litre water) on the infested and developing bunches is recommended.

<u>Management of leaf-eating caterpillars</u>

To be cost-effective and environment-friendly in the control of leaf-eating caterpillars, IPM should be adopted. Chemical control should be based on early detection based on regular census. When infestation is higher than threshold value, for young palms (1 to 6 years), spray with 0.005% cypermethrin) using knapsack sprayer or mist-blower (0.01 % cypermethrin).

For tall mature palms (> 6 years), trunk injection using e.g. methamidophos (10ml undiluted/hole). To minimize spread to adjacent blocks, treat a buffer zone of 5 palms around the infested blocks first. It is useful to coordinate spraying with neighbouring infested estates for more effective control.

It will be useful to plant beneficial plants (*Cassia cobanensis*) on the road sides for biological control. *Cassia cobanensis* establishes well on peat under non flooded condition. It can be propagated easily from seeds or cuttings for large scale planting. *Cassia Cobanensis* produces nectar from flowers and leaf stipules throughout the year and is therefore effective in attracting predators and parasitoids for biological control of leaf-eating caterpillars esp. bagworms.

Alternative hosts to bagworms e.g. Acacia mangium, should not be planted in the peat estates.

Chemical treatment for control of leaf eating caterpillars to be carried out only when census figures are above threshold numbers (Lim, 2005b).

<u>Ganoderma management</u>

Basal Stem Rot (BSR) caused by *Ganoderma boninense* or *Ganoderma zonatum* is a major disease of oil palm planted on peat soils. On first generation oil palm from logged-over forests, normally Ganoderma infection is rare during the first 6 to 7 years after planting. Thereafter incidences may increase. The pattern of disease distribution by enlarging patches indicated that the disease is spread by root contact from primary disease focal points or inoculum sources.

Presently there is no effective cure for Ganoderma infection. Preventive and ameliorative treatments which are commonly carried out showed various degree of effectiveness. More research is needed to overcome this serious threat on peat e.g. selection and breeding/cloning of Ganoderma tolerant materials. Yearly census of Ganoderma infection is recommended and appropriate sanitation practice carried out on severely infected or dead palms by excavating the infected boles and root mass (Lim, 2005b).

Weed management on peat

The moist environment in peat favours luxuriant growth of weeds especially in areas of high rainfall such as in Sarawak (4,000 to 5,500 mm/year). However newly drained peat is relatively weed-free for about six months after land preparation. With zero-burning, most of the early weed species are indigenous, mainly ferns (especially *Nephrolepis biserrata, Stenochlaena palustris, Dicranopteris linearis*), sedges (e.g. *Fimbristylis acuminata, Cyperus rotundus*) and woody species (e.g. *Uncaria spp., Macaranga spp., Melastoma malabathricum*) (Lim, 2003). Subsequently, other species are brought in by agricultural activities, road materials, wind and water e.g. *Mikania micrantha, Merremia spp., Mimosa pudica, Asystasia intrusa, Digitaria spp., Ischaemum muticum, Imperata cylindrica, Eleusine indica*, etc.

Timely spraying of noxious weeds with selective herbicides to promote the growth of desirable ground cover is advocated to minimise the weed succession problem. The strategy is to keep the palm circles clean and interrows devoid of noxious weeds (especially *Imperata, Mikania micrantha, Ischaemum muticum*, etc.).

It is important to carry out weed control without delay on the harvesting paths and palm circles of 2.5 m radius, to ensure good accessibility and crop recovery especially loose fruit collection. Choice of spray equipment and herbicides must be based on cost-effectiveness and labour productivity as well as safety to workers and minimal impact to the environment.

Herbicides which are quick acting and do not destroy the root system of soft weeds are preferred as they help to strengthen the peat surface for mechanisation. *Fimbristylis acuminata* with extensive surface root system is either encouraged or planted on peat roads for the same purpose (Lim, 2002). Clean-clear weeding that reduces the natural enemies of leaf-eating caterpillars should be avoided as it may lead to outbreaks of nettle caterpillars and bagworms.

High water-table (less than 25 cm from the peat surface) and periodic floodings should be minimised as such conditions expedite proliferation of several weed species on peat especially *Uncaria spp*. Due to the fast weed growth in peat areas, any delay or neglect in weed control will lead to rapid deterioration of the field condition. Weedy fields especially the palm circles will lower the efficiency of important agro-management practices especially FFB evacuation, manuring, pest control and supervision.

Cost to maturity on peat

The costs involved in oil palm cultivation from logged-over forest on deep peat are rather variable and site specific. Good site selection for planting oil palm is crucial to minimize cost and maximize yield. Peat areas with good drainability, inherently good water table with but not prone to periodic floodings, well humified sapric horizon and with a good source of road building materials are plus points to maximize yields and minimize costs of oil palm cultivation especially on deep peat.

The initial development cost on logged-over jungles is quite subjective depending on the location and work specifications especially the intensity of roads, drains, bunds, water control structures and other requirements. The total cost to maturity (3 years after planting) on peat compared to mineral soil is given in Table 6.

Table 6: Estimated cost to maturity on peat (3 years)

Items	Peat RM/ha	
	Plantation 1	Plantation 2
Land Preparation	1675	1392
Planting and Supplying	1100	958
Weeding and Covers	925	736
Manuring	4550	2057
Pest and Disease	675	75
Infrastructure	3835	5530
Road	4320	3349
Bridges and culverts	450	193
Drains	1160	1944
Others	180	100
TOTAL	18870	10849
Estate General	1950	1466
Depreciation	600	481

Loan Interest	1100	1006
Grand Total	**22520**	**13802**

Note- Land cost, capital expenditures and loan interest are excluded.
The maturity period is taken at 36 months after planting.
Plantation 1 is estimated costs in 2008 while Plantation 2 is actual costs in 2003.

To offset the high initial development cost on peat, it is important to achieve high early yields. Planted at 160 palms/ha and with good agro-management practices, FFB yields in excess of 15 tonnes/ha were reported in the first year of harvesting (Mohd Tayeb, 2005; Xaviar *et al*., 2004).

The second cycle of oil palm planting on peat will cost lower as the basic infrastructure of roads and drainage can be reused. Yield of second generation oil palm on deep peat is also expected to be better (Xaviar *et al*., 2004).

Conclusions

With better understanding of the peat characteristics, improved peat planting technologies and best agro-management practices, oil palm planting on peat can be carried out sustainably on properly selected peat areas. Continuous training at the estate level on management is important to avoid making costly mistakes. More research is still needed to optimize yield and maximize sustainability of oil palm plantings on deep tropical peat.

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