CHAPTER II
LITERATURE REVIEW

2.1 Teak

2.1.1 General Characteristics

Teak's name in botany is *Tectona grandis*. Teak is a large deciduous tree, a tall up to 30 m. Barks are pale brown, thin, flaking in narrow vertical strips, white inner bark. Leaves are broadly obviated or oval with shortly pointed and size 15–60 cm long by 12–35 cm wide. Young shoots densely covered with yellowish star-shaped hairs. Leaf margins are entire. Stalk 1-5 cm [5]. Teak is native to Southeast Asia (approximate latitudes of 23° to 10° N) such as India, Myanmar, Laos and Thailand [6]. Teak in Thailand is found extensively in the north and stretches along the western border at altitudes between 100-900 meters above mean sea level [7].

2.1.2 Limiting Factors

There are many factors limiting the distribution and growth pattern of Teak. These major factors include climate, soil and topography. These factors are compiled by Kaosa-ard [8] and are summarized as follows:

Soil: The most suitable soil for teak is deep and well drained alluvial soil with an optimum range of soil pH between 6.5 and 8.0 and with a relatively high calcium (Ca) and phosphorus (P) content.

Rainfall: Although the range of annual rainfall in the Thai teak region is 1,000 to 1,800 mm, the most favorable range of rainfall for better growth and timber quality of teak is about 1,200 mm.

Temperature: The optimum temperatures for growth and development of teak seeding is between 27/22°C to 36/31°C (day/night temperature)

Light: Teak is a light-demanding species and the optimum light for its growth and development is between 75 to 100 percent of the full sun light.

Topography: Teak may grow from sea level up to 1200 meters, but growth is slower on high elevations and on steep slopes.

2.1.3 Teak Plantation

Teak plantations were established in India as early as the 1840. Near the end of the 19th century, Teak plantations were extended to other tropical and subtropical regions. In 1945, a national large-scale teak planting program was initiated by the Royal Forest Department (RFD) [6]. The first teak plantation in Thailand was in Phrae province in the northern region. Teak has become a top priority species in the national forest planting program and commercial plantations of this species have been extensively established, particularly throughout the northern region. At present, the RFD, the Forest industry Organization (FIO) and the Thai Plywood Company (TPC) are the major organizations planting teak in Thailand.

2.1.4 Management of Teak Plantation

Planting technique: Teak in Thailand is established by the stump planting method. In this method, seedlings are grown in a nursery. The stumps are out-planted easily by plugging them into the ground. Under favorable growth conditions, the survival rate can be high [8]. Planting spacing of teak should be relatively wide in order to promote rapid development of the saplings; on average spacing should be 3 x 3 meter, which is used in Thailand [9].

Maintenance: The common management includes spacing, weeding, fire protection, insect and disease protection and thinning. According to Centeno [10] the first thinning should take place when the dominant height of stand is 9 to 9,5 meters and the second thinning when dominant height reaches 17 to 18 meters. A rotation of 25 to 40 years can be considered as the optimum cycle for Teak plantations.

2.1.5 Utilization

Teak is considered as an attractive, light but strong wood material with great resistance against fungi, humidity and insect damages. Without remarkable splitting, cracking, warping or materially altering shape of wood material, teak timber is found to be a user-friendly material for processing [2]. Production of sawn timber uses for construction and decorative while production of immature round-wood from plantation thinning, mainly for utilization as posts and poles [11].

2.2 Remote sensing

2.2.1 Definition of remote sensing

The remote sensing was “The science of deriving information about an object from measurements at a distance from the object, i.e., without actually coming into contact with it” [12] Or this one from Avery [13]: “Remote sensing may be defined as the detection, recognition, or evaluation of objects by means of distant sensing or recording devices.” By specifying the key words “deriving information” and “detection, recognition, or evaluation” these definitions suggested that the most important contribution promised by remote sensing was in the conversion of the collected data to information products; the true value and challenge of remote sensing would be realized in the data interpretation and subsequent applications.

2.2.2 Remote sensing system

A remote system using electromagnetic radiation has four components: a source, interactions with the earth’s surface, interaction with the atmosphere and sensor [14]. (Figure 2-1)

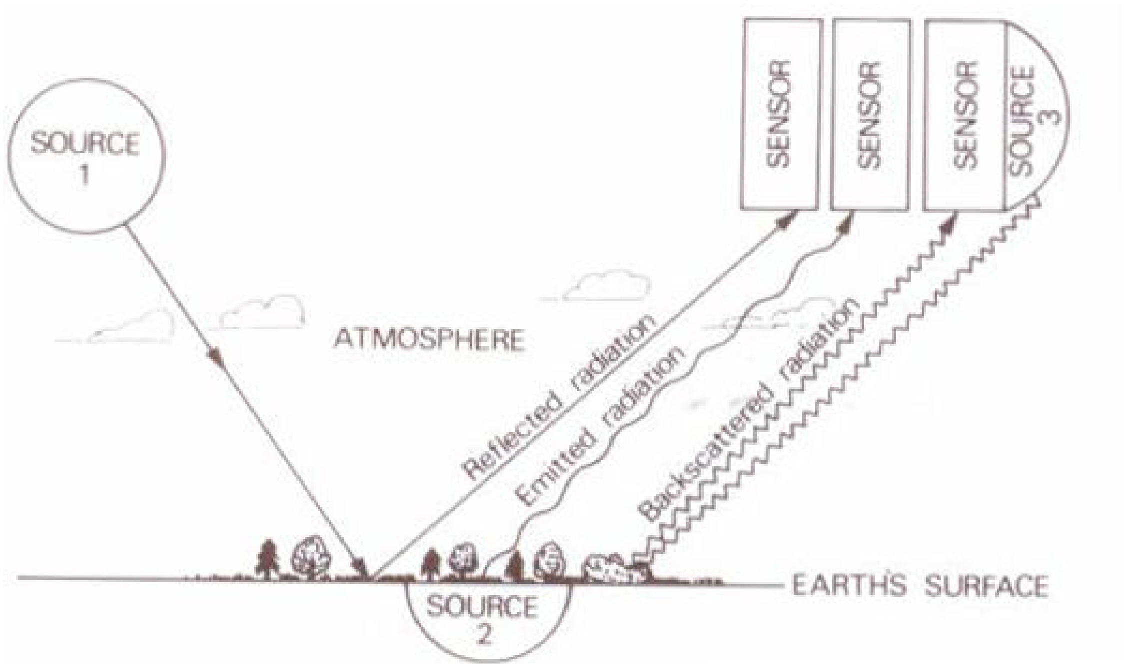

Figure 2-1 Remote sensing system [14]

Electromagnetic energy reaching the earth's surface from the sun is reflected, transmitted or absorbed. Reflected energy travels upwards thought, and interacts with, the atmosphere; that the part of it which enters the field of view of the sensors is detected and converted into a numerical value that transmitted to a ground receiving station on the earth.

The characteristics of imaging remote sensing instrument can be summarized in term of their spatial, spectral, and radiometric resolutions. The spatial resolution is the ability to measure property, is its instantaneous field of view (IFOV). The IFOV is defined as the area on the ground. The term of spectral resolution refers to the width of these spectral bands measured in micrometers (µm) or nanometers (nm).The width and numbers of spectral bands determine the degree of discriminating power. The third important property, radiometric resolution refers to the number of digital quantization levels used to express the data collected by sensor. The greater the number of quantization levels the greater the detail in the information collected by the sensor. The different solutions of an earth observing system should be selected with the aim of investigation in mind [15].

2.2.3 Landsat thematic mapper (TM)

The Landsat series of satellites provides the longest continuous record of satellite-based observations. As such, Landsat is an invaluable resource for monitoring global change and is a primary source of medium spatial resolution earth observation used in decision-making [16].

The TM sensor is a scanning optical-mechanical sensor that records energy in the visible, reflective-infrared, middle-infrared, and thermal infrared regions of the electromagnetic spectrum. The Landsat TM data have a ground-projected IFOV of 30 x 30 meters for bands 1-5 and 7. The thermal infrared band 6 has a spatial resolution 0f 120 x 120 meters. The quantization level is 8 bit (value from 0 to 255) [17]. The characteristics of the TM spectral bands are shown in table 2-1.

Table 2-1 Characteristics of the Landsat Thermatic Mapper (TM) spectral bands [17]

Band		**Spectral Resolution (µm)**	**Characteristic**
Number	**Name**		
1	Blue	0.45-0.52	Provides increased penetration of water bodies, as well as supporting analyses of land use, soil, and vegetation characteristics. The shorter-wavelength cutoff is just below the peak transmittance of clear water, while the upper-wavelength cutoff the limit of blue chlorophyll absorption for healthy green vegetation. Wavelengths below 0.45 µm are substantially influenced by atmospheric scattering and absorption.
2	Green	0.52-0.60	This band spans the region between the blue and red chlorophyll absorption bands and therefore corresponds to green reflectance of healthy vegetation.

Table 2-1 Characteristics of the Landsat Thermatic Mapper (TM) spectral bands (Cont.)

Band		Spectral Resolution (µm)	Characteristic Number
Number	Name		
3	Red	0.63-0.69	This is the red chlorophyll absorption band of healthy green vegetation and represents one of the most important bands for vegetation discrimination. It is also useful for soil-boundary and geological-boundary delineations. This band may exhibit more contrast than bands 1 and 2 because of the reduced effect of atmospheric attenuation. The 0.69 µm cutoff the significant because it represents the beginning of a spectral region from 0.68 to 0.75 µm, where vegetation reflectance crossovers take place that can reduce the accuracy of vegetation investigations.
4	Near-infrared	0.76-0.90	For reasons discussed, the lower cutoff for this band was placed above 0.75 µm. This band is especially responsive to the amount of vegetation biomass present in scene. It is useful for crop identification and emphasizes soil/crop and land/water contrasts.
5	Mid-infrared	1.55-1.75	This band is sensitive to the turgidity or amount of water in plants. Such information is useful in crop drought studies and in plant vigor investigations. In addition, this is one of few bands that can be used to discriminate between clouds, snow, and ice, which are important in hydrologic research.

Table 2-1 Characteristics of the Landsat Thermatic Mapper (TM) spectral bands (Cont.)

Band		Spectral Resolution (μm)	Characteristic Number Number
Number	Name		
6	Thermal infrared	10.4-12.5	This band measures the amount of infrared radiant flux emitted from surfaces. The apparent temperature is function of the emissivity and the true or kinetic temperature of the surface. It is useful for locating geo-thermal activity, thermal inertia mapping for geologic investigations, vegetation classification, vegetation stress analysis, and soil moisture studies. The sensors often capture unique information on differences in topographic aspect in mountain areas.
7	Mid-infrared	2.08-2.35	This is an important band for the discrimination of geologic rock formations. It has been shown to be particularly effective in identifying zones of hydrothermal alteration in rocks.

Radiometric characterization and calibration of Landsat data is a prerequisite for creating high-quality science data, and consequently, high-level downstream products. Thus, it extracts useful biophysical information. Calculation of at-sensor spectral radiance is the fundamental step in converting image data from multiple sensors and platform into a physically meaningful common radiometric scale. During process, pixel value from raw, unprocessed image data are converted to unit of absolute spectral radiance. The converting the at-sensor spectral radiance to top-of-atmosphere (TOA) reflectance is second step. These variations can be significant geographically and temporally [16].

2.2.4 Remote sensing of vegetation

Plants have adapted their internal and external structure to perform photosynthesis. This structure and its interaction with electromagnetic energy have a direct impact on how leave and canopies appear spectrally when recorded using remote sensing instruments [17]. Chlorophyll is the most important plant pigment absorbing blue and red light. Thus, the spectral reflectance curve rises in green wave bands. In addition, there are many factors that cause difference spectral such as percent canopy closure, temporal characteristics, managed phonological cycles, and so on.

Another utilization data is extracting data by the vegetation indices which defined as dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation [17]. There are a lot of vegetation indices in use. A select few are summarized as follows.

Cohen [18] suggests that the first true vegetation index was the simple ratio (SR), which is the near-infrared (NIR) to red reflectance ratio described in Birth and McVey [19]:

$$SR = \frac{NIR}{RED}$$

Normalized Difference Vegetation Index (NDVI) was developed by Rouse et al. [20] that the transformation of the visible (red) and near-infrared bands of satellite information. The NDVI is an alternative measure of vegetation amount and condition. The NDVI values range from -1 to 1. Healthy vegetation will have a high NDVI value. Bare soil and rock will have NDVI values near zero. Clouds, water, and snow are negative NDVI values [21]. The NDVI is calculated with the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

In some case, the NDVI is unable to highlight subtle differences in canopy density. It has been found to improve by using power degree of the infrared response. The calculated index has been termed as advanced vegetation index (AVI). It has been more sensitive to forest density and physiognomic vegetation classes. The AVI has been calculated using equation [22]:

NIR - RED < 0 AVI = 0

NIR - RED > 0 AVI = [(NIR +1) x (256 - RED) x (NIR - RED)] $^{1/3}$

Bare soil index (BI) is formulated with Blue, Red, NIR and medium infrared (MidIR) information. The underlying logic of this approach is based on the high reciprocity between bare soil status and vegetation status. By combining both vegetation and bare soil indices in the analysis, one may assess the status of forestlands on a continuum ranging from high vegetation conditions to exposed soil conditions. The BI values range from 0 to 200 [22]. The BI is calculated with the following formula:

$$BI = \frac{(MidIR + RED) - (NIR + BLUE)}{(MidIR + RED) + (NIR + BLUE)} \times 100 + 100$$

In the classification of plantation, Taweesuk and Thammapala [23] identify and map teak plantation using expert classification, they carried out various pre-processing steps of spatial data from spectral database by the NDVI and normalize difference moisture index (NDMI) from Landsat 5 and 7. Iglesias [24] developed age class model of Eucalyptus plantation from the integration of NDVI, BI and Water Index (WI) and percent accuracy for age class classification is 60.63 percent. Nilubol [25] establish a model for age class identification of Para rubber in Krabi province. NDVI, BI, WI and Advance Vegetation Index (AVI) were also employed to help identify the stages. Accuracy assessments for four stages were: Young stage (1-7 years old), Harvest stage (>7-20 years old), Mature stage (>20-24 years old) and Logging stage (>24 years old) of 65.95, 69.92, 70.83 and 61.11 percent, respectively.

2.3 Biomass

2.3.1 Biomass formation

Botanical biomass is formed through conversion of carbon dioxide (CO_2) in the atmosphere into carbohydrate by the sun's energy in the presence of chlorophyll and water. Plants absorb solar energy in a process called photosynthesis. In the presence of sunlight of particular wavelengths, green plants break down water to obtain electron and use them to turn CO_2 into glucose (represented by CH_mO_n), releasing O_2 as a waste product. The chlorophyll promotes the absorption of carbon dioxide from the atmosphere, adding to the growth of biomass [26]. The process can be described by this equation:

$$6CO_2 + 6H_2O + \text{sunlight} \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Biomass increment is the annual increase in dry weight and volume of wood, bark, foliage and coarse root. Biomass increment occurs most rapidly in young stand, and can approach zero in over-mature stands [27]. The biomass of trees are usually expressed in units of dry organic matter per unit area (e.g., tons ha^{-1} or grams m^{-2}).

2.3.2 Measuring forest plantation biomass

The direct assessment of the woody biomass of a tree is done by a destructive process. This procedure can be very time and cost consuming. As an alternative to the direct determination of biomass, Brown [28] suggested an "expansion" of the volume of over bark to biomass by means of a volume-weighted average wood density factor. The method assumes the availability of precise volume estimates. Applications should be limited to cases where this assumption is justified. Extensive biomass assessments generally follow a two-phase procedure (Figure 2-2). First is destructive sample of trees and develop regression analysis and then collect sample for calculate tree biomass.

The majority of the biomass equations are in the form $Y = aX^b$, where Y is the weight of stem or branches or leaves (kg), X is the $DBH^2.Ht$ ($cm^2.m$) and a, b are constant value of equation [29]. The existing biomass equations were selected from the geographical regions closest to sample area. Estimating the biomass density of plantations can be done using techniques similar to those for native forests but also easier because tree form is likely [28].

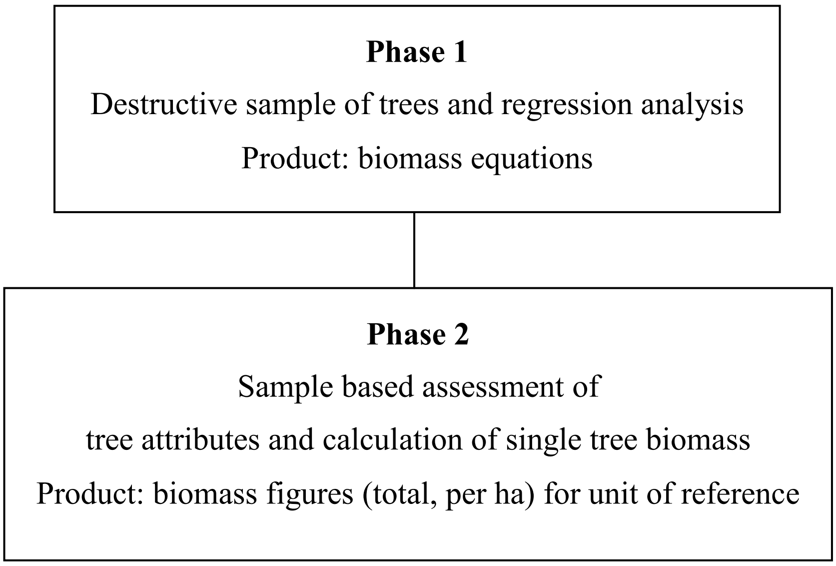

Figure 2-2 Phases of biomass assessment [30]

Viriyabuncha [31] adjusts equation to estimate the above-ground biomass of teak plantation in Thailand was conducted in the plantation areas of Forest Industry Organization. The procedure of the study was 1) to cut down the teak as sample trees 2) to synthesis data of teak from reviewing literature at Mae Cheam Plantation and Sop Phueng Plantation. From the study, it was found that the relationship, in the form of allometric equation, DBH^2 Ht and stem biomass (Ws), total above-ground (Wt) and stem volume (Vs) of teak in each site has the tendency of more or less the same equation. Consequently it can be employed for the estimation of growth and yield of teak in different sites by having the value of equation as follows:

$$Wt = 0.0358(DBH^2Ht)^{0.9468} \quad R^2= 0.9851$$

$$Ws = 0.0271(DBH^2Ht)^{0.9435} \quad R^2= 0.9915$$

$$Wl = 0.0205(DBH^2Ht)^{0.6850} \quad R^2= 0.8090$$

$$Wb = 0.0013(DBH^2Ht)^{1.1339} \quad R^2= 0.9304$$

The recommendation of Pumijumnong [38] studied which about above ground and below ground biomass of teak plantation in various ages, Uthai Thani province, Thailand said the study of above ground biomass has many limiting factors such as plantation management, planted interval, etc. Another relate study, Samek and Skole [39] study on Carbon 2 Markets Small-Holder Agro forestry Project by conducted the baseline carbon stock in 2008 and 2009 of 94 small-holder farmers of Teak plantation in Thailand. Collecting data by field measurements then compute above ground biomass following allometric equation. And Calculating Carbon Stock used 50 percent of total biomass. They separated Teak to two groups including thinned and unthinned. The result shown that estimated annual sequestration rate is 10.62 ton CO_2/ha/yr.

2.4 Study area

The study area is located at Khun Mae Kham Mee Plantation belonging to the FIO in Rong Kwang district, Prae province, northern Thailand at the latitude of 18°22’-18°29’N and the longitude of 100°24’-100°29’E. The total area of Khun Mae Kham Mee Plantation is around 3,308.80 ha. The management units consist of unproductive area (Conservation Zone and High Conservation Value Zone) and productive area. (Figure 2-3)

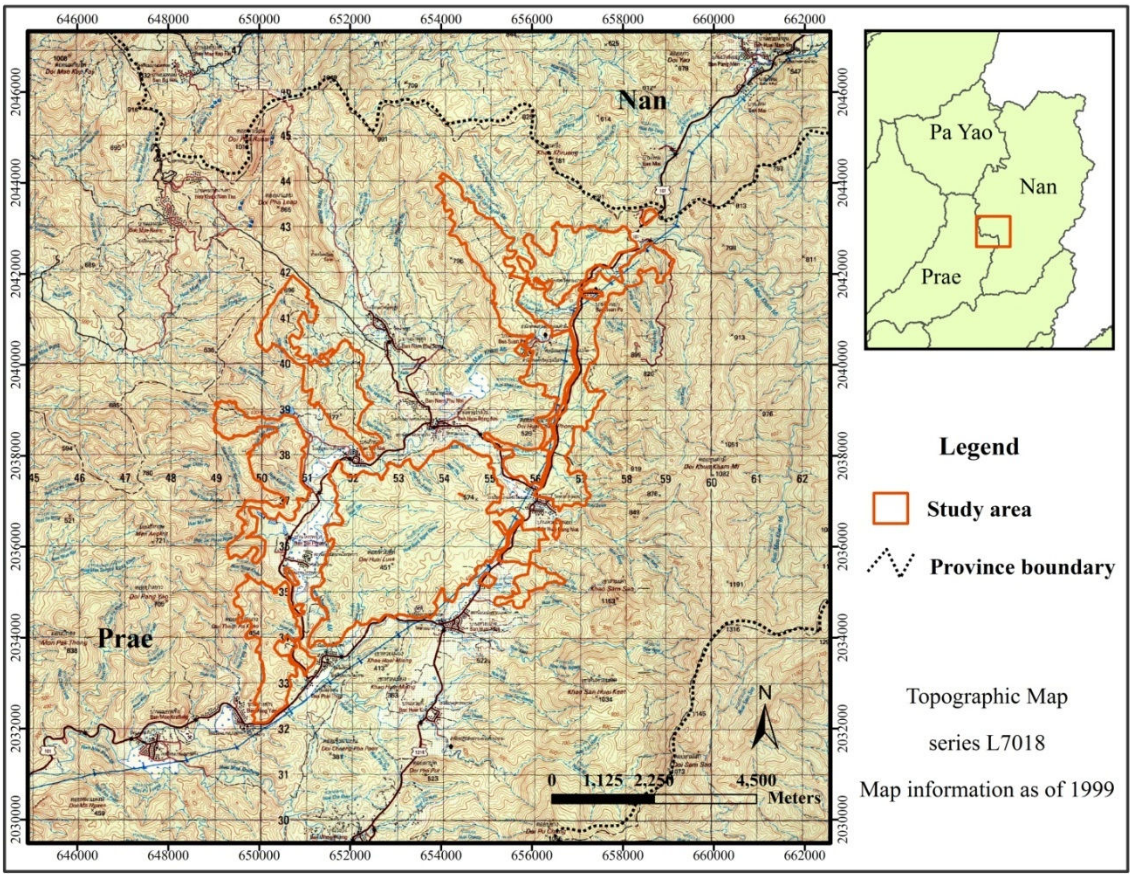

Figure 2-3 Study area

2.4.1 Topography

The topography of the majority of the study area is high-mountain, with deep creek and scattered rock outcrops. The soils are mostly gravel and silt loam texture. Top soil is brown color. Soils are moderately acidic, with medium amounts of organic matter, with a relatively high calcium (Ca) and low phosphorus (P) content. The elevation about 350-700 m above mean sea level [40].

2.4.2 Climate

Weather atmosphere, meteorology and hydrology conditions of Khun Mae Kham Mee Plantation are under the influence of the South-west and the North-east monsoon. Mean temperature is 27.2 °C at Northern meteorological center's Prae station (years 1978-2008). April is the hottest month with the average temperature of 30.8°C, while December is the coldest month with average temperature of 22.7°C. The average rainfall is 113.4 mm at Royal Irrigation Department's Khun Mae Kham Mee

Plantation station (years 1978-2008). The maximum rainfall is on August (273.0 mm), while minimum is on January (4.6 mm) and mean annual precipitation is between 1,260 – 1,340 mm yr^{-1}. (Figure 2-4)

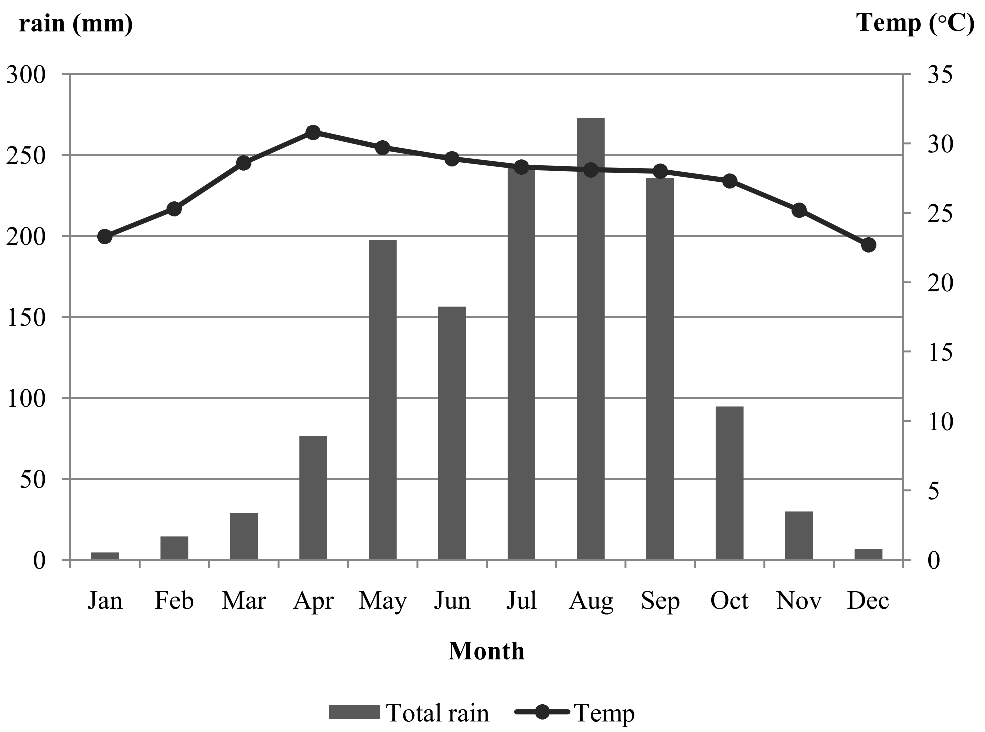

Figure 2-4 The Diagram of the Average of Temperature (°C) at Prae station and the Monthly Rainfall (mm.) at Khun Mae Kham Mee Plantation station between the years 1978-2008 [40]

2.4.3 Plantation management

Plant spacing of teak is 4 x 4 meters. The thinning operations of Teak plantations start at the age of 10 years and do it again at the age of 15 years and 22 years, respectively. The thinning is cut some of trees to promoted growth. And final cutting and replanting at the age of 30 years.