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SOIL PHYSICAL AND CHEMICAL PROPERTIES IN COMPARTMENT 5 OF GUNUNG SIKU FOREST RESERVE

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SOIL PHYSICAL AND CHEMICAL PROPERTIES IN COMPARTMENT 5 OF GUNUNG SIKU FOREST RESERVE

by

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DECLARATION

I declare that this thesis entitled Soil Physical and Chemical Properties in Compartment 5 of Gunung Siku Forest Reserve is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 09th JANUARY 2017

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Soil Physical and Chemical Properties in Compartment 5 of Gunung Siku Forest Reserve

ABSTRACT

This study concentrates on soil conditions at Compartment 5 of Gunung Siku Forest Reserve in Cameron Highlands, Malaysia after reforestation due to illegal opening of crop cultivation for past few years. As an effort of reforestation treatment at that area, four species were planted on 2015 which are *Nageia wallachiana*, *Agathis borneensis*, *Shorea platyclados* and *Gymnostoma sumathranum*. The objective of this study is to compare the soil physical properties such as soil pH, soil moisture content, soil texture and soil colour as well as the soil chemical properties such as soil organic matter and concentration of metal elements of the upper slope (1460m) and the lower slope (1413m) located at Compartment 5 of Gunung Siku Forest Reserve. The result obtained shows that the pH value at the study area is classified as moderately acidic to neutral with a range between pH 5.0 to pH 7.2 and the locations is statistically proven to affect the soil pH value due to downslopes movement of HCO_3^-. The soil moisture content varies between 1% (extremely dry) to 8% (extremely moist) due to change in humidity and density of vegetation covers at each slopes. Meanwhile, the soil texture are moderately coarse and generalized as sandy clay loam with a strong brown colour. In a period of eight month from February to October, the soil organic matter at the study area increases from 3.52% to 4.49% for the upper slope while the lower slope decline from 4.96% to 3.77% due to difference in climate and soil pH. Two macronutrients which are Mg with a total concentration of 3.97 mg/kg (February) and 4.60 mg/kg (October) whereas K with 29.44 mg/kg (February) and 28.74 mg/kg (October) provide efficient essential nutrients for plant growth successfully. Another three heavy metal elements were identified which are Pb (February - 0.55 mg/kg and October - 0.61 mg/kg) as well as Zn and Cu that decreases in level of concentrations from 0.65 mg/kg to 0.26 mg/kg and from 0.47 mg/kg to 0.26 mg/kg in a period of eight respectively. In overall, the results clearly shows that the soil at Compartment 5 of Gunung Siku Forest Reserve is fertile and suitable to aids in plant growth. Other than that, data obtained in this study can acts as a baseline data for any future researches related to soil physical and chemical properties at Compartment 5 of Gunung Siku Forest Reserve.

Sifat Fizikal dan Sifat Kimia Tanah di Kompartment 5, Hutan Simpan Gunung Siku

ABSTRAK

Kajian ini tertumpu kepada keadaan tanah di Kompartment 5, Hutan Simpan Gunung Siku, Cameron Highlands, Malaysia setelah penanaman semula yang diakibatkan oleh pembukaan ladang pertanian secara haram sejak beberapa tahun yang lalu. Sebagai satu usaha untuk menghutankan semula kawasan tersebut, empat tanaman telah ditanam pada tahun 2015 iaitu *Nageia wallachiana*, *Agathis borneensis*, *Shorea platyclados* dan *Gymnostoma sumathranum*. Objektif kajian ini ialah untuk membandingkan sifat fizikal tanah iaitu pH tanah, kandungan lembapan tanah, tekstur tanah dan warna tanah serta sifat kimia tanah bagi kawasan cerun tinggi (1460m) dan kawasan cerun rendah (1413m) di Kompartment 5, Hutan Simpan Gunung Siku. Keputusan yang diperolehi menunjukkan bahawa pH tanah di kawasan kajian diklasifikasi sebagai berasid sederhana ke neutral dengan jumlah pH diantara pH 5.0 ke pH 7.2 dan perbezaan lokasi juga telah dibukti secara statistik memberi kesan kepada kandungan pH tanah akibat dari pergerakan ke bawah HCO_3^- ke kaki cerun. Kandungan lembapan tanah juga berbeza diantara 1% (sangat kering) ke 8% (sangat lembap) disebabkan perubahan iklim dan kepadatan tumbuhan-tumbuhan renek di setiap cerun. Selain itu, tanah di kawasan ini juga mempunyai tekstur yang agak kasar dan diklasifikasikan sebagai lempung tanah liat berpasir dengan warna coklat pekat. Dalam tempoh lapan bulan bermula pada Februari sehingga Oktober, bahan organik tanah di kawasan kajian meningkat daripada 3.52% ke 4.49% di cerun tinggi manakala cerun rendah menurun daripada 4.96% ke 3.77% akibat dari perbezaan iklim dan pH tanah. Dua makronutrien iaitu Mg dengan jumlah kepekatan 3.97 mg/kg (Februari) dan 4.60 mg/kg (Oktober) manakala K dengan 29.44 mg/kg (Februari) dan 28.74 mg/kg (Oktober) membekalkan nutrien-nutrien yang penting secara efisien untuk tumbesaran pokok. Selain itu, tiga logam berat telah dikenal pasti iaitu Pb (Februari - 0.55 mg/kg dan Oktober - 0.61 mg/kg) serta Zn dan Cu yang masing-masing kepekatannya menurun dari 0.65 mg/kg ke 0.26 mg/kg dan dari 0.47 mg/kg ke 0.26 mg/kg dalam tempoh lapan bulan. Secara kesuluruhannya, keputusan yang diperolehi menunjukkan secara jelas bahawa tanah di Kompartment 5, Hutan Simpan Gunung Siku adalah subur dan sangat sesuai dalam membantu pertumbuhan pokok. Selain daripada itu, data yang diperolehi dari kajian ini akan dijadikan sebagai data baseline bagi apa-apa kajian berkaitan sifat fizikal dan sifat kimia tanah di Kompartment 5, Hutan Simpan Gunung Siku pada masa hadapan.

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cm	Centimetre
Feb	February
ha	Hectares
m	Metre
kg	Kilogram
lb	Pounds
mg/kg	Milligram per kilogram
mins	Minutes
Oct	October
p.m.	Post meridian
yr	Year
AAS	Atomic Absorption Spectrometer
ANOVA	Analysis of Variance
EP	Execution Plan
GHG	Greenhouse gases
HDF	Hill Dipterocarp Highland
LDF	Lowland Dipterocarp Forest
LMF	Lower Montane Forest
LOI	Loss on Ignition
PRF	Permanent Forest Reserve
UDF	Upper Dipterocarp Forest
UMF	Upper Montane Forest
XRF	X-ray Fluorescence
NRE	Ministry of Natural Resources and Environment Malaysia
DID	Department of Irrigation and Drainage
DOE	Department of Environment
FDPM	Forestry Department Peninsular Malaysia
Pahang SFD	Pahang State Forest Department
USEPA	United States Environmental Protection Agency
Al	Aluminium
Ba	Barium
Ca	Calcium

Ca^{2+}	Calcium ion
Cl	Chlorine
CO_2	Carbon dioxide
Cu	Copper
Fe	Iron
H^+	Hydron
H_2CO_3	Carbonic acid
HCO_3^-	Bicarbonate
K	Potassium
K^+	Potassium ion
Mg	Magnesium
Mg^{2+}	Magnesium ion
Mn	Manganese
Na^+	Sodium ion
P	Phosphorus
Pb	Lead
Rb	Rubidium
S	Sulphur
Si	Silicon
Ti	Titanium
Zn	Zinc
Zr	Zirconium

CHAPTER 1

INTRODUCTION

1.1 Background of the study

At the end of 2014, 83.5% of 5.80 million hectares (ha) Malaysia's forested land, have been gazetted as Permanent Reserved Forests (PRF) under the National Forestry Act, 1984 (FDPM, 2014). From that particular figures, Pahang has contributed about 2 068 082 ha of forested land with 80.41% of them are PRF (FDPM, 2014). Overall in 2014, there is 18 771 747 ha of PRF in Raub / Cameron Highlands with 20.65% of them are from Cameron Highlands (Pahang State Forestry Department, 2014).

Cameron Highlands, a small district in Pahang is located on Titiwangsa Range that is between two state borders, Kelantan and Perak in the North and West respectively (Barrow, 2006). Cameron Highland is distributed with variety of forest types such as Lowland Dipterocarp Forest (LDF) which is between 100 m – 300 m elevations, Hill Dipterocarp Highland (HDF) with an elevation of 300 m – 750 m, Upper Dipterocarp Forest (UDF) that is between 750 m – 1200 m, Lower Montane Forest (LMF) at 1 000 m – 1 200 m elevation and Upper Montane Forest (UMF) that have elevation above than 1 500 m (Kumaran & Ainuddin, 2006).

With an area of 1 060 ha, Gunung Siku Forest Reserve is classified as HDF and tropical montane cloud forest that act as a water catchment area as well as a habitat for endemic and rare flora (Peh *et al.*, 2011; Kumaran & Ainuddin, 2006). The trees on the upper montane zone are largely confined to members of the Coniferae, Ericaceae and Myrtaceae families (Perumal & San, 1998). Most of the cloud forests in

Malaysia soils are derived from weather igneous or sedimentary rocks (Kitayama, 1992; Proctor *et al.*, 1988).

However, uncontrolled opening of the forest for illegal agriculture plantation has led the Ministry of Natural Resources and Environment Malaysia (NRE) to formulate an Execution Plan (EP) Cameron Highlands Dream that aimed to rehabilitate Cameron Highlands (FDPM, 2014). According to FDPM Annual Report 2014, some of the activities outlined are enforcement and greening of areas in Cameron Highlands through tree planting in degraded areas especially those that have been illegally occupied either within or outside the PRF.

Thus, to tackle the issues that related to illegal opening of the Gunung Siku Forest Reserve, four crop species were planted in the study area on 2015 which are; *Nageia wallachiana* (Podo Kebal Musang), *Agathis borneensis* (Damar Minyak), *Shorea platyclados* (Meranti Bukit) and *Gymnostoma sumathranum* (Rhu Bukit) with a 3 m x 3 m length planting distance. These species are chosen because they are suitable to the highland ecosystem and able to achieve optimum growth at UDF (FDPM, 2014).

This Strategic Collaboration Program on Tree Planting at Cameron Highlands is collaboration among NRE with the cooperation of FDPM, Pahang State Forest Department (Pahang SFD), Department of Environment (DOE), Department of Irrigation and Drainage (DID) and other related departments under NRE (FDPM, 2014).

1.2 Problem statement

Studies on reforestation in highland are very scarce in Malaysia. Anthropogenic activities in highland such as the development of crop cultivation sector lead to deforestation as happened in Gunung Siku Forest Reserve, Cameron Highland. The application of fertilizers and pesticides for crop cultivation may cause the soil to become infertile and leads to desertification as fertilizers and pesticides can alter soil conditions. Tree planting on the polluted soils can aid in restoring the soil’s nutrients and regulate the soil fertility. Without trees, the excess carbon dioxide in the atmosphere cannot be regulated optimally and eventually increased the global temperature and leads to climate change.

1.3 Objective

The objective of this study is:

1.3.1 To compare the soil physical and chemical properties of the upper slope and the lower slope located at Compartment 5 of Gunung Siku Forest Reserve.

CHAPTER 2

LITERATURE REVIEW

2.1 Climate change

Climate change is happening globally with agriculture, forestry and land-use-change act as the major contributors to 25% of total emissions of greenhouse gases (GHG) (Neufeldt *et al.*, 2011). Neufeldt (2011) also mentioned that the "greenhouse gas effect" is vital for more balance ecosystem. However, additional warming due to anthropogenic activities may lead to climate to change over the time. GHG eventually will lead to another environmental impact which is global warming. Increasing in temperature will increase the rate of respiration while the rate of photosynthesis is reduced. However, the impact of climate on a forest ecosystem will vary depending upon what factors limit tree regeneration and growth (Bravo *et al.*, 2008).

In Malaysia, global warming may threaten the cloud forest biodiversity and these may lead to deforestation (Peh *et al.*, 2011). Increase in temperature during global warming increasing the rate of evapotranspiration and these dry conditions causing the trees to wilt and eventually die (Malhi *et al.*, 2014). Malhi *et al.* (2014) also concluded that the interaction between global climate change and regional deforestation may make Amazonian forests vulnerable to large-scale degradation.

2.2 Deforestation

Based on Figure 2.1, 2.2 and 2.3, it can be observed that the temperature in Cameron Highlands increased throughout the year from 1981 until 2010 due to increase in anthropogenic activities such as land clearing for agriculture in Cameron Highland. This activities had adverse effects on water catchment areas, resulting in stream diversion, reduced water storage capacities of reservoirs and excessive accumulation of silt at the Sultan Abu Bakar hydroelectric dam (Barrow, 2006).

In relating agriculture sector with the climate change and deforestation, major emissions of GHG to the atmosphere during agriculture activities are via the application of nitrogen-based fertilisers, topsoil degradation and erosion as well as energy-related emissions such as irrigation, heating and fertiliser production (Neufeldt *et al.*, 2011).

Kitayama (1994) also mentioned that the use of heavy pesticide and cultivation in montane forest usually involves large amounts of commercial fertilizer (as cited in Neufeldt *et al.*, 2011). Fertilisers contained heavy metals such as copper (Cu), lead (Pb), and zinc (Zn) may severely inhibit the organic contaminants in the soil and acts as the main threat to the plants and animals (Chibuike & Obiora, 2014).

Other than deforestation, flash flood and landslide also had occurred at Cameron Highland. On 5th November 2014, continuous rainfall causing the water level of Ringlet River in Cameron Highlands to increase resulting in mud floods at 0700 p.m. with four casualties being reported (Malaysian Meteorological Department, 2014).

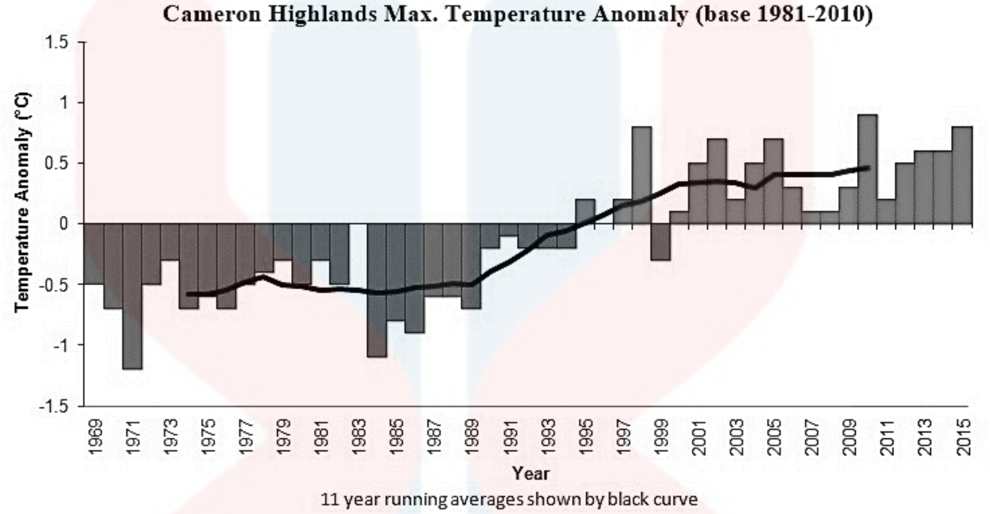

Figure 2.1: Cameron Highlands maximum temperature anomaly (base 1981 – 2010). (Source: Malaysian Meteorological Department, 2016a)

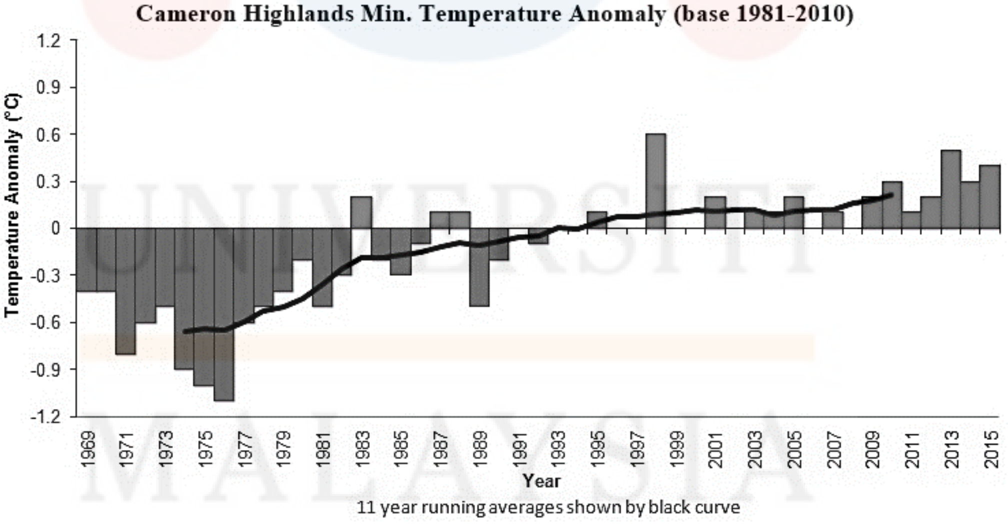

Figure 2.2: Cameron Highlands minimum temperature anomaly (base 1981-2010). (Source: Malaysian Meteorological Department, 2016d)

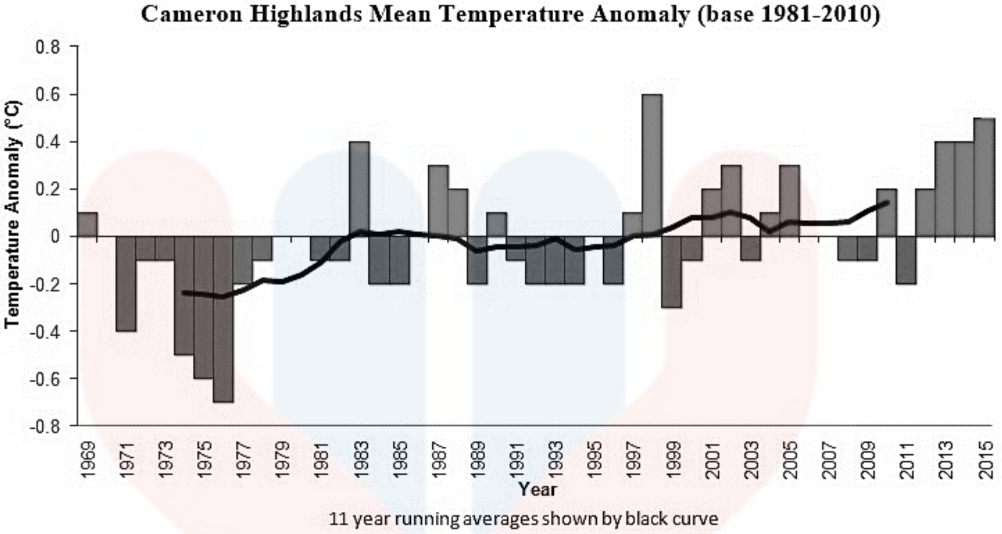

Figure 2.3: Cameron Highlands mean temperature anomaly (base 1981-2010).
(Source: Malaysian Meteorological Department, 2016b)

2.3 Soil

2.3.1 Soil Formation

There are two stages that involved in the formation of soil from parent material which are; the alteration of the primary mineral constituents of the parent rocks and paedogenesis (Fernandes & Bacchi, 1998; Kabata-pendias & Pendias, 2000). Kabata-Pendias and Pendias (2000), as well as Fernandes and Bacchi (1998), also state that physical and chemical processes of weathering aids in alteration of the primary mineral constituents whereas paedogenesis is due to the formation of a soil profile from the weathered rock material. According to Kabata-pendias and Pendias (2000) also, both weathering and paedogenic processes cannot be distinguished as they are closely interrelated and may occur at the same time.

The soil is a natural body, having both mineral and organic components as well as physical, chemical and biological properties (Kabata-pendias & Pendias, 2000). Based on Kabata-pendias and Pendias (2000) also, soils are composed of three phases which are solid, liquid and gaseous that exhibits properties resulting from the physical and chemical equilibriums of these phases. Chemical composition, mineral structure and the state of dispersion are important factors influencing soil properties (Kabata-pendias & Pendias, 2000).

2.3.2 Soil pH and Moisture Content

Soil pH value is influenced by the land use and management. Conversion of forestland to cropland can resulting in drastic pH changes after a few years (U.S Department of Agriculture, 2006). These changes caused by loss of organic matter, removal of soil minerals when crops are harvested, erosion of the surface layer and effects of nitrogen and sulphur fertilizers.

Variability in surface soil moisture content is strongly influenced by a variety of climatological and meteorological factors including incoming solar radiation, wind, humidity and most importantly precipitation (Petropoulos *et al.*, 2014). Reynolds (1970) was the first person propose that variability in surface soil moisture content might be largest after rainfall due to soil heterogeneity is at maximum whereas the opposite would occur after a prolonged dry period (Petropoulos *et al.*, 2014).

2.3.3 Heavy Metals in Soil

Contamination of soils by heavy metals has become a critical environmental concern due to their potential adverse ecological effects (Yadav, 2010). Heavy metals in soil may modify soil properties especially the soil biological properties by affecting the number, diversity, and activities if soil microorganisms (Chibuike & Obiora, 2014). Based on Chibuike and Obiora (2014), high metal concentrations in the soil causing the number of beneficial soil microorganism to reduce and lead to a decrease in organic matter decomposition leading to a decline in soil nutrients. The most abundance heavy metals in contaminated soils are lead, chromium, arsenic, zinc, cadmium, copper, and mercury. Oancea *et al.* (2005) conclude in their research that the heavy metals inhibit plant growth, causing structure damage and decline physiological and biochemical activities as well as of the function of plants.

Zinc (Zn) is essential in the soil for plant growth. However, an excess level of Zn concentrations in the contaminated soils may cause phytotoxicity and may inhibit many plant metabolic functions, resulting retarded growth and cause senescence (Yadav, 2010). Zinc toxicity also limiting the growth of roots and shoots as well as causing chlorosis in the younger leaves which can extend to older leaves after prolonged exposure to high soil Zn levels (Choi *et al.*, 1996; Ebbs & Kochian, 1997; Fontes & Cox, 1998; Yadav, 2010).

Cu is considered as micro nutrients for plants and plays an important role in carbon dioxide (CO_2) assimilation and adenosine triphosphate (ATP) synthesis (Thomas *et al.*, 1998; Yadav, 2010). However, according to Yadav (2010), Cu toxicity in soils induces stress and causes injury to plants. Lewis *et al.* (2001) also mentioned that Cu can lead to plant growth retardation and leaf chlorosis.

Lead (Pb) is one of the most abundant and distributed toxic elements in the soil (Yadav, 2010). Sharma and Dubey (2005) concluded that Pb toxicity causing decreased in plants photosynthetic rate inhibits activities of many enzymes, upsets mineral nutrition, and water balance, changes the hormonal status and affects the membrane structure and its permeability. Some of the visual non-specific symptoms of Pb toxicity are including stunted growth, chlorosis and blackening of the root system and eventually declining the crop productivity (Sharma & Dubey, 2005).

Visible symptoms of toxicity differ for each species and individual plants, but most common and nonspecific symptoms are chlorotic or brown points on leaves and leaf margins, and brown, stunted, coralloid roots (Boechat *et al.*, 2016; Kabata-pendias

& Pendias, 2000). However, these heavy metals considered safe unless the concentrations exceed the regulatory limits on heavy metals in soils as stated by USEPA in 1993 as below:

Table 2.1: Regulatory limits on heavy metals applied to soil.

Heavy Metal	Maximum Concentration in Sludge (mg/kg)	Annual Pollutant Loading Rates		Cumulative Pollutant Loading Rates	
		(kg/ha/yr)	(lb/A/yr)	(kg/ha)	(lb/A)
Arsenic	75.00	21.90	1.80	41.00	36.60
Cadmium	85.00	85.00	1.70	39.00	34.80
Chromium	3000.00	150.00	134.00	3000.00	2679.00
Copper	4300.00	75.00	67.00	1500.00	1340.00
Lead	420.00	21.00	14.00	420.00	375.00
Mercury	840.00	15.00	13.40	300.00	268.00
Molybdenum	57.00	0.85	0.80	17.00	15.00
Nickel	75.00	0.90	0.80	18.00	16.00
Selenium	10.00	5.00	4.00	100.00	89.00
Zinc	7500.00	140.00	125.00	2800.00	2500.00

(Source: USEPA, 1993)

CHAPTER 3

MATERIALS AND METHOD

3.1 Study Area

Cameron Highlands is significantly cooler than Malaysia's lowlands, with an annual mean temperature trend between 17.2^{o}C to 18.5^{o}C recorded from 1969 to 2015 as shown in Figure 3.1 (Barrow *et al.*, 2009; Malaysian Meteorological Department, 2016c). Malaysian Meteorological Department (2016e) also recorded in Figure 3.2 that annual rainfall trend for Cameron Highlands varies between 2000mm to 3500mm from year 1951 to 2015.

This study was conducted at an area of 2.5 hectares located at Compartment 5 of Gunung Siku Forest Reserve, Cameron Highlands. The geographic coordinates of the study area are 4°35'49.92" latitude with a longitude of 101°23'48.47" which is 1.2 km from the Second East-West Highway.

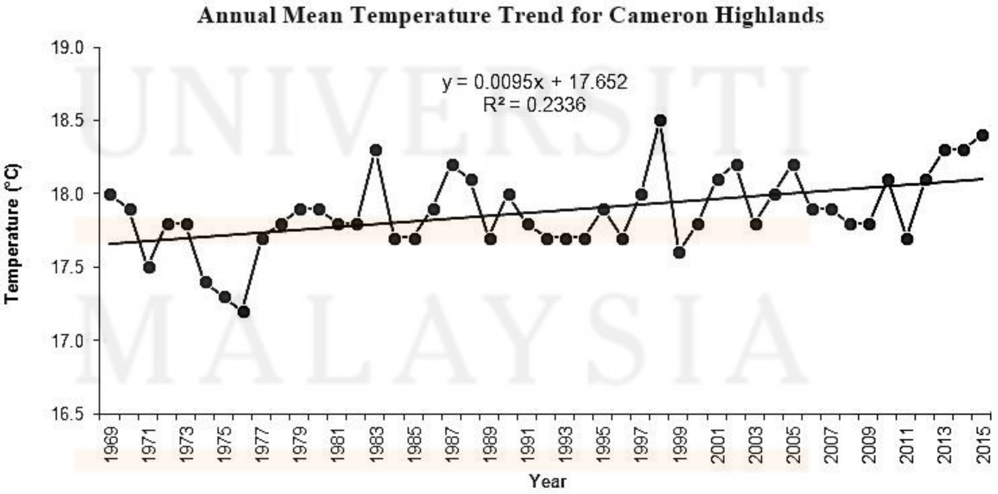

Figure 3.1: Annual mean temperature for Cameron Highlands.
(Source: Malaysian Meteorological Department, 2016c)

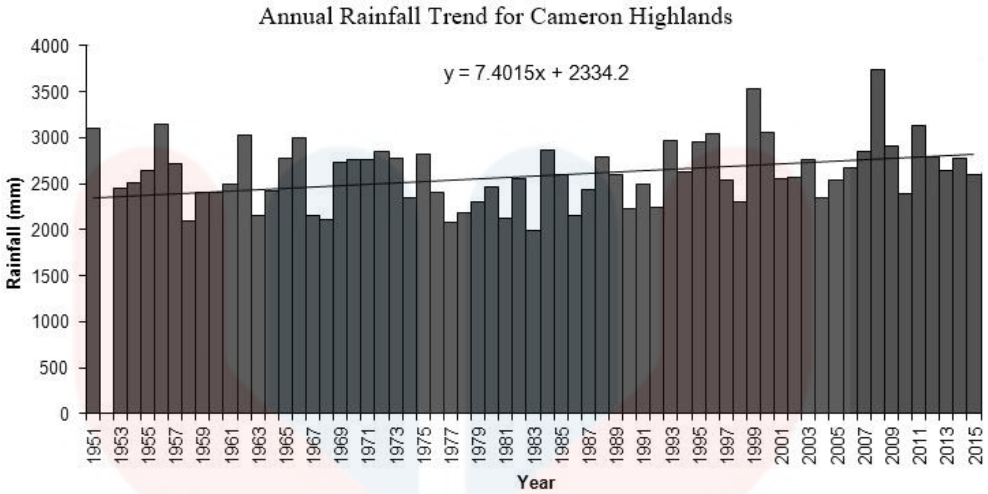

Figure 3.2: Annual rainfall for Cameron Highlands.
(Source: Malaysian Meteorological Department, 2016e)

Perumal and San (1998) recorded a few mountain trees at Cameron Highlands can such as:

Table 3.1: Examples of mountain trees in Cameron Highlands.

Family	Species
Actinidiaceae	*Saurauia mahmudii*
	Saurauia malayana
	Saurauia napaulensis
	Saurauia ulcani
Aquifoliaceae	*Illex glomerata*
	Illex kelsallii
Araliaceae	*Acanthopanax malayanus*
	Dendrapanax maingayi
	Schefflera tristis
Dipterocarpaceae	*Dipterocarpus retusus*
	Shorea platyclados
Elaeocarpaceae	*Elaeocarpus glabrescens*
	Eleocarpus nitidus Jack var. *velutinus*
	Eleocarpus nitidus var. *wrayi*
	Eleocarpus symingtonii
Ericaceae	*Lyonia ovalifolia*
	Rhododendron longifiorum
	Rhododendron moulmainense
	Rhododendron wrayi
Fagaceae	*Castanopsis rhamnifolia*
	Castanopsis scortechinii
	Lithocarpus bennetti
	Lithocarpus ewyckii
	Lithocarpus hendersonianus
	Lithocarpus machaphailii
	Lithocarpus neorobinsonii
Guttiferae	*Calophyllum symingtonianum*
	Garnicia spp.
	Mesua purseglovei

(Source: Perumal & San 1998)

Based on the Reconnaissance Soil Map of Peninsular Malaysia (1968), the soil located at Cameron Highlands is classified as steep land that consists of red-yellow podzolic soils with lithosols on acid to intermediate igneous rock (Soil Survey Division, Soils and Analytical Services Branch, Division of Agriculture and Fisheries, 1970). The site is located on a highland with an average elevation of approximately 1335 metre to 1469 metre above the sea levels.

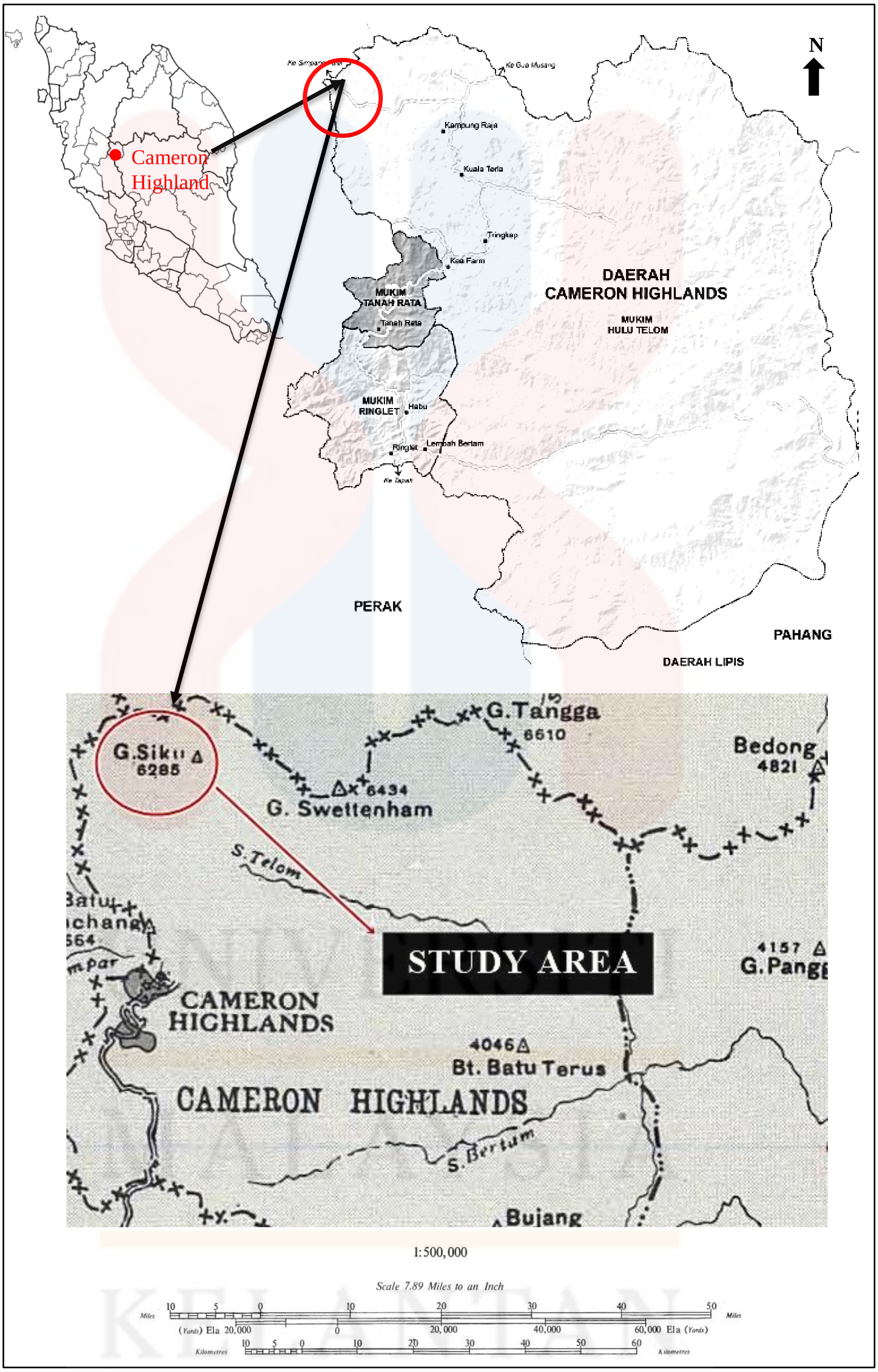

Figure 3.3: A map illustrating the location of the study area.
(Source: Edited from the Renaissance Soil Map of Peninsular Malaysia, 1968)

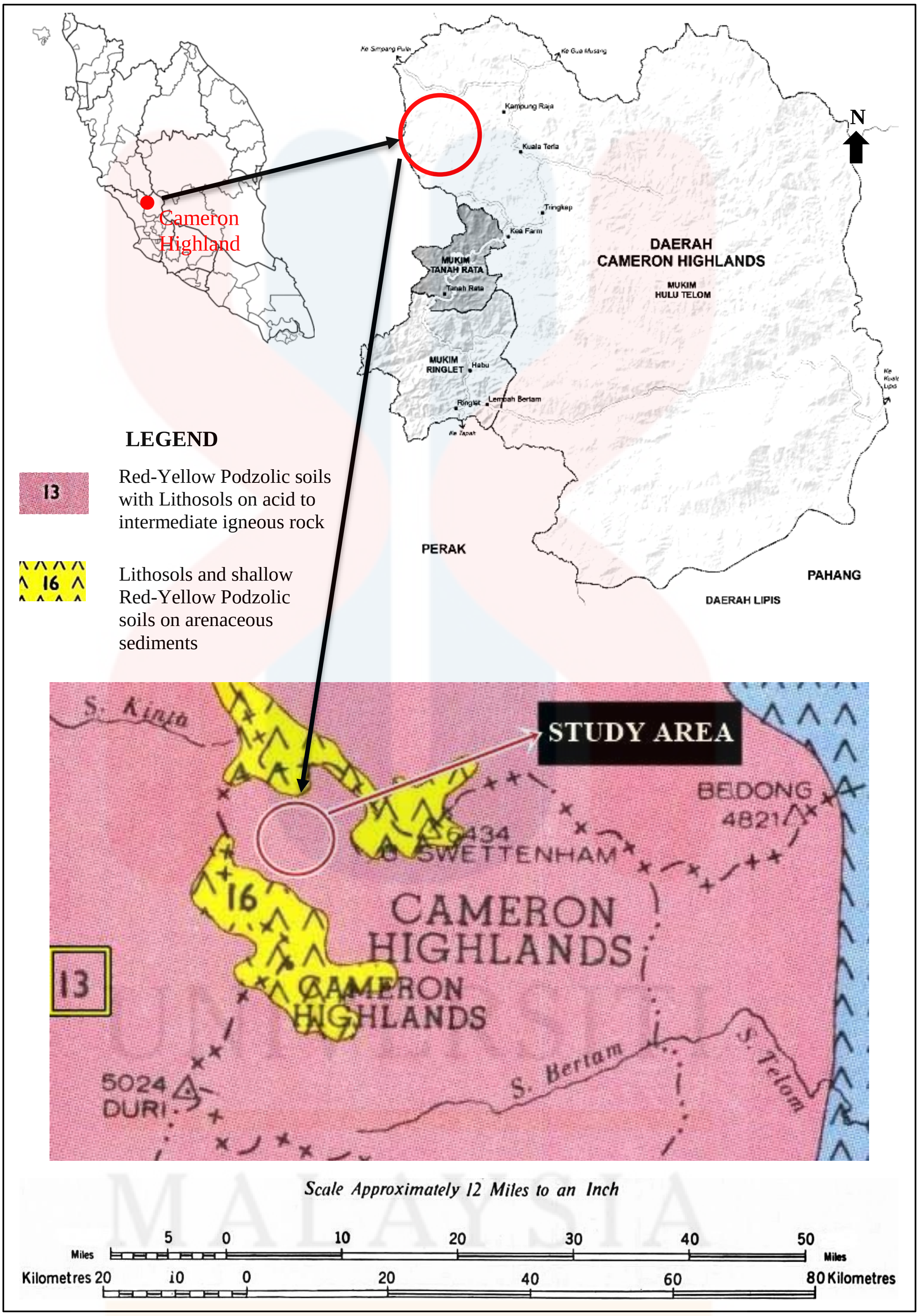

Figure 3.4: A map illustrating the soil type at the study area.
(Source: Edited from the Generalized Soil Map Peninsular, 1970)

3.2 Materials

The main materials that were used to study the soil physical and chemical properties are the soil samples collected from the established plots at Compartment 5 of Gunung Siku, Cameron Highlands.

Firstly, the soil pH and moisture content will be measured in-situ using Takemura Soil pH and Moisture Tester DM-15. This Takemura tester combines both pH and moisture meter and easily determined the soil pH and moisture content on the study site. Then, the soil colour was compared to the Munsell Book of Color that provides a notation for any colour in the universe with a complete and careful selection of colours arranged in orderly sequences of HUE, VALUE, and CHROMA (Munsell, n.d.). Other than that, the texture of the soil was determined using feel method.

Concentration of metal elements in soils were tested using Bruker AXS S2 RANGER X-ray fluorescence (XRF). According to Bruker AXS (2013), the S2 Ranger uses a 50kV X-ray tube to directly excite the X-ray fluorescence in a sample and XFlash will detect the X-ray fluorescence radiation of the sample. The multi-channel analysed divides up the different energies and accumulates counts to form intensity VS. energy spectrum (Bruker AXS, 2013). XRF is used rather that Atomic Absorption Spectrometer (AAS) because XFR can provide rapid, multi-element measurements with minimal sample preparation (Pyle *et al.*, 1996).

3.3 Method

3.3.1 Collection of Sample

Stratified random sampling was used to establish four plots with 20 m width x 20 m length each at the study area. The strata which were two different slopes and simple random sample were taken from each stratum. Stratified random sampling was selected to differentiate between the strata and increase the accuracy of estimates over the entire population (Singh, 2012).

The experimental plots were divided into two different slopes which are the upper slope (US_1 and US_2) and the lower slope (LS_1 and LS_2). The plot was marked using caution tape before collecting the soil samples. Soil sampling was collected in the middle of the plot diagonally at three sampling points with a distance of ± 5m. The soil samples is taken at month February 2016 and October 2016 to compare each physical and chemical properties.

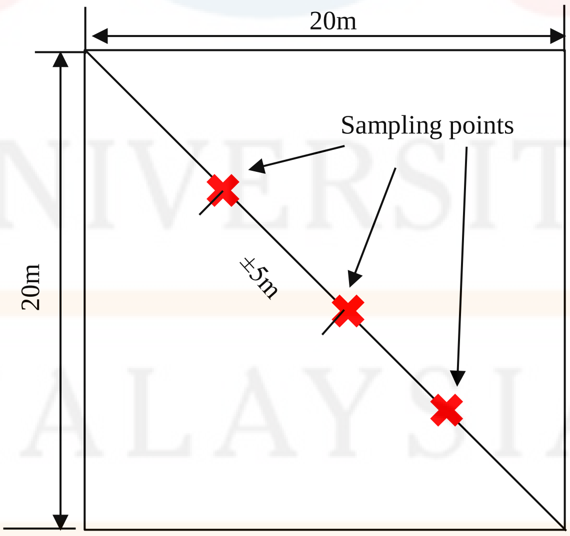

Figure 3.5: Experimental plot with three sampling points diagonally.

Dutch auger was used to collect soil samples at two different depths; 0 cm – 15 cm and 15 cm – 30 cm. Thus, a total of eight soil samples were collected as follows; 4 plots x 2 depths x 1 replicates. Collected samples were placed in the Ziplock bag before being taken to the laboratory and stored in the freezer for laboratory analysis.

As mentioned before, the soil pH and moisture content were measured in-situ using Takemura pH and Moisture Tester DM-15. The metallic electrode of the Takemura tester was inserted into the soil at the sampling points and the readings for both pH and moisture content were recorded.

3.3.2 Preparation of Sample

The samples were analysed in the laboratory at Universiti Malaysia Kelantan, Jeli Campus. The samples were allowed to defrost at room temperature before being used for the physical and chemical analysis. The soil was homogenized by mixing both slopes according to their respective slopes and depths. $US_{1\ (0\text{-}15)}$ samples was mixed with $US_{2\ (0\text{-}15)}$ samples while $US_{1\ (15\text{-}30)}$ samples was mixed with $US_{2\ (15\text{-}30)}$ samples. The samples for lower slopes were homogenized with the same method as the upper slopes.

Approximately 150 g of the defrosted soil was used for physical analysis and another 30 g from each sample was allowed to dry in the oven for 24 hours at a temperature of 105^{o}C. This method is crucial in order to avoid any excess moisture that will affect the data. After 2 hours of heating, 5 g of soil samples were taken from each location and grounded using pestle and mortar to increase the surface area of the soil before being stored in Zip-lock bags that were put inside a desiccator. Desiccator is a glass container contained silica gels that acts as a moisture absorbance thus keeping the samples dry. This samples were used specifically for soil organic matter analysis.

Another 25 g of soil inside the oven were allowed to dry for another 22 hours before being analysed for chemical analysis. After 24 hours, the soil were grounded using pestle and mortar and sieved using 150mm-sieve in order to allow the samples to fully homogenize. All the samples were stored in Zip-lock bags and put inside the desiccator.

3.3.3 Physical Analysis

The soil colour in dry and wet conditions were determined using Munsell Book of Color Chart. Approximately 2 g of soil sample was taken and put on a piece of white paper. Then, the colour of the soil was compared with the colour chart in the Munsell Book of Color Chart. Another 2 g of soil sample was taken and mixed with distilled water before being compared with the colour chart. Both dry and wet colour notation, as well as the colour name, were recorded.

The soil texture was determined using feel method. Approximately 4 g of soil sample was taken and added with water gradually until the soil can be formed into a ball. Pressure was applied on the ball for determining the firmness of the ball. Water was added if the ball fall apart because of too dry or if the ball is too wet, more soil was added. The ball was then placed between the thumb and forefinger before being pushed upward gently using thumb to form a ribbon. The ribbon formed is uniform in width and thickness and allowed to extend over the finger, breaking due to its own weight and pulled by the gravity force. The length of the ribbon was determined and classified whether it is less than 1 inch, between 1 inch to 2 inches or over than 2 inches. A pinch of the soil was taken from the ribbon and excessively wet with distilled water before gently rub on the palm to determine whether the soil have a gritty or smooth texture.

3.3.4 Chemical Analysis (Soil Organic Matter Analysis)

The soil organic matter was determined by taking 20 g of the soil sample after 2 hours of drying in the oven at 105°C and put into the crucibles. Before that, the initial mass of the crucibles is taken and recorded. The crucibles with the soil were heated using furnace for 2 hours at 375°C and allowed to dry at room temperature for 30 mins. After that, the mass of the dried soil and crucible is weighted and the mass of organic matter is determined using the equation below:

$$\text{Mass of organic matter (g)} = \frac{\text{(mass of soil \& crucible before heating) (g)}}{\text{(Final mass of crucible with burned soil)(g)}}$$

(Equation 3.1)

From the mass of the organic matter above, the percentage of organic matter was determined using the equation below:

$$\text{Organic matter \%} = \frac{\text{(mass of organic matter) (g)}}{\text{(mass of soil before heat)(g)}} \times 100$$

(Equation 3.2)

3.3.4 Chemical Analysis (Concentration of Metal Elements)

The soil samples were taken from the desiccator and sent to X-Ray Laboratory for XRF Analysis. The laboratory assistant assists in application of XRF to determine the concentration of the extractable cations and heavy metal. The results obtained were in mg/kg.

3.3.6 Statistical Analysis

The pH and moisture content data, as well as the soil organic matter, were subjected to two factor analysis of variance (ANOVA) with replication at 95% confidence level with *p*-value more than 0.05.

The concentration of heavy metals and extractable cations were subjected to two factor analysis of variance (ANOVA) without replication at 95% confidence level with *p*-value more than 0.05.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil pH and Moisture Content

4.1.1 Soil pH

Figure 4.1 shows the average soil pH value for the upper slope and the lower slope for both months. It is clearly shown that both slopes increase in the value of pH in a period of eight months where in February, the pH value is increases from 5.00 to 6.00 whereas the pH value in October also increases from 5.95 to 6.48.

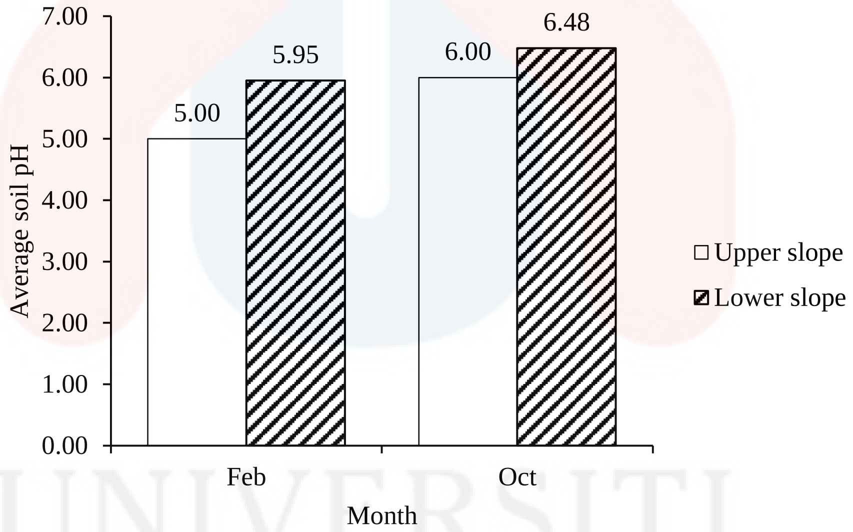

Figure 4.1: Average soil pH value.

Previous studies have identified that soil pH from ridges to the toe slopes increases due to downslopes movement of bicarbonate, HCO_3^- (Bickley & Fisher, 2013). Carbonic acid (H_2CO_3) is formed between the reaction of CO_2 and water in the soil is further dissociates to H^+ that tends to react within the soil profiles and HCO_3^- that leaches downslope in the company of cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ (Bickley & Fisher, 2013).

Table 4.1: Statistical analysis for soil pH.

ANOVA: Two-Factor with Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample (Location)	10.32	3	3.44	60.08	$3.05x10^{-13}$	2.90
Columns (Month)	3.03	1	3.03	52.84	$2.93x10^{-08}$	4.15
Interaction	1.29	3	0.43	7.51	$6.13x10^{-04}$	2.90
Within	1.83	32	0.06			
Total	16.46	39				

* The mean difference for location is highly significant at the *P*-value < 0.05.
* The mean difference for month is highly significant at the *P*-value < 0.05.

Based on Table 4.1, there is significant evidence that location may affect the soil pH value. Figure 4.1 shows that the upper slope have lower pH value (Feb – 5.00; Oct – 6.48) compared to the lower slope (Feb – 5.95; Oct – 6.48) for both month. In relation to the leaching of HCO_3^- before, the leached HCO_3^- from the upper slope consume H^+ in the lower slope thus increasing the soil pH value at the lower slope area for both month causing pH value for the lower slope is higher (Feb – 5.95; Oct – 6.48) than the upper slope (Feb – 5.00; Oct – 6.48).

The pH for soil samples collected from the study area is varied from pH 5.00 to pH 7.20 and can be classified as moderately acidic to neutral. A range of organic and inorganic acids and elements such as iron are likely to acidify the soil solution after acid hydrolysis starting from minerals or from the exchange complex (Pansu & Gautheyrou, 2006). This can be proven by referring to Table 4.2 where the concentration of iron (Fe) is between 23.00 mg/kg to 27.20 mg/kg for each locations. High concentration of iron in the soil may due to the construction materials used during the illegal crop cultivation before the Strategic Collaboration Program on Tree Planting at Gunung Siku Forest Reserve.

Table 4.2: Concentration of iron (Fe).

Month	Location	Concentration (mg/kg)
February	US$_{0-15}$	23.00
	US$_{15-30}$	24.20
	LS$_{0-15}$	26.00
	LS$_{15–30}$	27.20
October	US$_{0-15}$	24.50
	US$_{15-30}$	24.60
	LS$_{0-15}$	26.80
	LS$_{15–30}$	26.50

According to Pansu and Gautheyrou (2006), because of many different types of equilibrium likely to be established at different times which oscillate under the influence of varies internal and external factors, it is essential to consider pH measurement from a broader perspectives. Pansu and Gautheyrou (2006) also state that waterlogging of the soil undoubtedly has the most influence on the physicochemical environment. Variation in seasonal moisture can significantly alter the concentration of the soil solution by hydrolysis and by the release of protons or cations, dissolution and leaching or on the contrary by concentration and precipitation (Pansu & Gautheyrou, 2006).

Referring to Table 4.3, it is clearly shown that the average moisture content in October is lower compared to the moisture content in February. In February, the humid condition resulting in high moisture content in the soil thus reducing the soil pH. Soil pH decreases over time in a process called soil acidification due to leaching from high amounts of rainfall (U.S Department of Agriculture, 2006). In dry climates which occurred in October, the moisture content drops resulting in less intense of soil weathering and leaching thus soil pH value approaching neutral. This statement is supported by the two-factor ANOVA applied (Table 4.1) where there is significant evidence that different month may affect the pH value.

Table 4.3: Soil pH and moisture content for four plots.

Location	**Trial**	**pH**		**Moisture content (%)**	
		Feb	**Oct**	**Feb**	**Oct**
	1	6.60	6.50	2.00	1.00
	2	6.00	6.50	6.00	3.00
US_1	3	6.00	6.50	8.00	1.00
	4	6.00	6.50	8.00	5.00
	5	6.00	6.50	8.00	1.00
Average		6.12	6.50	6.40	2.20
	1	6.00	6.80	8.00	1.00
	2	6.00	6.40	8.00	3.00
US_2	3	6.00	6.60	8.00	3.00
	4	6.00	6.40	8.00	1.50
	5	5.00	6.60	8.00	3.50
Average		5.80	6.56	8.00	2.40
	1	5.00	5.80	8.00	8.00
	2	5.00	5.60	6.00	6.00
LS_1	3	5.00	6.40	8.00	3.50
	4	5.00	6.00	8.00	3.00
	5	5.00	6.20	8.00	3.00
Average		5.00	6.00	7.60	4.70
	1	6.50	6.80	3.00	2.00
	2	7.00	7.00	1.00	1.00
LS_2	3	7.00	7.00	1.00	1.00
	4	7.00	7.00	1.00	1.00
	5	7.00	7.00	5.00	1.00
Average		6.90	6.96	2.20	1.20

* US_1 = Upper slope 1, US_2 = Upper slope 2, LS_1 = Lower slope 1, LS_2 = Lower slope 2, Feb = February, Oct = October.

4.1.2 Soil Moisture Content

Figure 4.2 shows that in February, the upper slope have higher moisture content (7.20%) compared to the lower slope (4.90%). Whereas on October, the upper slope have lower moisture content (2.30%) compared to the lower slope (2.95%). Based on Table 4.4, both month and location have significant evidence effect on the soil moisture content.

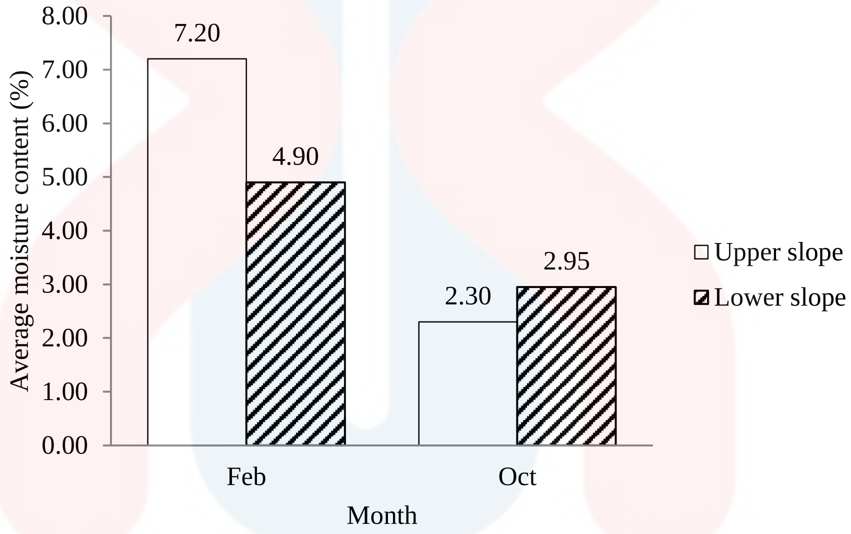

Figure 4.2: Average soil moisture content.

Table 4.4: Statistical analysis for soil moisture content.

ANOVA: Two-Factor with Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample (Location)	109.87	3	36.63	14.41	$4.09\text{x}10^{-06}$	2.90
Columns (Month)	117.31	1	117.31	46.17	$1.11\text{x}10^{-07}$	4.15
Interaction	28.72	3	9.57	3.77	$2.01\text{x}10^{-02}$	2.90
Within	81.30	32	2.55			
Total	337.19	39				

* The mean difference for the location is highly significant at *P*-value < 0.05.
* The mean difference for month is highly significant at *P*-value < 0.05.

As mentioned before, one of the factor influencing the soil pH is the humidity. High humidity in February contributes to high moisture content (7.20%) thus reducing the soil pH value (pH 5.00) as soil acidification and leaching are actively occurred on the upper slope. High humidity also affecting the soil moisture content in the lower slope in February, with a pH value of 5.95, the moisture content drops to 4.90%.

Other than that, high vegetation cover is another factor effecting the soil moisture content. A vegetation cover can significantly modify the temperature and moisture condition of the soil by altering the amounts of light and water that reach the soil surface, by reduction in runoff and an increase in percolation as well as increased in water loss as a result of evapotranspiration (Bickley & Fisher, 2013).

In February, lower slope have more vegetation cover compared to the upper slope thus the moisture content at lower slope (4.90%) is less than the upper slope (7.20%). Low light penetration to the soil surface causing less water loss due to slows rate of evapotranspiration and runoff seeps slowly throughout the soil profiles. However, on October, the upper slope exposed more to sunlight radiation as the climate become drier compared to the lower slope. The increased of light intensity and temperature may cause the rate of evapotranspiration to increase thus reducing the soil moisture content at the upper slope. As a result, the soil moisture content decreased from February to October or both slopes where the upper slope reduced from 7.20% to 2.30% whereas the lower slope declined from 4.90% to 2.95%.

A significant number of studies have investigate the complex interrelationships between and cumulative effects of multiple climatological and environmental factors on the soil moisture content (Famiglietti *et al.*, 1998; Nyberg 1996; Petropoulos *et al.*, 2014; Robinson & Dean 1993; Western *et al.*, 1999). Slope, aspect, curvature, specific contributing area and relative elevation are the topography-related parameters that affect the distribution of soil moisture content in the topsoil layer (Petropoulos *et al.*, 2014). Based on Nyberg (1996), slope have been shown to have a direct control on the solar irradiance received that affects the rate of evapotranspiration from the land surface and thus affecting the soil moisture content (Petropoulos *et al.*, 2014).

Bickley and Fisher (2013) state that tree roots can effectively exploit soil moisture content even when the soil moisture content is low as happened during October. The plants roots absorb water from the soil to recover the water lost by transpiration as well as for metabolic activities (Bickley & Fisher, 2013).

4.2 Soil Textural Classification

Soil texture determines the moisture and nutrient-holding capacity of soil and an important variable in determining the site quality for tree growth (Bickley & Fisher, 2013). Based on Table 4.5, the soil texture for each location can be classified as sandy clay loam that have a moderately coarse texture with 20% to 35% of clay range, 70% to 100% sand range and 65% to 80% of silt range and formed ribbons with a length between 1 to 2 inches long (Bickley & Fisher, 2013).

According to Ramade (1981), soil texture governs most of the properties of the soil, its permeability, its capacity to retain water, its ability to make the nutrients stored in the clay-humus complex available to plant, its ability to withstand mechanical working of the top soil and lastly the ability to support permanent plant cover (Khan Towhid Osman, 2013).

Table 4.5: Soil texture classification using feel method.

Location	Trials	Gritty		Smooth		Sticky		Ribbon length		Textural class name	
		Feb	Oct	Feb	Oct	Feb	Oct	Feb	Oct	Feb	Oct
US $_{0-15}$	1	Y	Y	N	N	N	N	1.3	1.6	Sandy clay loam (Moderately coarse)	Sandy clay loam (Moderately coarse)
	2	Y	Y	N	N	N	N	1.8	1.8		
	3	Y	Y	N	N	N	N	2.0	1.4		
Average								1.7	1.6		
US $_{15-30}$	1	Y	Y	N	N	N	N	1.3	1.3	Sandy clay loam (Moderately coarse)	Sandy clay loam (Moderately coarse)
	2	Y	Y	N	N	N	N	1.5	1.3		
	3	Y	Y	N	N	N	N	1.7	1.6		
Average								1.5	1.4		
LS $_{0-15}$	1	Y	Y	N	N	N	N	1.5	1.5	Sandy clay loam (Moderately coarse)	Sandy clay loam (Moderately coarse)
	2	Y	Y	N	N	N	N	1.9	1.6		
	3	Y	Y	N	N	N	N	1.6	1.6		
Average								1.7	1.6		
LS $_{15-30}$	1	Y	Y	N	N	N	N	1.8	1.6	Sandy clay loam (Moderately coarse)	Sandy clay loam (Moderately coarse)
	2	Y	Y	N	N	N	N	2.0	1.5		
	3	Y	Y	N	N	N	N	1.5	1.8		
Average								1.8	1.6		

* US $_{0-15}$ = Upper slope at 0-15cm depth, US $_{15-30}$ = Upper slope at 15-30cm depth, LS $_{0-15}$ = Lower slope at 0-15cm depth, LS $_{15-30}$ = Lower slope at 15-30cm depth, Y = Yes, N = No, Feb = February, Oct = October

4.3 Soil Colour

Soil colour indicates the amount of organic matter in the soil which is generally well correlated with soil fertility (Bickley & Fisher, 2013). Based on Table 4.6, soil colour from the soil sample can be generalized into strong brown. Darker shades of soil indicated that the soil is rich with organic matter and clay mineral contributes to the dark colouring conditions (Schroeder & Kingston, 2000).

Based on Figure 3.5, soils located at Compartment 5 of Gunung Siku Forest Reserve is classified as Podzols with Munsell hue of 7.5YR that appears as yellowish brown, brown or reddish brown in colour due to domination of goethite (Blume *et al*., 2016; Generalized Soil Map of Peninsular, 1970). According to Blume *et al.* (2016), yellow, brown and red hues soils usually indicates aerobic conditions and synonyms with high oxygen inputs and rarely occurring water saturation.

Table 4.6: Determination of soil colour using Munsell Book of Color Chart.

Location	Dry notation		Dry name		Wet notation		Wet name	
	Feb	**Oct**	**Feb**	**Oct**	**Feb**	**Oct**	**Feb**	**Oct**
US $_{0\text{-}15}$	7.5YR 3.5/4	7.5YR 4/6	Dark brown / brown	Strong brown	7.5YR 5.5/8	7.5YR 4/6	Strong brown / reddish yellow	Strong brown
US $_{15\text{-}30}$	7.5YR 4.5/6	7.5YR 4/6	Strong brown	Strong brown	7.5YR 4.5/4	7.5YR 4/6	Brown	Strong brown
LS $_{0\text{-}15}$	7.5YR 4.5/6	7.5YR 5/8	Strong brown	Strong brown	7.5YR 5.5/8	7.5YR 5/8	Strong brown / reddish yellow	Strong brown
LS $_{15\text{-}30}$	7.5YR 5.5/6	7.5YR 5.5/8	Strong brown / reddish yellow	Strong brown / reddish yellow	7.5YR 5.5/8	7.5YR 5.5/8	Strong brown / reddish yellow	Strong brown / reddish yellow

* US $_{0\text{-}15}$ = Upper slope at 0-15cm depth, US $_{15\text{-}30}$ = Upper slope at 15-30cm depth, LS $_{0\text{-}15}$ = Lower slope at 0-15cm depth, LS $_{15\text{-}30}$ = Lower slope at 15-30cm depth, Feb = February, Oct = October

4.4 Soil Organic Matter

Figure 4.3 shows the mass of soil organic matter content and percentage of soil organic matter. In February, the upper slope with a mass of 0.18 g have a 3.52% soil organic matter whereas the upper slope in October have 4.49% of soil organic matter. The lower slope have 4.96% of soil organic matter in February and decreases to 3.77% in October.

In a period of eight months starting from February until October, soil organic matter for the upper slope increases in time from 0.18 g to 0.22 g with a slow rate of 0.0005 g per month whereas the lower slope shows declination in soil organic matter contents from 0.25 g to 0.19 g with a rate of 0.00075 g per month. The statistical analysis obtained (Table 4.7 and Table 4.8) concluded that there are no significance evidence that the difference in locations and month affect the mass of soil organic matter content as well as the percentage of soil organic matter.

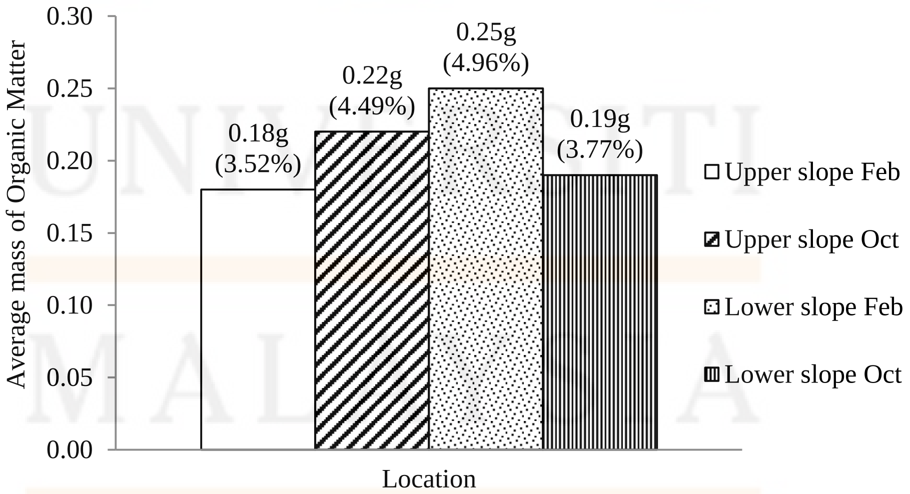

Figure 4.3: Mass of soil organic matter.

Table 4.7: Statistical analysis for mass of soil organic matter.

ANOVA: Two-Factor with Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*sig*
Rows (Location)	0.02	3	0.01	1.91	0.17	no
Columns (Month)	0.00	1	0.00	0.05	0.82	no
Inter	0.03	3	0.00	2.43	0.10	no
Within	0.05	16	0.00			
Total	0.10	23	0.00			

* The mean difference for the location is not significant at *P*-value < 0.05.
* The mean difference for month is not significant at *P*-value < 0.05.

Table 4.8: Statistical analysis for percentage of soil organic matter.

ANOVA: Two-Factor with Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*sig*
Rows (Location)	1.37	3	0.46	0.33	0.81	no
Columns (Month)	0.64	1	0.64	0.46	0.51	no
Inter	4.77	3	1.59	1.14	0.36	no
Within	22.26	16	1.39			
Total	29.04	23	1.26			

* The mean difference for the location is not significant at *P*-value < 0.05.
* The mean difference for month is not significant at *P*-value < 0.05.

Soil organic matter is greatly influenced by the climate which consists the temperature and moisture, topography, types of vegetation and litters, time, the effects of farming practices as well as types of crops (Pansu & Gautheyrou, 2006). In February, the humid climate causing increases in soil moisture content while decreasing the soil pH value thus increasing the soil organic matter for both slopes (Upper slope – 3.52%; Lower slope – 4.96%). In dry climate that occurred in October, low moisture content increased the soil pH value and resulting in declination of soil organic matter for both slopes (Upper slope – 4.49%; Lower slope – 3.77%). This indicates that the climate and soil pH affects the soil organic matter content for the soil samples at Compartment 5 of Gunung Siku Forest Reserve.

As mentioned in the problem statement, application of fertilizers and pesticides from the illegal crop cultivation may alter the soils conditions thus reducing the soil fertility and leads to desertification. According to Schnitzer and Khan (1978), the interaction of chemicals in fertilizers and pesticides with organic matter is an important factor affecting the fate of both fertilizers and pesticides in the soil environment. However, main limitations occurred in understanding the organic matter and pesticides as well as fertilizers interaction is the complex nature of soil organic matter and the numerous processes in soil environment that operating simultaneously (Schnitzer & Khan, 1978).

Khan Towhid Osman (2013) state that the main importance of soil organic matter to the environment is the carbon sequestration. Carbon compromises about 45% of the mass of soil organic matter and the amount of carbon added to the soils by trees varies tremendously among forests (Bickley & Fisher, 2013). According to Binkley and Fisher (2013), the accumulation of soil organic matter in soil may related to the rate of which trees fix carbon from the atmosphere. As climate change alter the global temperature, the rate of plant growth increases and the microbial activities as well as organic matter decomposition increases thus neutralizing the fertilizers and pesticides residue in the soil (Khan Towhid Osman, 2013).

However, weight loss determination by Loss-on-Ignition (LOI) method applied in this study can be subject to errors caused by volatilization of substances other than the organic materials and incomplete oxidation of carbonaceous materials (Combs & Nathan, 1998).

4.5 Concentration of Metal Elements.

Two extractable cations which are magnesium (Mg) and potassium (K) as well as three heavy metals that are lead (Pb), copper (Cu) and zinc (Zn) were determined using XRF. Metal elements accumulate in or on aerial plant parts through deposition from the air or can be absorbed through the roots from the soil solution (Blume *et al.*, 2016). At Compartment 5 of Gunung Siku Forest Reserve, additional metal and heavy metals elements from the application of fertilizers and pesticides during the illegal agricultural activities may accumulate and altering the natural forest soil conditions. The trees planted during the Strategic Collaboration Program on Tree Planting at Cameron Highland may aids in neutralizing those harmful residues comes from the fertilizers and pesticides.

Further on this section, the upper slope is indicate as US whereas lower slope is indicate as LS. The depth of the soil location at 0 – 15 cm is written as 0 – 15 while depth at 15 – 30 cm is written as 15 – 30 cm. Thus, US $_{0\text{-}15}$ actually discussed on the upper slope at 0 – 15 cm depth, US $_{15\text{-}30}$ discussed on the upper slope at depth 15 – 30 cm, LS $_{0\text{-}15}$ discussed on the lower slope at 0 – 15 cm depth and lastly the LS $_{15\text{-}30}$ discussed on the lower slope at 15 – 30 cm depth.

4.5.1 Macronutrients

Based on Figure 4.4, the concentration of Mg in February is higher at US $_{0-15}$ (2.15 mg/kg) followed by LS $_{0-15}$ (1.82 mg/kg) and both US and LS with the depth of 15 - 30cm have 0.00 mg/kg Mg concentration. However, the concentration of Mg at US $_{0-15}$ and LS $_{0-15}$ decreases in October from 2.15 mg/kg to 1.60 mg/kg and from 1.82 mg/kg to 1.55 mg/kg respectively. In contrast, Mg concentration at LS $_{15-30}$ increases in from 0.00 mg/kg in February to 1.45 mg/kg in October while US $_{15-30}$ remains 0.00 mg/kg Mg concentration. Overall, the upper slope have higher concentration of Mg (2.15 mg/kg) compared to the lower slope (1.82 mg/kg) in February whereas in October, the lower slope have higher Mg concentration (3.00 mg/kg) compared to the lower slope (1.60 mg/kg). The statistical analysis as shown at Table 4.9, indicates that both location and different in month shows no significant evidence in concentration of Mg in the soil.

Table 4.9: Statistical analysis for concentration of magnesium in soil.

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (month)	0.04961	1	0.0496	0.1251	0.75	10.1279
Columns (location)	4.5803	3	1.5268	3.8511	0.15	9.2766
Error	1.1893	3	0.3964			
Total	5.8193	7				

* The mean difference for month is not significant at *P*-value < 0.05.
* The mean difference for the location is not significant at *P*-value < 0.05.

Magnesium is an essential macronutrients elements for plant and classified as a metal according to its physicochemical properties (Kabata-pendias & Pendias, 2001; Marschner, 2002). Magnesium exists as Mg $^{2+}$ cation in the soil solution and absorb through root absorption mechanism (Jr. Jones, 2012). According to Jr. Jones (2012) also, the availability of Mg declines if soil pH value is less than 5.4 and increases as pH increases.

Based on Table 4.3, the soil located at Compartment 5 of Gunung Siku Forest Reserve have a pH range from 5.00 to 7.20 and indicates that the soil have an efficient Mg content for supporting the plant growth. Some of additional magnesium applied into soils that acts as a liming material by neutralizing soil acidity or as a fertilizers are; Kieserite (magnesium sulphate), Epsom salts (magnesium sulphate), potassium magnesium sulphate and magnesium oxide (Jr. Jones, 2012).

Table 4.10: Soil extractable cation and heavy metal concentration.

Location	Element	Feb (mg/kg)	Oct (mg/kg)
US $_{0-15}$	Mg	2.15	1.60
	K	7.23	6.46
	Pb	0.12	0.15
	Cu	0.22	0.15
	Zn	0.30	0.24
US $_{15-30}$	Mg	0.00	0.00
	K	6.42	6.65
	Pb	0.15	0.17
	Cu	0.13	0.11
	Zn	0.17	0.16
LS $_{0-15}$	Mg	1.82	1.55
	K	7.72	7.75
	Pb	0.14	0.15
	Cu	0.12	0.00
	Zn	0.18	0.00
LS $_{15-30}$	Mg	0.00	1.45
	K	8.07	7.88
	Pb	0.14	0.14
	Cu	0.00	0.00
	Zn	0.00	0.00

* US $_{0-15}$ = Upper slope at 0-15cm depth, US $_{15-30}$ = Upper slope at 15-30cm depth, LS $_{0-15}$ = Lower slope at 0-15cm depth, LS $_{15-30}$ = Lower slope at 15-30cm depth, Feb = February, Oct = October, Mg = Magnesium, K = Potassium, Pb = Lead, Cu = Copper, Zn = Zinc

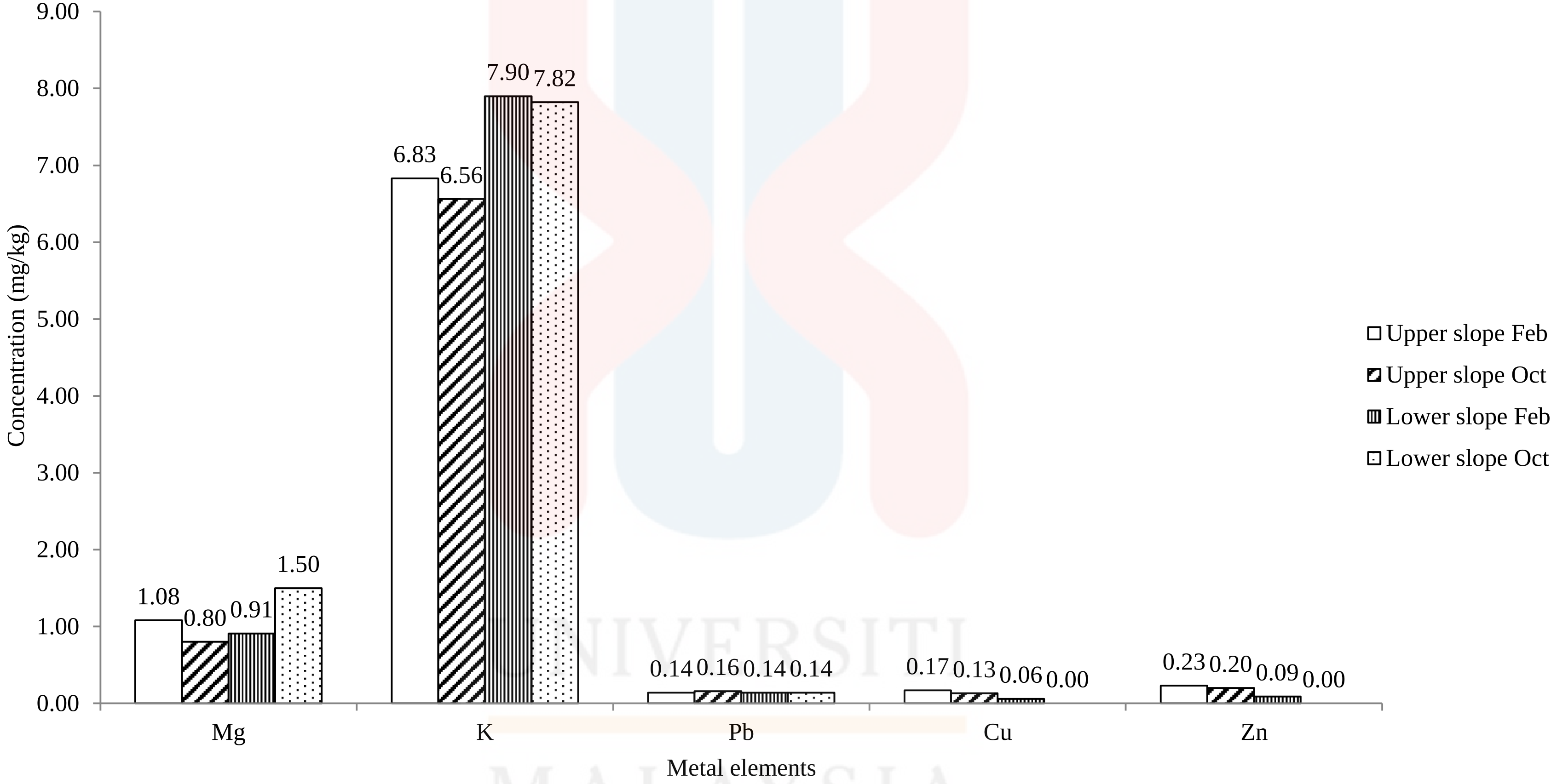

Figure 4.4: Concentration of metal elements.

According to Table 4.10, LS $_{15-30}$ indicates the highest level of K concentration in February with 8.07 mg/kg followed by LS $_{0-15}$ at 7.72 mg/kg, US $_{0-15}$ at 7.23 mg/kg and lastly US $_{15-30}$ with 6.42 mg/kg. In October, LS $_{15-30}$ still contained the highest level of K concentration with 7.88 mg/kg followed by LS $_{0-15}$ at 7.75 mg/kg, the US $_{15-30}$ with 6.65 mg/kg and lastly the US $_{0-15}$ with 6.46 mg/kg. In a period of eight months, the US $_{0-15}$ and LS $_{15-30}$ decreases in concentration of K from 7.23 mg/kg to 6.46 mg/kg and 8.07 mg/kg to 7.88 mg/kg respectively. In contrast, both US $_{15-30}$ and LS 0-15 increases in the concentration of K from 6.42 mg/kg to 6.65 mg/kg and 7.72 mg/kg to 7.75 mg/kg respectively. Overall, the concentration of K is the highest at lower slope for both month (Feb – 15.79 mg/kg; Oct – 15.63 mg/kg). The statistical analysis (Table 4.11) indicate that the different in month have no significant evidence to the concentration of K in the soil but the location have significant evidence to the concentration of K.

Table 4.11: Statistical analysis for concentration of potassium in soil.

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (Month)	0.0613	1	0.0613	0.6559	0.48	10.1280
Columns (Location)	2.8681	3	0.9561	10.2380	0.04	9.2766
Error	0.2802	3	0.0934			
Total	3.2096	7				

* The mean difference for month is not significant at *P*-value < 0.05.

* The mean difference for the location is not significant at *P*-value < 0.05.

Potassium also is a major essential element for plants and maintained water status of the plants (Jr. Jones, 2012). K is absorbed as a cation (K^+) by plants root via diffusion in the soil solution and fertilizers sources for K usually are from potassium sulphate, potassium magnesium sulphate and potassium nitrate (Blume *et al.*, 2016; Jr. Jones, 2012). According to the result obtained, soil samples from Compartment 5 of Gunung Siku Forest Reserve contained high level of potassium as the pH value is at optimum level for the potassium uptake by plants from the soil solution which is between pH 6 to pH 8 (Jr. Jones, 2012).

4.5.2 Heavy Metals

By referring to Table 4.10, US $_{15\text{-}30}$ shows the highest concentration of Pb concentration in February with 0.15 mg/kg followed by LS $_{0\text{-}15}$ (0.14 mg/kg) LS $_{15\text{-}30}$ (0.14 mg/kg) and lastly $_{\text{US }0\text{-}15}$ with 0.12 mg/kg. In October, US $_{15\text{-}30}$ still dominating the highest level of Pb concentration with 0.17 mg/kg followed by LS $_{0\text{-}15}$ with 0.15 mg/kg, US $_{0\text{-}15}$ (0.15 mg/kg) and LS $_{15\text{-}30}$ have the lowest concentration of Pb with 0.14 mg/kg. US $_{0\text{-}15}$, US $_{15\text{-}30}$ and LS $_{0\text{-}15}$ shows increases in concentration of Pb in a period of eight month with a difference of 0.03 mg/kg, 0.02 mg/kg and 0.01 mg/kg respectively.

Whereas LS $_{15\text{-}30}$ does not shows any differences in the level of Pb concentration for both month. Overall, in February, the lower slope have higher concentration of Pb (0.28 mg/kg) compared to the upper slope (0.27 mg/kg) while in October, the upper slope have higher Pb concentration (0.32 mg/kg) compared to the lower slope (0.29 mg/kg). Both location and difference in month does not shows any significant evidence to the concentration of Pb in the soil.

Table 4.12: Statistical analysis for concentration of lead in soil.

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (Month)	0.00	1	0.00	3.76	0.15	10.1280
Columns (Location)	0.00	3	0.00	2.02	0.29	9.2766
Error	0.00	3	$9.34\text{x}10^{-05}$			
Total	0.00	7				

* The mean difference for month is not significant at *P*-value < 0.05.
* The mean difference for the location is not significant at *P*-value < 0.05.

Table 4.10 also shows that Cu concentration in February is higher at the upper slope (0.35 mg/kg) compared to the lower slope (0.12 mg/kg). It is the same in October which the upper slope have higher Cu concentration with 0.26 mg/kg compare to the lower slope which are 0.00 mg/kg. The Cu concentration in February is the highest at US $_{0\text{-}15}$ (0.22 mg/kg) followed closely with 0.13 mg/kg (US $_{15\text{-}30}$) and the LS $_{0\text{-}15}$ with 0.12 mg/kg. Whereas in October, US $_{0\text{-}15}$ have the highest Cu concentration with 0.15 mg/kg and followed by US $_{15\text{-}30}$ with 0.11 mg/kg. The LS $_{15\text{-}30}$ in both month does not contain any Cu concentration whereas the concentration of Cu in LS $_{0\text{-}15}$ decreases from 0.12 mg/kg to 0.00 mg/kg. The statistical analysis (Table 4.13) indicates that the difference in month have no significant evidence to the concentration of Cu in the soil but the location have significant evidence to the concentration of Cu.

Table 4.13: Statistical analysis for concentration of copper in soil.

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (Month)	0.00	1	0.00	3.91	0.14	10.13
Columns (Location)	0.04	3	0.01	9.88	0.05	9.28
Error	0.00	3	0.00			
Total	0.05	7				

* The mean difference for month is not significant at *P*-value < 0.05.
* The mean difference for the location is significant at *P*-value < 0.05.

Other than that, Table 4.10 also shows that Zn concentration is the highest at US $_{0\text{-}15}$ for both month which are 0.30 mg/kg in February and 0.24 mg/kg in October. However, the concentration of Zn decreases across the time for each location. The US $_{0\text{-}15}$ decreases with a difference of 0.06 mg/kg, US $_{15\text{-}30}$ decreases with 0.01 mg/kg and LS $_{0\text{-}15}$ decreases with 0.18 mg/kg. Overall, the upper slope have higher level of Zn concentration for both month (Feb – 0.47 mg/kg; Oct – 0.40 mg/kg) compared to the lower slope (Feb – 0.18 mg/kg; Oct – 0.00 mg/kg). Based on the statistical analysis

(Table 4.14) obtained, both the location and difference in month does not have significant evidence to the concentration of Zn.

Table 4.14: Statistical analysis for concentration of zinc in soil.

ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (Month)	0.01	1	0.01	3.83	0.15	10.13
Columns (Location)	0.07	3	0.02	8.26	0.06	9.28
Error	0.00	3	0.00			
Total	0.09	7				

* The mean difference for month is not significant at *P*-value < 0.05.
* The mean difference for the location is not significant at *P*-value < 0.05.

Pb, Cu and Zn is classified as heavy metals in soil with Cu and Zn acts as essential micronutrients for plants while Pb is the most potential pollutant that readily accumulates in soils and sediments (Jr. Jones, 2012; Sharma & Dubey, 2005). However, the total level of heavy metals detected in the soil samples for each slopes from Compartment 5 of Gunung Siku Forest Reserve does not exceed the Regulatory Limits for Heavy Metals as stated by USEPA (Table 2.1).

The total of Pb for both slopes is 0.55 in February and 0.61 in October while the maximum concentrate of Pb in sludge is 420. The levels of Cu also does not exceed the regulatory limits which is 4300 mg/kg as the results obtained for total Cu levels in both slopes is 0.47 in February and 0.26 in October. Zn level also is below its regulatory limits which is 7500 mg/kg with the concentration of Zn obtained at the sites is 0.65 in February and 0.40 in October. This indicate that these three elements acts as essential elements for the plants and does not contaminate the soil or threaten the plant growth at the location.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This study is carried out with an objective of to compare the soil physical and chemical properties of the upper slope (1460m) and the lower slope (1413m) located at Compartment 5 of Gunung Siku Forest Reserve, Cameron Highland.

The soil pH value for both slopes is at the highest during October (upper slope –pH 6.00 ; lower slope – pH 6.48) whereas the soil moisture content for both slopes is at the highest in February (upper slope – 7.20% ; lower slope – 4.90%). The soil pH obtained is classified as moderately acidic to neutral which is between pH 5.0 to pH 7.2.

The soil moisture content at Compartment 5 of Gunung Siku Forest Reserve is affected by humidity and vegetation cover thus varying the soil moisture content from 1% (extremely dry) to 8% (extremely moist). High humidity during February increases the soil moisture content at the upper slope to an average of 7.20% whereas the lower slope have lower soil moisture content (4.90%) compared to the upper slope due to less light penetration as high density of vegetation cover at the lower slope. However, on October, increased in light intensity and temperature exposed to the upper slopes causing the soil moisture content to become lower (2.30%) compared to the lower slope (2.95%).

The soil texture for the soil samples is generalized into sandy clay loam with a strong brown colour which shows that the soil is fertile and suitable for a successful plant growth. In a period of 8 months from February to October, the soil organic matter content increases from 3.52% to 4.49% for the upper slope while the lower slope decline in the percentage of soil organic matter which is from 4.96% to 3.77%. As climate become drier, the soil pH will decreases as soil moisture content increases.

The soil sample from Compartment 5 of Gunung Siku Forest Reserve in both month contained large concentration of potassium with 29.44 mg/kg (February) and 28.74 mg/kg (October), followed by magnesium with 3.97 mg/kg (February) and 4.60 mg/kg (October) and lead (February - 0.55 mg/kg and October - 0.61 mg/kg). However, level of zinc and copper decreases from 0.65 mg/kg (February) to 0.26 mg/kg in October and from 0.47 mg/kg to 0.26 mg/kg respectively. The concentration of macronutrients which are Mg and K in the soil samples can efficiently aids in plant growth whereas the heavy metals (Pb, Cu and Zn) does not exceed the regulatory limits for heavy metals as issued by USEPA (1993) thus shows that the soil at Compartment 5 of Gunung Siku Forest Reserve is free of heavy metals contamination.

From the results obtained, it shows that the soil at Compartment 5 of Gunung Siku Forest Reserve is fertile and suitable to aids in the plant growth of the plants species planted during reforestation treatment which are *Nageia wallachiana*, *Agathis borneensis*, *Shorea platyclados* and *Gymnostoma sumathranum*. It can be predicted that the current soil conditions which are; pH range from moderately acidic to neutral, moderately course texture with strong brown colour, optimum level of soil organic matter, efficient level of macronutrients and the heavy metals does not exceed the regulatory limit is maintained in the future as the plant growth and become natural forest with an exception in change of climate or natural disaster. Other than that, this study can acts as a baseline data for any future researches related to soil physical and chemical properties at Compartment 5 of Gunung Siku Forest Reserve

Within this scope of research, there are some recommendations that could be taken for future consideration. Firstly, investigation on soil bulk density could be done as soil bulk density is a basic soil property that can be influence by some soil physical and chemical properties. Based on Chaudari *et al.* (2013), identification of soil bulk density is essential for soil management, soil compaction as well as an input for models that predict soil processes. If soil bulk density is analysed, the soil compaction at Compartment 5 of Gunung Siku Forest Reserve can be identified and further action can be taken to ensure the plant growth is a success.

Second, Atomic Absorption Spectrometer (AAS) could be use in order to identify the concentration of extractable cations and heavy metals in the soil. AAS has a very high sensitivity, better precision and have low detection limits for some elements (Perkin-Elmer, 1996). Thus, the metal elements in the soil samples can be identified precisely and avoiding from a null results as happened to the concentration of copper and zinc during February and October.

Last but not least, a green technology which is phytoremediation can be applied to prevent, control and remedies heavy metals in the soil at the study area. Phytoremediation is a plant-based technology with a low-tech and cost-effective technology that utilizes the potential of plants and their associated microbial flora for environmental clean-up (Salt *et al*., 1998). It has been reported that plants possess a great ability in tolerance with heavy metal pollution without being seriously harmful (Pirzadah *et al*., 2015). If phytoremediation is applied at Compartment 5 of Gunung Siku Forest Reserve, the level of silicon (Si), titanium (Ti) and zirconium (Zr) obtained in the results that usually contained in industrial construction materials can be reduced. This elements may enter the soil from the construction of greenhouse during illegal crop cultivation.

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APPENDIX A

LOCATION OF PLOTS

Table A1: Location of the plots.

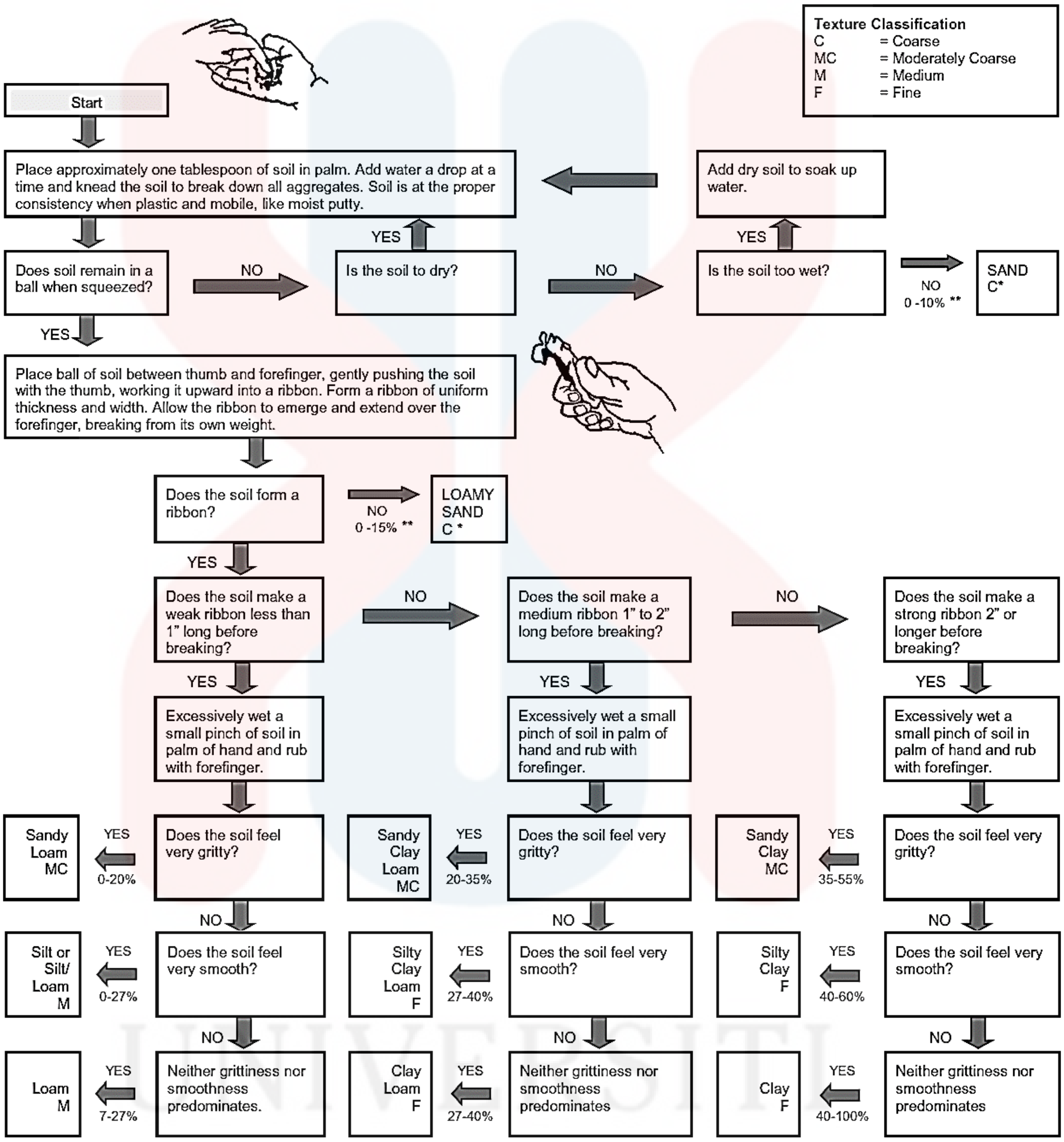
Plot	Elevation (m)	Coordinate	
US_1	1465	N 04°35'59.5"	E 101°25'24.3"
US_2	1458	N 04°35'58.8"	E 101°25'21.6"
LS_1	1423	N 04°36'03.0"	E 101°25'24.3"
LS_2	1404	N 04°36'02.6"	E 101°25'25.7"

Where,
* US = Upper slope
* LS = Lower slope
* N = North
* E = East

APPENDIX B

PELAN TANAMAN KAWASAN LAPANG

APPENDIX C



- * Sand Particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sand are not visible without magnification and there is a gritty feeling to a very small sample ground between the teeth. Some fine sand particles may be just visible. Medium sand particles are easily visible. Examples of sand size descriptions where one size is predominant are; very fine sand, fine sandy loam, loamy coarse sand.
- ** Clay percentage range.

Figure C1: Procedure for analyzing soil texture by feel method.
(Source: Thiens *et al*., 2008 modified from Thiens, 1979)

APPENDIX D

SOIL CHEMICAL PROPERTIES

Table D1: Soil organic matter at four plots.

Location	Month	Mass (g)	Trial 1	Trial 2	Trial 3	Average
US $_{0-15}$	Feb	Mass of empty crucible	32.91	33.03	32.72	32.89
		Mass of soil	5.00	5.00	5.05	5.02
		Mass of (crucible and soil)	37.91	38.03	37.77	37.91
		Final mass of (crucible and dry soil)	37.75	37.81	37.59	37.71
		Mass of OM	0.16	0.23	0.18	0.19
		Percentage of OM (%)	3.2	4.56	3.66	3.81
US $_{0-15}$	Oct	Mass of empty crucible	37.73	38.06	38.06	37.95
		Mass of soil	5.01	5.00	5.01	5.01
		Mass of (crucible and soil)	42.74	43.06	43.06	42.95
		Final mass of (crucible and dry soil)	42.56	42.85	42.85	42.75
		Mass of OM	0.18	0.20	0.21	0.20
		Percentage of OM (%)	3.59	4.05	4.28	3.97
US $_{15-30}$	Feb	Mass of empty crucible	34.16	33.38	33.86	33.80
		Mass of soil	5.01	5.00	5.02	5.01
		Mass of (crucible and soil)	39.17	38.38	38.88	38.81
		Final mass of (crucible and dry soil)	93.02	38.21	38.72	56.65
		Mass of OM	0.15	0.17	0.16	0.16
		Percentage of OM (%)	2.99	3.42	3.28	3.23
US $_{15-30}$	Oct	Mass of empty crucible	35.17	33.61	33.45	34.08
		Mass of soil	5.00	5.01	5.01	5.01
		Mass of (crucible and soil)	40.17	38.62	38.45	39.08
		Final mass of (crucible and dry soil)	40.01	38.46	38.03	38.83
		Mass of OM	0.16	0.17	0.43	0.25
		Percentage of OM (%)	3.20	3.33	8.49	5.01
LS $_{0-15}$	Feb	Mass of empty crucible	36.95	36.96	36.96	36.95
		Mass of soil	5.01	5.00	5.02	5.01
		Mass of (crucible and soil)	41.96	41.96	41.97	41.96
		Final mass of (crucible and dry soil)	41.77	41.76	41.77	41.77
		Mass of OM	0.19	0.20	0.20	0.20
		Percentage of OM (%)	3.79	3.99	4.03	3.94
LS $_{0-15}$	Oct	Mass of empty crucible	36.14	36.22	36.14	36.17
		Mass of soil	5.00	5.01	5.01	5.01

LS $_{0-15}$		Mass of (crucible and soil)	41.14	41.23	41.16	41.18
		Final mass of (crucible and dry soil)	40.98	41.07	40.99	41.01
		Mass of OM	0.16	0.17	0.17	0.17
		Percentage of OM (%)	3.20	3.33	3.37	3.30
LS $_{15-30}$	Feb	Mass of empty crucible	35.30	36.29	36.36	35.99
		Mass of soil	5.00	5.00	5.01	5.00
		Mass of (crucible and soil)	40.30	41.29	41.38	40.99
		Final mass of (crucible and dry soil)	39.97	41.02	41.09	40.69
		Mass of OM	0.33	0.28	0.29	0.30
		Percentage of OM (%)	6.60	5.52	5.84	5.99
LS $_{15-30}$	Oct	Mass of empty crucible	34.39	34.29	34.29	34.32
		Mass of soil	5.02	5.02	5.02	5.02
		Mass of (crucible and soil)	39.41	39.31	39.30	39.34
		Final mass of (crucible and dry soil)	39.15	39.12	39.11	39.13
		Mass of OM	0.26	0.18	0.20	0.21
		Percentage of OM (%)	5.18	3.65	3.91	4.25

* US $_{0-15}$ = Upper slope at 0-15cm depth, US $_{15-30}$ = Upper slope at 15-30cm depth, LS $_{0-15}$ = Lower slope at 0-15cm depth, LS $_{15-30}$ = Lower slope at 15-30cm depth, Feb = February, Oct = October, OM= Organic matter

Table D2: Metal concentrations detected by XRF for US $_{0-15}$ in February.

Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	32.70	Si KA1/EQ20	12196.00
Fe	26	23.00	Fe KA1/EQ20	28362.00
Al	13	21.30	Al KA1/EQ20	3968.00
K	19	7.23	K KA1/EQ20	4053.00
Ca	20	3.70	Ca KA1/EQ20	2580.00
Ti	22	2.42	Ti KA1/EQ20	2250.00
P	15	2.15	P KA1/EQ20	1081.00
Mg	12	2.15	Mg KA1/EQ20	71.70
Cl	17	1.55	Cl KA1/EQ20	2509.00
S	16	1.30	S KA1/EQ20	1108.00
Zr	40	0.57	Zr KA1/EQ20	29.10
Mn	25	0.41	Mn KA1/EQ20	499.70
Zn	30	0.30	Zn KA1/EQ20	264.90
Rb	37	0.22	Rb KA1/EQ20	37.70
Cu	29	0.22	Cu KA1/EQ20	173.50
Pb	82	0.12	Pb LA1/EQ20	33.90
Ba	56	0.11	Ba KA1/EQ40	1.14

Table D3: Metal concentrations detected by XRF for US $_{0-15}$ in October.

Evaluation Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	32.50	Si KA1/EQ20	11947.00
Fe	26	24.50	Fe KA1/EQ20	30327.00
Al	13	22.30	Al KA1/EQ20	4120.00
K	19	6.46	K KA1/EQ20	3631.00
Ca	20	3.28	Ca KA1/EQ20	2318.00
Ti	22	2.64	Ti KA1/EQ20	2503.00
P	15	1.76	P KA1/EQ20	877.10
Mg	12	1.60	Mg KA1/EQ20	52.50
Cl	17	1.53	Cl KA1/EQ20	2462.00
S	16	1.15	S KA1/EQ20	975.40
Zr	40	0.57	Zr KA1/EQ20	28.50
Mn	25	0.44	Mn KA1/EQ20	540.80
Zn	30	0.24	Zn KA1/EQ20	206.50
Rb	37	0.23	Rb KA1/EQ20	37.40
Cu	29	0.15	Cu KA1/EQ20	118.80
Pb	82	0.15	Pb LA1/EQ20	40.50

Table D4: Metal concentrations detected by XRF for US $_{15-30}$ in February.

Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	36.00	Si KA1/EQ20	13278.00
Fe	26	24.20	Fe KA1/EQ20	30377.00
Al	13	23.60	Al KA1/EQ20	4526.00
K	19	6.42	K KA1/EQ20	3601.00
Ti	22	2.45	Ti KA1/EQ20	2356.00
Ca	20	2.37	Ca KA1/EQ20	1682.00
P	15	1.42	P KA1/EQ20	686.30
Cl	17	1.24	Cl KA1/EQ20	1969.00
Zr	40	0.61	Zr KA1/EQ20	31.10
Mn	25	0.38	Mn KA1/EQ20	473.30
Rb	37	0.27	Rb KA1/EQ20	44.80
Zn	30	0.17	Zn KA1/EQ20	146.60
Pb	82	0.15	Pb LA1/EQ20	40.00
Ba	56	0.13	Ba KA1/EQ40	1.37
Cu	29	0.13	Cu KA1/EQ20	101.00

Table D5: Metal concentrations detected by XRF for US $_{15-30}$ in October.

Evaluation Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	35.30	Si KA1/EQ20	13316.00
Fe	26	24.60	Fe KA1/EQ20	31251.00
Al	13	23.90	Al KA1/EQ20	4709.00
K	19	6.65	K KA1/EQ20	3823.00
Ti	22	2.48	Ti KA1/EQ20	2430.00
Ca	20	2.40	Ca KA1/EQ20	1732.00
Cl	17	1.31	Cl KA1/EQ20	2143.00
P	15	1.15	P KA1/EQ20	573.60
Zr	40	0.63	Zr KA1/EQ20	31.90
Mn	25	0.37	Mn KA1/EQ20	469.90
Rb	37	0.25	Rb KA1/EQ20	42.90
Pb	82	0.17	Pb LA1/EQ20	46.50
Zn	30	0.16	Zn KA1/EQ20	142.70
Cu	29	0.11	Cu KA1/EQ20	84.80

Table D6: Metal concentrations detected by XRF for LS $_{0\text{-}15}$ in February.

Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	33.30	Si KA1/EQ20	12317.00
Fe	26	26.00	Fe KA1/EQ20	32574.00
Al	13	22.40	Al KA1/EQ20	4160.00
K	19	7.72	K KA1/EQ20	4448.00
Ti	22	2.54	Ti KA1/EQ20	2476.00
Ca	20	1.91	Ca KA1/EQ20	1364.00
Mg	12	1.82	Mg KA1/EQ20	60.00
Cl	17	1.35	Cl KA1/EQ20	2232.00
P	15	0.83	P KA1/EQ20	413.60
Zr	40	0.80	Zr KA1/EQ20	39.20
Mn	25	0.35	Mn KA1/EQ20	437.50
Rb	37	0.25	Rb KA1/EQ20	40.80
Zn	30	0.18	Zn KA1/EQ20	159.10
Pb	82	0.14	Pb LA1/EQ20	38.40
Cu	29	0.12	Cu KA1/EQ20	88.20

Table D7: Metal concentrations detected by XRF for LS $_{0\text{-}15}$ in October.

Evaluation Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	33.80	Si KA1/EQ20	12494.00
Fe	26	26.80	Fe KA1/EQ20	33885.00
Al	13	22.80	Al KA1/EQ20	4258.00
K	19	7.75	K KA1/EQ20	4474.00
Ti	22	2.64	Ti KA1/EQ20	2636.00
Mg	12	1.55	Mg KA1/EQ20	51.50
Cl	17	1.39	Cl KA1/EQ20	2287.00
Ca	20	0.82	Ca KA1/EQ20	588.70
Zr	40	0.74	Zr KA1/EQ20	36.40
P	15	0.62	P KA1/EQ20	308.90
Rb	37	0.28	Rb KA1/EQ20	45.10
Mn	25	0.22	Mn KA1/EQ20	274.90
Pb	82	0.15	Pb LA1/EQ20	40.40

Table D8: Metal concentrations detected by XRF for LS $_{15-30}$ in February.

Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	34.00	Si KA1/EQ20	12549.00
Fe	26	27.20	Fe KA1/EQ20	33790.00
Al	13	23.00	Al KA1/EQ20	4320.00
K	19	8.07	K KA1/EQ20	4616.00
Ti	22	2.72	Ti KA1/EQ20	2671.00
Cl	17	1.40	Cl KA1/EQ20	2286.00
Zr	40	0.97	Zr KA1/EQ20	46.80
Ca	20	0.83	Ca KA1/EQ20	585.90
P	15	0.44	P KA1/EQ20	215.60
Rb	37	0.27	Rb KA1/EQ20	43.50
Mn	25	0.25	Mn KA1/EQ20	308.40
Pb	82	0.14	Pb LA1/EQ20	36.4

Table D9: Metal concentrations detected by XRF for LS $_{15-30}$ in October.

Evaluation Method: Metal

Formula	Z	Concentration (mg/kg)	Line 1	Net int.
Si	14	33.10	Si KA1/EQ20	11887.00
Fe	26	26.50	Fe KA1/EQ20	32670.00
Al	13	22.60	Al KA1/EQ20	4086.00
K	19	7.88	K KA1/EQ20	4417.00
Ti	22	2.58	Ti KA1/EQ20	2498.00
Mg	12	1.45	Mg KA1/EQ20	46.30
Cl	17	1.39	Cl KA1/EQ20	2226.00
Ca	20	1.01	Ca KA1/EQ20	700.80
S	16	0.82	S KA1/EQ20	687.00
P	15	0.75	P KA1/EQ20	365.70
Zr	40	0.70	Zr KA1/EQ20	34.00
Rb	37	0.28	Rb KA1/EQ20	44.90
Mn	25	0.23	Mn KA1/EQ20	284.70
Pb	82	0.14	Pb LA1/EQ20	36.00
Ba	56	0.11	Ba KA1/EQ40	1.06