UNIVERSITI PUTRA MALAYSIA

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COMPARISON OF CHEMICAL PROPERTIES ON PEAT SWAMP SOIL BEFORE AND AFTER TIMBER HARVESTING IN SIBU FOREST

BY

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Dedication

To my handsome father, Salimin Bin Kusoh,
Who shares my passion of gardening

To my elegant mother, Samsah Bt. Salleh,
Whose invisible support lasted till the end

To my handsome brother and cute sister,
Whose carefree attitude inspires me

To all my friends
Whose enormous care always lifted my spirit

ABSTRACT

Sarawak has a large area of peat in Malaysia. This study was conducted to determine the comparison of chemical properties based on soil acidity, cation exchange capacity (CEC), soil organic matter (SOM), total carbon, total nitrogen, total phosphorus, available potassium and C:N ratio, before and after timber harvesting on tropical peat swamp forest. Peat soil samples were taken at 0-15 cm dept on 6 plots with 0.1 hectare each plot at Batang Igan forest in Sibu Sarawak, Malaysia. The soil samples were analyzed for soil acidity, cation exchange capacity, soil organic matter, total carbon, total nitrogen, total phosphorus and available potassium. Data was analyzed by using Unpaired T-test, Statistical Analysis System (SAS) version 9.2. The tropical peat swamp forest indicate its specific natural state such as rich in soil pH KCl and C:N ratio were not significant, soil pH water, cation exchange capacity, soil organic matter, total carbon, total nitrogen, total phosphorus, and available potassium were significant different between before and after timber harvesting. This tropical peat swamp forest also acidic soil in range 3.2 - 4.0 % and had large amounts of total carbon (before 48.85 %, after 48.30 %), low CEC (before 68.04 cmol/kg, after 46.17 cmol/kg), high soil organic matter content (before 97.70 %, after 96.59 %), low mineral nitrogen (before 0.79 %, after 1.18 %), and high C:N ratio (before 74.04 %, after 53.25 %) low phosphorus (before 219.20 mg/L, after 312 mg/L) and low available K (before 330.60 mg/L, after 613.90 mg/L). The low nitrogen and phosphorus suggests that this peat swamp forest typically represent shallow peat. This study found that the comparison before and after of some parameter were significant different, such as pH-water, CEC, SOM, total C, total N, total P and available K. Meanwhile, some parameter are not significantly different, such as pH KCl, and C:N ratio.

ABSTRAK

Sarawak mempunyai keluasan tanah gambut yang luas di Malaysia. Kajian ini adalah untuk menentukan perbezaan sifat-sifat kimia berdasarkan keasidan tanah, keupayaan pertukaran kation, bahan organik, jumlah karbon, jumlah nitrogen, jumlah fosforus, kalisum tersedia dan nisbah karbon dan nitrogen sebelum dan selepas penuaian balak di hutan paya tropika. Sampel tanah diambil pada kedalaman 0-15cm pada enam kawasan seluas 0.1 hektar setiap kawasan di hutan Batang Igan Sibu Sarawak, Malaysia. Sampel tanah yang diambil di analisis kandungan keasidan tanah, keupayaan pertukran kation, bahan organik, jumlah karbon, jumlah nitrogen, jumlah fosforus, kalisum tersedia dan nisbah karbon dan nitrogen. Data daripada kajian ini di analisis dengan menggunakan sistem analisis statistik versi 9.2. Hutan paya tropika berada dalam keadaan berasid dalam julat 3.2 - 4.0 % dan mempunyai kandungan simpanan karbon yang tinggi (sebelum 48.85 % dan selepas 48.30 %), keupayaan pertukaran kation yang rendah (sebelum 68.04 cmol/kg dan selepas 46.17 cmol/kg), bahan oganik yang tinggi (sebelum 97.70 % dan selepas 96.59 %), mineral nitrogen yang rendah (sebelum 0.79 % dan selepas 1.12 %) dan mempunyai nisbah karbon dan nitrogen yang tinggi (sebelum 74.04 % selepas 53.25 %). Selain itu, kandungan fosforus adalah rendah (sebelum 219.20 mg/L dan selepas 312 mg/L) dan kandungan kalium tersedia yang rendah (sebelum 330.60 mg/L dan selepas 613.90 mg/L). Kandungan nitrogen dan fosforus yang rendah adalah disebabkan oleh tanah gambut yang rendah. Daripada kajian ini didapati bahawa terdapat perbezaan antara parameter pH-air, keupayaan kapasiti kation, bahan organik, jumlah karbon, jumlan nitrogen dan jumlah fosforus serta kalium tersedia. Selain daripada itu, sesetengah parameter tidak menunjukkan perbezaan dimana parameternya adalah pH-KCl dan nisbah karbon dan nitrogen.

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APPROVAL

I certify that this research project report entitled "**Comparison of Chemical Properties on Peat Swamp Soil Before and After Timber Harvesting in Sibu Forest**" has been examined and approved as a partial fulfillment of the requirement for the degree of Bachelor of Science Bioindustry in the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ha	Hectare
%	Percentage
±	plus minus
cm	Centimeter
µm	Micrometer
nm	Nanometer
mL	Milileter
mm	Milimeter
mg	Miligram
m	Meter
°C	Degree Celsius
ppm	Part per million
Pg	Picogram
Gt	Gigatone
kg/ha	Kilogram per hacter
$g\ kg^{-1}$	Gram per kilogram
$g\ kg^{-1}\ yr^{-1}$	Gram per kilogram per year
mg/kg	Miligram per kilogram
m/km	Meter per kilometer
meq/100 g	Mill equivalent per hundred gram
cmol/kg	Center mole per kilogram
g	gram
g/cm^3	gram per cubic centimeter
mg	miligram
min	minute
N	Newton
M	Mole
pH	Acidity
CEC	Cation Exchange Capacity
SOM	Soil Organic Matter
SOC	Soil Organic Carbon
SIC	Soil Inorganic Carbon
SAS	Statistical Analysis System
C	Carbon
N	Nitrogen
P	Phosphorus
K	Potassium
USDA	United State Development Agriculture

CHAPTER 1

INTRODUCTION

1.1 Introduction

Peat swamp forests are tropical moist forests where waterlogged soils prevent dead leaves and wood from fully decomposing, which over time creates thick layer of acidic peat. Large areas of these forests are being logged at high rates. Peat in strict definition usually refers to the accumulation of a purely one hundred percent of organic material (Andriesse, 1972). Peat as organic soils on the basis of mass composition for example soils that contain at least 65 % organic matter or conversely and have less than 35 % mineral content (Tie and Kueh, 1979). Soil Division of Sarawak define the soil based on profile partition for example soils that have 50 cm or more organic soil matter within 100 cm or more than twice that of mineral soil materials overlying bedrock within 50 cm (Anderson, 1983). USDA defines a soil type as organic soils if more than half of the upper 80 cm of the soil is organic or if organic soil material of any thickness rests on rock or on fragmental material having interstices filled with organic materials (Soil Survey Staff, 1998).

Peat soil is also call organic soil which is form in the surface layers. It occurs in three geomorphic situations, there are lowland coastal swamps, inland swamps and valleys and high altitude which are free draining situations and highland swamps. Peat swamps are part of fragile environment threatened by land development like agricultural and urban, logging such as unsustainable logging practices and over harvesting of commercial species, fire which is deliberate or accidental and alteration of the hydrology by the construction of dams for oil pipelines. Most peat swamps are

generally elevated 4 - 9 m above the adjacent river courses and the surface slopes vary gently between 1-2 m/km.

Peat soil is a representative material of soft soils and classified as highly organic. In general, peat is mainly composed of fibrous organic matters, for example partly decomposed plants such as leaves and stems. Peat has largely organic residues of plants, incompletely decomposed through lack of oxygen. Because peat swamps are not drained by flooding, they are nutrient-deficient and acidic where pH usually is less than 4. Compared with other moist forest echo regions, peat swamp forests are not as species-rich or high in endemics.

The recent harvesting operation on peat swamp forest is utilizing the heavy machinery which it not appropriate for the wetland forest. So after applying this harvesting operation, it will give the impact into peat swamp forest soil properties, such as the changes of soil properties both physically and chemically. This research is important to clarify the impact of harvesting operation into peat swamp forest in term of chemical properties of peat swamp forest soil.

1.2 Objective

The objectives of this study was to compare pH, cation exchange capacity, soil organic matter, total carbon, total nitrogen, total phosphorus and available potassium (K) of peat swamps soil, before and after harvesting at Batang Igan Forest in Sibu.

CHAPTER 2

LITERATURE REVIEW

2.1 Formation of Peat

Peat is a type of organic soil, which consists of more than 70 % of organic content. Peat deposits are found all over the world where conditions are favorable for their formation but they are most extensive in areas with cold climates. Malaysia is one of the countries in the world that some 3 million hectares that is about 8 % covered with peat soil. In Sarawak peat covers about 1.66 million hectares constituting 13 % of the state (Anderson, 1983).

Peat soil is found almost everywhere in this world except the arid climate regime such as the desert. Peat is formed when plants die and decompose in anaerobic condition. When the activity of microbes increases, the decomposition of the plants remains is enhanced. Peat soil in Malaysia is defined as an organic soil with a depth of at least 0.5 m and contains a maximum of 35 % of mineral content. It is called muck, if the mineral content is in between 35 % and 65 % (Tie and Kueh, 1979).

Peat soil in Malaysia is categorized as problem soil for agricultural production. It is less fertile and not suitable for agriculture purpose (Coulter, 1960). Malaysian peat is naturally coarse, woody in structure, fibrous in texture and contains less mineral, very acidic, and least used for agriculture purposes (Hammond, 1981), with water holding capacity 20 - 30 times the dry weight and less aeration. Cation exchangeable capacity is very high and very low base saturation (Joseph *et al.*, 1974; Chenu *et al.*, 2000).

According by Buol *et al.* (1973) in their findings concluded that there are two major stages in the formation of peat. They are the accumulation stage and the maturation stage. In the accumulation stage, all the organic materials are washed away and tend to gather in the swampy area which becomes enriched with nutrients. On the surface there will be lots of growth of the flora which eventually collapsed and make part of the system. At maturation stage, it refers to the decomposition due to drop in water level, within the horizon.

2.2 Soil Acidity (pH)

Soil acidity (pH) of organic soils in Sarawak was found to be highly correlated with the decomposition rate, higher the pH greater the decomposition rate. Almost all organic soils in Sarawak are very acidic with pH ranging from 3.2 - 4.0 (Mohamed *et al.*, 2002). Variations within this range are caused either by admixtures of mineral soil which generally increase the pH or by specific locations in the peat swamp, variations occur in different sections of the dome shaped (Ombrogenous) peat swamps where the surface layer of the thickest section are lower in pH compared to the shallower organic soils near the edge (Andriesse, 1988).

Peat swamps have developed on marine clay sediment that were deposited during periods of high sea level and contain high concentration of pyrite (FeS_2). When the pyrite is oxidized upon exposure to air, sulfuric acid is formed and the pH value of the soil fall to below 4 and sometimes even to below 3 (Lucas, 1982).

Since the peat soil in Sarawak is very acidic, the pH is low, so the slower or lower decomposition rate resulting in low net N mineralization in soil because there is very small number of acid tolerant decomposing microorganisms in the soil. Hence

generally, the Nitrogen content (% total N) in the acidic peat soil is low. The amount of net mineralized N (in weight basis) in peat soils was two times higher than in mineral soils. However, amount of mineralized N and CEC (in volume basis) were only 20 % of those in weight basis (Mohamed *et al.*, 2002).

Volarovich and Churaev (1968) have stated that, the higher the soil pH the greater the decomposition rate of the peat soil. The soil acidity is important in this study since it can influence the exchange capacity of peat soil. Studies by Helling, Chesters and Coey quoted by Lucas (1982) shows 73 meq/100 g at pH 3.5, 127 meq/100 g at pH 5.0, 131 meq/100 g at pH 6.0, 163 meq/100 g at pH 7.0 and 215 meq/100 g at pH 8.0 can be obtained.

2.3 Cation Exchange Capacity (CEC)

Peat swamps most commonly found in swamp coastal lowland. Most farmland is affected by Aluminum and ion toxicity, salinity, low quantities of major nutrient and low base status, as well as by soil acidification and is consequently abounded. The potential of the ionic strength and the concentration of organically complexes Al and Al oxide particles associated with organic matter to modify the CEC. Most important factor that regulating CEC seemed to be the organic matter concentration (Attanandana and Vacharotaya, 1996; Philips, 1998).

The Cation Exchange Capacity measured at pH 7.0 is very high (usually more than 50 meq/100 g) but is considerably less at soil pH in the field because most of the surface charges are pH dependent (Sime Darby Services, 1999). Andriesse (1988) quoting Volarovich and Churaev (1968) stated that the ion adsorption and exchange

is associated with the hydrophilic colloids of the organic soils, namely the humic acids and hemicelluloses. The occurrence of ion adsorption both at the surface of loose particles as well as inside the loose particles of the hydrophilic colloids explains the high CEC values usually found in organic soils (Mohamed *et al.*, 2002).

Organic soils in Sarawak tend to be highly saturated with hydrogen ions. Therefore, the base saturation is low. The average exchangeable cations in the surface are 5.68 meq/100 g, 4.55 meq/100 g and 0.41 meq/100 g soil respectively (Tie and Kueh, 1979). Hence, the high CEC values of organic (peat) soil will enable more NH_4^+ ions, which are released during organic matter decomposition to be adsorbed to the cation exchange sites of colloids of the organic soils, given the ability to leach out H^+ ions which are abundant in organic soils. According to Witter and Kirchmann (1988), the peat had a very high affinity for ammonia and a high adsorption capacity (23.4 mg NH_3–N g^{-1}). With the fact that NH_4^+ ion is also a source of Nitrogen in organic soil, high CEC values in peat soil will increase N content of soil.

CEC is capacity of soil to absorb exchangeable cations. Adsorbed, exchangeable cations resist being leached from the soil and are quite available for plant use. Soils with high clay content tend to have a large capacity for retaining both water and available nutrients. The total cation exchange capacity of soil is the total number of exchanges sites of both organic and minerals colloids. For most soil, organic matter is the component with the greatest cation exchangeable capacity while clay has variable cation exchangeable capacity. The sand and silt fraction have exposed unsatisfied negative bond, but due to a low specific surface they contribute little to the cation exchangeable capacity of most soil (Oades *et al.*, 1989). Variable charge is

associated primarily with oxides and soil organic matter (SOM). Oxides express positive charge at the nature pH, due to their high point of zero variable charge (pH 0). SOM is the most important contributor to the CEC in the soil. Generally, about 25 - 90 % of the totals CEC are responsible by SOM to the surface horizons of mineral soil (van Dijk, 1971).

Decomposition of organic matter produces a variety of organic compounds which can exhibit exchange properties. Exchange properties in the soil play an important role in the agricultural management of soils in manipulating the chemical fertility. The exchange capacity of both mineral and organic soil materials depends on the number of negatively charged exchange sites. This adsorbs cations Ca, Mg, K and Na which replace the hydrogen ions at the sites. The ion adsorption and exchange is associated with the hydrophilic colloids of the peat, such as the carboxylic radical within the humic acids and hemicelluloses (Volarovich and Churaev, 1968). The sites located inside loose particles and main surfaces of hydrophilic colloids take part in the ion exchange. This explains the high exchange capacity values found in peats. In most tropical soils, cation exchange capacity and exchangeable base concentrations become limiting factors in soil productivity (Mehlich, 1942). Volarovich and Churaev (1968) investigated on fresh peat by using calcium adsorption which gave exchange capacity values of 100 - 180 meq/100 g of dry matter at pH 5.5 - 6.5 for eutrophic peat, whereas oligotrophic peats showed an exchange capacity of only 10 - 20 meq/100 g. Table 1 below shows CEC of tropical and temperate peats.

Table 1: Cation Exchange Capacity Value at pH 7

Type of peat	Location	CEC in meq/100 g.
Sphagnum 1	Finland	140
Sedge 1	Finland	70
Woody 1	Finland	100
Saw-grass 1	Florida, USA	208
Forest (woody) 2	Malaysia	106
Forest (woody) 3	Indonesia	125
Forest (woody) 4	Ivory Coast	23.0 (other method)

Source: Lucas, 1982.

Referring to a study done in anoxic peat, from about 0.1 m below the water table, decomposition rates decrease sharply (Clymo and Pearce, 1995; Daulat and Clymo, 1998). The possible explanation, is that the cations essential for microbial growth are conserved below the water table with increasing depth (Damman, 1978), while the strength of the cation exchange capacity increases with decreasing depth (Tummavuori and Sironen, 1983). Thus, cations become less available to micro-organisms with increasing depth, limiting decay. This shows that cation exchange capacity of peat influences the decomposition rate that directly influences the carbon and nitrogen storage within the soil.

2.4 Soil Organic Matter (SOM)

Soil organic matter is a fundamental component of soil and the global carbon (C) cycle. Soil organic matter controls many of the chemical, physical and biological properties of the soil (Doran *et al.*, 1994). The estimated amount of organic C stored

in world soils is about 1100 – 1600 Pg, more than twice the C in living vegetation (560 Pg) or in the atmosphere (750 Pg) (Sundquist, 1993). Hence, even relatively small change in soil C storage per unit area could have a significant impact on the global C balance soil organic matter is derived mostly from plant residue. Plants convert CO_2 into tissue through photosynthesis. Upon their death, plant tissues decompose, primarily by soil microorganisms, and most of the C in the plant material is eventually released back into the atmosphere as CO_2. Between 10 % and 20 % of the C in plant residue from SOM, sometimes referred to as "humus." Some of this C can persist in soil for hundreds and even thousands of years. Associated with the C in soil organic matter are many essential plant nutrients–primarily N, P and S. Concentration of soil organic matter range from 0.2 to over 80 % in peat soils although the typical range for temperate soils is 0.4 - 10 % (Smith *et al.*, 1992). While it is a minor component of soil, SOM is essential to the living component of soil. Soil organic matter serve as an energy source for most soil microorganisms and provide the nutrient for plant and the soil biological community. Thus, knowledge of SOM dynamics is crucial for the understanding of global cycling and plant production.

The accumulation of SOM is dependent on the quantity and quality of organic residue inputs, largely as plant material, the rates of microbial decomposition, and the capacity of the soil to store organic matter. The quality of the plant residue affects both the extent and rate of decomposition. Labile C compounds such as simple sugars degrade relatively rapidly and more completely to CO_2. On the other end of the spectrum, lignin is more difficult to degrade. Most microorganisms do not have the capacity to completely degradation products from the precursors to soil

organic matter. Generally, the C:N ratio is a guide of decomposability. A ratio > 30 slows decomposition and immobilizes N; a ratio < 20 releases N and allows microbial decomposition to proceed. Lignin content or Lignin:N ratio are also used to assess organic matter degradability.

The rate of microbial decomposition of plant material and soil organic matter also is a function of climate. As temperature increases, generally for every 10° C increase, microbial activity doubles (Q_{10} = 2). Soil water content also is important, optimum microbial activity occurs at near "field capacity" which is equivalent to 60 % water-filled spore (Linn *et al.*, 1984). When the soil becomes waterlogged, decomposition slows and becomes less complete. Peat soils often are a result of these waterlogged conditions. As soils dry, decomposition is also slowed. The third factor affecting the amount of soil organic matter is soil texture – primarily clay content and mineralogy. Clay content stabilizes soil organic matter by two mechanisms. First, organic molecules are chemically bound to clay surfaces, which retards degradation. Clay with high adsorption capacities, such as montmorillinitic clay, is effective in retention of organic molecules. Secondly, soils with greater clay content increase the potential for aggregate formation. Macro-aggregate physically protect organic matter trapped inside the aggregate from microbial degradation. Generally, aggregate > 25 μm provide the greatest protection (van Veen and Paul, 1981; Jastrow and Miller, 1996).

Soil organic matter is not one definable entity. Since SOM is formed from plant material and microbial decomposition products, it is a myriad of organic compounds. There have been several theories on the formation of soil humus but the most widely

accepted theory is that organic residues undergo decomposition by microorganisms (Paul and Clark, 1996). The altered compounds and new compounds synthesized by soil microbes polymerize through chemical or enzymatic reaction. Thus, SOM is undergoing constant transformation.

Along with carbon, SOM contains important plant nutrients. Soil organic matter can be a source or sink of plant nutrients. Plant productivity is directly associated with SOM content and turn over. Approximately 90 - 95 % of the soil N, 40 % of soil P and 90 % of the soil S is associated with SOM (Smith *et al.*, 1992). Generally, the C:N:P:S ratio is 100:10:1:1. In agriculture soils, approximately 2 - 4 % of the organic matter is rendered available for plant uptake on an annual basis.

2.5 Total Carbon (C)

Total carbon in soil is consisting of soil organic carbon and soil inorganic carbon. It influences its composition and concentration in soil which in turn influences its effectiveness in aggregation through associations with cation and soil particles. Soil organic carbon (SOC) is the carbon from organic matter. Aggregate stability is very closely with the organic carbon content. The organic matter appears to be a predominant indicator of aggregate stability. SOC is assumed to stabilize aggregate against disruptive process by two major actions. First, organic matter increase the cohesion of aggregate, through the binding of mineral particles by organic polymer or through the physical enmeshment of particles by fine roots, fungal hyphae or cynobacteria (Tisdall and Oedes, 1982). Second, organic matters decrease the wettability of aggregate by slowing their rate of wetting and thus extent of slaking (Chenu *et al.*, 2000).

The chemical properties of the SOC will determine their charge and complex capacities and also influence decomposition rates which have direct effects on aggregation (Schulten and Leinweber, 2000). The aggregate binding effect by labile SOC is rapid but transient (Kay, 1998) while slower decomposing of SOC has subtler effects on aggregation, but the effect may be longer lived (Martens, 2000). Soil inorganic carbon (SIC) exists in soil as primary and secondary minerals. Primary carbonates originate from parent rock material while secondary carbonates are form from primary carbonates when they are dissolved and translocated by water with organic acid and/or CO_2 from soil and atmosphere. Under conditions of decrease moisture or increase pH, cation, bicarbonate (HCO_3), dissolved carbonates and CO_2 can react with available cations to form secondary carbonate coatings on primary soil particles (Bronick and Lal, 2005).

Forest management can result in positive and negative impact on the quantity and quality of soil organic residue, rates of carbon and nitrogen mineralization as well as soil microbial community structure (Grayston and Renneberg, 2006). Alteration in these ecosystem components and functions through forest management practices can impact carbon dynamics. Carbon storage at the ecosystem level depends on the balance between photosynthesis C input and losses in the form of soil respiration (Janzen, 2006).

Timber harvesting reduces C input and increase C loss due to increase soil respiration (Balsen and Firestones, 2005). After a forest disturbance particular group of soil microorganisms become more prevalent (Ponder and Tadros, 2002). During forest management, changes in microbial community structure and activity can lead

to an alteration or reduction in soil organic matter pools by the modification of quantity of available substrates, as well as rate of substrate degradation (Paul *et al.*, 2006).

Determination of organic carbon content in organic soils is important, particularly for calculating the C/N ratio of the material (which is relevant for agricultural development purposes). The C/N ratio is also an indication of the degree of humification of the organic materials. The values can range from 12 - 60 % (Andriesse, 1988). Organic carbon content has been normally found to be higher at the surface than in the subsoil. Kanapathy (1976) gave values ranging from 58 % at the surface and 25 % in the subsoil. This pattern is better associated to deep organic soils due to the large content of ligneous materials in oligotrophic Histosols. Shallower organic soils have less accumulation of lignin.

2.5.1 Carbon Sequestration

Soil organic matter is made out of 57 % of carbon by weight. Plants synthesize organic compounds using sunlight energy and combines with carbon dioxide from the atmosphere and water. Soil organic matter is created by the recycling of these organic compounds from plants, animals, and microbes into the soil. Well decomposed organic matter forms humus in the soil that provides a carbon and energy source for soil microbes and plants. Thus, carbon sequestration is the process of capturing and securing storage of carbon that would otherwise be emitted to or remains in the atmosphere. The idea is to prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to

secure storage and remove carbon from the atmosphere by various means and stores it (Jones *et al.*, 2005).

Soil and forest have an important influence in the carbon dioxide level in the atmosphere and 20 % of annual carbon dioxide emission is contributed by deforestation. Agricultural ecosystems represent an estimated 11 % of the earth's land surface which includes some of the most productive and carbon-rich soils. As a result, they have a significant role in the storage and release of carbon within the terrestrial carbon cycle (Lal *et al.*, 1995). According to Bohn (1976) and Post *et al.* (1982) global soils contain approximately about 202 to 860 Gt of carbon. Although, Malaysia does not have much data on carbon sequestration, we can refer to studies done in Indonesia because of its climate and topography which is more similar to Malaysia.

Naturally, carbon sequestration is high in our forest ecosystem. This, natural carbon sequester tend to lose their carbon storage because of human activities. In Finland, 60 % of the original peatland area has been drained. As a result, the net ecosystem carbon dioxide exchange of agricultural peatlands is dominated by carbon dioxide release over carbon dioxide uptake due to the combined effects of low water table, mechanical disturbance such as tilling and fertilization (Davidson and Ackerman, 1993).

The carbon emissions from Finnish peatlands, used for agricultural purpose were estimated to be 2.5 tons, which is 3 % of all the national greenhouse gas emissions. Agriculture is responsible for 10 % of total green house gas emissions in Finland,

and organic soils are the most important agricultural sources of carbon dioxide and nitrogen dioxide. Studies show that conversion of native vegetation into cultivation in tropical regions causes changes in soil properties, including loss of organic matter, increased bulk density and decreases in exchangeable cations and base saturation (Lugo *et al.*, 1986).

2.6 Total Nitrogen (N)

Most of the nitrogen found in organic soils is in the organic form. Nitrogen levels in the surface layers of deep organic soils are generally higher than those in the shallow peat (Andriesse, 1988). Nitrogen content vary widely with a range of 0.3 - 4.0 % on dry weight basis. The percent total Nitrogen of peat soil is not high, when expressed on volume basis. When compared to mineral soil on volume basis, the Nitrogen content (% total N) of peat soil is lower because the bulk density of peat soil is lower (Mohamed *et al.*, 2002).

Nitrogen is one of the major nutrients affecting soil fertility (Heumann *et al.*, 2002). The content of various forms of this element in the soil depends primarily on the processes of immobilization and organic matter mineralization. The soil levels of nitrogen forms available to plants are generally low, and they range from 1 - 5 % (Bednarek and Tkaczyk, 2002). The micro-Kjeldahl method is most commonly used to determine nitrogen content in soil.

Nitrogen is the one most often limiting for plant growth. Many soils contain large amounts of nitrogen, but most of it is tied up in the organic fraction of the soil and only slowly released. Nitrogen becomes available for plant use from organic nitrogen

sources which must be converted to inorganic forms before they are available to plants. Nitrogen is available to plants as either ammonium (NH_4^+) or nitrate (NO_3^-). In most soils, ammonium is quickly converted to nitrate. Nitrate is not held on soil particles and is easily dissolved in water. Thus, it is susceptible to leaching (Borken and Matzner, 2004).

Therefore, the timing and rate of nitrogen fertilization are important for both the plant growth and environmental standpoint. On peat soils, nitrogen applied early in the season can be easily leached out of the root zone with heavy rainfall or irrigation. Nitrogen deficiency may result, as well as an increased potential for nitrate contamination of groundwater. Because of the mobility of nitrate in soils and the complex transformations of nitrogen from soil organic matter, soil tests for nitrogen are not reliable for predicting nitrogen needs in many situations (Borken and Matzner, 2004).

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another. The route that nitrogen follows in and out of the soil system is collectively called the "nitrogen cycle" and is biologically influenced. Once in the soil, nitrogen is redistributed by several pathways, partially because of the large number of chemical species that nitrogen forms in oxidation states ranging from N^{-3} to N^{+5}. The conversion of nitrogen from one species to another occurs in several biogeochemical process including ammonification, nitrification, mineralization, immobilization, denitrification, plant up-take, and organic decomposition. These processes are primarily controlled by oxidation-reduction conditions, bacterial respiration, and soil temperature (Bednarek and Tkaczyk, 2002).

Peat soil is a common term used to refer the organic soil consisting of partially decomposed organic matter, which its natural state had been a waterlogged basin and the accumulation of organic material has been faster than its decomposition (Andriesse, 1974). While mineral soil is, a soil composed of mineral or rock derivatives with little organic matter. The problems in utilization of peat soil lies in their physical and chemical characteristics. Basically, peat which is also known as organic soil contain excessive amount of water which causes poor aeration and low bulk density compared to mineral soil. Therefore, peat provides an unbalanced nutritional medium for plant growth. The availability of nitrogen is very low and the release of N for crop use is too slow to meet crop demands, as mineralization rate is slow at low pH and the reduced condition of the soil (Cabrera and Kissel, 1988).

Peat soil also has specific characteristics such as pH of less than 4.0, high organic matter and cation exchange capacity and low base saturation. It also have a larger amount of reserve H^+ and other nutrients (such as phosphorus) which buffer the pH change. This keeps the soil pH always stable. These characteristics reduce the availability of nutrients especially K, Ca, and Mg that are bound in such way that it is difficult for them to be utilized by plants (Boelter, 1969).

Generally, total nitrogen contents in peat soil are high when compared with mineral soil. However, the amount of nitrogen available to the plant is important. While available nitrogen is indirectly determined by factors influencing the total nitrogen content other factors such as temperature, moisture, aeration and acidity play a role. Normally in peat soil, most of the nitrogen is in the organic form but small quantities

of nitrate are usually present in better drained soils in which organic materials oxidize rapidly.

According to Mohamed *et al.* (2002), nitrogen content varies widely with a range of 0.05 - 2.05 % and about 0.15 % being representative for cultivated soil for dry weight basis of peat soil. However, nitrogen in peat is not high as thought, when expressed on volume basis and will decrease with depth instead of increasing. Driessen (1977) is worth quoting: "A normal peat soil with bulk density of 0.1 g/cm^3 and a nitrogen content of 2 % contains only 2000 kg N/ha in its upper 10 cm (assumed wood-free), whereas a mineral surface horizon with only 0.5 % nitrogen but a bulk density of 1 g/cm^3 contains 5000 kg/ha. In this light, values for nitrogen content of over 2 % which are generally considered to be high should be considered as low".

In considering the many transformations and reactions of nitrogen in soils, there are some major points to keep in mind. Although nitrogen can be added to soil in either organic or inorganic forms, plants take up only inorganic nitrogen (that is, NO_3^- and NH_4^+). Commercial nitrogen fertilizers, legumes, manures, and crop residues are all initial sources of NO_3^- and NH_4^+ and once in the plant or in the water supply it is impossible to identify the initial source. Nitrate is always present in the soil solution and will move with the soil water. Inhibiting the conversion of NH_4^+ and NO_3^- can result in less nitrogen loss and more plant uptake; however, it is not possible to totally prevent nitrification. There is no way to totally prevent the movement of some NO_3^- to water supplies, but some management practices can keep losses within acceptable limits (Humphrey and Pluth, 1996).

2.6.1 Importance of Nitrogen

According to Neary (2006), nitrogen has traditionally been considered one of the most important elements in the soil for the plant nutrient. It is an essential component of the proteins that build cell material and plant tissue. Plants, especially crops need a lot of nitrogen because it is part of many important compounds, including protein and chlorophyll.

Nitrogen is changing its chemical form continually and moving from plants through animals, soils water and the atmosphere (Wiederholt and Johnson, 2005). Plants respond to nitrogen in soil in many ways. Generally, nitrogen speeds growth of plants by having vigorous growth, large leaves and long stem internodes. Plants also use water when they have ample nitrogen. Most microorganisms and plants obtain N from the surrounding soil and water. Soil with lacking N show the deficiency effect in plant growth rate and leaves colour. Plant growth and crop yield usually increase when N is added, despite the presence of N in soils.

Just as too little N can cause problems, too much N can also cause problems. These problems can extend to plants, humans, animals, and the environment. About 97 % of soil nitrogen resides in organic matter, the soils storehouse of nitrogen. According to Neary (2006), organic matter and N losses from the surface mineral soil could have lasting effect on the long-term productivity and sustainability of the soil, particularly when they occur on nutrient-deficient sites.

2.7 Total Phosphorus (P)

The word phosphorus or P refers to the element and is also used as a general term when a particular chemical form of P is not being designated. For example, the total P content of a soil or plant material is usually expressed as percent P. P_2O_5 is a chemical produced during fertilizer analysis, but does not exist in either fertilizers or soils. Basically, P is an element that is present in small amounts in some rocks (average total P content of rocks is 1.2 %). As these rocks break down the P is released and becomes available for plants to take up and incorporate it into organic compounds. It is essential for plant growth. It stimulates growth of young plants, giving them a good and vigorous start. The total P content includes the total extractable P and soil solution P. P management and nutrition has both economic and environmental implications (Benjamin and Haygarth, 2000).

Total P includes Mineral P and organic P. Total P concentration in surface soils varies between about 0.02 % and 0.10 %. Mineral P constitutes 20 - 85 % of total soil P, depending upon the soil itself, particularly the soil organic matter content. Generally, formation of Aluminium and Ferum phosphates by precipitation or sorption, limits P solubility in acid soils while Calcium phosphates limit P solubility in alkaline soils. This shows that the maximum P solubility in equilibrium with P minerals is at pH 6.5. By the same time, the minimum amount of P retention, or fixation, (within the range of common soil pH values) is at approximately pH 6.5 (Neil *et al.*, 2001).

Organic P constitutes 15 % to 80 % of total P (and exactly complements the 30 % mineral P since soluble P is numerically negligible.) Soil organic matter typically

contains C:N:P:S in a ratio of 140:10:1.3:1.3, so that knowledge of the amount of organic matter will provide an estimate of the amount of organic P. Organo-P is cleaved by enzymes called phosphates, which are present in many soil organisms and produced by some plants as well. In some soils, P is the most limiting plant nutrient. In the tropics soil, where the pH of the soil is in the acid range tend to have a great P-fixing capacity. Soil organic matter levels have a very low P-fixing capacity.

Extractable P is also known as available P. It is the amount of P in the soil available for plants uptake mostly as H_2PO_4 or HPO_4. The soil usually contains less than 12 %. This is less than a one half day supply for a rapid growing plant. As P is used by plants it must be quickly replaced in order to maintain adequate levels of available P in the soil. P availability needs to be defined with respect to an external sink such as plants, plant community or crop. Plants differ in their ability to extract P from soils. Method for the determination of available P in an agronomic context never measure the quantity of P available to a crop, but measure a pool of soil P that is somehow related to that portion of soil P which is plant available (Gupta, 1999).

The average soil solution phosphorus concentration is about 0.05 ppm and varies widely among soils. The solution P concentration required by most plants varies from 0.01 - 0.30 ppm and depends on the crop species and level of production. P solubility expressed as the mean activity of dicalcium phosphate in equilibrium solutions increases regularly with the amounts of P adsorbed in the monolayer region on the surfaces of various materials likely to be present in calcareous soils. Values of the mean activity of dicalcium phosphate in equilibrium soil solutions increased as a direct function of the amount of phosphate added as concentrated superphosphate.

Differences in P solubility behavior between soils of varying texture are explained by measurements of the surface area and the capacity of the soils for monolayer adsorption of P (Cole and Olsen, 1959). The majority of soils contain a certain amount of adsorbed phosphate, so negative adsorption is observed if the analysis is carried out with solutions containing little or no phosphate. The technique is based on the analysis of the quantity of phosphate bound to the soil in the equilibrium state when soil samples are suspended in solutions containing various concentrations of phosphate (Miller, 1998).

2.8 Soil Potassium (K)

There are 4 general classes of soil potassium. The first is the mineral potassium which comprises about 90 - 98 % of a soil's total K supply. These minerals are very resistant to weathering and release negligible K to crops. The second will be slowly available potassium and it comprises from 1 - 10 % of the total soil K. It is held tightly between clay minerals and is released only slowly to plants. The third is the exchangeable potassium which comprises about 1 % of the total K but it is available to plants. The final class is the solution potassium which is available to plants but also susceptible to losses from leaching and it represents about 0.5 % of the total soil K (Kilmer *et al.*, 1968).

Potassium is present in igneous, sedimentary and metamorphic rocks and comprises about 25 g kg^{-1} of the earth's crust (Sheldrick, 1985). In mineral soils, K generally ranges between 0.4 and 30 g kg^{-1} (Sparks, 1987) with most agricultural soils containing between 10 and 20 g kg^{-1} (Jackson, 1964; Xie and Hasegawa, 1985). Total K contents in soils generally range between 10,000 and 50,000 kg ha^{-1} in the

upper 0.2 m of the soil profile. The K content in a soil is a reflection of its parent material, degree of weathering and amount of K fertilizer added minus losses due to crop removal, erosion and leaching.

Much like soil phosphorus, soil potassium (K) is present in large quantities. Only a small fraction of this total amount is plant available. Unlike phosphorus, potassium is not precipitated with other ions in the soil solution, but is adsorbed on the CEC of the soil or trapped between soil mineral layers. To measure exchangeable potassium, a solution containing a high concentration of another cation is added to the soil (usually ammonium acetate). The ammonium from the solution knocks potassium off the CEC and other exchange sites. The amount knocked off is measured and used to identify how much will become plant available over growing season.

Exchangeable K is defined as the fraction that occupies sites in the soil colloidal complex (Malavolta, 1985). The exchangeable K held by different bond strengths at the non-specific adsorption sites viz planar and edge positions of clay minerals and at the negative charges created by the carboxylic and phenolic groups of humus colloids compared to the pH dependent negative sites on clays. Although the exchange sites on clay particles caused by isomorphous substitution are relatively constant in numbers, the negative charges on the humus colloids and on the edges of the amorphous clay minerals increase as pH increases because of the dissociation of H^+ from weak acid groups (Gast, 1977). The amount of K held by clay minerals at exchange sites depends on kinetic as well as thermodynamic factors (Parfitt, 1992) and the affinity of the exchange sites for K is related to the nature of the soil surface

and the concentration of K in relation to other exchangeable cations, mostly divalent ions, present in the soils (Barbagelata and Mallarino, 2004).

McLean and Watson (1985) suggest that exchangeable K is approximately sufficient for near-maximum yields, when the K content in the soil solution is 5 % of the exchangeable K, and approximately 5 % of the K requirement of a crop is in solution at one time. In soils with small amounts of micaceous minerals, less preferential bonding to the clay would allow a larger percentage of the K to be in the solution phase. K is held on the cation exchange complex of the soil (clay and organic matter), which can range from 60 - 200 ppm K in the soil. K can be replaced by H^+, Ca^{2+}, Mg^{2+}, Al^+, etc. at the exchange site (acid weathering will remove K from the soil).

Based on report done by Edmeades (1982), the mean exchangeable K values for Thai and Indonesian paddy soils were 0.34 and 0.47 meq/100 g soil, comparable to the mean of Japanese soils, 0.40 meq/100 g soils. Malaysian soils had a relatively lower exchangeable K mean of 0.17 meq/100 g soil, which may have been because of their acidic nature. Exchangeable K levels were higher in Rendzinas, Grumusols and Andosols. Peat soils, reddish-brown lateritic soils, red-yellow Podzolic soils and low humic gley soils had lower exchangeable K levels. But irrigation water in Malaysia usually contains an adequate supply of potassium so crops seldom suffer from potassium deficiency.

In other study on New Zealand's soil, usually exchangeable K as a component of total soil K is below 2 % between 10 and 400 ppm. In many dairy-farming soils of

New Zealand, this value varies from 1 - 5 % of the total K content (Williams and Roberts, 1988). The exchangeable K is more related to the type of clay and its net negative charge. For example, the exchangeable K levels of allophanic soils are relatively small, whereas soils with large amounts of vermiculite or mica have greater amounts of exchangeable K (Parfitt, 1992).

Furthermore, weathering of micas results in decreased particle size, increased surface area and hence increased negative charge, indicating the soils that contain greater amounts of smectite minerals may have more exchangeable K than those containing interstratified micaceous materials, though the latter group may contain more non-exchangeable K is plant-available. The level of exchangeable K was also found to be affected by the nature of deposits and the climate. Increasing exchangeable K levels with increasing rainfall where loess accumulated, but decreasing levels where loess did not accumulate (Hay *et al.*, 1976).

CHAPTER 3

METHODOLOGY

3.1 Study Site

This field experiment was conducted on peat swamps soil forest at Batang Igan, Sibu as shown in Figure 1. Six plots were randomly established in this area, then 24 soil samples before and 24 after soil samples were taken from peat swamp forest. The soil samples was taken from the site of sampling covering 6 blocks, 20 x 50 m for each block and 50 m gap between each block (Figure 2). The soil samples was taken before and after certain period of times and evaluation carried out. Peat auger was used to take soil samples from one depth which are 0-15 cm, 48 samples before and after were taken from each corners and the middle of a plot then they were homogenized to make a composite sample. Proper labeling was done to avoid identification errors during transfer. These composite samples were then air-dried, homogenized and passed through a 2 mm sieve then kept for further analysis. Then the samples analyzed in laboratory. The analysis involving analysis for the soil acidity, cation exchange capacity, total carbon, total N, total P and available K of peat soil samples.

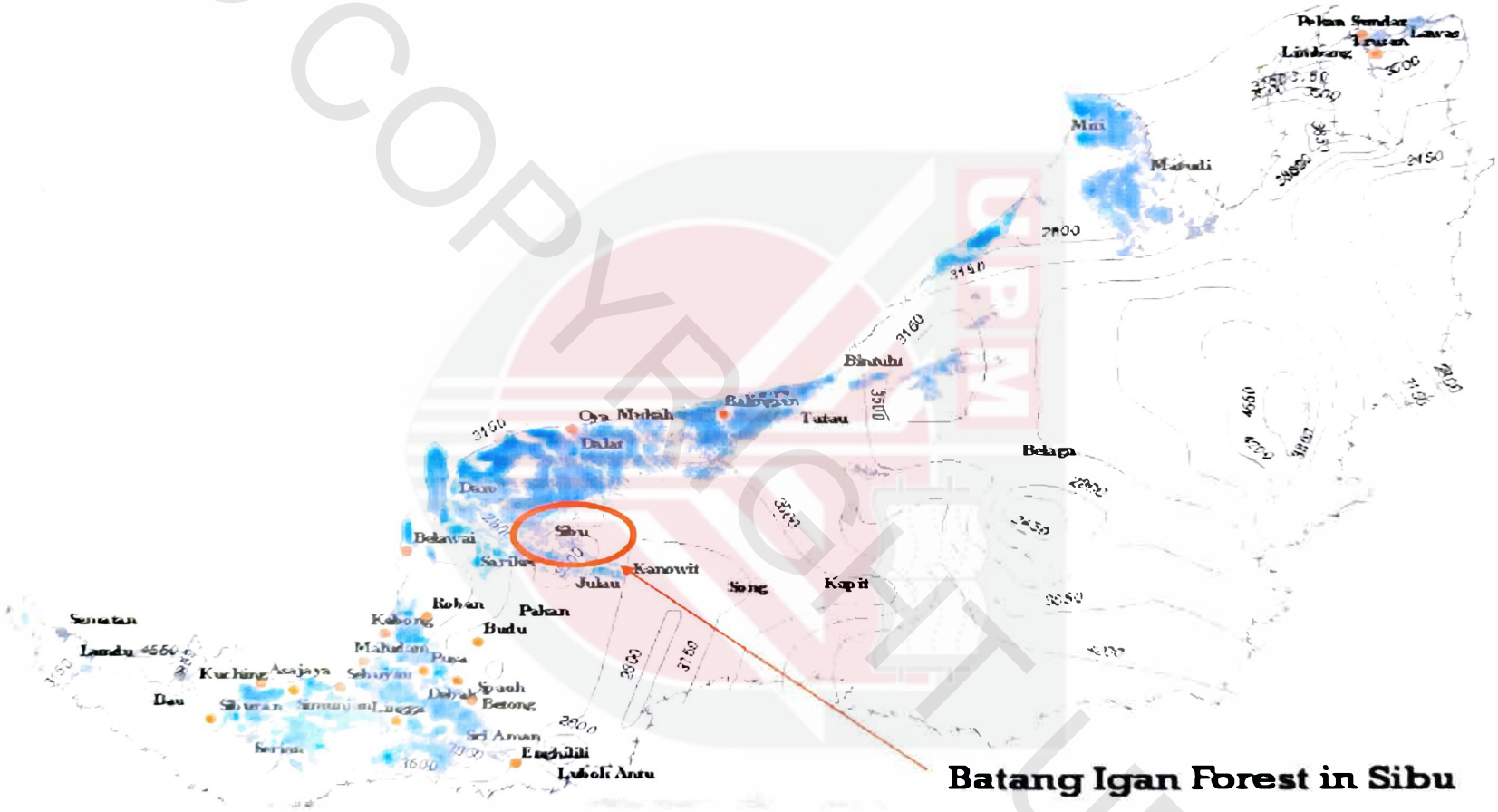

Figure 1: Study Area at Batang Igan Peat Swamp Forest in Sibu, Sarawak

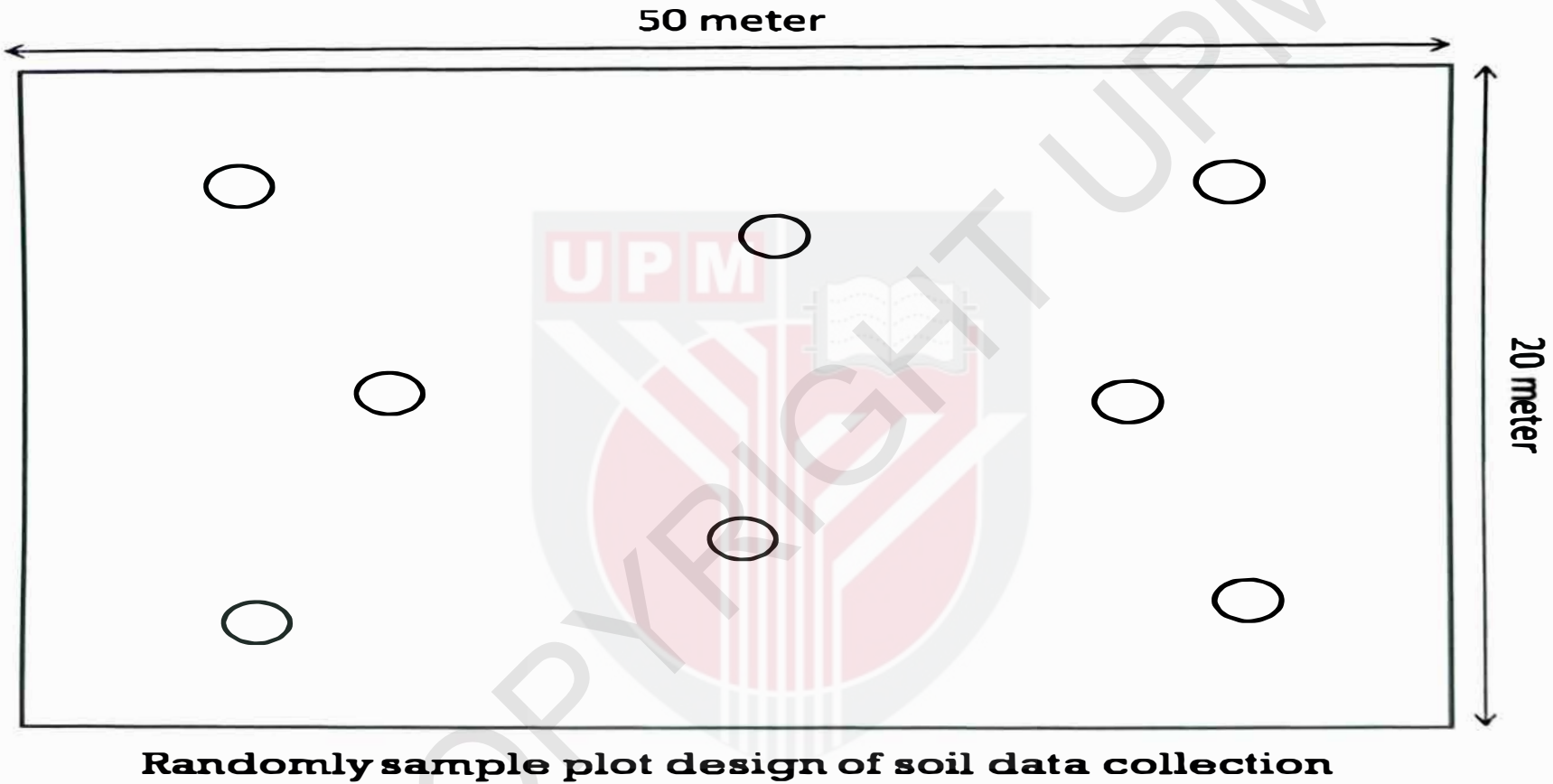

Figure 2: Field layout

3.2 Soil Analysis

3.2.1 Determination of Soil pH KCl and pH Water (H_2O)

Determination of pH was done by using pH meter. The electrical conductance of the solution was measured using the meter. The conductance was correlated in the machine to pH values which were read directly. The ratio of the soil and water was 1:2:5. The calibration was between buffer 4 and 7. Weight 10 g air dry soil sample into plastic vial, add 25 mL 1 N KCl and water shake for 15 minutes and read the pH using a calibrated, to pH water was done calibrated after 24 hour.

3.2.2 Determination of Cation Exchange Capacity (CEC)

Determination of cation exchange capacity (CEC) was done by using the leaching method (Ammonium acetat method). A 10 g of sieved soil sample was placed in a leaching tube and covered with a Whatman filter paper. The soil sample was leached using a 100 mL of 1 M of ammonium acetate (1 M NH_4OAc), then the sample was washed using ethanol. Again the same sample was leached using a 100 mL of 0.1 M of potassium sulfate (0.1 M K_2SO_4) the leachate was collected Afterwards, Pipette 10 mL of the sample into distillation flask with 10 mL of 40 % NaOH. Distilled and collect distillate in 10 mL of 2 % boric acid-indicator solution. The colour changes from purple to green during distillation. A boric acid is prepared by weighing 80 g of pure boric acid in a 5 L flask marked to indicate a volume of 4 L. Add about 3500 mL of distilled water. Heat and swirl until the boric acid dissolves and then allow it to cool. Add 80 mL of mixed indicator (0.099 g bromocresol green + 0.066 g methyl red in 100 mL of ethanol). Add 0.1 M NaOH until the solution becomes reddish purple (pH 4.8 - 5.0). Make up the solution to 4 L with distilled water. Removed the 50 mL conical flask containing the distillate when twice of the original volume (20

mL) is obtained. Titrate against 0.01 M HCl or 0.01 M H_2SO_4 until the colour change from green to purple. This directly gives the CEC in meq/100 g of soil or cmol(+)/kg of soil.

Calculation:

[CEC = (Titrate value (mL) x concentration of acid used x 100/10 x 1000/10)/10 = (meq/100 g or cmol/kg)]

3.2.3 Determination of Soil Organic Matter (SOM) and Total Carbon (C)

Organic matter and carbon can determination by using the dry combustion method (loss on ignition method). Place air-dry sample in an oven and dry it at 60 °C for 24 hours and cool it in a desiccators. Then, take the initial weight of silica or porcelain dish, place 5 g of sample into a silica or porcelain. Take a weight of the crucible plus the sample, placed the sample in the muffle furnace and initially ash at 300 °C for 1 hour and raise the temperature to 550 °C and continue with the ashing for 8 hours and allow the sample to cool down before inspection. Take the weight of sample and crucible after ashing.

Calculation:

[OM = Initial weight of sample (g) – final weight of (g)/Initial of sample (g) x 100/58]

[TC = Initial weight of sample (g) – final weight of (g)/Initial of sample (g) x 58/100]

3.2.4 Determination of Total Nitrogen (N) (Kjeldahl Method)

Extraction and determination of total N was done by weighed of 0.1 g soil into kjeldhal digestion tubes. Then the soil was wet with a few drops of water and 5 mL

concentrated sulphuric acid. One tablet of kjeldhal catalyst was added then the samples were shaked about 30 minutes to equilibrate it. After 30 minutes, the sample was heat in a digestion block at 180 °C for 1 hour, then the temperature was increased to 320 °C for 4 to 5 hour until samples become colourless, and then allowed to cool down. On cooling, 30 mL distilled water was added. The sand fraction should be left in the kjeldhal flask if any and the volume was making up when the solution is cool.

On cooling process, the samples in digestion tubes can be transferred into 100 mL volumetric flasks and make up to samples of 100 mL with distilled water. The sample was pipette into distillation flask about 10 mL and added 40 % of NaOH into it. Then, distillation processed was done and collect distillate in 10 mL of 2 % boric acid-indicator solution. The colour was changed from purple to green during distillation.

A boric acid indicator was prepared by weighed 80 g of pure boric acid in a 5 L flask marked to indicate a volume of 4 L. About 3500 mL of distilled water was added then heat and swirl it until the boric acid dissolves and then allow it to cool. Mixed indicator containing 0.099 g bromocresol green and 0.066 g methyl red in 100 mL of ethanol was added about 80 mL into the solution. Then, 0.1 M NaOH was added until the solution becomes reddish purple with pH of the solution about pH 4.8 - 5.0. After that, the solution was making up to 4 L with distilled water. Removed the 50 mL conical flask containing the distillate when twice of the original volume (20 mL) was obtained. Then titration process was done against 0.01 M HCl or 0.01 M H_2SO_4 until the colour of the solution changed from green to purple.

Calculation:

[% N = [(V-B) x M x R x 14.01/ Wt x 1000] x 100]

3.2.5 Determination of Total Phosphorus (P)

3.2.5.1 Preparation of Stock Solutions

Stock solution was prepared for extracting solution (aqua regia solution), phosphorus standards solutions 5 ppm, molybdate acid and ascorbic acid according to the standard procedure and stored at refrigerator for the Blue Method.

3.2.5.2 Extracting Sample (Aqua Regia Method)

Weight 5 g of soil sample was soaked overnight in 50 mL of aqua regia solution. It was digested at 180 - 200 °C for one hour on a hot plate. Transferred the sample into 100 mL volumetric flask and distilled water was added into the sample to make-up to 100 mL in volume.

3.2.5.3 Colour Development (Blue Method)

Pipette 10 mL soil extract (depending on P content in sample) into 50 mL volumetric flask, add 8 mL reagent B anda make up to 50 mL with distilled water shake and leave for 15 minit for colour development (colour change to blue colour). Total P was analyzed by using spectrophotometer at 882 nm wavelengths.

Calculation:

[Total P = C x V/M x D (mg/L @ ppm)]

3.2.6 Determination Available Potassium (K)

Available K was determined by using leaching method (ammonium acetate method). First leachate by using Ammonium acetate 1 M NH4OAc pH 7 is used to determine the amount of basic cations bases (Ca, Mg, K and Na) in the soil. Leachate sample is analyzed by Atomic Absorption Spectrophotometer (AAS).

Calculation:

[Available K = C x V/M x D (mg/L @ ppm)]

3.3 Statistical Analysis

Independent t-test was used to compare the significance of timber harvesting chemical properties before and after for peat swamp soil forest. Statistical Analysis System (SAS) version 9.2 was used for the statistical analysis (SAS, 1989).

CHAPTER 4

RESULTS

4.1 Soil Acidity (pH)

Table 2 are the data analyzed by using T-test (Unpaired) shows that there are no significant different between the soil acidity (pH KCl) before and after timber harvesting. The soil acidity (pH H_2O) shows that there significant different between before and after timber harvesting. Based on the Table 2, conclusion can be made from the data which is the pH in KCl and H_2O value (KCl 3.73±0.03), (H_2O 3.43±0.02) after harvesting is higher compared to pH KCl (3.71±0.04) and H_2O (3.25+0.01) before timber harvesting. Soil pH in KCl solution ranges from pH 3.39 - 4.03 before and pH 3.32 - 4.05 after timber harvesting while in H_2O solution ranges from pH 3.13 - 3.44 before and pH 3.22 - 3.67 after timber harvesting.

Table 2: Soil acidity (pH KCl and pH Water) before and after timber harvesting

Variable	Mean	
	Before	After
pH(KCl)	3.71±0.04[a]	3.73±0.03[a]
pH(H_2O)	3.25+0.01[a]	3.43±0.02[b]
Range (KCl)	3.39-4.03	3.32-4.05
Range (H_2O)	3.13-3.44	3.22- 3.67

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.2 Cation Exchange Capacity (CEC)

Table 3 is data analyzed by using t-test (Unpaired) shows that there are significant different between the cation exchange capacity (CEC) before and after timber harvesting. Based on Table 3, the conclusion can be made from the data is that the CEC value (68.04±1.99 cmol/kg) before is higher compared to CEC (46.17±1.36 cmol/kg) after timber harvesting. CEC before the timber harvesting ranges from 54.00 - 90.00 cmol/kg and after timber harvesting range from 37.00 - 62.00 cmol/kg.

Table 3: Cation Exchange Capacity (CEC) before and after timber harvesting

Variable	Mean	
	Before	After
CEC (cmol/kg)	68.04±1.99[a]	46.17±1.36[b]
Range	54.00-90.00	37.00-62.00

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.3 Soil Organic Matter (SOM)

Be based on Table 4, data analyzed by using t-test (Unpaired) shows that there are significant different between the soil organic matter (SOM) before and after timber harvesting. Based on this table, conclusion can be made from the data is that the SOM value (97.69±0.91 %) before harvesting is higher compared to SOM (96.59±1.42 %) after timber harvesting. SOM before the timber harvesting ranges from 95.71 - 98.97 % and after timber harvesting range from 93.53 - 98.54 %.

Table 4: Soil Organic Matter (SOM) before and after timber harvesting

Variable	Mean	
	Before	After
SOM (%)	97.69±0.91[a]	96.59±1.42[b]
Range	95.71-98.97	93.53-98.54

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.4 Total Carbon (C)

Total Carbon from peat swamp soil, before and after timber harvesting was shown in Table 5. Data analyzed by using T-test (Unpaired) shows that there are significant different between the total C before and after timber harvesting. Based on this table, conclusion can be made from the data is that the total C value (48.85±0.09 %) before is higher compared to total C (48.30±0.14 %) after timber harvesting. Total C before the timber was harvested is ranges from 47.86 - 49.49 % and 46.76 - 49.27 % after timber harvesting.

Table 5: Total Carbon (C) before and after timber harvesting

Variable	Mean	
	Before	After
TC (%)	48.85±0.09[a]	48.30±0.14[b]
Range	47.86-49.49	46.76-49.27

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.5 Total Nitrogen (N)

Total N in peat swamp soil were showed in Table 6. Data analyzed by using t-test (Unpaired) shows that there are significant different between total N before and after timber harvesting. From Table 6, conclusion can be made from the data is that the total N value (0.79±0.06 %) before is fewer compared to total N (1.18±0.11 %) after timber harvesting. Total N before the timber harvesting ranges from 0.21 - 1.47 % and after timber harvesting range from 0.40 - 2.52 %.

Table 6: Total Nitrogen (N) before and after timber harvesting

Variable	Mean	
	Before	After
Total N (%)	0.79±0.06[a]	1.18±0.11[b]
Range	0.21-1.47	0.40-2.52

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.6 Total Phosphorus (P)

Data analyzed by using t-test (Unpaired) shows that there are significant different between the total P before and after timber harvesting (Table 7). From this table, conclusion can be made from the data is that the total P value (219.20±18.79 mg/L) before is fewer compared to total N (312.00±34.98 mg/L) after timber harvesting. The total N before the timber harvesting ranges from 82.53 - 383.80 mg/L and after timber harvesting range from 14.93 - 653.47 mg/L.

Table 7: Total Phosphorus (P) before and after timber harvesting

Variable	Mean	
	Before	After
Total P (mg/L)	219.20±18.79[a]	312.00±34.98[b]
Range	82.53-383.80	14.93-653.47

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.7 Available Potassium (K)

Table 8 shows the soil available K in peat swamp soil forests, before and timber harvesting. Data analyzed by using t-test (Unpaired) shows that there are significant different between the available K before and after timber harvesting. Based on the table, conclusion can be made from the data is that the available K value (330.60±20.66 mg/L) before is fewer compared to available K (613.90±42.92 mg/L) after timber harvesting. The available K before the timber harvesting ranges from 188.80 - 557.80 mg/L and after timber harvesting range from 172.20 - 994.60 mg/L.

Table 8: Available Potassium (K) before and after timber harvesting

Variable	Mean	
	Before	After
Available K (mg/L)	330.60±20.66[a]	613.90±42.92[b]
Range	188.80-557.80	172.20-994.60

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

4.8 C:N Ratio

Table 9, shows the C:N ratio in peat swamp soil forests, before and timber harvesting that here was no significant difference between the C:N ratio before and after timber harvesting. Based on this table, the conclusion can be made from the data is that the C:N ratio value (74.04±8.47 %) before is decreased to C:N ratio value (53.25±6.52 %) after timber harvesting. The ranges are 33.23 - 232.48 % before timber harvesting and 19.04 - 118.54 % as timber was harvested.

Table 9: C:N ratio before and after timber harvesting

Variable	Mean	
	Before	After
C:N ratio (%)	74.04±8.47[a]	53.25±6.52[a]
Range	33.23-232.48	19.04-118.54

Note: Means with different letters within column indicate significant difference between before and after timber harvesting by independent t-test at $p \leq 0.05$

CHAPTER 5

DISCUSSION

5.1 Soil Acidity (pH)

Soil acidity is one of the chemical properties of soil. It is important in order to determine fertility of the soil and related to other nutrients and also others chemical properties. Soil physical disturbance also are able to lead the change of chemical properties of soil. This present study has shows that there are no significant different of pH KCl before and after timber harvesting. Means of soil pH KCl before harvesting is 3.71±0.04 while after the harvesting period is 3.73±0.03. Compare to the soil ph water, there are significant difference before (3.25±0.01) and after (3.43±0.02) timber harvesting. This is because pH H_2O indicates the current soil pH during sampling while pH KCl indicates the condition of soil pH in long term. The range of soil pH before and after was lies between the typical standard ranges of pH for organic soil. As reported by Mohamed *et al.* (2002), that almost of organic soil in Sarawak are very acidic soils with pH ranging from 3.2 to 4.0.

5.2 Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is pH dependent. Tie, (1988) has pointed out that the standard value of CEC for peat soil is in range of 40 - 135 cmol/kg. As the pH increase, the CEC also increase and vice versa. From statistical analysis, present study showed that timber harvesting has an influence on the CEC value as the mean before harvesting is 68.04±1.99 cmol/kg and 46.17±1.36 cmol/kg after the harvesting period.

There is a slight change of soil pH after timber harvesting affect the value of CEC as the mean after harvesting is lower than mean before harvesting. The mean of CEC value was decrease as decrease of pH due to low base saturation of organic soil in Sarawak that highly saturated with hydrogen ions as reported by Tie and Kueh (1979).

Reported by Sime Darby Services (1999) describe that high CEC values of organic (peat) soil enable more NH_4^+ ions, which are released during organic matter decomposition to be adsorbed to the cation exchange sites of colloids of the organic soils, given the ability to leach out H^+ ions which are abundant in organic soils.

5.3 Soil Organic Matter (SOM)

Soil organic matter influences many of the chemical, physical and biological properties of the soil. The decomposition rates of SOM will affect the properties of soil. It depends on the amount of organic matter available and rate of decomposition. According to statistical analysis, the study showed that timber harvesting has influence on the SOM value as the mean before harvesting is 97.69±0.91 % and 96.59±1.42 % after the harvesting period.

The statistical analysis shows decreasing of SOM. However, the value is still high which is in the standard typical range as it is more than 90 % of SOM in peat soil (Paul *et al.*, 1996). According to Tie (1990), the fact is that most of the organic soils in Sarawak in their natural state, show very little difference in term of the degree of decomposition of the organic material.

Organic matter loss due to timber harvesting is well established. This is because of the destruction of the native vegetation cover and tillage of soils that can result in a rapid decay of the organic matter that has accumulated in them over a long period of time. This stimulated decomposition has usually results the rapid decrease of the organic matter content in the soils when they are placed in crop production. The productiveness of soil is also usually decreases more or less in proportion to the supply of organic matter, the decrease in productivity during cultivation perhaps more marked in timbered soils (Webster *et al.*, 1990).

On the other hand, there is maybe some doubt whether most of timbered soils contain less total organic matter after a number of years of cropping compare to when it was first put under cultivation. It is true that the organic matter is distributed through a much thicker section of the soil. However, it does not appear in a very dark soil except in thin layer at the surface.

Likewise the original, organic matter that ready to decay has been decomposed and the humus now present is more resistant to decay. It is difficult to obtain the accurate data in this study because there is no way to sampling a virgin timbered soil properly. No one knows how much or if any of the forest litter should be include in the sample. Much of the litter is burned with the brush during clearing the land. The ash, rich in mineral nutrients, and the remnants of the litter are plowed into the soil and so provide nutrient for the crops grown during the long term (Jones *et al.*, 1997).

After a period of years, most of the humus in the soil has developed from the root and residue of the crop grown. The same difficulties are not encountered in sampling

cropped and virgin prairie soils. Studies on such sample show a marked decline of organic matter content during the long term of cropping, flowed by a continuous but decreasingly less rapid loss until virtually an equilibrium is reached (Charle , 2004).

5.4 Total Carbon (C)

Total carbon consists of organic and inorganic organic carbon. This present study recorded that total carbon of the peat soil forest is changed before and after timber harvesting. Mean of total carbon before timber was harvest is 48.85±0.095 % and 48.30±0.14 % after the period of harvesting. From the value of mean shows that total carbon was decline after timber was harvested. (Eswaren *et al.*, 1993; Brady, 2002) reported that total carbon range for peat soil is 12.0 - 57.0 %. The total carbon is related to the soil organic matter. After harvesting, organic matters of the soil become decrease because of no input of organic matter from the plant since it was harvested.

Similar as reported by Nye and Greenland (1960) and Cunningham (1963), soil organic matter declines rapidly after soil is exposed due to clearing activities. Soil organic matter begins to decline as soil temperature increases when exposed to sunlight due to loss in canopy cover and shifts the equilibrium between accumulation and decomposition. When this condition occurs, decomposition rate will increase because of rapid activities of soil microorganism as the environment was favorable to them. Rapid decomposition will make the carbon are most utilize by microorganism and consequently change the value of total carbon in the peat soil.

5.5 Total Nitrogen (N)

Generally, total nitrogen contents in peat soil are high when compared with mineral soil. However, the amount of nitrogen available to the plant is important. While available nitrogen is indirectly determined by factors influencing the total nitrogen content other factors such as temperature, moisture, aeration and acidity play a role. Normally in peat soil, most of the nitrogen is in the organic form but small quantities of nitrate are usually present in better drained soils in which organic materials oxidize rapidly. According to Mohamed *et al.* (2002), nitrogen content varies widely with a range of 0.05 - 2.05 % and about 0.15 % being representative for cultivated soil for dry weight basis of peat soil. However, nitrogen in peat is not high as thought, when expressed on volume basis and will decrease with depth instead of increasing.

After timber harvesting of peat swamp forest, there are a difference of Total N of the soil. Total N after the timber harvesting was higher as the mean is 1.18±0.11 % compare to the content of Total N before timber harvesting with mean 0.79±0.06 %. This is because after logging, the water table was decrease. This condition promotes more oxygen in the soil space and it will increase decomposition rate cause of increasing of soil microorganism's activities. The increment of decomposition of peat, increase N into the soil.

The nitrogen of this peat swamp forest was found to be within the range of shallow peat (Mohamed *et al.*, 2002). This also indicates that our research site has very low mineral nitrogen (NH_4^+ or NO_3^-) which is important for plant growth (Brady and Weil, 2002). However, in this strongly acidic and anaerobic or flooded soil, the

population of nitrifying bacteria is usually small or absent. Hence, the amount of ammonium-N in this soil was considerably greater than that of nitrate-N because of the low nitrification activity (Juo and Franzluebbers, 2003). Furthermore, the low amount of nitrogen in peat surface is sensitive to water table level.

5.6 Total Phosphorus (P)

Total phosphorus of the soil in peat swamp forest showed a big changed before and after timber harvesting. Total P after timber harvesting was slightly higher than before harvesting where the value of mean is 312.00±34.98 mg/L and 219.20±18.79 mg/L before timber harvesting. The result shows that total P lower compared to standard range (400 -1000 mg/L). Peat soil is high in organic matter content. When rapid decomposition occur due to the changed of environment after logging, the more P are released into the soil (Kanapathy, 1976).

Rowell (1994) reported that total P is higher in peat soil because peat is an organic soil which contains large amount of decomposed organic matter. In peat soil, humus particles are the residues of organic matter decay. Peat is usually contains greater P content than the layer below due to the adsorption of added P and greater biological activity and accumulation of organic material. As organic phosphate from solution, mineral and organic phosphate becomes soluble by mineralization and the activities of P-dissolving bacteria.

Besides that, peat with high humification has the largest content of P bound to humic substances which is not immediately available. Larger P contents are found in the surface horizons of swamp soil such as peat because they are more humified and

enriched with metal oxides (HCl-P) and humic substances (NaOH-P). This relationship can be explained by the fact that humic substances are formed gradually during humification. Due to the concomitant mineralization, organic P from dead plant material in the process of decomposition and P from fertilizers are permanently fixed to these newly-formed humic substances, to organic decomposition products, and to metal oxides. At the same time, the peat is enriched by P due to humification (Koppisch, 2001).

5.7 Available Potassium (K)

This present study showed that the available K in the soil is significant different before and after timber harvesting as the mean before is 330.60±20.66 mg/L and 613.90±42.92 mg/L as the mean after timber harvesting. This value shows the increasing of available K in the soil after logging. This is due to rapid decomposition of organic matter since the soil environment has changed after logging.

When desiccating of water occurs, the soil aeration has increase. Soil organisms activities will increase and this will promote decomposition process occur rapidly. Decomposition process will turn up the nutrient inside organic matter into the available form which is from organic to inorganic form. As this condition occur, more nutrients are available especially K. However, the quantity of available potassium or held in an easily exchangeable condition at any one time often very small (Brady and Weil, 2002).

Referring to Weil (2002), Soil pH has influence to the availability of potassium content in soil. He also stated that the annual loss of potassium by leaching is greater than usual in acid soil such as in the study site.

5.8 C:N Ratio

C:N ratio is an indication of the degree of humification of the organic materials as stated by Andriesse (1988). Generally C/N ratio in peat soil is high. According to Katase *et al.* (1991) the standard C:N ratio in peat soil in the range of 20.0 - 46.3 %. Timber harvesting has no influence to the C:N ratio as the value of C:N ratio has no significant change before and after the timber was harvest. Mean of C:N ratio is 74.04±8.47 % before timber harvesting and 53.25±6.52 % after timber harvesting. The value has changed as the soil was disturbed during harvesting process but however, according to statistical analysis by T-test shows there is no significant different.

Based on the carbon and nitrogen content before and after harvesting process there were significant differences in carbon and nitrogen content, however the significant differences between carbon and nitrogen content did not affect C:N ratio. This is because the process of changes in C:N ratio takes a lot of time before we are able to be discover.

CHAPTER 6

CONCLUSION

Throughout this study, it shows that there is a significant different of soil chemical properties before and after logging at peat swamp forest which is discovered from chemical analysis in the laboratory. Based on the chemical properties such as soil pH water, cation exchange capacity, organic matter, total carbon, total nitrogen, total phosphorus, and available potassium that have been done shows a significant difference. Result from analysis of pH KCl solution and C:N ratio show that there is no significant difference before and after timber harvesting. Cation exchange capacity and C:N ratio reduces after timber harvesting while other properties such as total nitrogen, total phosphorus and available potassium increases, and a slight changes of organic matter and total carbon after harvesting was done. Based from statistical analysis, it shows that no difference before and after timber harvesting. On the other hand, it shows that logging has affected to the chemical properties of peat soil.

Beside the bad impact of harvesting operation into peat swamp forest soil as mention above, there is also a good impact of harvesting operation into peat swamp forest soil in term of nutrients such as the increasing of total nitrogen, total phosphorus and available potassium in peat swamp forest soil. The common effect of logging is loses of carbon storage in the peat soil to the atmosphere. Consequently, it will increase the earth temperature and cause global warming.

For the next study, it is recommended that to add more parameter such as physical and chemical properties to be analyzed so that the effect can more detectable. Based on the observation, logging activities can be done at peat soil but in proper management.

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PUBLICATION OF THE PROJECT UNDERTAKING

This is to certify that I have no objection to publish the project entitled "**Comparison of Chemical Properties on Peat Swamp Soil Before and After Timber Harvesting in Sibu Forest**" by the supervisor in a joint authorship. However, it has to be evaluated by the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus and published in the form approved by the Faculty.

MUHAMAD ISMAWI BIN SALIMIN

Date: 09 May 2009