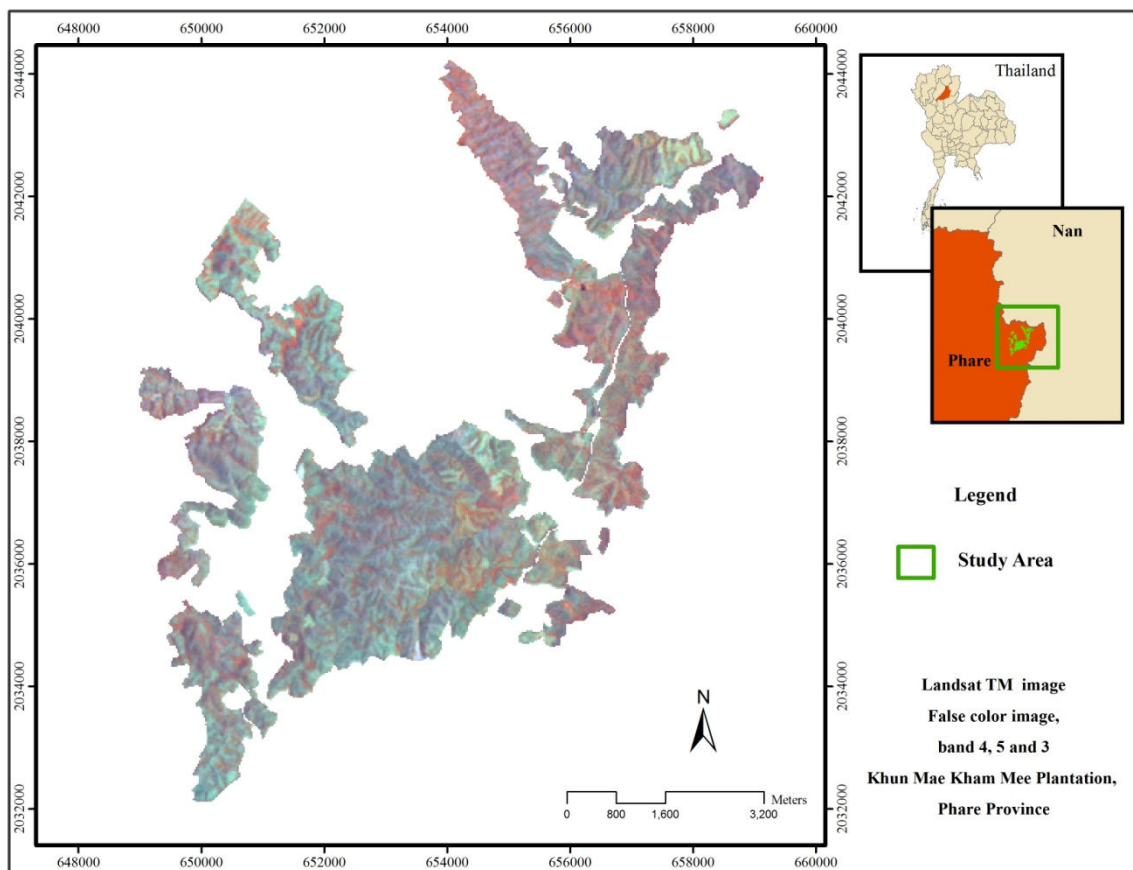


## CHAPTER IV

### RESULTS AND DISCUSSIONS

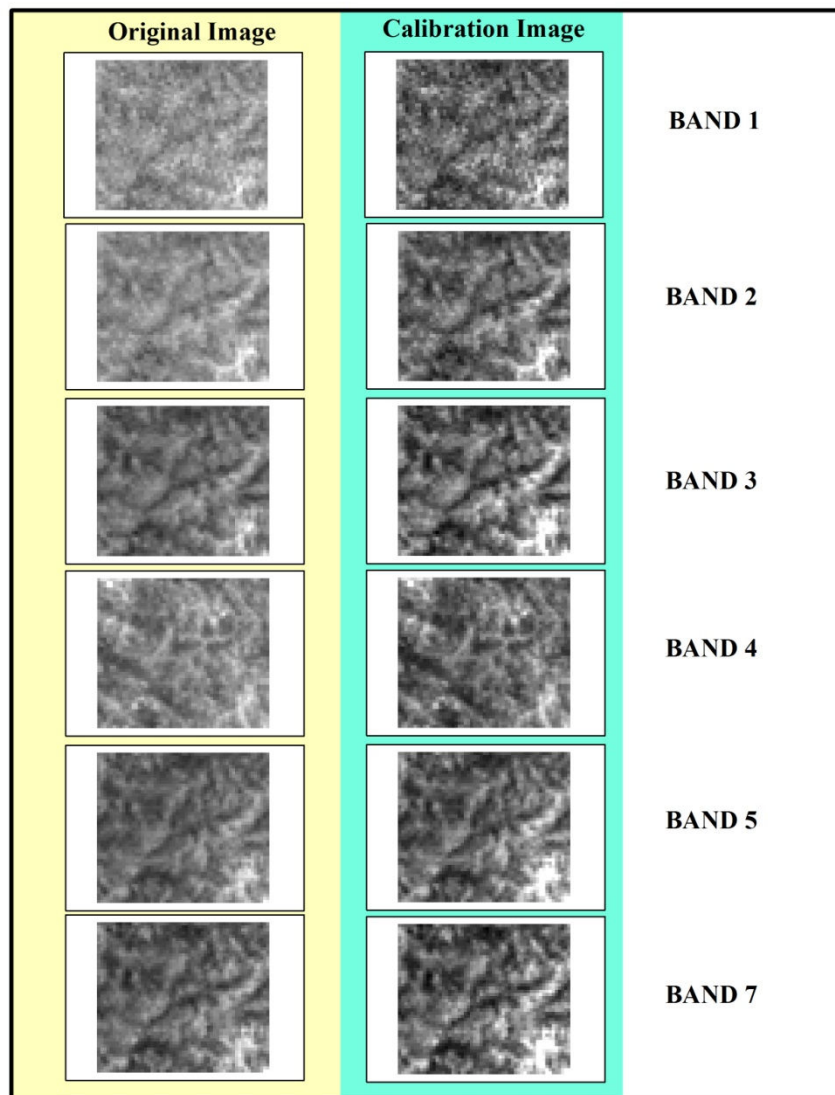
#### 4.1 Classification of Teak plantation and Non-Teak plantation

The Landsat image band 1-5 and 7, path/row 130/47, was the main imagery source for data processing in this study. The co-register by image-to-image method was utilized for geometric correction. Then, the image had been masked to Khun Mae Kham Mee Plantation boundary in order to process next procedure as shown in figure 4-1.



**Figure 4-1 Pre-process image of Landsat TM, Khun Mae Kham Mee Plantation, 2010**

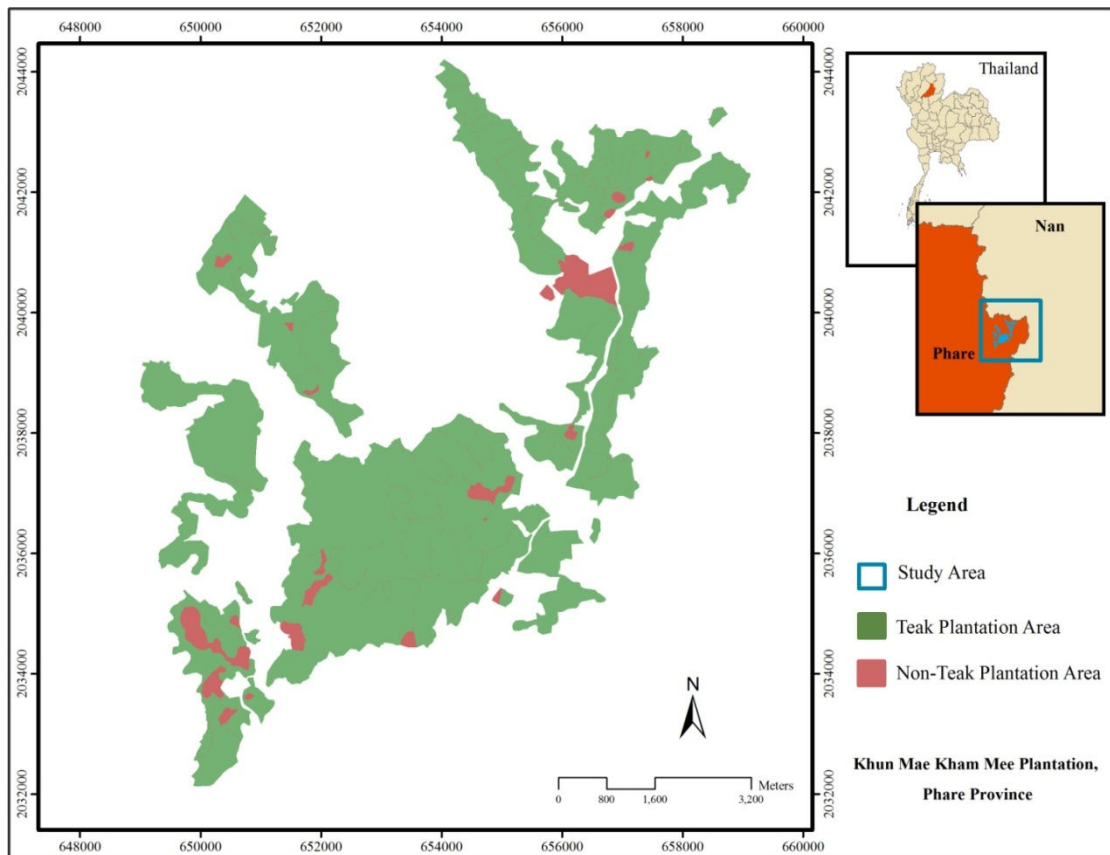
The radiometric calibration was converting digital numbers (DN) to Top-of-atmosphere reflectance (TOA) using knowledge of the lower-upper limit and involved factors. The procedure would be improves the ability of image to compare the adjacent area, as shown in figure 4-2



**Figure 4-2 Landsat TM image of Khun Mae Kham Mee Plantation, An original image band 1-5, 7 is on the left and a calibration image band 1-5, 7 is on the right.**

In the classification of Teak plantation, semi-automatic image interpretation (Hybrid interpretation) by means of integration between computerized and visualize interpretation were used. In computerized section, the maximum likelihood classification was used. The training areas were set from ground truth data

which was taken during the survey in 26-28 April 2010. Then, visual interpretation based on land use information data from Land Development Department was used to delineate Teak plantation area. The result of the hybrid image interpretation was classification of the study area into Teak plantation and non-Teak plantation area in Khun Mae Kham Mee Plantation, as shown in figure 4-3



**Figure 4-3 Teak plantation and non-Teak plantation area in Khun Mae Kham Mee Plantation, 2010**

The total of 20 sample points which distributed to all land cover from ground truth was used to verify classification accuracy. Result of the error matrix was presented in percentage of each land cover classification. The accuracy of Teak plantation and Non Teak plantation were 81.81% and 88.88%, respectively. And total accuracy was 85.00%. (Table 4-1) And Kappa Index was 0.70 which represented moderate agreements.

**Table 4-1 Confusion matrix of hybrid interpretation classification and ground truth**

		Hybrid interpretation Classification		
		Teak plantation	Non Teak plantation	Overall
Ground Truth	Teak plantation	9	1	10
	Non Teak plantation	2	8	10
	Overall	11	9	20
% Accuracy		<b>81.81</b>	<b>88.88</b>	<b>85.00</b>

Source: Analysis

## 4.2 Age Stage identification of Teak plantation

### 4.2.2 Image operation

In the image operation that is extracting data by the vegetation indices. The indices selected for this study include Advanced Vegetation Index, Bare Soil Index and water index.

#### 1) Advanced vegetation index (AVI)

Advanced vegetation index is used to grouping forest density and physiognomic vegetation classes. It uses Red band (band 3) and near infrared (band 4). The AVI is calculated with the following formula:

$$\text{NIR} - \text{RED} < 0 \quad \text{AVI} = 0$$

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

Where: AVI = Advanced vegetation Index

NIR = Near Infrared reflectance value

RED = Visible Red reflectance value

## 2) Bare soil Index (BI)

Bare soil index is a normalized index of the difference sums of two separating the vegetation with different background particularly completely bare, sparse canopy and dense canopy etc. It uses Blue band (band 1), Red band (band 3), near infrared (band 4) and Middle infrared (band 5). The BI index is calculated with the following formula:

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

Where: BI = Bare soil Index  
 BLUE = Visible Blue reflectance value  
 RED = Visible Red reflectance value  
 NIR = Near Infrared reflectance value  
 MidIR = Middle Infrared reflectance value

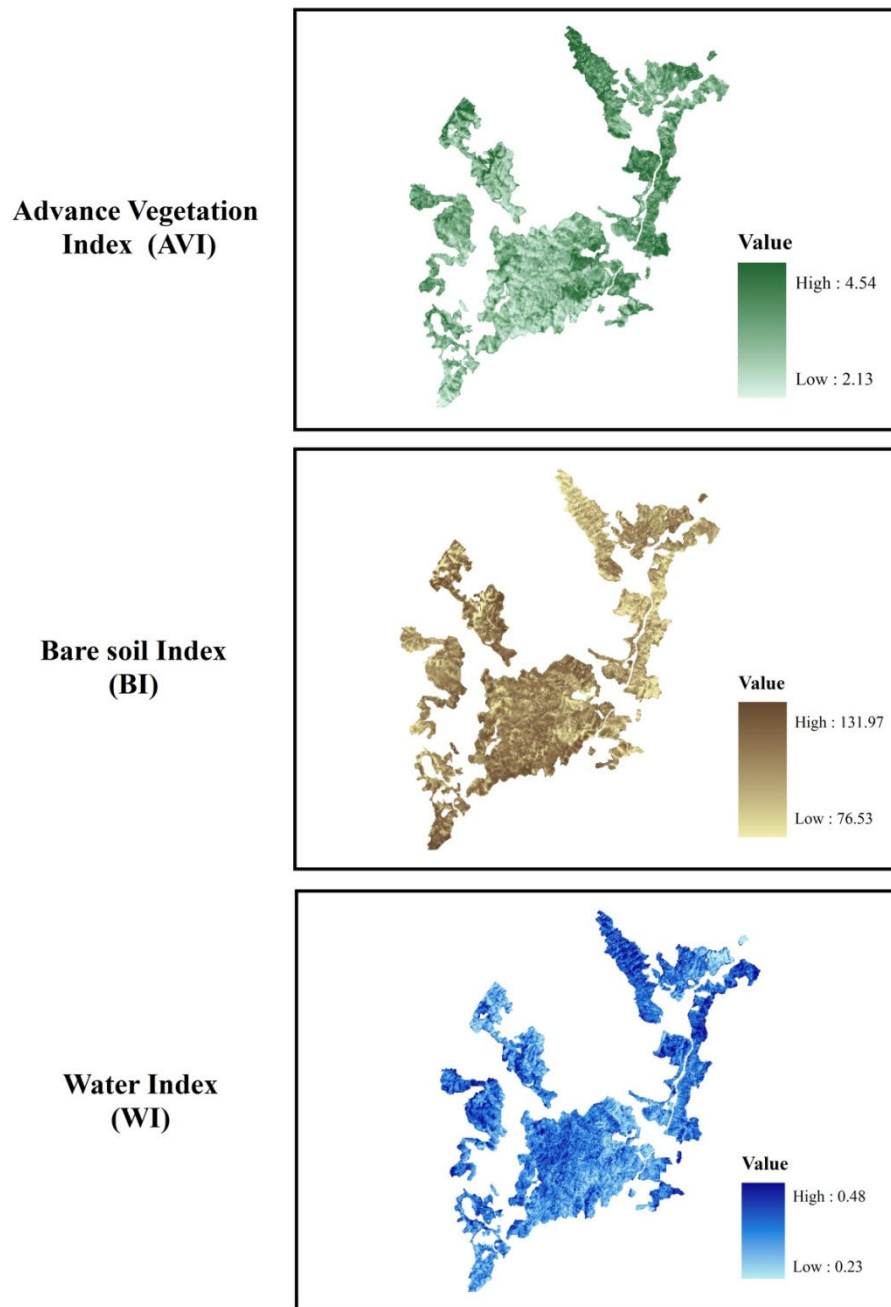
## 3) Water Index (WI)

It uses Green band (band 2) and Middle infrared (band 5). The WI is calculated with the following formula:

$$WI = \frac{GREEN}{MidIR}$$

Where: WI = Water Index  
 GREEN = Visible Green reflectance value  
 MidIR = Middle Infrared reflectance value

The result showed in figure 4-4 which the darkened color was higher value and light color was lower value. The indices have some characteristics as follows. The AVI reacts sensitively for the vegetation quantity by increases as the vegetation increase. The BI increases as the bare soil exposure degrees of ground increase. WI, the typical range of non-water area ranges between 0 - 1. The value close to 1 has meaning that the areas contain the elements of water than other areas.

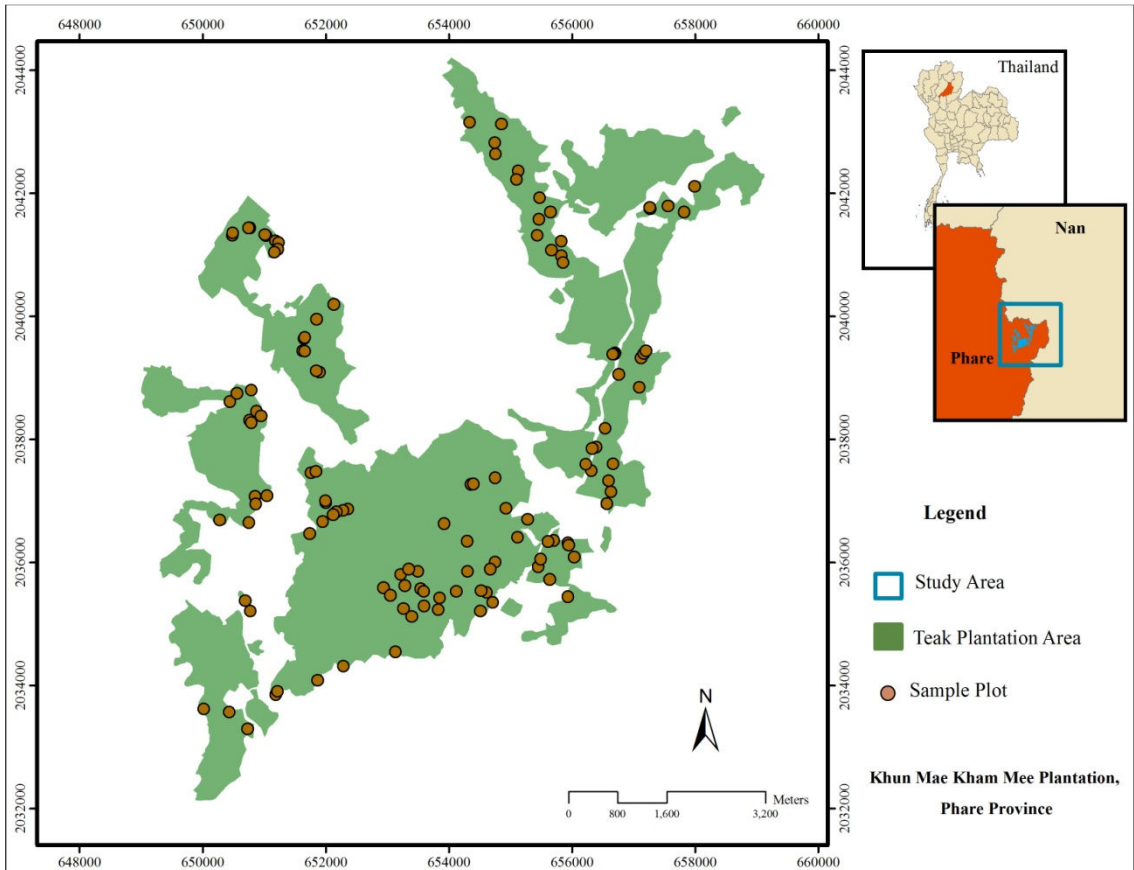


**Figure 4-4 Image operation resulted**

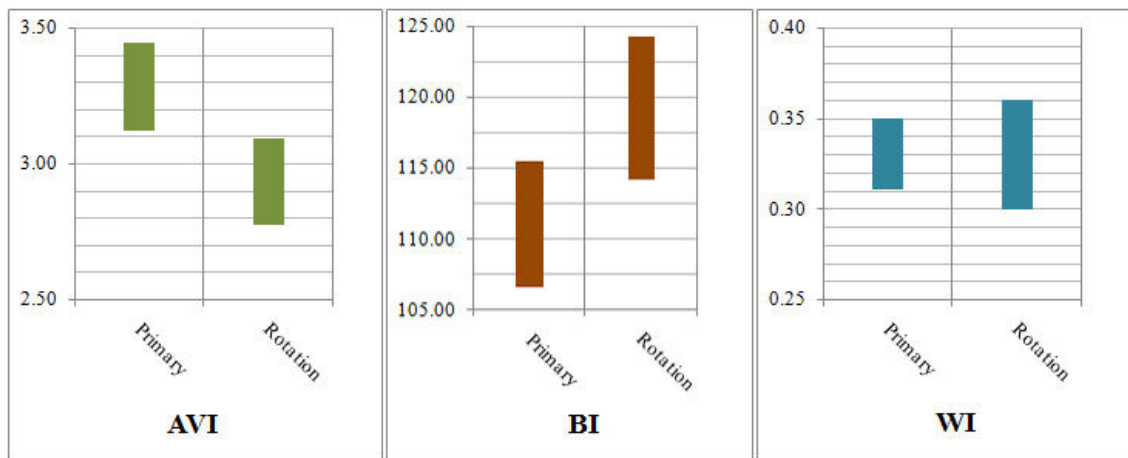
### 4.2.3 Sampling data

The total of sampling data as shown in figure 4-5, the sampling distributed to available Teak age class and the coordinate of sampling was used in the extracting pixel value data of each index. The values of average and standard division were used to generate the signature of Teak age stage as show in figure 4-6. And from figure 4-7,

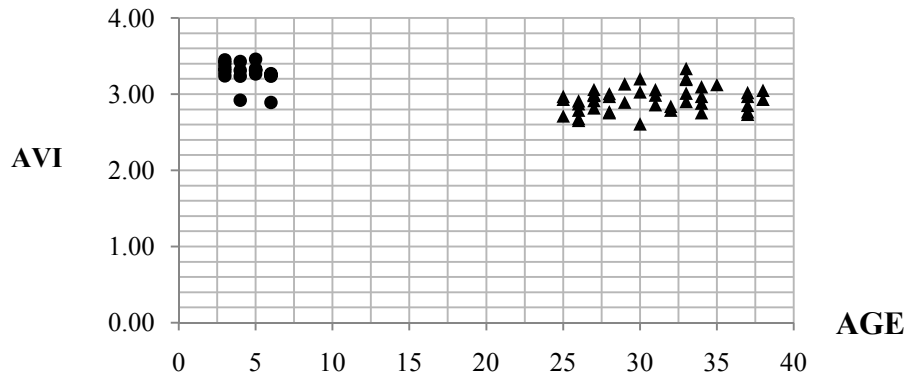
the result of various indices presented that the primary stage; average of AVI, BI and WI were 3.28, 111.01 and 0.33 respectively. The rotation stage; average of AVI, BI and WI were 2.94, 119.20 and 0.33 respectively. The details of it show in appendix A. Descriptive statistic is described in descending.



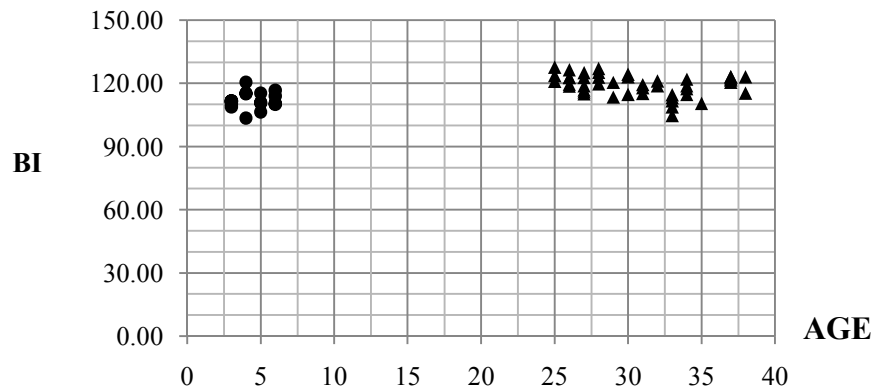
**Figure 4-5 Plot sampling on the study area**



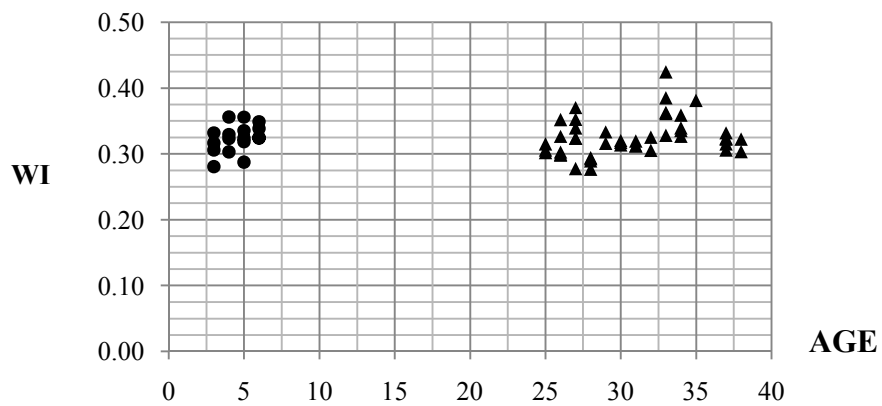
**Figure 4-6 Signature of Teak age stage**



	Mean ± SD	Minimum	Maximum
Primary stage	3.28 ± 0.16	2.89	3.57
Rotation stage	2.94 ± 0.16	2.61	3.34



	Mean ± SD	Minimum	Maximum
Primary stage	111.01 ± 4.42	102.00	120.47
Rotation stage	119.20 ± 5.00	104.67	127.64



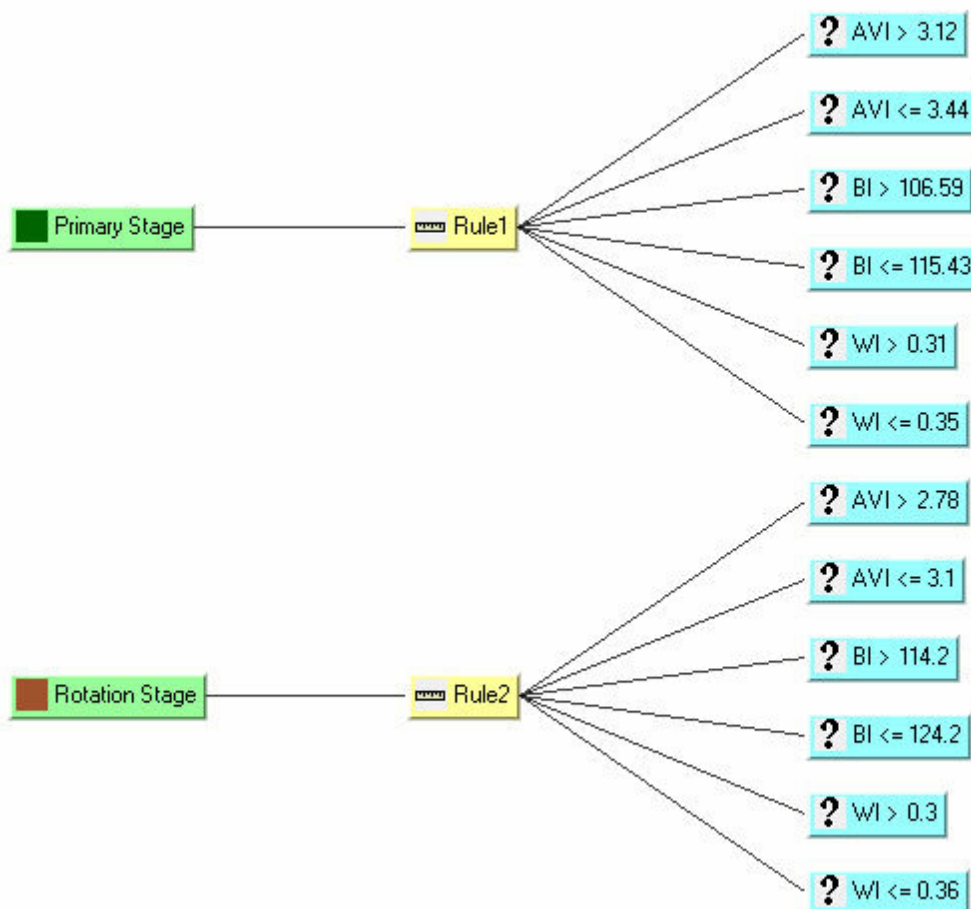
	Mean ± SD	Minimum	Maximum
Primary stage	0.33 ± 0.02	0.28	0.36
Rotation stage	0.33 ± 0.03	0.28	0.42

● Primary stage ▲ Rotation stage

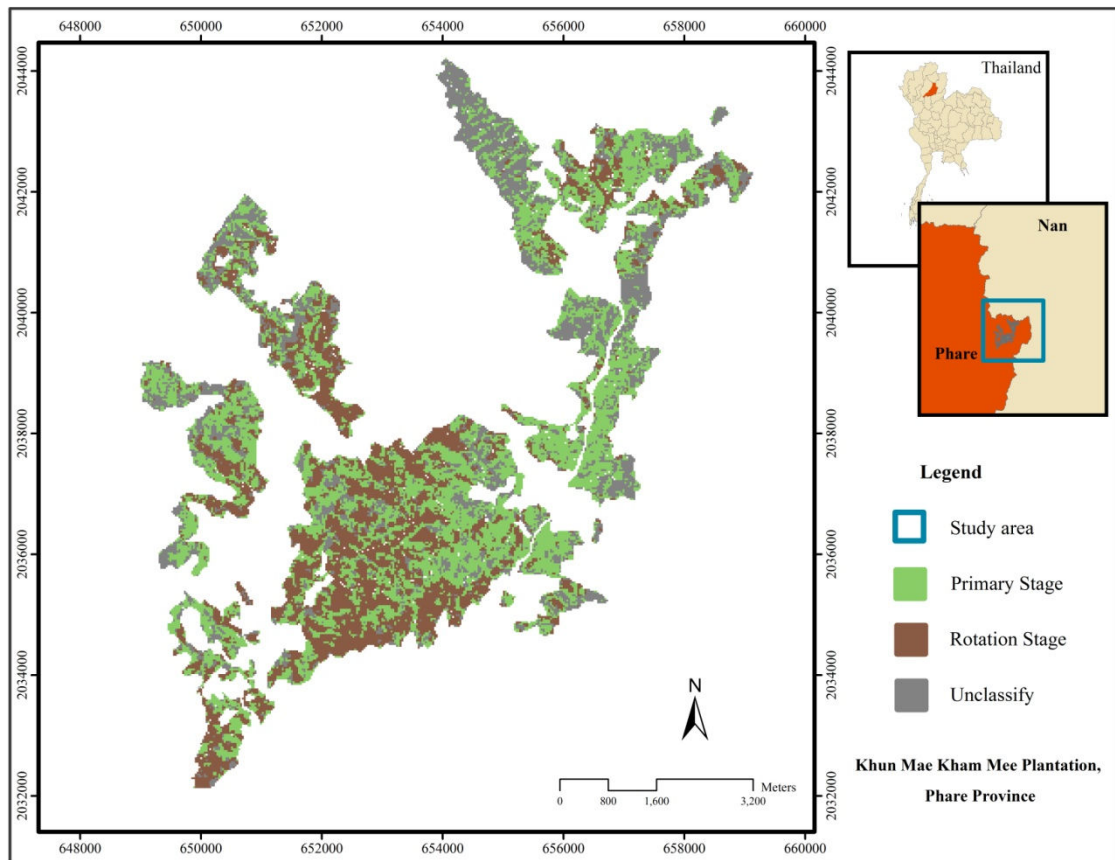
Figure 4-7 Scatter plots between age and indexes and descriptive statistic

### 4.2.3 Classification by Logical Operation

Logical operation for age class classification was carried out to comparison in terms of accuracy of the regression model classification system. The logical operation used values of AVI, BI and WI for each age stage in the classification and knowledge-based tool. The knowledge-based system delineated Teak age-class by rule then union forms from decision tree. The threshold values of NDVI, BI and WI were used to generate the knowledge-based system for classifying the age class of Teak in Khun Mae Kham Mee Plantation as show in figure 4-8. And the age class map using logical operation shows in Figure 4-9. The result found two age stage and unclassified area. Primary stage and rotation stage were 1,407.42 (45.32%) and 914.58 (29.45%) ha respectively. Unclassified area was 783.27 ha (25.22%).



**Figure 4-8 Condition for logical operation classification**



**Figure 4-9 Classification resulted by logical operation**

#### 4.2.4 Classification by regression model

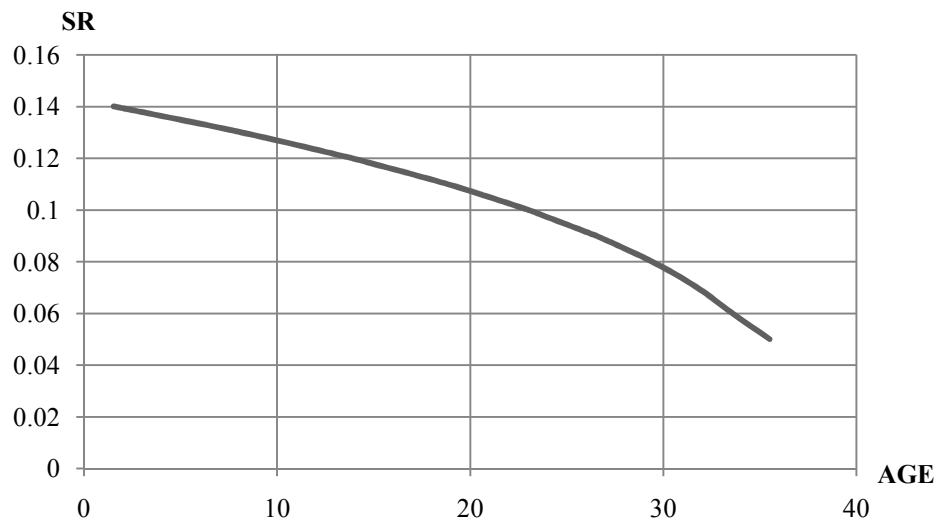
##### 4.2.4.1 Correlation Analysis

The correlation between indexes (AVI, BI and WI) and age-class that were outstanding at 0.01 levels reached negative 0.66, positive 0.54 and positive 0.08 respectively. The result found AVI which indicate the vegetation quantity was highest correlation. And WI was lowest correlation showing a few relations. From the result, the researcher chose some indexes related to the vegetation which had been studied in plantation were added in analyze. Found that the Normalized Difference Vegetation Index (NDVI), the Greenness Index (from Tasseled Cap transformation) and the simple ratio (SR) reached negative 0.69, 0.67 and 0.70 respectively. (The details of other vegetation indexes showed in Appendix A) It showed the higher were vegetation indexes when compared with BI and WI which were the physical indexes. All of vegetation indexes were imported to regression analysis to find the best fit equation.

#### 4.2.4.1 Regression Analysis

Perform the best fitted equation of linear and non-linear regression which could be in various forms such as logarithmic, inverse, quadratic, exponential, etc. By determine the dependent variable and the independent variables as the available age and the vegetation index respectively. Then, the best fits equation was selected by the highest of the correlations coefficients ( $R^2$ ) value of each equation which the best fit equation was the Cubic model. The coefficient value of model reached 0.63. The details of all indexes are showed in table 4-2.

From the figure 4-10, the trend of SR and Age was in the opposite direction. The SR value's the primary stage more than the rotation stage. Because the SR value computed from NIR and RED reflectance value which leaf pigment will be interact with both bands. In dry season, Teak showed an almost denuded canopy (seasonal impact) which was seen as lesser absorbance in the RED band, while discrepancy was seen in the NIR region [50] according to the study and Priya and Bhat [51] found that the primary stage, trees retained some leaf but the rotation stage trees lost their leaves complete.



$$\text{Age} = 7.52 - 207.839\text{SR} + 2,065.338\text{SR}^2 - 6,107.702\text{SR}^3 \quad R^2 = 0.63$$

**Figure 4-10 Cubic model resulted**

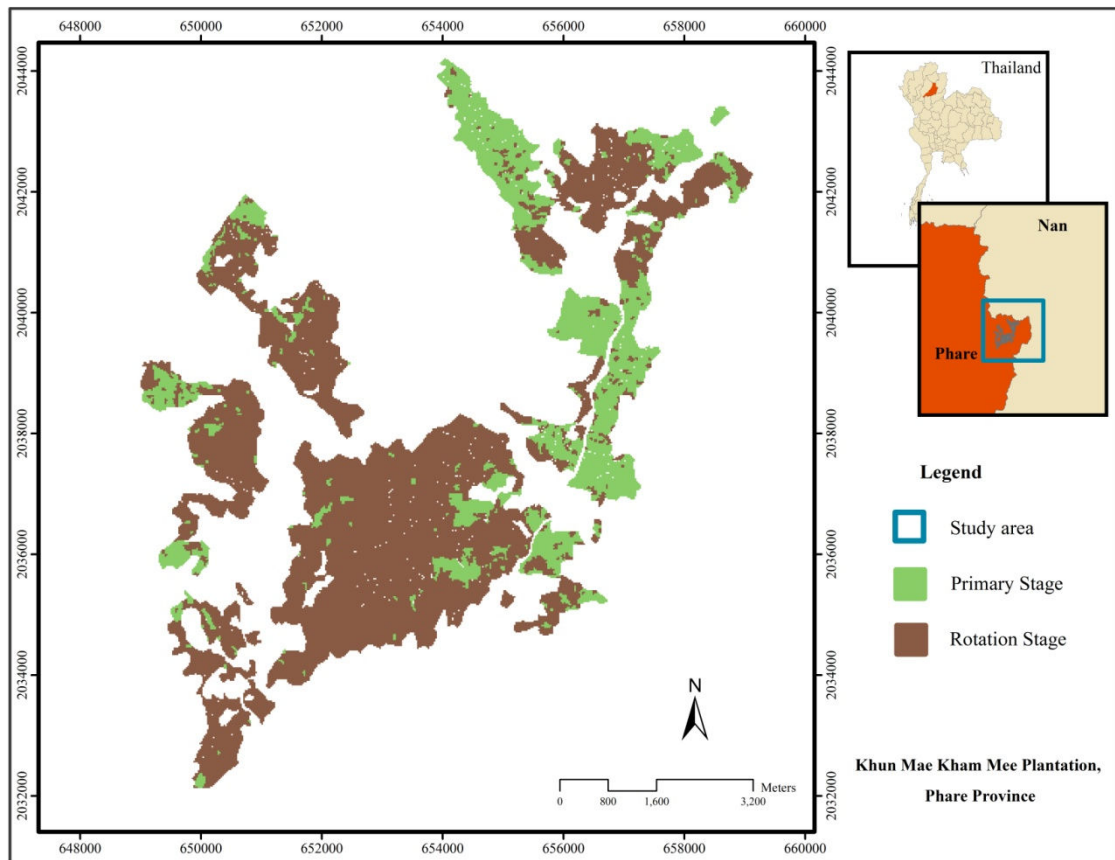
**Table 4-2 The resulted of regression analysis**

Index	equation		R <sup>2</sup>
AVI	Linear	Age = 133.27 -36.36AVI	0.43
	Logarithmic	Age = 144.00 - (109.32 ln(AVI))	0.42
	Inverse	Age = -85.13 + (326.17 / AVI)	0.40
	Cubic	Age = -223.51 + 139.01AVI – 6.17AVI <sup>3</sup>	0.49
	Exponential	Age = 78,161.69e <sup>(-2.77)AVI</sup>	0.48
BI	Linear	Age = 1.11BI -107.25	0.29
	Logarithmic	Age = -590.55 + (128.88 ln(BI))	0.29
	Inverse	Age = 150.30 - (14,848.86 / BI)	0.29
	Cubic	Age = -305.99 + 3.69 BI – 6.4E-5 BI <sup>3</sup>	0.3
	Exponential	Age = 1.0E-3e <sup>0.8 BI</sup>	0.32
WI	Linear	Age = 10.96 + 36.01WI	< 0.01
	Logarithmic	Age = 34.96 + (10.90 ln(WI))	< 0.01
	Inverse	Age = 32.75 - (3.25 / WI)	< 0.01
	Cubic	Age = 64.52 – 1,209.01WI <sup>2</sup> – 2,475.89WI <sup>3</sup>	0.02
	Exponential	Age = 8.44e <sup>2.13WI</sup>	< 0.01
NDVI	Linear	Age = 63.73 – 116.73NDVI	0.46
	Logarithmic	Age = -19.108 - (39.19 ln(NDVI))	0.41
	Inverse	Age = -14.20 + (12.43 / NDVI)	0.36
	Cubic	Age = 11.31 + 108.97NDVI – 547.95NDVI <sup>3</sup>	0.53
	Exponential	Age = 414.42e <sup>(-9.09)NDVI</sup>	0.53

**Table 4-2 The resulted of regression analysis (cont.)**

Index	equation		R <sup>2</sup>
GREENNESS	Linear	Age = -301.70 -470.24SR	0.41
	Logarithmic	-	-
	Inverse	Age = 347.20 + 223.72 / SR)	0.42
	Cubic	Age = -3,310.04 – 7043.06SR – 4,439.53SR	0.47
	Exponential	Age = 2.54E-10e <sup>(-36.12)SR</sup>	0.46
SR	Linear	Age = -0.209 + 15.672SR	0.56
	Logarithmic	Age = 4.947 + (1.542 ln(SR))	0.53
	Inverse	Age = 2.83 + (-0.14 / SR)	0.49
	Cubic	Age = 7.52 – 207.839SR + 2,065.338SR <sup>2</sup> – 6,107.702SR <sup>3</sup>	0.63
	Exponential	Age = 2.312e <sup>1.91SR</sup>	0.56

Next, Model Maker was used to generate relation map between SR and Teak age-class. Then, extracted pixel value data of the result map and reclassified based on range of age stage value as shown in figure 4-11 And computed area of each age stage. Two age-classes were classified. The result showed that the rotation stage was 2,262.37 ha or 72.73 % of Teak plantation area. Second was the primary stage (848.20 ha or 27.27 %).



**Figure 4-11 Classification resulted by regression model**

#### 4.2.5 Accuracy Assessment

The total of 30 sample point which distributed to all age-class from ground truth data taken in April 2010 were used to verify classification accuracy. Result was presented in percentage of each age stage classification. By logical operation; the accuracy of primary stage and rotation stage were 50.00% and 84.62% respectively. And total accuracy was 56.67%. (Table 4-3) By regression model; the accuracy of primary stage and rotation stage were 84.21% and 63.64% respectively. And total accuracy was 73.92%. (Table 4-4) The highest total accuracy was the classification of regression model then used the result to calculate Teak plantation area.

And Kappa Index of each age stage classification was 0.25 and 0.48, respectively that meant the logical operation represented the poor agreement while the regression model represented the moderate agreement.

**Table 4-3 Confusion matrix of Logical operation classification and ground truth**

		Age Class Model Classification			
		Unclassified	Primary stage	Rotation stage	Overall
Ground Truth	Primary stage	2	6	2	10
	Rotation stage	3	6	11	20
	Overall	5	12	13	30
% Accuracy		-	<b>50.00</b>	<b>84.62</b>	<b>56.67</b>

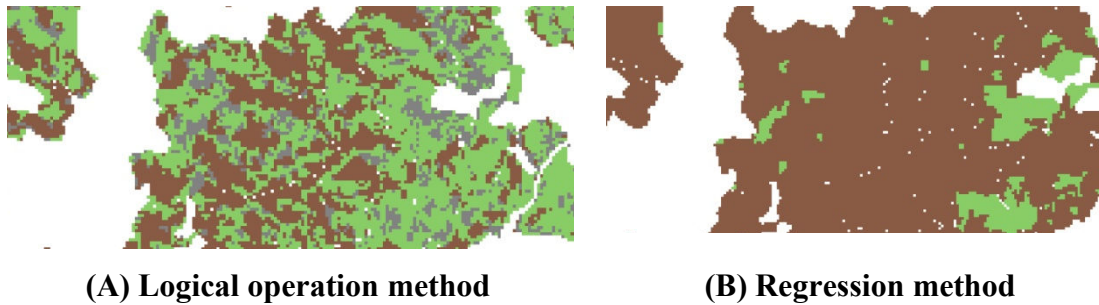
Source: Analysis

**Table 4-4 Confusion matrix of Regression Model classification and ground truth**

		Age Class Model Classification		
		Primary stage	Rotation stage	Overall
Ground Truth	Primary stage	7	3	10
	Rotation stage	4	16	20
	Overall	11	19	30
% Accuracy		<b>84.21</b>	<b>63.64</b>	<b>73.92</b>

Source: Analysis

In addition to assessed for accuracy with both methods, when considered in area information data of Khun Mae Kham Mee Plantation found the primary stage showed 935.97 ha and the rotation stage showed 2171.27 ha which close to the result of regression method. From figure 4-12, the characteristic of the result area found the logical operation method showed mix age stage (A) and the regression method showed large pieces age stage (B) which the result of logical operation method is not consistent conditions fact that planting teak plantation is growing into large pieces.

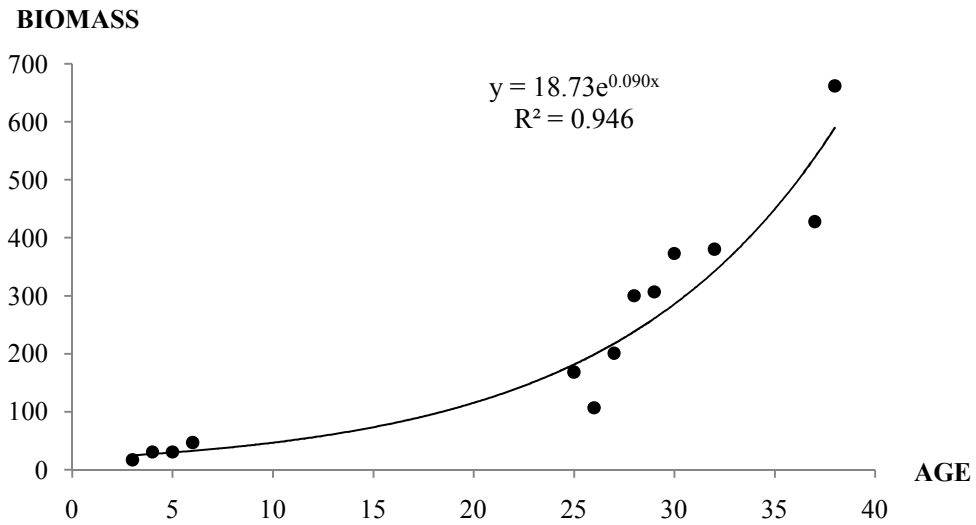


**Figure 4-12 The characteristic of the classification result**

### 4.3 Carbon Storage

#### 4.3.1 Aboveground biomass of stand

To calculate the aboveground biomass of Teak plantation was applied the allometric equation of Viriyabuncha et al [31]. The result showed that the aboveground biomass of stands in Scatter plots (Figure 4-13) which the aboveground biomass per tree of various teak age-classes increased with the rising age. And the relationship between biomass and age was in exponential form with  $R^2 = 0.946$ . The equation was  $y = 18.73^{e^{0.09x}}$ . Where;  $y =$  Biomass of stand and  $x =$  Age of Teak. Considering the average biomass of the age stage per tree found that the primary stage and the rotation stage were 26.40 and 244.71  $\text{kg.tree}^{-1}$ . The density was found that the rotation stage was the least which reached 0.04  $\text{tree m}^{-2}$ . The density of the primary stage was 0.05  $\text{tree m}^{-2}$  because of this stage did not reach the thinning time. The highest aboveground biomass per square meter was the rotation stage which reached 7.70  $\text{kg.m}^{-2}$ . It was clearly because of biomass per tree was greater than primary stage. The followed by the primary stage 1.32  $\text{kg.m}^{-2}$ . The details as shown in table 4-5.



**Figure 4-13 Relationship between aboveground biomass of stand and age of Teak**

**Table 4-5 The Aboveground Biomass of each age stage**

Age-class	Absolute Density (tree.m <sup>-2</sup> )	W <sub>S</sub>	W <sub>B</sub>	W <sub>L</sub>	W <sub>T</sub>	Biomass content (kg.m <sup>-2</sup> )
Primary stage	0.05	20.17	3.83	2.40	26.40	1.32
Rotation stage	0.04	180.04	52.80	11.88	244.71	7.70

Note: W<sub>S</sub> = Stem biomass  
W<sub>B</sub> = Branch biomass  
W<sub>L</sub> = Leaf biomass  
W<sub>T</sub> = Total aboveground biomass

### 4.3.2 Aboveground biomass per age-class

The area of each age stage of Teak plantation was calculated based on the output map of the classification which the highest total accuracy. Then, calculate aboveground biomass per age stage. The result showed that rotation stage was 174,209.49 tons. Followed was primary stage (11,196.24 tons).

### 4.3.3 Carbon Storage

The carbon storage by Teak was dependent on the amount of biomass produced by the plantation. The Teak plantation in Khun Mae Kham Mee Plantation had a total area of 3,110.57 hectares. The total area of Teak plantation stored aboveground carbon at 92,702.865 tons. Divided into the primary stage was 5,598.12 tons and the rotation stage was 87,104.74 tons. Table 4-5 shows the capacity of different age stages of Teak plantation to store aboveground carbon. The capacity to store carbon of primary stage and rotation stage were 6.60 and 38.50 ton.ha<sup>-1</sup>.

**Table 4-6 Carbon storage of Teak plantation age stage**

<b>Age-class</b>	<b>Carbon storage (ton.ha<sup>-1</sup>)</b>	<b>Total carbon storage (ton)</b>
Primary stage	6.60	5,598.12
Rotation stage	38.50	87,104.74