# EXPERT CLASSIFICATION FOR AGE CLASS IDENTIFICATION OF OIL PALM PLANTATION IN KRABI PROVINCE

**JARUNYA KITIPHAISANNON**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT**
**OF THE REQUIREMENTS FOR**
**THE DEGREE OF MASTER OF SCIENCE**
**(INFORMATION MANAGEMENT ON ENVIRONMENTS AND RESOURCES)**
**FACULTY OF GRADUATE STUDIES**
**MAHIDOL UNIVERSITY**
**2005**

**ISBN 974-04-5930-7**
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Thesis
Entitled

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was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science
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# ACKNOWLEDGEMENT

Eventually, my quest for knowledge in master's degree was ended when I had already finished this thesis. Along the journey, I had encountered a large number of difficulties. Whenever I was in trouble, fortunately, many people had helped me to go through those hard situations.

The first group of people who always remained engraved on my mind was my dearest family especially my father, my mother, my elder brother, and my younger one. They attended me and inspired me with confidence all the time.

Next, I was extremely grateful to Associate Professor Dr. Sura Pattanakiat, my thesis advisor, who did not only counsel me to work on this thesis but also gradually develop my practical skills. Besides, many excellent suggestions from Associate Professor Dr. Charlie Navanugraha were also attributed to success of this thesis.

I would like to thank Assistant Professor Prasong Saguantam. Although he had loads of work, he spent his precious time in advising me and correcting my wording in this thesis until it was completed. Furthermore, I appreciated Assistant Professor Saranya Sucharitakul who favoured me by discussing the statistical problems until I had the great solution. Besides, thanks to P' Siam Lawawirojwong who give superior suggestions that I cannot done my thesis without them.

I also had to express my thanks to the sources of information: the LANDSAT-5 TM image contributed by Geo-Informatics and Space Technology Development Agency (Public Organization), the general information of Krabi from Department of Environmental Quality Promotion, and some information from Land Development Department.

I was deeply indebted to many sponsors who had supported my field work in Krabi which were Tan Bok Koranee National Park for the convenient accommodation; the Krabi Oil-Palm Farmers Cooperative Federation Limited (KFCF), Ao Luk Land Settlement Co-operatives Limited, Univanich Palm Oil Public Company Limited, Krabi Provincial Agricultural Extension Office, the city hall of Krabi for the palm information, and several people in the field for their generosity and kindness.

I would like to express my gratitude to everyone whom I knew by chance and who participated in this success both physically and spiritually. Because of the limitation of this page, I truly regretted that I was unable to write all of your names.

Ultimately, I thank you – the reader – who are reading this thesis. I would be absolutely delighted to know that this thesis could distribute the valuable knowledge to many people beyond my estimation.

Future is unforeseeable. A path of life is leading to the unpredictable distance. Life should be continued carefully and persistently. Every single minute is priceless and should not be wasted. Every life must learn all the time as it is said that "*Time and Tide Wait for No Man*".

Jarunya Kitiphaisannon

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EXPERT CLASSIFICATION FOR AGE CLASS IDENTIFICATION OF OIL PALM PLANTATION IN KRABI PROVINCE

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ABSTRACT

The objective of this study is to apply the Geo-Information Technology including Remote Sensing, Global Positioning System, and Geographic Information System integrated with Expert System in order to generate a knowledge base system for age class identification of oil palm plantation.

Rule base under the knowledge base for oil palm classification is generated from the relationship of multiple regressions related with Water Index (WI), Bare Soil Index (BI), Normalized Differential Vegetation Index (NDVI), and Advance Vegetation Index (AVI). These equations are used to define age class stage of oil palm plantation which can be divided into 4 classes: Young stage (1-3 years old), Intermediate stage (4-10 years old), Productive stage (11-20 years old), and Mature stage (more than 20 years old)

The percentages of accuracy for each class using expert classification are 92.19, 50.88, 80.00, and 12.50 respectively. Meanwhile, the percentages of accuracy for maximum likelihood classification are 90.63, 42.11, 40.54, and 72.34 respectively. Therefore, the accuracy for each age class stage from the expert classification is higher than the maximum likelihood classification. Furthermore, the overall accuracy of the expert classification is about 63.11%, and the maximum likelihood classification is only about 60.33%. Thus the accuracy of the expert classification is about 2.78% higher than the maximum likelihood classification

In conclusion, application of the Geo-Information Technology and Expert System provides useful information about classification on age class of oil palm plantation.

KEY WORDS : OIL PALM / AGE CLASS / EXPERT CLASSIFICATION / KRABI PROVINCE

69 P. ISBN 974-04-5930-7

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ระบบผู้เชี่ยวชาญเพื่อจำแนกชั้นอายุของปาล์มน้ำมันในจังหวัดกระบี่ (EXPERT CLASSIFICATION FOR AGE CLASS IDENTIFICATION OF OIL PALM PLANTATION IN KRABI PROVINCE)

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อประยุกต์ใช้เทคโนโลยีด้านภูมิสารสนเทศ (Geo-Information Technology) อันประกอบด้วย เทคโนโลยีด้านการสำรวจระยะไกล (Remote Sensing) ระบบพิกัดภูมิศาสตร์ (Global Positioning System) และ ระบบสารสนเทศภูมิศาสตร์ (Geographic Information System) ร่วมกับระบบผู้เชี่ยวชาญ เพื่อสร้างฐานความรู้ในการจำแนกปาล์มตามช่วงอายุที่มีความถูกต้อง ความน่าเชื่อถือ และความรวดเร็วมากขึ้น

กฎเกณฑ์การจำแนกในฐานความรู้เพื่อจำแนกช่วงอายุของปาล์มน้ำมันถูกสร้างขึ้นจากสมการถดถอยซึ่งคำนวณจากความสัมพันธ์ของช่วงอายุที่เก็บรวบรวมได้จากภาคสนาม และดัชนีที่เป็นตัวแทนของน้ำ (Water Index: WI), ดิน (Bare Soil Index: BI) และพืช (Normalized Differential Vegetation Index: NDVI และ Advance Vegetation Index: AVI) สมการดังกล่าวถูกนำมาทำนายช่วงอายุ ที่ถูกแบ่งเป็น 4 ช่วง ได้แก่ ช่วงแรกเริ่ม (1-3 ปี) ช่วงระยะกลาง (4-10 ปี) ช่วงผลผลิต (11-20 ปี) และช่วงอายุมาก (20 ปีขึ้นไป) ที่เป็นไปได้ในพื้นที่

ผลการตรวจสอบความถูกต้องจากการจำแนกช่วงอายุของปาล์มน้ำมันทั้ง 4 ช่วงด้วยระบบผู้เชี่ยวชาญ (Expert Classification) พบว่ามีค่าความถูกต้องเท่ากับร้อยละ 92.19, 50.88, 80.00, 12.50 และ 12.50 ตามลำดับ และความถูกต้องรวมเท่ากับร้อยละ 63.11 และเมื่อเปรียบเทียบกับวิธีการจำแนกประเภทข้อมูลแบบความน่าจะเป็นไปได้สูงสุด (Maximum Likelihood) พบว่ามีค่าความถูกต้องเท่ากับร้อยละ 90.63, 42.11, 40.54 และ 72.34 ตามลำดับ และความถูกต้องรวมเท่ากับร้อยละ 60.33 ดังนั้น ระบบผู้เชี่ยวชาญจึงมีความถูกต้องจากการจำแนกสูงกว่าการจำแนกประเภทข้อมูลแบบความน่าจะเป็นไปได้สูงสุด เท่ากับร้อยละ 2.78 ซึ่งสรุปได้ว่าระบบผู้เชี่ยวชาญเพื่อการจำแนกข้อมูล มีประสิทธิภาพในการเพิ่มความถูกต้องจากการจำแนกให้สูงมากขึ้น

กล่าวโดยสรุปแล้วการประยุกต์ใช้เทคโนโลยีด้านภูมิสารสนเทศร่วมกับระบบผู้เชี่ยวชาญสามารถใช้ในการจำแนกปาล์มตามช่วงอายุได้

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# CHAPTER I
# INTRODUCTION

## 1.1 Background Justification

The original oil palm was in Africa. It has been induced to Thailand through Indonesia and Malaysia. Since 1968, in the area of 40,000 rai, it has been encouraged to be in the form of trading in the South of Thailand. Its plantation was famed over the duration of time, so the area of plantation has been expanded. The area of oil palm plantation in 1988 and 2001 were 655,000 rai and 177,600 rai, respectively. According to this figure, the oil palm plantation area prediction in 2006 will be 2,000,000 rai. (Department of Agricultural Extension, 2003)

Oil palm plantation became more famous since it can be used in various forms including food and non-food. Besides, the oil palm's transformer has been used in not only household but also industry sectors. Moreover, it can produce much of oil, one-forth of all oil plant. Furthermore, under lacking of gasoline situation, Bio-diesel research has been supported to be alternative solution of energy crisis.

Thirty-four percent of the oil palm plantations in Thailand grow in Krabi Province. It has been expanded from 475,846 rai in 2000 to 563,908 rai in 2003 (Office of Agricultural Economics, 2003). The community of oil palm management cooperative such as Land Settlement Co-operatives Limited was founded in each amphoe. In 2004, The Krabi Oil-Palm Farmers Cooperative Federation Limited (KFCF) was established in order to managing oil palm stock, operating the cooperation, and doing research on oil palm development topic.

To improve the potential of oil palm plantation management, it needs enough information in order to make the best strategies. The age class of oil palm plantation area are one of the basic information which is classified only by expertise. Application of expert system and geo-informatics technology can generate the expert-like system

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to classify age class of oil palm plantation. Therefore, this application can also lead to intense updating informational requirements for management of oil palm.

## 1.2 Objectives

1.2.1 To develop knowledge base for classify age class of oil palm plantation in Krabi province by using geo-informatics technology.

1.2.2 To generate expert system for classify age class of oil palm plantation in Krabi province by using ERDAS IMAGINE knowledge classifier.

## 1.3 Conceptual Framework

Apply expert system with geo-informatics technology including Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) as illustrate in figure 1-1

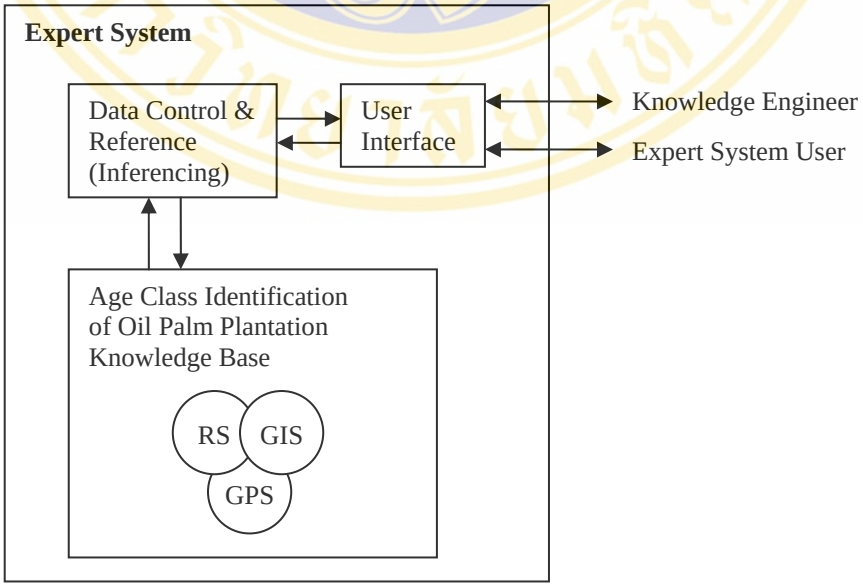


Figure 1-1 Conceptual Framework Diagram

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## 1.4 Scope of Study

1.4.1 Methodology

Generate expert system for age classes identification from Knowledge Classifier attached in Erdas Imagine by using combination of expert system theory and geo-informatics technology.

1.4.2 Study site

This study takes place in Krabi province which is located on the west coast of south region in Thailand. The area is 4,708.512 square kilometers where consists of 8 Amphoes, 51 Tambols, and 383 Villages.

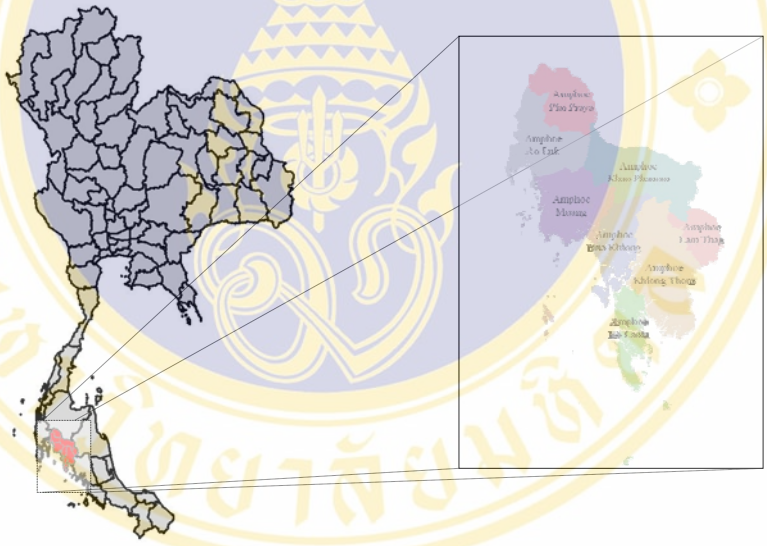

Figure 1-2 Study Area

## 1.5 Expected Result

1.5.1 Knowledge base to classify age class of oil palm plantation in Krabi province.

1.5.2 Expert system to classify age class of oil palm plantation in Krabi province.

1.5.3 Age class of oil palm plantation in Krabi province.

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# CHAPTER II
# LITERATURE REVIEWS

## 2.1 Study Area

Krabi province is situated in southwest of Thailand. It peripheral also cover 30 islands in Andaman Sea. General topographic condition of Krabi is mountain, hill, and plain. The still pristine jungles include white mangrove, mangrove swamp, and evergreen forest.

Krabi's mountainous physical geography is broken by highland and plain on the mainland with natural forest those dominate by Dipterocarpaceae. The Krabi River flows 5 kilometers through the city and its estuary is at Tambon Pak Nam. Its sandy clay soil conditions are perfect for plantations, such as para-rubber tree, palm, mango, coconut, and coffee.

Tropical monsoon climate creates two distinct seasons. The summer is in between January to April and the rainy season is prolong during May to December. Monsoon winds change directions according to season. Temperatures range between 16.9 and 37.3 degrees Celsius and the annual rainfall averages 2,568.5 mm.

The total area of Krabi province is around 4,708.512 square kilometers. It administrative boundaries divided into 8 amphoes which consists of Amphoe Mueang Krabi, Amphoe Ao Luek, Amphoe Khao Phanom, Amphoe Khlong Thom, Amphoe Ko Lanta, Amphoe Lam Thap, Amphoe Nuea Khlong, and Amphoe Plai Phraya.

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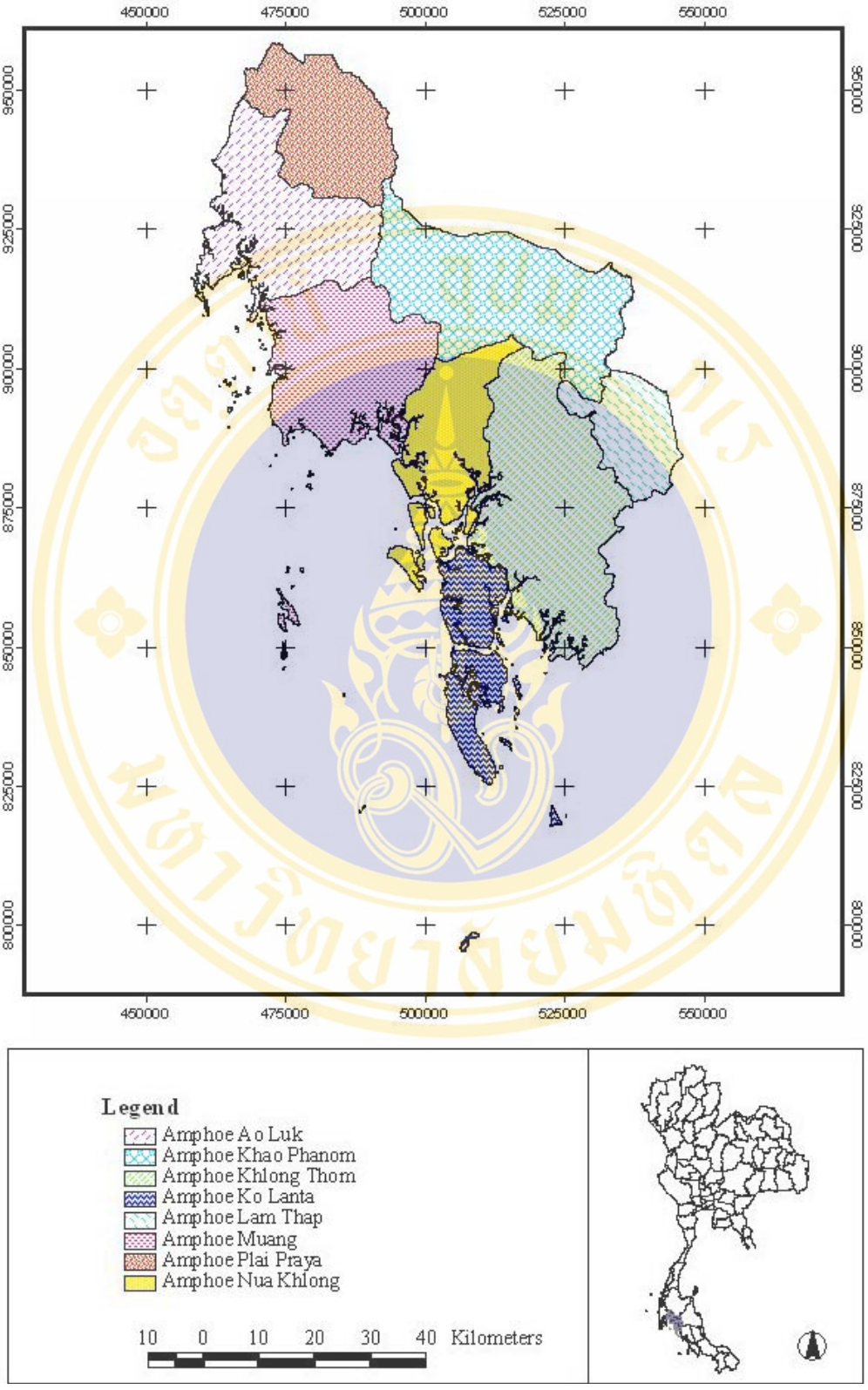


*Source: Department of Environmental Quality Promotion, (No date).*

Figure 2-1 Krabi Provincial's Boundary

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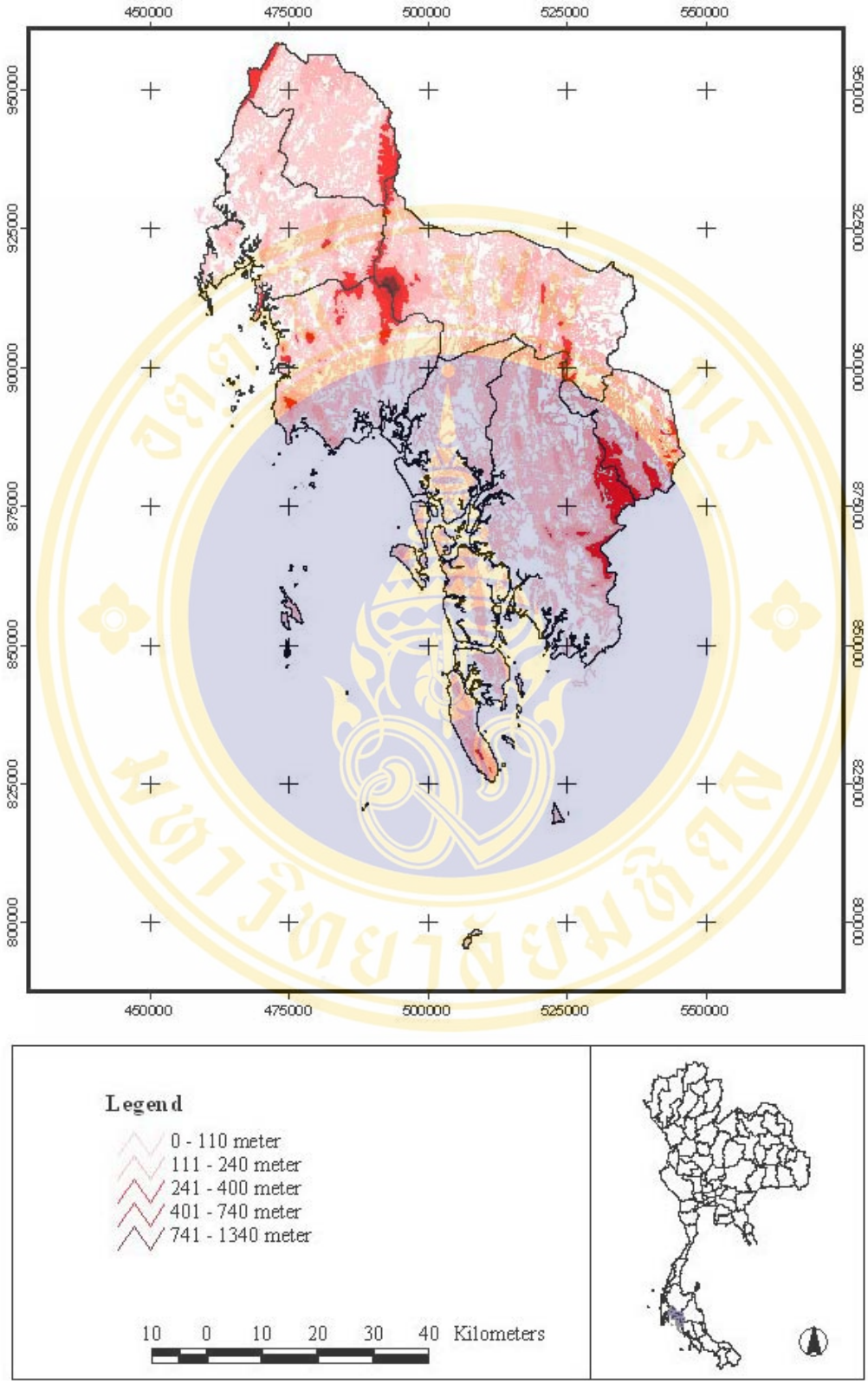


*Source: Department of Environmental Quality Promotion, (No date).*

Figure 2-2 Topographic Feature of Krabi Province

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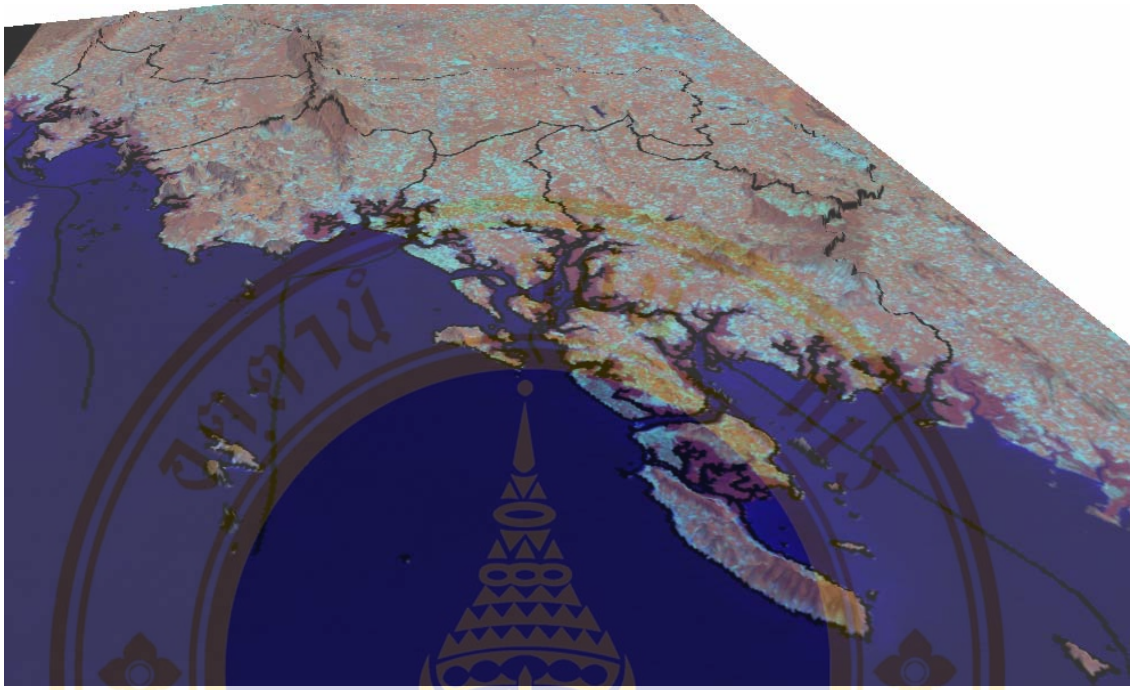

*Source: GISTDA and Department of Environmental Quality Promotion, (No date).*

Figure 2-3 Krabi province's topology

## 2.2 Oil Palm

### 2.2.1 General Characteristics and Physionomy

The oil palm tree is a tropical plant which commonly grows in warm climates at altitudes of less than 1,600 feet above mean sea level. There is one species, the Noli or *Elaeis oleifera* (H.B.K) Cortes which is native of America continent; another species is *Elaeis guineensis* Jacq. which originates from the Gulf of Guinea in West Africa (hence its scientific name) and better known as the African oil palm.

This tree produces one of the most popular edible oils in the world – a versatile oil of superb nutritional value. It is the most prolific of all oil plants and in commercial terms the one which offers major prospects of development.

Oil palm is normally monoic; in other words, it has both male and female flowers on the same tree. It produces thousands of fruits, in compact bunches whose weight varies between 10 and 40 kilograms. Each fruit is almost spherical,

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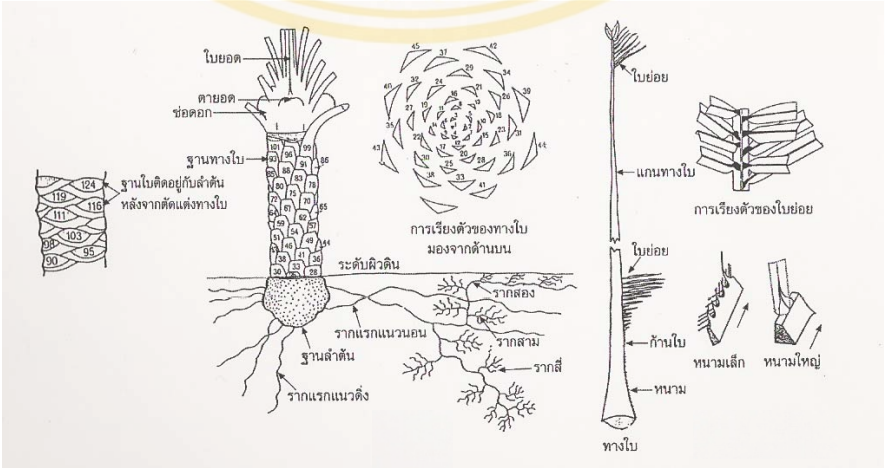
ovoid or elongated in shape. Generally the fruit is dark purple, almost black before it ripens and orange red when ripe.

Some 40 leaves crown the stately column of the oil palm and as it reaches middle age its leaves spread out - between 10 and 25 feet in length – and almost parallel to the ground. Each leaf has short thorns at its base and about 250 leaflets in an irregular pattern on both sides of the petiole. Thus, these leaflets are not continuous like the tines of a feather. In fact, the irregular appearance of the frond is one of the characteristic features of this species.

The fruit has a single seed – the palm kernel – protected by a wooden endocarp or shell, surrounded by a fleshy mesocarp or pulp. This fruit produces two types of oil: one extracted from the pulp (palm oil) and the other from the kernel (palm kernel oil).

Its stem stands straight in the form of an inverted cone. In the wild it may grow to heights of one hundred feet and more. The stems of young and adult plants are wrapped in leaves which give them a rather rough appearance. The older trees have smooth stems apart from the scars left by the leaves which have withered and fallen off.

Primary roots grow downwards from the base of the palm and radiate outwards in a more or less horizontal direction close to the surface of the ground. Their length and depth depend on the type of soil.




*Source: Teera Akesomtramate, et al., 2546.*

Figure 2-4 Root, stem, and leaf characteristic of oil palm

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2.2.2 Oil Palm Production

Oil palm is economic crop which is growth in tropical monsoon climate. The main oil palm producer of the world is shown in table 2-1.

Table 2-1 Oil palm production in the world, 2000 – 2002

| Country | Area (1,000 rai) | | | Yields (1,000 tons) | | | Yields/rai (kg.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2000 | 2001 | 2002 | 2000 | 2001 | 2002 |
| **Total** | **62,026** | **65,769** | **67,343** | **12,395** | **125,791** | **136,066** | **1,941** | **1,913** | **2,021** |
| Malaysia | 19,219 | 20,688 | 21,063 | 56,600 | 58,950 | 67,400 | 2,945 | 2,849 | 3,200 |
| Indonesia | 12,588 | 13,750 | 15,000 | 36,380 | 38,300 | 40,000 | 2,890 | 2,785 | 2,667 |
| Nigeria | 19,250 | 19,875 | 19,875 | 8,220 | 5,800 | 5,800 | 427 | 428 | 428 |
| Thailand | 1,303 | 1,457 | 1,644 | 3,256 | 4,089 | 4,001 | 2,500 | 2,807 | 2,434 |
| Columbia | 842 | 866 | 906 | 2,470 | 2,600 | 2,650 | 2,933 | 3,002 | 2,924 |

*Source: Office of Agricultural Economics, 2004.*

In 2002, Thailand's oil palm plantation area is 1,643,861 rai which produced 4.0 million tons of oil palm as table 2-2. According to better compensation than other plant like para rubber and rice, oil palm plantation is encouraged to almost all of country.

Table 2-2 Oil palm production in Thailand, 2000 – 2002

| Province | Area (rai) | | | Yields (tons) | | | Yields/rai (kg.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2000 | 2001 | 2002 | 2000 | 2001 | 2002 |
| **Total** | **1,302,624** | **1,456,798** | **1,643,861** | **3,256,078** | **4,088,943** | **4,001,376** | **2,500** | **2,807** | **2,434** |
| Krabi | 475,846 | 532,058 | 563,908 | 1,222,448 | 1,571,167 | 1,402,645 | 2,569 | 2,953 | 2,487 |
| Chumphon | 259,349 | 280,076 | 317,648 | 635,146 | 766,008 | 777,576 | 2,449 | 2,735 | 2,448 |
| Surat Thani | 370,229 | 390,110 | 460,567 | 944,824 | 1,127,418 | 1,129,889 | 2,552 | 2,890 | 2,453 |
| Satun | 64,383 | 69,308 | 73,508 | 151,493 | 171,121 | 164,060 | 2,353 | 2,469 | 2,232 |
| Trang | 49,454 | 52,183 | 55,828 | 115,030 | 134,945 | 128,908 | 2,326 | 2,586 | 2,309 |

*Source: Office of Agricultural Economics, 2004*

Owing to oil palm characteristic, it attains prominence in the south of Thailand such as Krabi, Surat Thani etc. The oil palm distillation industrial factory is established on scatter area of south region as shown in figure 2-5

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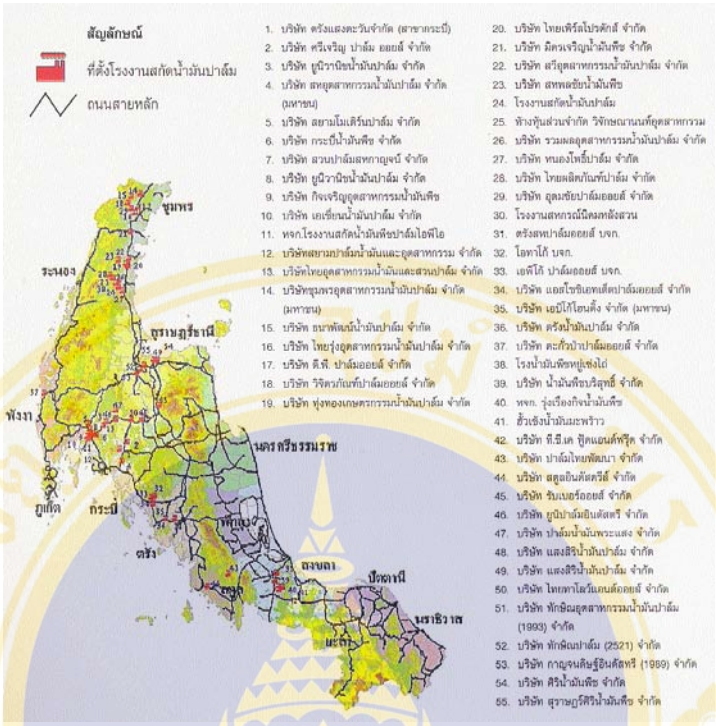


*Source*: *Teera Akesomtramate, et al., 2546.*

Figure 2-5 Oil palm's distillation industrial factory location

2.2.3 Limiting Factors

Succeed in oil palm plantation in encouraged with limited factors of oil palm. There are four important factors of limited factors as following

1) *Topographic factor*s such as slope, aspect, topology, etc. Oil palm should grow in flat plain or undulating topology.

2) *Soil factors* such as soil depth, soil structure, soil adhesion, pH, thickness of organic matter plate, soil permeability, etc. Because lacking of essential fertility and moisture, laterite soil or soil with pebble are not suitable for oil palm plantation.

3) *Altitude from mean sea level.* The area of less than 500 meter above mean sea level is more appropriate for oil palm plantation.

4) *Climatic factors* include annual rain fall, light, temperature, wind speed, etc. Rain is the most influenced factor to limited oil palm product. It should be 2,200-3,000 millimeter per year. In addition, oil palm area should locate in area of

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which sun light is more than 2,000 hours/year, temperature in between 22-32 degree Celsius, low affected from wind speed and direction.

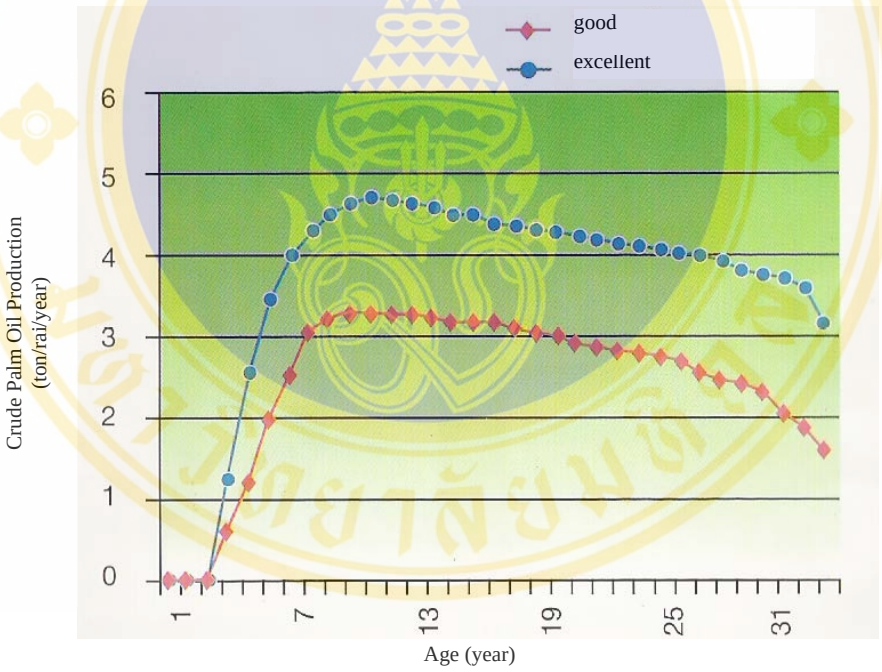
2.2.4 Age Classes Management and Utilization

In early stage of 10 years of oil palm plantation, it needs intensive tending and care. Because of that period is indicate oil palm productivity. There are interested intervals to nourish oil palm plantation including;

1) 0-3 year (Before giving product)

2) 4-10 year (Productive interval)

3) more than 10 year (Product declining period)




*Source: Teera Akesomtramate, et al., 2546.*

Figure 2-6 Oil palm production format

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Table 2-3 Potential of oil palm in Thailand by age classes, Dec 2001

| Age Class (year) | Area (rai) | Harvest Area (rai) | Amount of oil palm tree (tree/area) | Prediction amount of Yields of Crude Palm Oil Production | | Improving amount of Yields of Crude Palm Oil Production | |
|---|---|---|---|---|---|---|---|
| | | | | Annual (ton/harvest area) | Average (ton/rai) | Annual (ton/harvest area) | Average (ton/rai) |
| <4 | 449,999 | 0 | 9,899,978 | 0 | 0.00 | 0 | 0.00 |
| 4-6 | 221,713 | 221,713 | 4,877,686 | 290,444 | 1.31 | 549,848 | 2.48 |
| 7-9 | 209,450 | 209,450 | 4,607,900 | 619,972 | 2.96 | 917,391 | 4.38 |
| 10-20 | 635,838 | 635,838 | 13,988,436 | 2,002,890 | 3.15 | 2,937,572 | 4.62 |
| 21-25 | 235,400 | 235,400 | 5,178,800 | 680,306 | 2.89 | 1,002,804 | 4.26 |
| >25 | 47,600 | 47,600 | 1,047,200 | 116,144 | 2.44 | 182,308 | 3.83 |
| Total | 1,800,000 | 1,350,001 | 39,600,000 | 3,709,756 | 2.75 | 5,589,923 | 3.91 |

*Source: Teera Akesomtramate, et al., 2546.*

## 2.3 Geo-Informatics

Geo-Informatics is the science and technology of gathering, analyzing, interpreting, distributing and using geographic information. It encompasses a broad range of disciplines that can be brought together to create a detailed but understandable picture of the physical world and our place in it. These disciplines include:

2.3.1 Remote Sensing: Deriving digital models of an area on the earth. Using special cameras from airplanes or satellites, either the sun's reflections or the earth's temperature is turned into digital maps of the area. In order to view the results, the data must be rendered by specialized image processing software.

2.3.2 Geographic Information Systems (GIS): A computer application used to store, view, and analyze geographical information, especially maps.

2.3.3 Global Positioning System (GPS): A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver.

In additions, Surveying & Mapping are one of the supporting processes of geo-informatics. They are the measurement of dimensional relationships, as of horizontal

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distances, elevations, directions, and angles, on the earth's surface especially for use in locating property boundaries, construction layout, and mapmaking.

Geo-informatics is one of the fastest-growing technology sectors of the 1990s. Applications areas include: the environment, land management and reform, development planning, infrastructure management, natural resource monitoring and development; and coastal zone management and mapping etc.

## 2.4 Landsat Satellite

The Landsat Program is a joint effort of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to gather the Earth resource data using a series of satellites. NASA was responsible for developing and launching the spacecrafts. The USGS is responsible for flight operations, maintenance, and management of all ground data reception, processing, archiving, product generation, and distribution. A primary objective of the Landsat Program is to ensure a collection of consistently calibrated Earth imagery.

Landsat's mission is to establish and execute a data acquisition strategy that ensures the repetitive acquisition of observations over the Earth's land mass, coastal boundaries, and coral reefs and to ensure that the data acquired are of maximum utility in supporting the scientific objective of monitoring changes in the Earth's land surface.

Although, Landsat-1, Landsat-2 and Landsat-3 are no longer operating, Landsat-4 and Landsat-5 are still in orbit gathering data (ERDAS Inc, 1997). Landsat-6 was launched in October, 1993, but failed to reach the orbit. The current satellite Landsat-7 launched in April 15, 1999.

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Table 2-4 Characteristic of Landsat Satellite

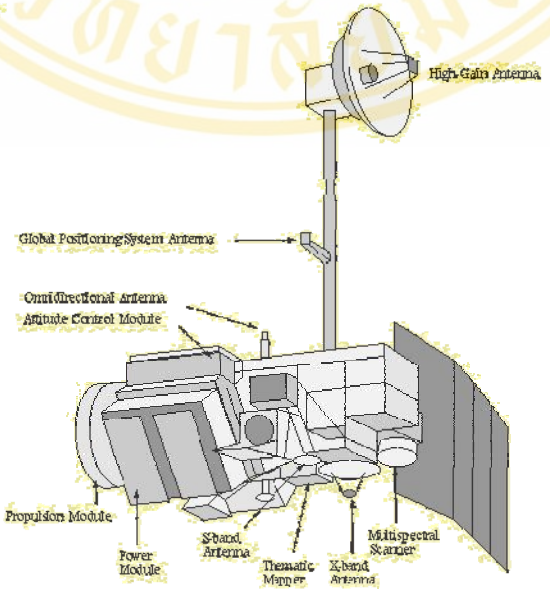
| Satellite | Launched | Decommissioned | Sensors |
|---|---|---|---|
| Landsat 1 | July 23, 1972 | January 6, 1978 | MSS and RBV* |
| Landsat 2 | January 22, 1975 | February 25, 1982 | MSS and RBV* |
| Landsat 3 | March 5, 1978 | March 31, 1983 | MSS and RBV* |
| Landsat 4 | July 16, 1982 | June 30, 2001 | MSS and TM |
| Landsat 5 | March 1, 1984 | (Operational) | MSS and TM |
| Landsat 6 | October 5, 1993 | (Did not achieve orbit) | ETM** |
| Landsat 7 | April 15, 1999 | (Operational) | ETM+** |

*The return beam vidicom (RBV) was essentially a television camera and did not achieve the popularity of the MSS sensor.
**The sensor onboard Landsat 6 was called the enhanced thematic mapper (ETM). Landsat 7 carries the enhanced thematic mapper plus (ETM+)

*Source: USGS, 2003.*

Thailand has satellite ground receiving station in order to receive both signals of Landsat-5 and Lansat7, however, due to technical failure Landsat 7's sensor, since Nov 2004, only signal of Landsat 5 is currently still recorded.

**Landsat 5** is the fifth satellite of the Landsat program. It was launched with the primary goal of providing a global archive of satellite images.




*Source : USGS, 2003.*

Figure 2-7 Illustration of the Landsat-4 and 5 spacecraft

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Table 2-5 Characteristic of Landsat-5

| | **Characteristic** |
|---|---|
| Manufactures: | General Electric |
| Spacecraft Instrument | Hughes Santa Barbara Remote Sensing |
| Mission | Currently operated by Space Imagine continue to receive TM images at U.S. Ground station and International ground stations |
| Instrument(s): | Thematic Mapper Plus (TM+) [Scan mirror spectrometer] |
| Mass | 2200 kg. |
| Swath Width | 185 km. |
| Revisit Interval | 16 days |
| Orbit | 705 km., sun-synchronus, 98.2 degrees inclination; Equatorial crossing time = 10.00am 1/-15 min. |
| Bands | Spectral range : Ground Resolution<br>Band 1 : 0.45 – 0.52 μm .: 30 m. (blue)<br>Band 2 : 0.52 – 0.60 μm.: 30 m. (green)<br>Band 3 : 0.63 – 0.69 μm.: 30 μm. (red)<br>Band 4 : 0.76 – 0.90 μm.: 30 m. (Near IR)<br>Band 5 : 1.55 – 1.75 μm.: 30 m. (Shortwave IR)<br>Band 6 : 10.4 – 12.5 μm.: 120 m. (Longwave or Thermal IR)<br>Band 7 : 2.08 – 2.35 μm.: 30 m. (Shortwave IR)<br>30 Meters (Resampled to 25 meters) |
| Launch Date | April 1984 |
| Mission Duration | 5 years |

*Source : Siam, 2002.*

Landsat 5 has significantly exceeded its designed life expectancy, and has a maximum transmission bandwidth of 85Mbps. It was deployed at an altitude of 705.3 km, a lower orbit than Landsat 4. It takes some 16 days to scan the entire Earth. The satellite is an identical copy of Landsat 4, and was originally intended as a backup - it therefore carries the same instruments, including the Thematic Mapper (TM) Multi-Spectral Scanner (MSS).

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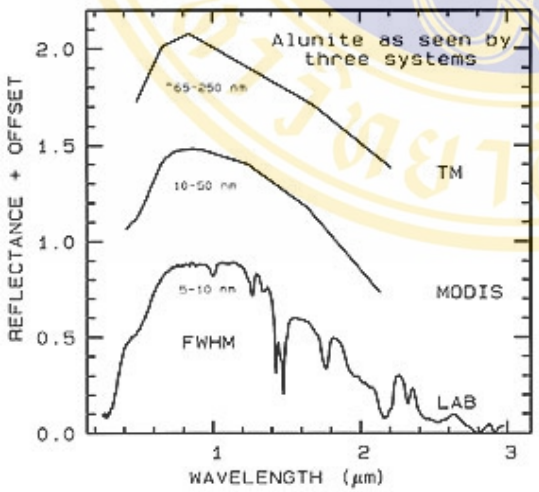
Table 2-6 Detectors record in each band of Landsat–5 (TM)

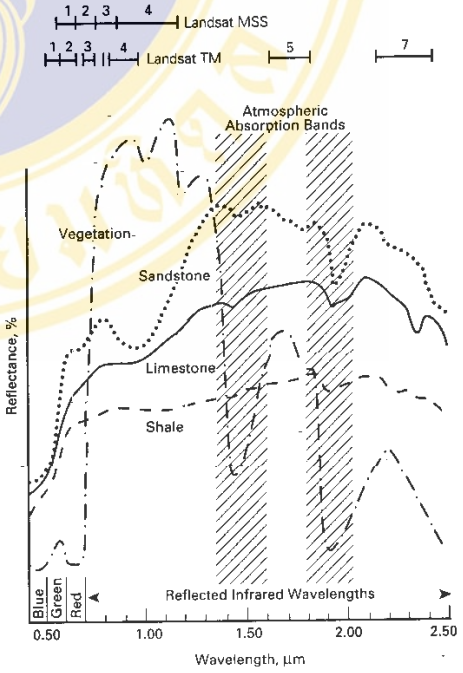
| Band | Wave length (μm.) | Spectral Bands | Usefulness |
|---|---|---|---|
| 1 | 0.45 - 0.52 | blue | For mapping coastal water areas, differentiating between soil and vegetation, forest type mapping and detecting cultural features. |
| 2 | 0.52 – 0.60 | green | Corresponds to the green reflectance of heating vegetation. Also useful for cultural feature identification. |
| 3 | 0.63 – 0.69 | red | For discriminating between many plant species. It is also useful for determining soil boundary and geological boundary delineation as well as cultural features. |
| 4 | 0.76 – 0.90 | near infrared | Responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil/crop and land/water contrasts. |
| 5 | 1.55 – 1.75 | shortwave infrared | Sensitive to the amount of water in plant. Useful in crop drought studies and in plant health analyses. This is also one of few bands that can be used to discriminate between cloud, snow and ice. |
| 6 | 10.40- 12.50 | thermal-infrared | For vegetation and crop stress detection, heat intensity, insecticide applications, and for locating thermal |
| 7 | 2.08 – 2.35 | shortwave infrared | For the discrimination of geologic rock type and soil boundaries, as well as soil and vegetation moisture content. |

*Source: National Center for Earth Resources Observation &, 2005 and Siam, 2002.*




(a) Alunite's as seen by three sensor systems

*Source : RST, nodate*




(b) Generalized Diagram of Spectral Reflectance Curve

*Source : University of Mississippi, 2003*

Figure 2-8 Spectral Reflectance curve

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The size and shape of full TM images from Landsats 4 and 5 are identical to the MSS images. At first glance, the quality and characteristics of these full scene TM images seem similar to those made by the MSS after optimal computer-based processing, but on closer inspection they do appear sharper. This apparent similarity is due to the need to resample the TM images for TV monitor displays (which are not high resolution systems capable of reproducing all TM pixels) by dropping some pixels. The influence of the better TM resolution (when un-resampled) becomes apparent whenever photographs of full scenes are enlarged (pictures more than a meter on a side can be produced with exceptional clarity) or subscenes are extracted and enlarged.

## 2.5 Image Interpretation

Three general methods have been used to interpret and extract information from Landsat and other remote-sensing images (Singhroy 1992) as following.

### 2.5.1 Photo interpretation

Photo interpretation is a visual interpretation of images based on feature tone (color), pattern, shape, texture, etc.

Black-and-white images represent light intensity variations for a single band. Color-composite images include three bands, each of which is color coded as shown in table 2-7

Table 2-7 Some common band combinations for Landsat TM color composite images

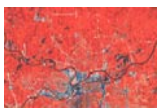
| Image | Bands | Usefulness |
|---|---|---|
| | 1,2,3 | Metropolitan Kansas City region. This image is a "natural color" composite that simulates normal color appearance of the scene. The urban area is depicted in white (highways, buildings, railroads), muddy water is brown, and vegetated areas are shown in dark green. Compare with the standard false-color version (below) of this same scene. |
|  | 2,3,4 | Kansas City metropolitan region. Standard false-color composite image formed from green, red, and short-infrared bands, color coded as blue, green, and red. Active vegetation appears red and pink, and water bodies are black. Urban structures appear in white to light blue shades. Compare with the natural-color version (above) of this same scene. |

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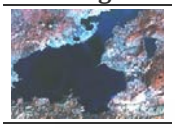
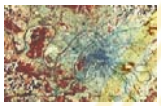
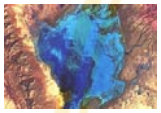
Table 2-7 Some common band combinations for Landsat TM color composite images (continued)

| Image | Bands | Usefulness |
|---|---|---|
|  | 1,2,7 | Special composite of visible and mid-infrared bands. The visible bands penetrate water and show suspended sediment in surface water. Volcanic mountains are visible around the lake. |
| | 2,3,5 | The edge of the Andes Mountains is seen flanked by extensive alluvial fans that form relatively flat surfaces. Straight lines and geometric designs (left center) are the archeologic "Nazca lines" of prehistoric origin. This special composite employs visible and mid-infrared bands. |
|  | 3,7,5 | Special false-color composite of Paris, France. Field of view is about 40 km across. Active vegetation appears brown/orange; suburban area is green/yellow; urban core is blue. |
|  | 4,5,7 | Infrared false-color composite of White Sands, New Mexico. The White Sands are dunes composed of gypsum sand blown from a nearby dry lake bed. In this image the gypsum dunes appear light blue, and the sand source area is dark blue. |

*Source: James S. Aber, 2002*

2.5.2 Spectral analysis

Spectral analysis is an identification of surface materials on the basis of spectral signatures, the combination of energy reflected and emitted from an object. Under clear, sunlit conditions, many objects have characteristic spectral signatures in the visible and short infrared portions of the spectrum.

Not only one of the spectral signatures but also various bands of multispectral images can be used to interpret satellite image. Different bands of a multispectral image may be combined to accentuate the interested areas.

Table 2-8 Some band ratios indices

| Index | Equation | Comment |
|---|---|---|
| Enhanced Vegetation Index (EVI) | $G * \frac{NIR - RED}{NIR + C_1 * RED - C_2 * BLUE + L}$ | The enhanced vegetation index (EVI) was developed to optimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. (Terrestrial Biophysics & Remote Sensing, 2005) |
| Green normalized difference vegetation index (GNDVI) | $\frac{NIR - GREEN}{NIR + GREEN}$ | Lymburner *et al.* 2000 |

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Table 2-8 Some band ratios indices (continued)

| Index | Equation | Comment |
|---|---|---|
| Modified Soil Adjusted Vegetation Index (MSAVI) | $\frac{NIR - RED}{NIR + RED + L}(1 + L)$ | It was developed by Qi et al. (1994) which was to provide a variable correction factor L. The correction factor used is based on the product of NDVI and WDVI. This means that the isovegetation lines do not converge to a single point. (University of Sheffield, 2005) |
| Moisture Stress Index (MSI) | $\frac{MIR}{NIR}$ | Rock et al (2005) utilities a moisture. |
| Normalized Difference Vegetation Index (NDVI) | $\frac{NIR - RED}{NIR + RED}$ | Its range is -1<=NDVI<=1. When the range was about -0.1, NIR value usually less than RED band, this occurred on low leaf saturation value. Whenever green area or it saturation increased it push NDVI closed to 0.6. (Siam, 2002) |
| Perpendicular vegetation index (PVI) | $((R_{soil} - R_{veg})^2 + (NIRsoil - NIR_{veg})^2)^{0.5}$ | Bright senescent vegetation or soil backgrounds tend to increase the orthogonal index values while decreasing the ratio index values for a given canopy while dark backgrounds show an opposite response (S. Z. DOBROWSKI, S.L USTIN, and J.A.WOLPERT., No date) |
| Ratio drought index (RDI) | $\frac{MIR}{NIR}$ | For the ratio drought index (RDI), Landsat TM bands 5/4 are utilized (Pinder & McLeod 1999) |
| Ratio vegetation index (RVI) | $\frac{NIR}{RED}$ | It can depict all surface water bodies, regardless of water depth or turbidity. The combination of surface drainage and vegetation patterns, depicted on infrared/red ratio images, may give valuable information about geomorphology (James S. Aber, 2002) |
| Specific leaf area vegetation (SLAVI) | $\frac{NIR}{RED + MIR}$ | Bands 3, 4 and 7 are employed for SLAVI. The latter measures an important ecological variable (Lymburner *et al.* 2000). |
| Soil Adjusted Vegetation Index (SAVI) | $(1 + L) * \frac{NIR - RED}{NIR + RED + L}$ | It minimized soil brightness influences from spectral vegetation indices which account for first-order soil –vegetation interactions and differential RED and NIR flux extinction through vegetated canopies (Huete, 1998). |
| Water Index (WI) | $\frac{GREEN}{SIR}$ | The value was then calculated to the range in between 0 to 255, but the typical range of non-water area was between 0 to 1 and the typical range of water area was between 1 to 255. So the values were used to differentiate the water area and non-water area. (Siam, 2002) |

Note
SIR = Shortwave Infrared reflectance value
NIR = Near Infrared reflectance value (spectral band 0.76-0.9 μ)
RED = Visible Red reflectance value (spectral band 0.6-0.7 μ)
GREEN = Visible Green reflectance value (spectral band of 0.5-0.6 μ)
G = Gain Factor
L = Canopy Background Brightness Correction Coefficient (0 to 1)
C1 = Atmosphere Resistance Red Correction Coefficient
C2 = Atmosphere Resistance Blue Correction Coefficient

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2.5.3 Data integration

Many innovative techniques can be used to create dramatic images of Landsat data combined with other kinds of remotely sensed, GIS data, or ground-based data. Digital elevation models (DEM) are especially useful in this regard. DEMs may be displayed as either contour maps, block diagrams, or shaded-relief images. Possible combinations include:

1. Landsat image draped over DEM block diagram; perspective view of the landscape with color coding from Landsat image.

2. Landsat image added to shaded-relief image; enhancement of topography visible in Landsat image.

3. Separation of water and land areas; color-coded DEM to show bathymetry of water bodies; land areas depicted by remotely sensed data (Shanks 1992).

**2.6 Expert System**

2.6.1 Definition

A computer system capable of giving advice in a particular knowledge domain, by virtual of the fact that it contains knowledge provided by a human expert in this domain. Thus, an expert system is a computerised advice-giver, that is capable of reasoning (as opposed to simply displaying items of data), but which is usually onfined to a rather narrow field of knowledge (its 'knowledge domain').

Experts interpret remote sensing images with knowledge based on experience. However computer assisted classification utilizes only very limited expert knowledge. The expert system, therefore, is a problem solving system which supports expert knowledge in a computer based system.

2.6.2 Expert System’s Architecture

The most important modules that make up a rule-based expert system is shown in figure 2-9. The user interacts with the system through a user interface which may use menus, natural language or any other style of interaction. Then an inference engine is used to reason with both the expert knowledge (extracted from our friendly

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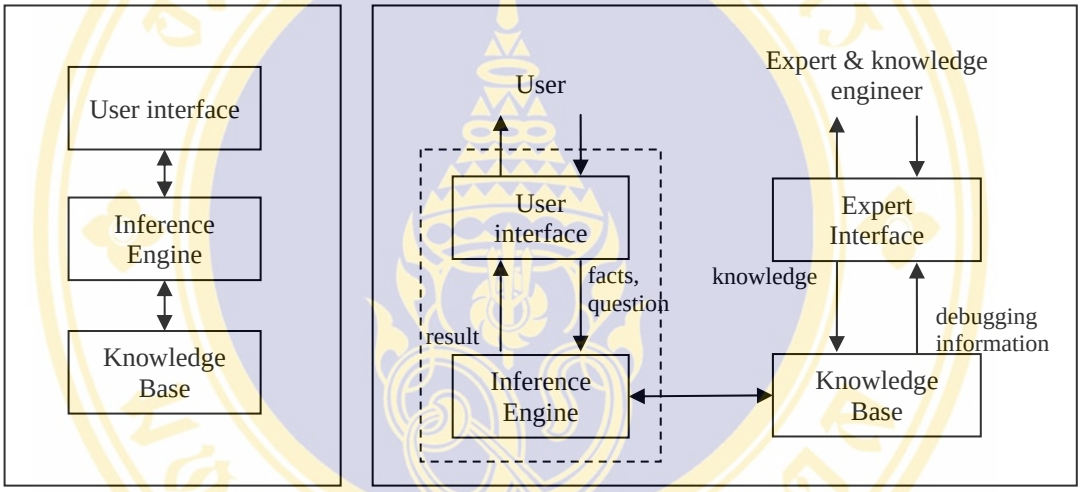
expert) and data specific to the particular problem being solved. The expert knowledge will typically be in the form of a set of IF-THEN rules. The case specific data includes both data provided by the user and partial conclusions (along with certainty measures) based on this data.

Almost all expert systems also have an explanation subsystem, which allows the program to explain its reasoning to the user. Some systems also have the knowledge base editors which help the expert or knowledge engineer to easily update and check the knowledge base.




(a) The "classic" architecture for an expert system

(b) A more elaborate diagram, describing essentially the same architecture

*Source : Middlesex University, 2004.*

Figure 2-9 Typical architecture of Expert System

2.6.3 Knowledge Requirement in Remote Sensing

The following two types of knowledge are required for an expert system in remote sensing.

(1) *Knowledge about image analysis* : Procedures for image analysis can be made only with adequate knowledge about image processing and analysis. A feedback system should be introduced for checking and evaluating the objectives and the results.

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(2) *Knowledge about the objects to be analyzed* : Knowledge about the objects to be recognized or classified should be introduced in addition to the ordinary classification method. The fact that forest does not exist over 3,000 meters above sea level, is one example of the type of knowledge that can be introduced

In many cases, knowledge can be represented as "if A is ..., then B becomes...." which is called the IF/THEN rule or production rule.

If the IF/THEN rule is fuzzy, then Fuzzy set theory can be also introduced to the expert system.

The expert system can be integrated with a geographic information system (GIS). It is necessary to accumulate experiences and to evaluate the knowledge for an expert system to be operationally applied.

## 2.7 Case Study Reviews

Many researchers donated their research areas on geo-information technology, expert classification, and oil palm plantation management as following

*Ibrahim, Zainal Abidin Hasan & Mariamni Khalid* (2000) has studied the application of optical remote sensing technology for oil palm management. They have investigated the relationship between Landsat Thematic Mapper (TM) relative radiance and phenology of oil palm for commercial estates in Selangor, Malaysia. This study focused on estimating oil palm phenology with special emphasis to planting age (1 - >20 years) and Leaf Area Index (LAI) to spectral radiance via multiple linear regression models. The carrier (predictor) variables that was considered for multiple regression are the six Landsat TM bands, Shadow Canopy Index (SI), Bare Soil Index (BIO), Normalised Vegetation index (NDVI), Advanced Vegetation Index (AVI), planting densities, soil units and relief.

The relative radiance recorded by Landsat TM for oil palm was negatively correlated with stand age. Middle Infrared wavebands (MIR) band 7 and 5 has shown high correlation (> 0.74) and more discriminating power (Lambda Wilk's coefficient) to discriminate the oil palm age classes. However, the visible and Near Infrared bands

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displayed insignificant correlation (< -0.05). Nevertheless, it is concluded that the developed regression model was able to produce reasonably accurate oil palm age classes at estate level from satellite image.

*A. Rikimaru and s. Miyatake* (1997) has been done their research on "Development of Forest Canopy Density Mapping and Monitoring Model using Indices of Vegetation, Bare soil and Shadow" which is to develop bio-phsycal analysis model for obtaining of forest Canopy Density (FCD) using LANDSAT TM data image analysis. The components FCD model are four factors; vegetation, bare soil, thermal and shadow.

This research has studied the relationship between forest conditions and the four indices (VI, BI, SI and TI). The result has shown that vegetation index response to all of vegetation items such as the forest and the grass land. Advanced vegetation index AVI reacts sensitively for the vegetation quantity compared with NDVI. Shadow index increases as the forest density increases. Thermal index increase as the vegetation quantity increases. Black colored soil area shows a high temperature. Bare soil index increases as the bare soil exposure degrees of ground increase. Integration of VD and SSI means transformation for forest canopy density value. Both parameter has dimension and has percentage scale unit of density. It is possible to synthesize both indices safely by means of corresponding scale and unit of each FCD = $(VD + SSI + 1)^{1/2} - 1$

The study on "Comparison of Supervised Classification and Expert Classification of SPOT Imagery: land cover and land use in Boone County, West Virginia" by *Janice Hardin* (2002) in order to prove trade-off of supervised classification (maximum likelihood classifier). This study's result specified that expert classification with simple knowledge base can better classify Landuse map of SPOT images of Boone Country, South East of Virginia. This conclusion is that expert and supervised classification have to generate from qualify training sites and variables. With supervised classification techniques, it have to homogenize training area. On the other hand, expert classification can perform more efficiency by using texture or others algorithm even if the data was deteriorated.

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*Laili Nordin* (2002) has investigated AIRSAR data for oil palm biomass inventory and mapping in Tapah, Malaysia. There are two main applications. First, retrieval of oil palm biomass by establishing empirical relationships between backscatter coefficient and conventional estimation of biomass based on model as well as ground data. Second, mapping oil palm plantation based on age using segmentation algorithms and classification.

The results of mapping oil palm plantation are very complex, variable and highly dispersed. Oil palm of ages 6, 7, 15 and 20 years can be discriminated in L-hh polarization and 25 years old in P-hh polarization, respectively, after de-speckling with the Gamma filter of 5 x 5 window. The oil palm of one and two years old are highly discriminated in L-hh polarization with the Frost Filter of 5 x 5 and 7 x 7 windows, respectively. Oil palm with an age of 25 years can be discriminated in P-hh polarization with the Lee filter of 5 x 5 window and the five years old oil palm can be discriminated in L-hv polarization with the Lee filter of 9 x 9 windows. Overall, the Gamma filter of 11 x 11 windows discriminates oil palm age classes more effectively than the rest. The main conclusion of this work is that the biomass and age of oil palm can be estimated, discriminated and mapped using AIRSAR images. Thus, the multi-polarization and multi-frequencies AIRSAR data can be useful in monitoring oil palm biomass production and distribution in Malaysia based on their ages.

*Prasad S. Thenkabail1, etc.* (2003) have developed biomass models to calculate carbon stock levels of the West African oil palms (*Elaeis guineensis*) using multi-date IKONOS images, wet and dry season. The study was conducted in two benchmark areas of derived savanna eco-region. Allometric equations related aboveground palm biomass to their stem heights. Using field plot data, empirical regression models were established to determine wet and dry biomass ($kg/m^2$) of oil palms. The best models were non-linear exponential types, involve band 3 or indices involving bands 3 and 1 or bands 3 and 4, and explained between 63 and 72 percent variability in data.

At landscape level, multi-date IKONOS data mapped oil palm plantations with an overall accuracy of 88 to 92 percent. However, the ability of IKONOS data to differentiate various age groups of oil palms was limited with a high degree of

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intermixing of classes. The best results were obtained when delineating agro-palm (mixed with agriculture and fallows), palm of 1-3 years, and palm of 4-5 years at an overall accuracy of 74.5 percent when all 4 IKONOS bands were used. The results indicated the need for additional spectral bands in the IKONOS sensor.

*Dana Jennings* (2002) has studied "Pilot Study using Knowledge-Based Classification on the Lower Youghiogheny River Basin, in Pennsylvania". This area has effected by coal mining result in eroded mountain, topographic change, and rapid distribution of acid mineral. Therefore, no living animal was alive. Moreover the effect has been distributed along 3,000 miles of that stream and in soil water content. Then, the objective of study concentrated in detection of mineral's distribution detected by thermal imagery in spring and winter season. Using knowledge based in expert system to classify cold and temperate material such as small fires, exhaust fans, and buildings. Then, automating the mapping of springs is occurred.

The result of this study point out to expert system generation. The generated knowledge classifier was still not to classify thermal from household and stream. Not only that, mosaic technique has an error to line up all images. Then image to classify is not the same parameter.

*Siam Lawawirojwong* (2002) has generated knowledge-based in expert system techniques to classify Land Cover of Bang Pakong Watershed using Landsat-7 (ETM+) imagery. The expert classification has applied the unsupervised classification (ISODATA clustering method) and knowledge-based operation which including spectral characters, GIS data (DEM and soil moisture regime) and spatial models (clump model, NDVI model, mean NDVI per zone model, WI model, mean WI per zone model, slope model, and aspect model) to classify the conditions for land cover category identification. The land cover categories are identified as residential and open space area, abandoned land, mixed deciduous forest, mangrove forest and wetland, paddy field, other vegetation, and water bodies.

The percentages of accuracy for each land cover categories using maximum likelihood classification are 62.5, 64.29, 81.82, 75, 64.71, 66.67, and 54.55, respectively. Meanwhile, the percentages of accuracy for the expert classification are

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75, 78.57, 90.91, 87.5, 70.59, 76.19, and 72.73, respectively. Therefore, the accuracy for each land cover category from the expert classification is higher than the maximum likelihood classification. Furthermore, the overall accuracy of the expert classification is about 78%, and the maximum likelihood classification is only about 67%. Thus the accuracy of the expert classification is about 11% higher than the maximum likelihood classification.

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# CHAPTER III
# MATERIALS AND METHODS

## 3.1 Materials

The hardware and software utilized in this study are as the following:

Hardware:

1. Personal computer with a specification of Intel Pentium IV Processor 2.4 GHz., 1GHz RAM, 60 GB. Hard disk
2. GPS Receiver
3. Digital Camera
4. Printer and Plotter

Software:

1. Image Analysis software: Erdas Imagine 8.6
2. GIS software: ArcViewGIS 3.3 and ArcGIS 8.3
3. Statistics Software: SPSS 12.0 for Windows
4. Operation System: WindowsXP Professional

## 3.2 Data Sources

Data sources of this study are gathered from various sources. To generate expert knowledge, Landsat-5 TM is mainly source for image data which overlaid with other GIS data and DEM sources. Table 3-1 is shown the data attribute and their details.

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Table 3-1 Various data sources for the study

| Raster Image | | | | | |
|---|---|---|---|---|---|
| Data | Path/Row | Bands | Resolution | Date | Source |
| Landsat-5 TM | 129/054 | 1-5,7 | 25 m | 25 Feb 2005, 03:18:40 | GISTDA* |
| Vector Data | | | | | |
| Data | Type | Scale | | Date | |
| Boundary | Polygon | 1 : 50,000 | | No reference | DEQP** |
| Contour | Line, Point | 1 : 50,000 | | No reference | DEQP** |

* Geo-Informatics and Space Technology Development Agency (Public Organization)
** Department of Environmental Quality Promotion

## 3.3 Study's Procedure

The process of this study is separated into 4 steps including; Pre-processing, Selection of oil palm plantation area, Expert Classification, and Accuracy assessment. As it's shown in figure 3-1

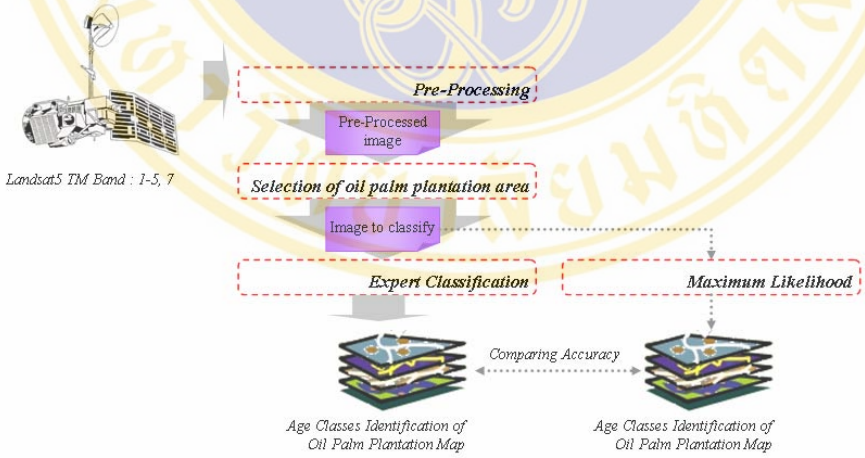


Figure 3-1 Study process

### 3.3.1 Pre-processing

Landsat-5 TM images (Band: 1-5 and 7) with path/row 129/054 have been used for data processing. To preparing this image, Radiometric, Atmospheric, Geometric correction method has been applied prior classification. Thus, the pre-

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processed image was performed to ensure high accuracy on both standardize reflectance value and coincide map projection. As shown in Figure 3-1.

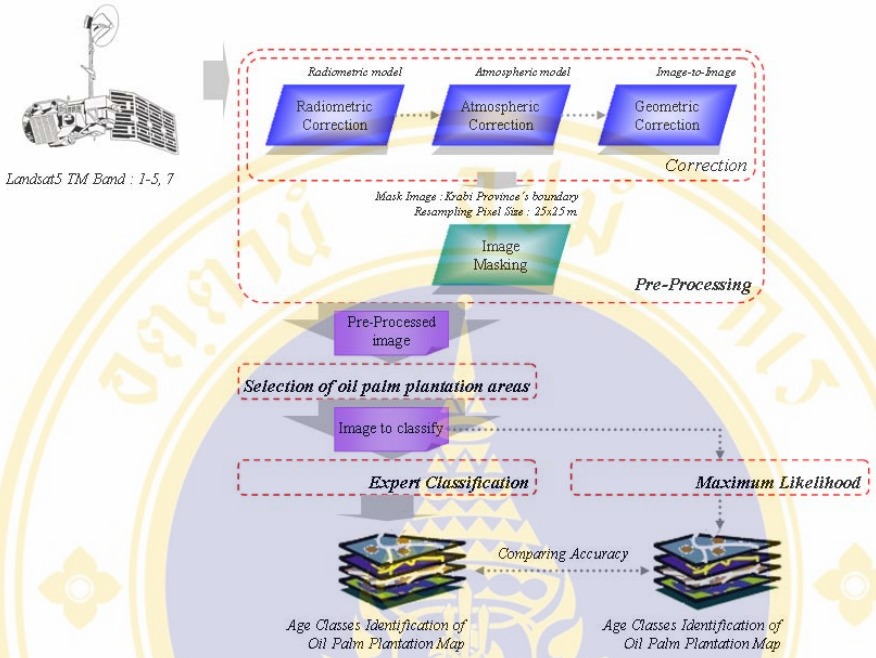


Figure 3-2 Pre-processing

### 3.3.2 Selection of oil palm plantation area

Oil palm plantations in the region is typically located in dense contiguous. It patches more than 5 rai in each. Each plot's structure is 8x8 or 9x9. Average tree density is about 22-26 trees per rai, depending on plot's structure. It can be founded on undulating topology which slope is less than 16 percent.

Oil palm plantation can usually be visually distinguished using false-color composite images (453-RGB) of Landsat-5 TM. Thus, it can be determined by using band ratio index.

In this study, image interpretation is semi-automatic technique. To prepare image for visual interpretation, ISOData with 30 classes, texture using image digital numbers within a window of interest such as 3 by 3 or 5 by 5 pixel matrixes, interested band ratio index, and sieve-out technique were utilized.

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The spectral threshold values of band ratio index (WI, NDVI and BI) and of reflective – infrared band (Band 4) and mid-infrared band (band 7) were chosen for masking oil palm plantation area in the ERDAS Imagine software as following;

IF *threshold value* > (Each Index) > *threshold value* then 1 ELSE NULL

When *threshold value* was determined based on ground truth data and photographs of the study area.

Afterwards, percent slope was used to break area more than 16 percents off. Then, the masking layer through spectral thresholding depicting predominant oil palm areas is further processed to remove non-oil palm areas.

Oil palm plantations are contiguous areas of few rais. Thereby, it was fairly straightforward to use sieve-out smaller areas such as individual trees, shrubs, and other isolated plantations that hold similar spectral characteristics but distinct textural patterns.

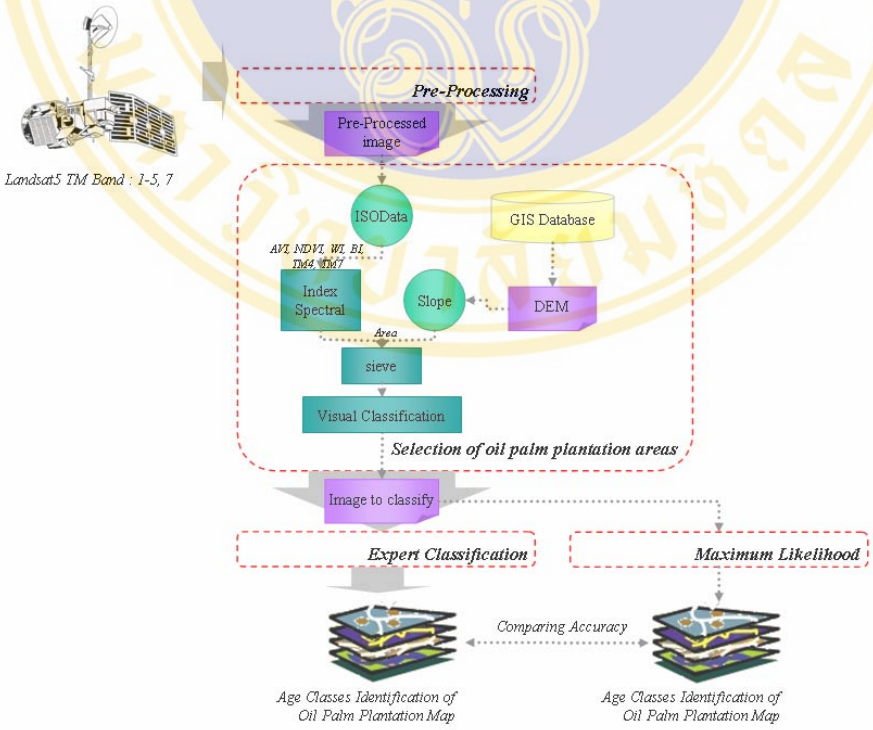


Figure 3-3 Selection of oil palm plantation area

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### 3.3.3 Expert classification

The Expert Classification is focuses on information extraction from semi-structured data by using rule and relationship of the information. Thereby, it consists of two parts: the Knowledge Engineer and the Knowledge Classifier.

#### 3.3.3.1 Knowledge Engineer

The Knowledge Engineer constructs knowledge bases to process the classification. It provides a user interface allows inputting a limited set of parameters to control the use of the knowledge base which consist of identification of the variables, rules, and output. As the procedure of this study is following:

1) Variables Defining

The variables used in Knowledge Engineer were raster imagery, vector coverages, spatial models, external programs, and simple scalars. The variables were used in this study are as following:

a) Satellite Imageries

This study has been utilized the after pre-processing image to be the main source.

b) Advanced Vegetation Index (AVI)

When assessing the vegetation status of forests, the new methods firstly examine the characteristics of chlorophyll-a by using a new Advanced Vegetation Index (AVI) that is calculated with the following formulae. (A. Rikimaru, 1997)

If NIR-RED < 0 then $AVI = 0$

Else if NIR-RED > 0 then $AVI = ((NIR + 1) \times (256 - RED) \times (NIR - RED))^{1/3}$

Where AVI = Advanced Vegetation Index

RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)

NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)

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c) Normalized Difference Vegetation Index (NDVI)

The most common measurement, Normalized Difference Vegetation Index (NDVI), shows the density of plant growth over the entire globe. The value was then normalized to the range between -1<=NDVI<=1 to partially account for differences in illumination and surface slope. The very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). It is a simple formula to generate NDVI image by using 2 image bands. If one band is in the visible region (RED band or band 3 of LANDSAT-TM data) and the other region is near infrared (NIR band or band 4 of LANDSAT-TM data). A popular mathematic equation is;

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

Where NDVI = Normalized Difference Vegetation Index
RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)
NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)

d) Bare Soil Index (BI)

The Bare Soil Index (BI) is formulated with medium infrared 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 forest lands on a continuum ranging from hi vegetation conditions to exposed soil conditions (A. Rikimaru, 1997).

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

Where BI = Bare Soil Index
BLUE = Visible Blue reflectance value (spectral band 0.45 - 0.52 µm)
RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)
NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)
SIR = Shortwave Infrared reflectance value (spectral band 2.08 – 2.35 µm)

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The range of BI is covered within 0 < BI < 200 (only 8 bits range)

e) Water Index (WI)

The water index was calculated from the reflected solar radiation in the shortwave-infrared (SIR) and green (GREEN) wavelength bands, which can be defined by following formula (Siam, 2002);

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

Where WI = Water Indices
GREEN = Visible Green reflectance value (spectral band of 0.5-0.6 μm)
SIR = Shortwave Infrared reflectance value (spectral band of 1.55 – 1.75 μm)

The value was then calculated to the range in between 0 to 255, but the typical range of non-water area ranges between 0 to 1 and the typical range of water area is in between 1 to 255. So, the values were used to differentiate the water area and non-water area.

2) Rules Defining

A rule was a conditional statement, or list of conditional statements about the variable's data values and/or attributes that determine an informational component or hypothesis. Multiple rules and hypotheses can be linked together into a hierarchy that ultimately describes a final set of target informational classes or terminal hypotheses. Confidence values associated with each condition were also combined to provide a confidence image corresponding to the final output classified image (ERDAS, 2004).

In this study, simple or multiple regressions of defined-variables were generated. They have been used to be the threshold of rule base and to classify age class of oil palm plantation.

3) Output or Hypothesis

According to the characteristic of oil palm age classes or stages, this study tends to classify of each categories following by their physical factors and characteristics. In which separated into four age classes, including:

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- 1 to 3 year old after planting : Young stage
- 4 to 10 years after planting : Intermediate stage
- 11 to 20 years old after planting : Productive stage
- More than 20 years old after planting : Mature stage

#### 3.3.3.2 The Knowledge Classifier

The Knowledge Classifier provides an interface for a non-expert to apply the knowledge base and create the output classification. Using created knowledge base, it can determine each area of age classes of oil palm plantation.

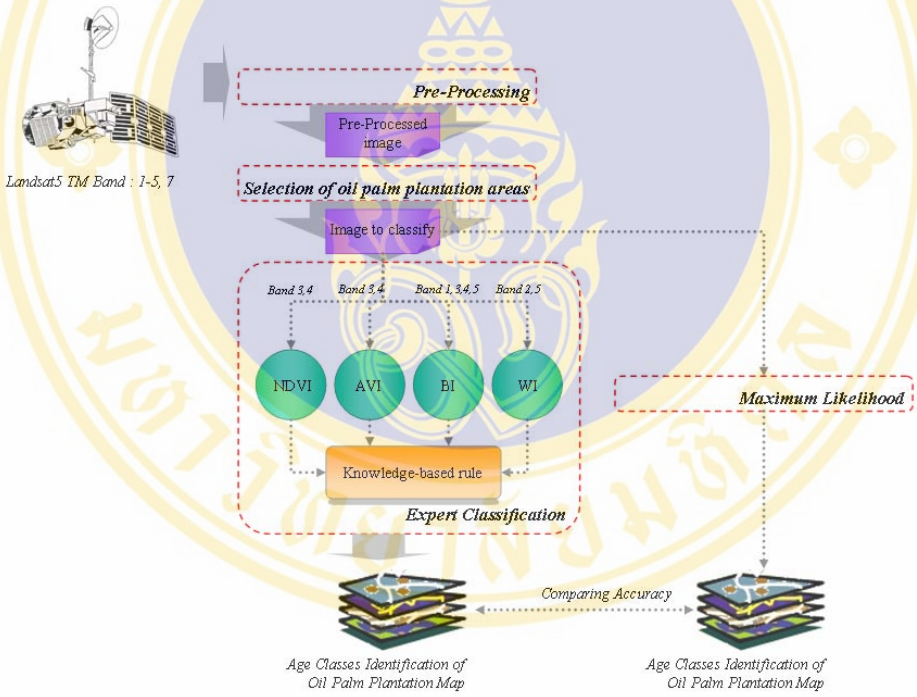


Figure 3-4 Expert classification's flow diagram

### 3.4 Verifying an Accuracy

The result of expert classification was analyzed and examined in both accuracy and reliability of the classification that provided the accuracy as more than 60 percent. Finally, knowledge-based system was obtained for expert classification. Hence, the

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result from maximum likelihood classification has been chosen in order to compare with the result from expert classification.

By using ground truth data, we are able to know the accuracy of the age class maps that enhance the expertise knowledge model and maximum likelihood.



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# CHAPTER IV
# RESULTS

## 4.1 Image Pre-Processing

Combination of Landsat-5 TM image's band 1-5 and 7 image, path/row 129/054, was the main imagery source for data processing in this study. The main task of the image preparation was radiometric and atmospheric correction by the 5S (Simulate the satellite signal in the solar spectrum) model and radiometric and atmospheric correction model. The co-register by image-to-image method was utilized for geometric correction. Then, the image had been masked to Krabi province boundary in order to process next procedure as shown in figure 4-1.

## 4.2 Selection of Oil Palm Plantation Area

Semi-automatic image interpretation by mean of integration between computerized and visualize interpretation were used. ISOData, texture application, threshold of spectral indices, and sieve-out techniques were used to prepare remote sensing image for visual classification as the detailed following.

In computerized section which most of the higher age class of oil palm area were depicted, the remote sensing image was used to generate 30 classes of ISOData. Then, threshold value of band ratio indices (AVI, NDVI, BI and WI) were chosen to delineated non-palm area. By using field survey's data, which were undertaken on the 16$^{th}$ - 22$^{nd}$ December, 2004 and 10$^{th}$ - 16$^{th}$ February, 2005, collaborated with spectral reflectance, the threshold of AVI, NDVI, BI, and WI were depicted as 141-155, 0.7-0.77, 55.6-61.9, and 0.49-0.55, respectively.

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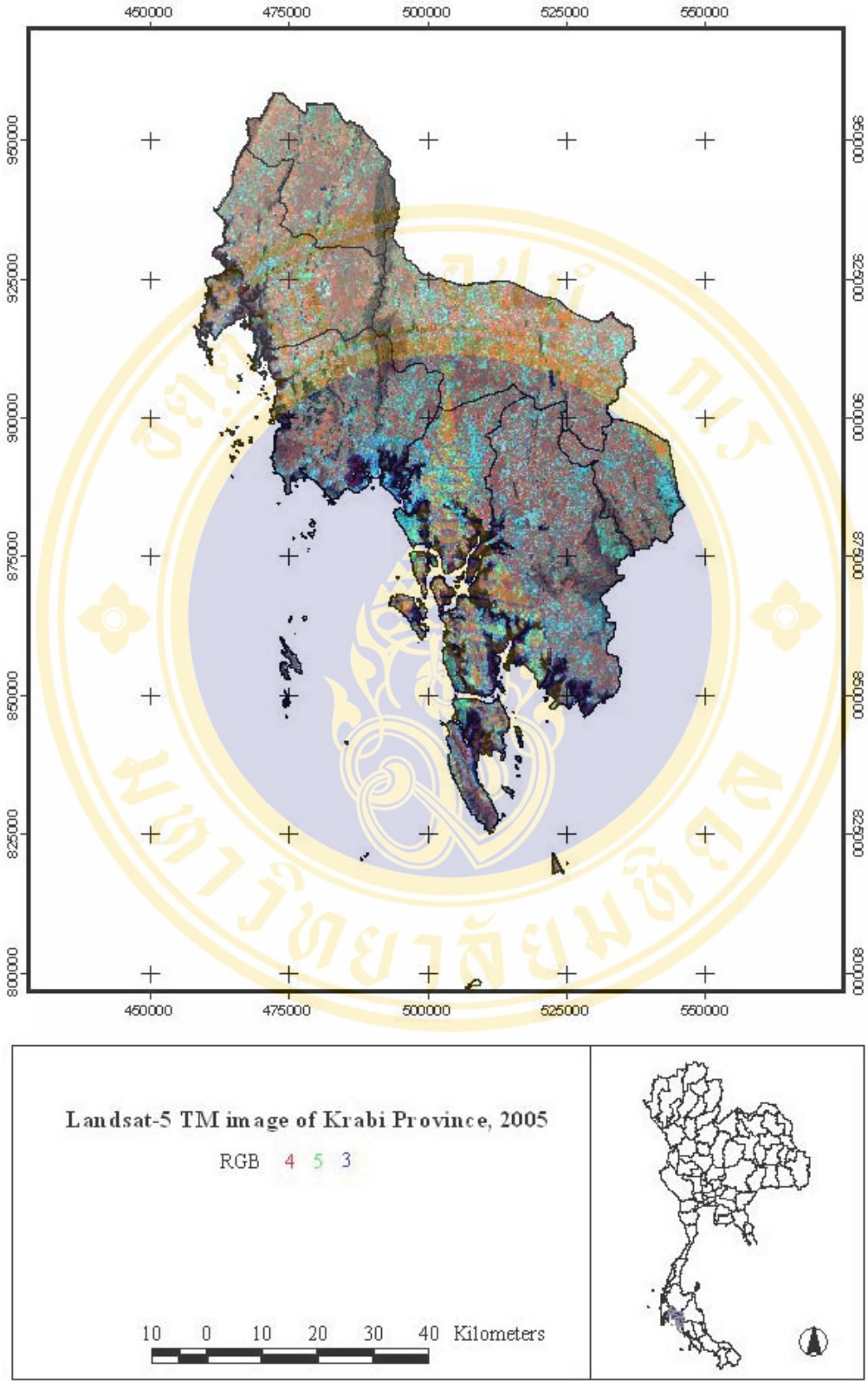


*Source: Analysis*

Figure 4-1 Pre-processed image of LANDSAT-5 TM, Krabi province, 2005

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Afterward, texture window size 3 x 3 has been manipulated to highlight the oil palm area. Then, sieve-out technique was used to eliminate the smaller areas than 5 rais (25 pixels) such as individual trees, shrubs, and other isolated plantation. Oil palm plantation is commonly grown well on flat terrain or plain topology in which not too complex slope such as undulated plain. To scope the oil palm plantation, the area of which slope more than 16 percent was eliminated by masking technique.

After finishing all of those processes, visual interpretations based on extensive ground truth data was use to delineated the lower age class of oil palm, which has almost the same spectral value of bare soil and abundant land, from non-oil palm plantation area. Hence, the main data source for next process was produced.

Thereby, only oil palm plantation area was masked to be the main source data for expert network as shown in figure 4-2.

## 4.3 Expert Classification

### 4.3.1 Model Application

The application models were created based on model spatial modeler for variables of knowledge-based generation. It was highly flexible tool when applying Model Maker together with Spatial Modeler Language. The Spatial Modeler Language was a modeling language that was linked internally by Model Maker to execute the operations specified in the graphical models. The details of both models were described as follows;

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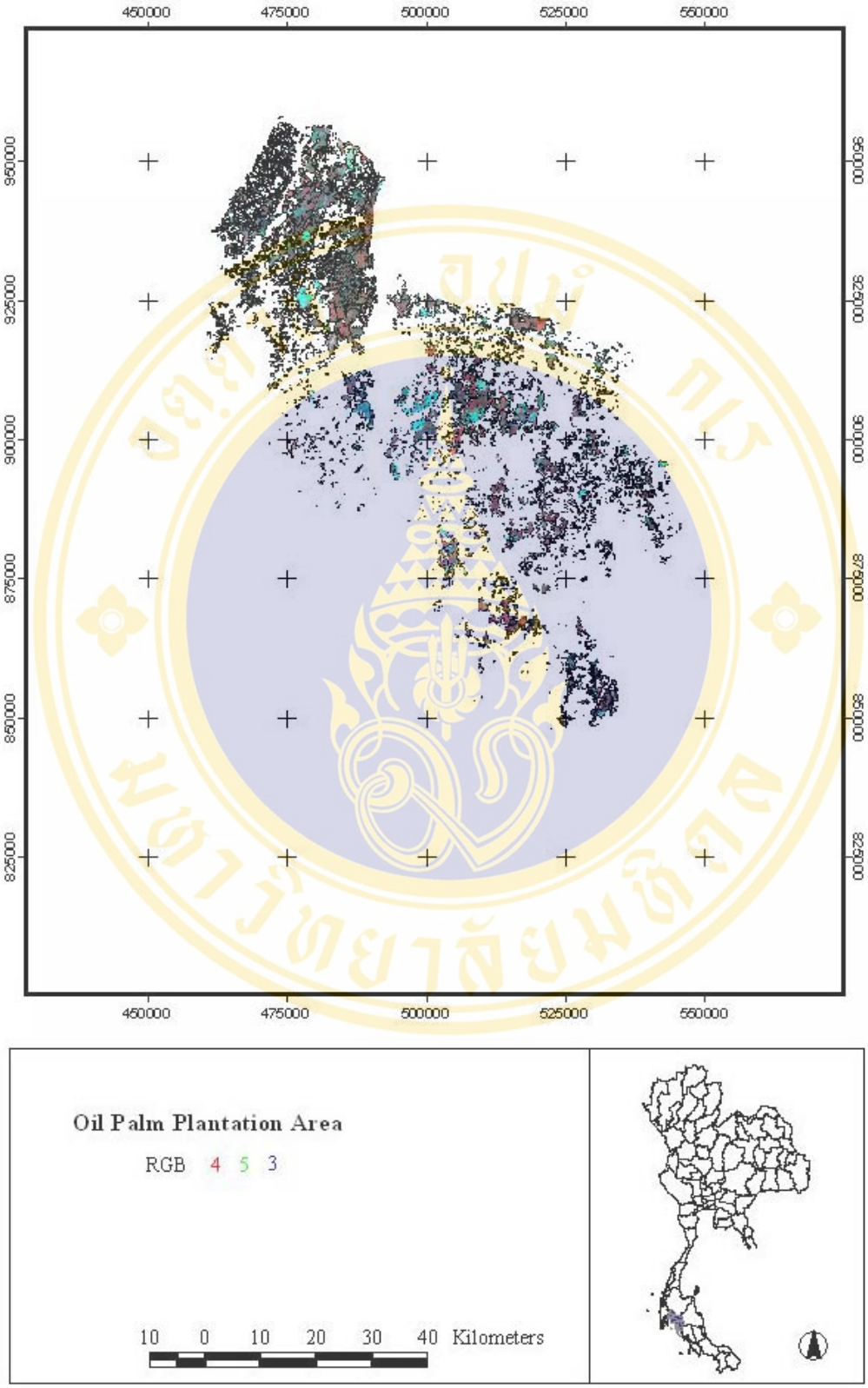


*Source: Analysis*

Figure 4-2 The final product ready for classification of oil palm in Krabi province called “Image to classify”, 2005

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**Advanced Vegetation Index (AVI) model**

Advanced Vegetation Index model is and algorithm applying for better vegetation clarification of plant reflectance grouping. That means plant or green vegetation differentiation can be in depth through age class identification; either stands density, leaf condition, stand composition, and etc.

In this case, assessing the oil palm status by using Advanced Vegetation Index, it used two satellite channels: RED band (LANDSAT TM band 3) and Near Infrared band (NIR or LANDSAT TM band 4). The formula is depicted as

If NIR-RED < 0 then $AVI = 0$

Else if NIR-RED > 0 then $AVI = ((NIR + 1) \times (256 - RED) \times (NIR - RED))^{1/3}$

Where AVI = Advanced Vegetation Index

RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)

NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)

Flow diagram is illustrated as figure 4-3

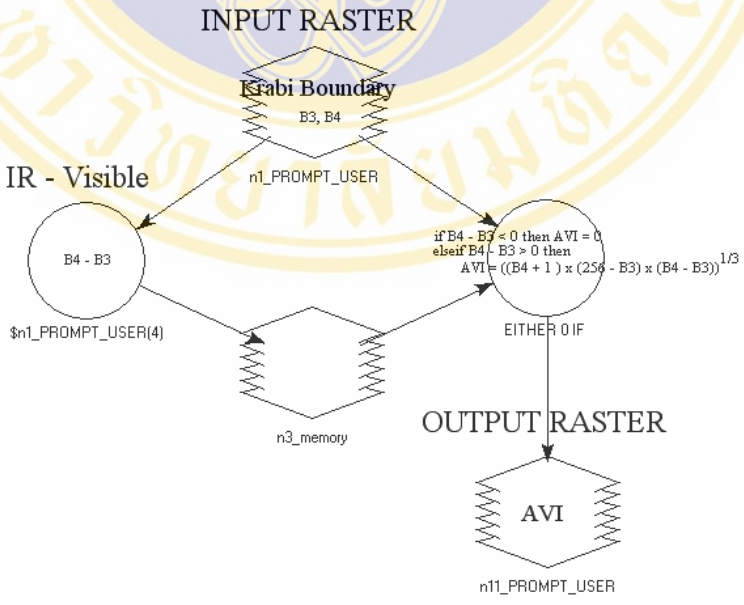


Figure 4-3 Advanced Vegetation Index (AVI) Model in Expert Classifier Model

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**Normalized Difference Vegetation Index (NDVI) model**

Another vegetation index for differentiate oil palm age class distribution is called Normalized Difference Vegetation Index.

This model was formulated for calculating the Normalized Difference Vegetation Index which utilized two satellite channels. One band was in the visible region (RED band LANDSAT TM band 3) and the other was the near infrared (NIR band or LANDSAT TM band 4). The relationship between those two bands, in term of NDVI, is as follow;

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

Where NDVI = Normalized Difference Vegetation Index
RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)
NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)

Flow diagram for expert classifier shown in figure 4-4

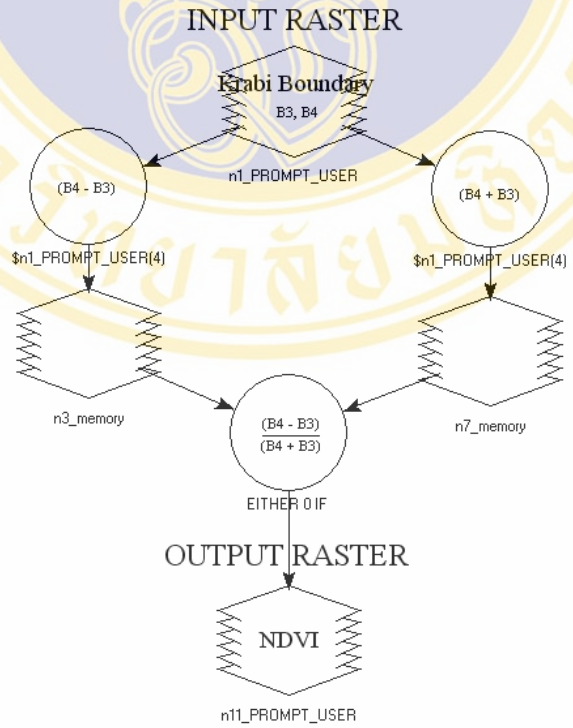


Figure 4-4 Normalized Difference Vegetation Index (NDVI) model in Expert Classifier Model

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**Bare Soil Index (BI) model**

Bare Soil Index is an algorithm using for discriminate the difference between soil and plant cover. It also applies for plant age class differentiation. Bare Soil Index was formulated from BLUE band (LANDSAT TM band 1), RED band (LANDSAT TM band 3), the near infrared (NIR band or LANDSAT TM band 4, and the reflected solar radiation in the shortwave-infrared (SIR band or LANDSAT-5 TM band 5). The Bare Soil Index (BI) model can be expressed as

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

Where BI = Bare Soil Index
BLUE = Visible Blue reflectance value (spectral band 0.45 - 0.52 µm)
RED = Visible Red reflectance value (spectral band 0.6-0.7 µm)
NIR = Near Infrared reflectance value (spectral band 0.76-0.9 µm)
SIR = Shortwave Infrared reflectance value (spectral band 2.08 – 2.35 µm)

The model was performed as shown in figure 4-5:

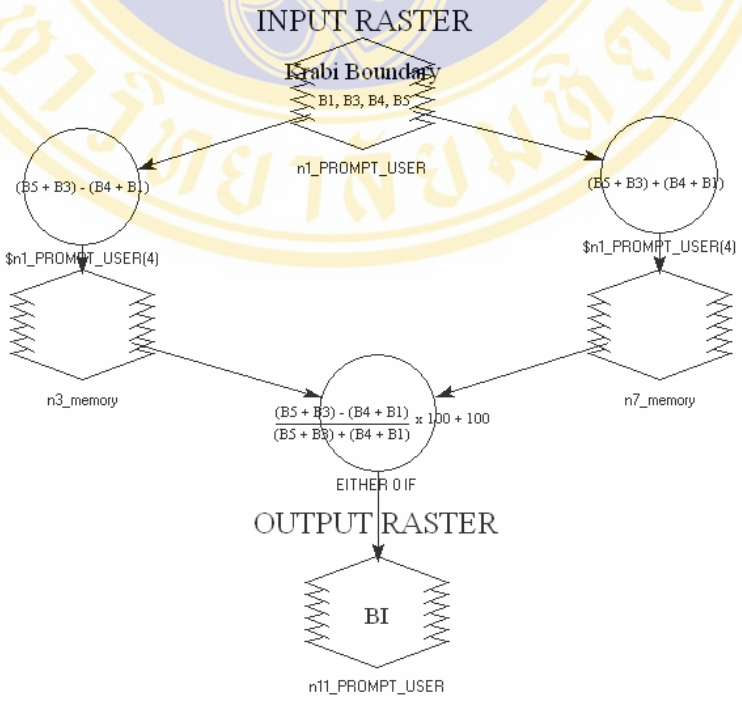


Figure 4-5 Bare Soil Index (BI) model in Expert Classifier Model

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**Water Index (WI) model**

This model formulated from the reflected solar radiation in the shortwave-infrared (SIR band or LANDSAT TM band 5) and green (GREEN band or LANDSAT TM band 2) wavelength bands. The WI equation is defined as

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

Where WI = Water Indices
GREEN = Visible Green reflectance value (spectral band of 0.5-0.6 μm)
SIR = Shortwave Infrared reflectance value (spectral band 2.08 – 2.35 μm)

The flow chart for classifier in this study was illustrated as shown in figure 4-6 by following;

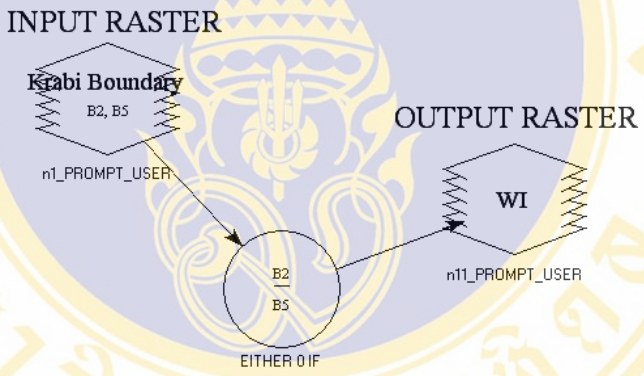


Figure 4-6 Water Index (WI) model in Expert Classifier Model

### 4.3.2 Determining Rule Base Using Multiple Regression

Rule bases of which used in this expert system are developed from stipulated interval values of band ratio indices. Interval values of each indices, AVI, NDVI, BI, and WI, were performed from the best fits equation of non-linear regression in SPSS for Windows software which can be in various forms such as logarithmic, inverse, quadratic, power, s-curve, growth, exponential, etc. Then, the best fits equation was selected by the least of Coefficient of Determination ($R^2$) and Standard Error of the Estimate (SE) value of each index equation.

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Then, the best of non-linear regression model of each band ratio indices are defined. The detail as shown by following; (See more detailed in Appendix)

- Advanced Vegetation Index (AVI) model

$$\text{Age} = 2.2937 \times 10^{-7} \bullet AVI^{3.7184} \qquad (R^2 = 0.6044)$$

- Normalized Difference Vegetation Index (NDVI) model

$$\text{Age} = 0.4747 e^{5.4332\, NDVI} \qquad (R^2 = 0.7274)$$

- Bare Soil Index (BI) model

$$\text{Age} = 788.3813 e^{-0.0580\, BI} \qquad (R^2 = 0.7856)$$

- Water Index (WI) model

$$\text{Age} = e^{6.3853 - \frac{1.6227}{WI}} \qquad (R^2 = 0.7022)$$

Next, Model Maker was used to generate each of the relation maps between indices and oil palm age. Then, those maps were integrated in order to generate the determining map. The integrated process used the probability of each map to decide what age class stage can be implied in those pixels. The probabilities were produced form the amount of the Coefficient of Determination ($R^2$) value which indicated more influent than the others.

The determining map was use to seek for stipulated interval values of each rule base. Thus, stipulated interval values of each age class stages are expressed in indices of suitable regression equation (see the detail in Appendix). Then, the signature of oil palm age class graphs were generated from those relations as shown in figure 4-7

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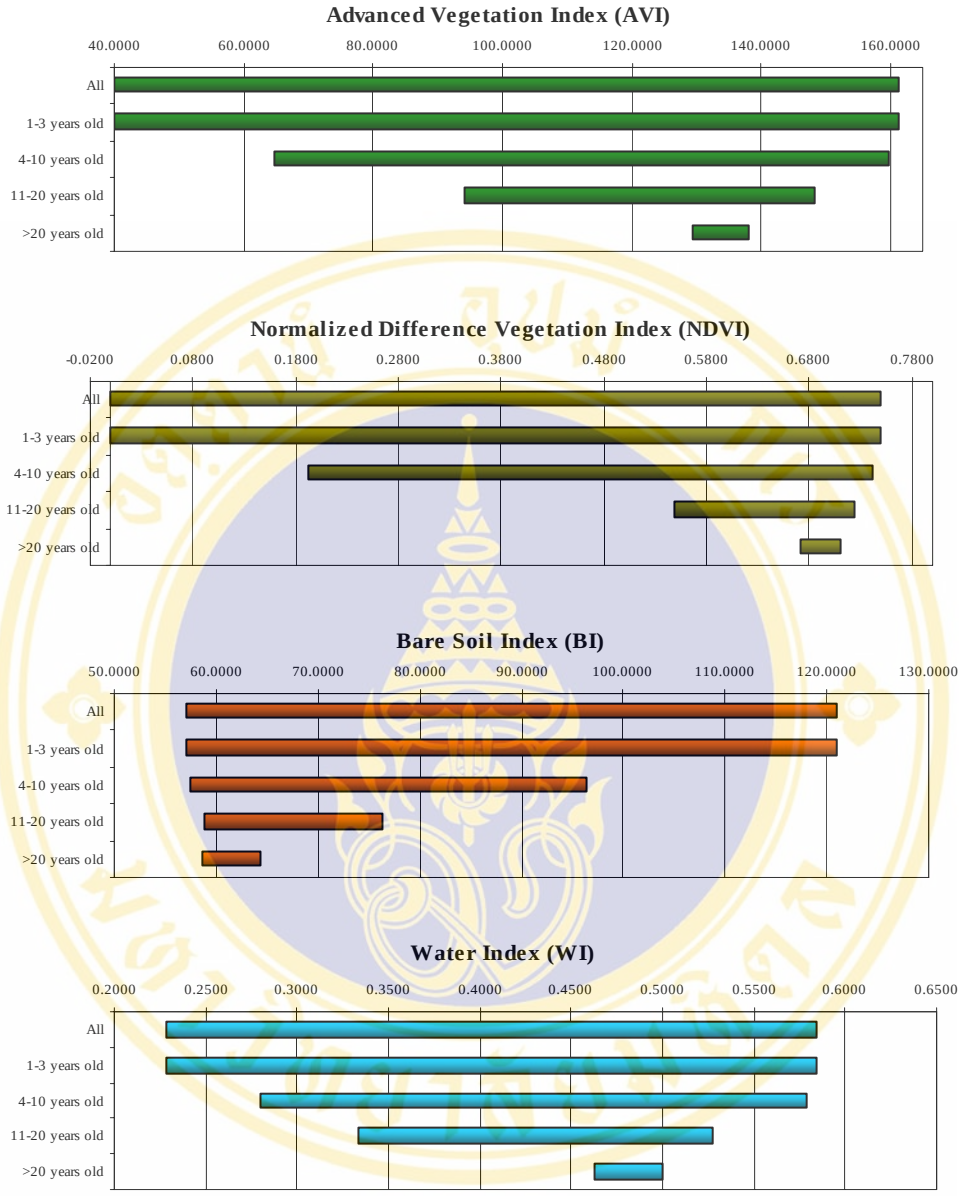


*Source : Analysis*

Figure 4-7 Signature of Oil Palm Age Class

The rule bases of age class were generated form intersection of all stipulated interval values of band ratio indices that is the same result when interpolated from all equations. In other word, again, if all of the results were not the same, it would be used the Coefficient of Determination ($R^2$) value of each equation to decide what age class stage imply in each pixel.

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### 4.3.3 Classification Experiment and Knowledge Representation

All defined variables, which included LANDSAT-5 (TM) imageries (band 1-5 and 7), AVI model, NDVI model, BI model, WI model, were used to generate the knowledge-based system for classifying the age class stages of oil palm in Krabi province.

Knowledge-base system inference was depicted from the relationships among variables data, rules, and outputs, with union or mixed forms from decision tree. Each stage classification rules were created from stipulated interval values of four indices value and their defining condition as mention above. The details of each stage classification rule were described as:

**Young stage of oil palm plantation (1-3 year)**

This class was classified when calculated, AVI, NDVI, BI, and WI, in between 18.2035 to 161.2300, 0 to 0.75, 57.1429 to 120.9960, and 0.2282 to 0.5847, respectively. Then age class of oil palm plantation was identified as stage 1 or young stage of oil palm plantation as shown in figure 4-8.

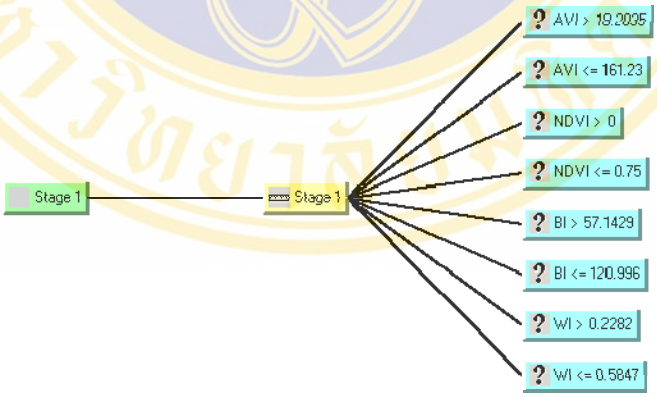


Figure 4-8 Rule of Young stage of oil palm plantation classification

**Intermediate stage of oil palm plantation (4-10 year)**

The assumption for intermediate stage was described when AVI, NDVI, BI, and WI, were ranging between 64.6043 to 159.7550, 0.1923 to 0.7407, 57.4899 to 96.3211, and 0.2796 to 0.5790., respectively as shown as shown in figure 4-9.

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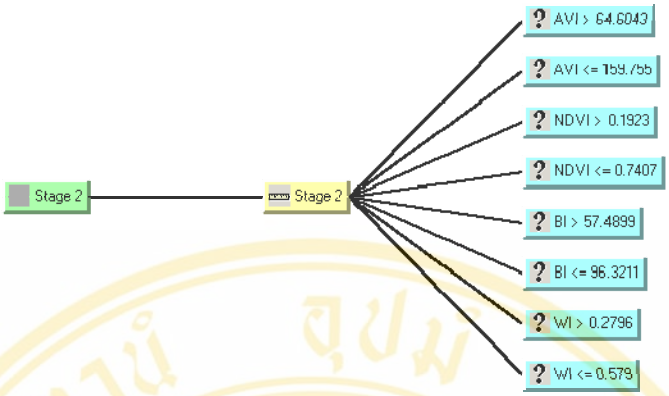


Figure 4-9 Rule of intermediate stage of oil palm plantation classification

**Productive stage of oil palm plantation (11-20 year)**

The criteria for productive stage was described when AVI, NDVI, BI, and WI, fall between 94.2714 to 148.2000, 0.5489 to 0.7241, 58.8235 to 76.2963, and 0.3333 to 0.5273, respectively as shown in figure 4-10.

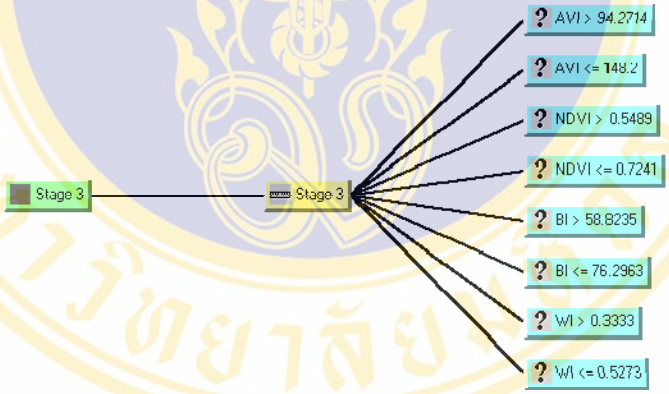


Figure 4-10 Rule of productive stage of oil palm plantation classification

**Mature stage of oil palm plantation (more than 20 year)**

This rule was described like flow diagram when calculated, AVI, NDVI, BI, and WI, in classes between 129.2760 to 138.1050, 0.6714 to 0.7099, 58.6873 to 64.3939, and 0.4630 to 0.5000, respectively. Then age class of oil palm plantation was identified as stage 4 or young stage of oil palm plantation as shown in figure 4-11.

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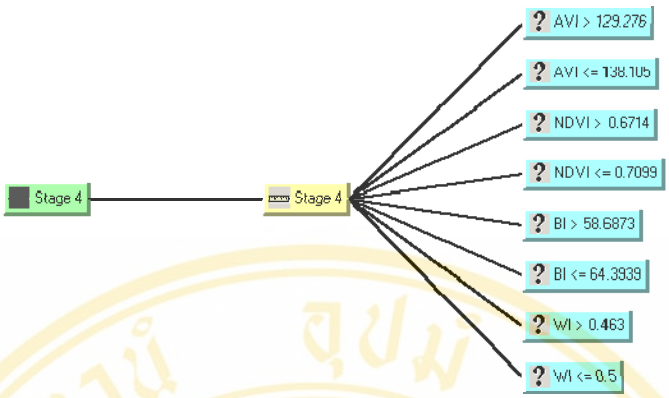


Figure 4-11 Rule of mature stage of oil palm plantation classification

## 4.4 Classification Accuracy

The total number of 244 age class sample points around Krabi province selected from ground truth data, which were undertaken on the 16th - 22nd December, 2004 and 10th - 16th February, 2005, were used to verify classification accuracy of each stage. There were use to examined with results from the expert classification and the maximum likelihood classification. The results were show in percentage of each classification stage. The accuracy from the expert classification was 92.19%, 50.88%, 80.00%, and 12.50%, respectively (Table 4-1). Meanwhile, the accuracy derived from the maximum likelihood classification includes 90.63%, 42.11%, 40.54%, and 72.34%, respectively (Table 4-2).

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Table 4-1 The land cover confusion matrix of expert classification and ground truth.

| | | Expert Classification | | | | | |
|---|---|---|---|---|---|---|---|
| | | Unclassified | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Overall |
| Ground Truth | Stage 1 | 1 | 59 | 4 | 0 | 0 | 64 |
| | Stage 2 | 0 | 4 | 29 | 24 | 0 | 57 |
| | Stage 3 | 1 | 0 | 13 | 60 | 1 | 75 |
| | Stage 4 | 0 | 0 | 5 | 37 | 6 | 48 |
| | Overall | 2 | 63 | 51 | 121 | 7 | 244 |
| % Accuracy | | 0.00 | 92.19 | 50.88 | 80.00 | 12.50 | 63.11 |

Note: Stage 1 is oil palm of 1 to 3 year old after planting (Young stage)
Stage 2 is oil palm of 4 to 10 years after planting (Intermediate stage)
Stage 3 is oil palm of 11 to 20 years old after planting (Productive stage)
Stage 4 is oil palm more than 20 years old after planting (Mature stage)

*Source: Analysis*

Table 4-2 The age class of oil palm classification confusion matrix of maximum likelihood classification and ground truth.

| | | Maximum Likelihood Classification | | | | | |
|---|---|---|---|---|---|---|---|
| | | Unclassified | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Overall |
| Ground Truth | Stage 1 | 0 | 58 | 6 | 0 | 0 | 64 |
| | Stage 2 | 0 | 4 | 24 | 15 | 14 | 57 |
| | Stage 3 | 1 | 0 | 8 | 30 | 36 | 74 |
| | Stage 4 | 1 | 0 | 1 | 12 | 34 | 47 |
| | Overall | 2 | 62 | 39 | 57 | 84 | 242 |
| % Accuracy | | 0.00 | 90.63 | 42.11 | 40.54 | 72.34 | 60.33 |

Note: Stage 1 is oil palm of 1 to 3 year old after planting (Young stage)
Stage 2 is oil palm of 4 to 10 years after planting (Intermediate stage)
Stage 3 is oil palm of 11 to 20 years old after planting (Productive stage)
Stage 4 is oil palm more than 20 years old after planting (Mature stage)

*Source: Analysis*

Comparison on accuracy obtained from expert classification and maximum likelihood classification had been done, subsequently (figure 4-12 and 4-13). It can be concluded that the result of the expert classification by selecting some sample area

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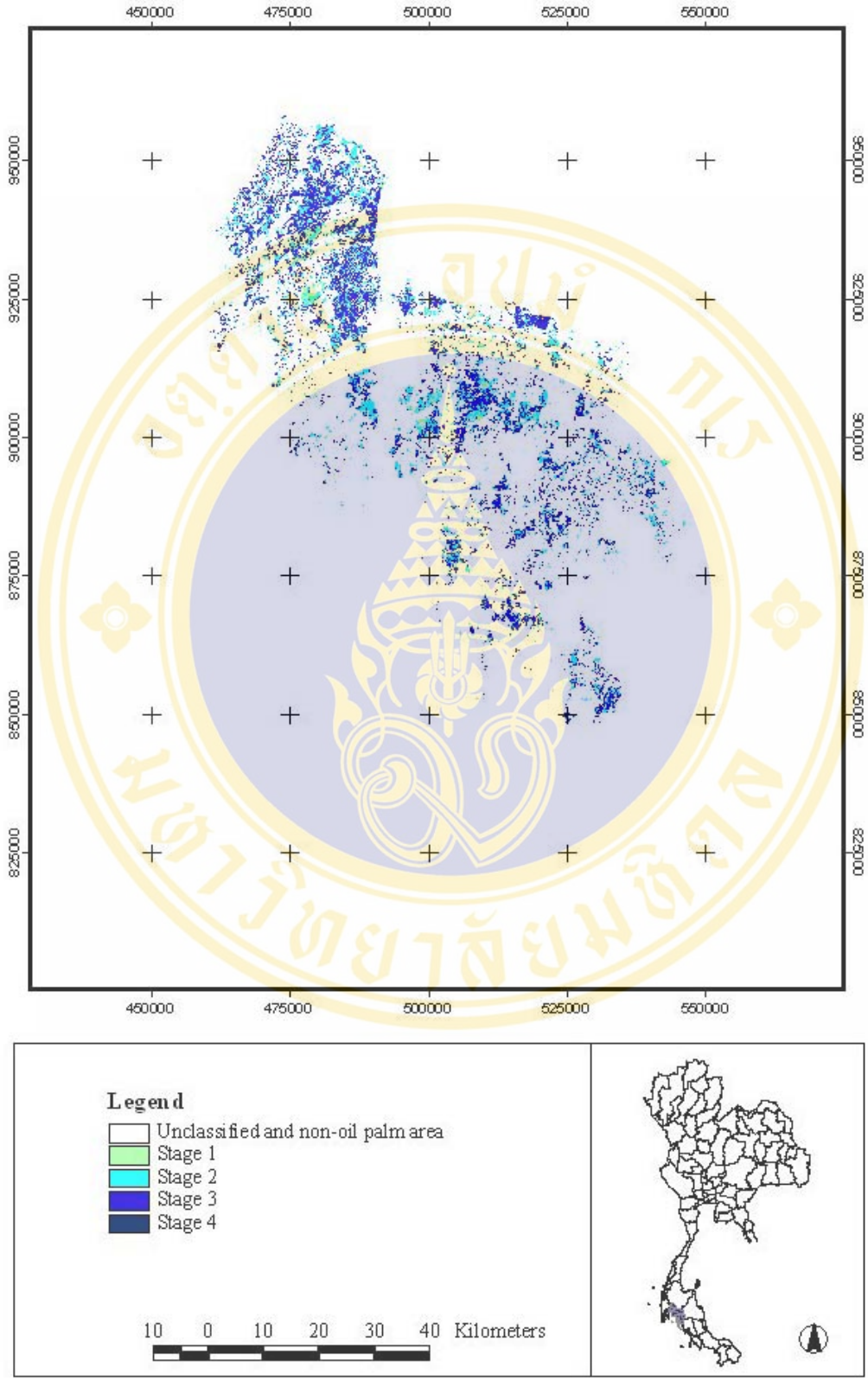


*Source: Analysis*

Figure 4-12 Classification result by expert classification

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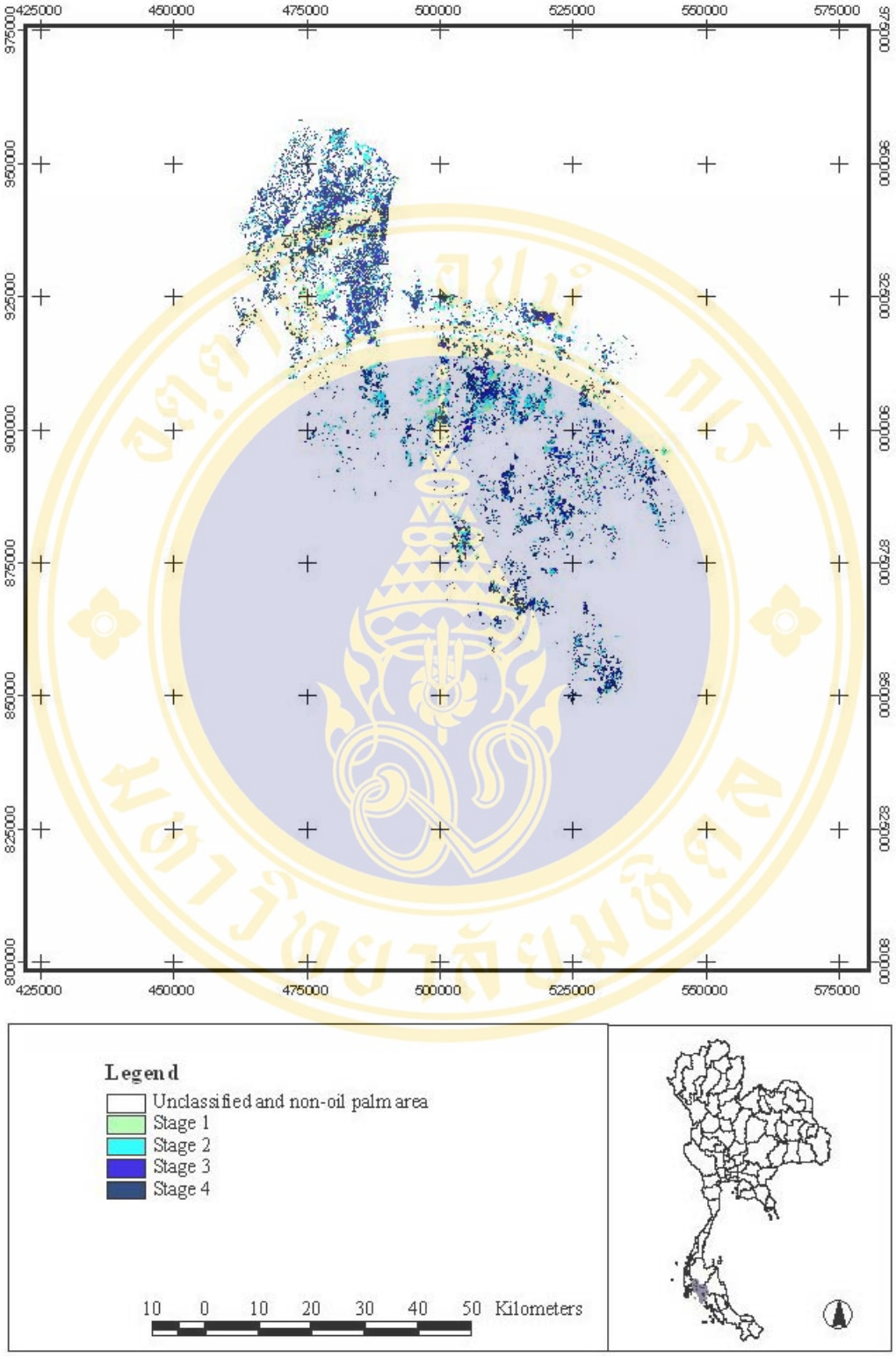


*Source: Analysis*

Figure 4-13 Classification result by maximum likelihood classification

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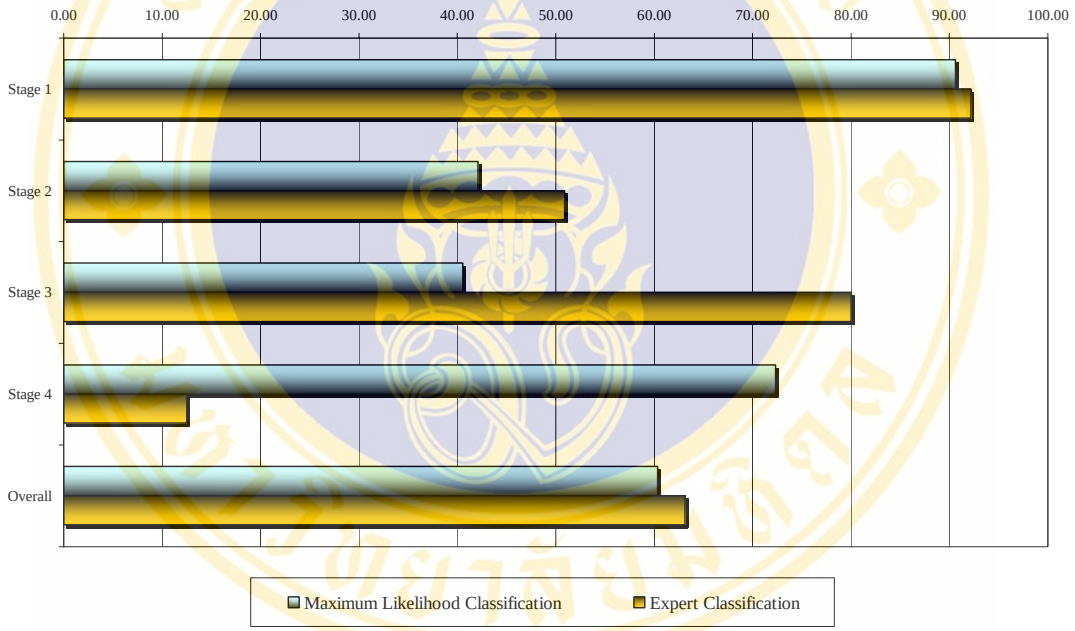
(244 points around Krabi province), provided the overall accuracy of about 63.11%, while the maximum likelihood classification gained about 60.33% only. figure 4-14 illustrated the accuracy of the expert classification of which 2.78% higher than the maximum likelihood classification.

Furthermore, it found that the accuracy for each age class stage of oil palm plantation from the expert classification, except stage 4, also provide higher accuracy than the maximum likelihood classification. Especially for productive stage (stage 3), its accuracy was 39.46% difference from those two techniques (Figure 4-18).




| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Overall |
|---|---|---|---|---|---|
| Expert Classification | 92.19 | 50.88 | 80.00 | 12.50 | 63.11 |
| Maximum Likelihood Classification | 90.63 | 42.11 | 40.54 | 72.34 | 60.33 |
| Summary | 1.56 | 8.77 | 39.46 | -59.84 | 2.78 |

*Source: Analysis*

Figure 4-14 The histogram of comparison between expert classification and maximum likelihood classification output

However, the result of expert classification of stage 4 was much less than that from maximum likelihood because indices band ratio values of stage 3 and stage 4 are

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almost the same. Thus, the classification value of stage 4 by using expert system was filled up in to stage 3 that may be why the result of stage 3 classification was better than that stage 4.

### 4.5 Age Class of Oil Palm Plantation Area in Krabi Province

The knowledge base of age class identification of oil palm in Krabi province has processed with Landsat–5 TM imagery. Then, the areas of each stages of oil palm plantation were calculated which can be summarized as the table 4 – 4

Table 4-3 The areas of each age class of oil palm plantation by using Expert System.

| Age (years) | | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Grand Total | Percentage |
|---|---|---|---|---|---|---|---|
| | | 1-3 | 4-10 | 11-20 | > 20 | | |
| **Amphoe Khao Phanom** | **km$^2$** | 7.11 | 67.61 | 107.15 | 0.14 | **182.01** | **20.72** |
| | **Rais** | 4,444.05 | 42,257.08 | 66,968.56 | 88.67 | **113,758.37** | |
| | **Percent** | 3.91 | 37.15 | 58.87 | 0.08 | **100.00** | |
| **Amphoe Khlong Thom** | **km$^2$** | 2.73 | 42.54 | 91.35 | 0.29 | **136.89** | **15.59** |
| | **Rais** | 1,704.01 | 26,584.78 | 57,091.12 | 179.30 | **85,559.21** | |
| | **Percent** | 1.99 | 31.07 | 66.73 | 0.21 | **100.00** | |
| **Amphoe Ko Lanta** | **km$^2$** | 0.05 | 1.26 | 2.73 | 0.00 | **4.04** | **0.46** |
| | **Rais** | 32.03 | 785.94 | 1,705.08 | 2.34 | **2,525.39** | |
| | **Percent** | 1.27 | 31.12 | 67.52 | 0.09 | **100.00** | |
| **Amphoe Muang** | **km$^2$** | 7.89 | 34.64 | 33.17 | 0.08 | **75.77** | **8.63** |
| | **Rais** | 4,929.08 | 21,648.71 | 20,733.88 | 47.66 | **47,359.33** | |
| | **Percent** | 10.41 | 45.71 | 43.78 | 0.10 | **100.00** | |
| **Amphoe Lam Thap** | **km$^2$** | 0.88 | 13.56 | 19.26 | 0.03 | **33.73** | **3.84** |
| | **Rais** | 549.05 | 8,477.36 | 12,039.61 | 17.58 | **21,083.60** | |
| | **Percent** | 2.60 | 40.21 | 57.10 | 0.08 | **100.00** | |
| **King Amphoe Nua Khlong** | **km$^2$** | 1.33 | 17.41 | 32.23 | 0.14 | **51.11** | **5.82** |
| | **Rais** | 830.41 | 10,881.05 | 20,144.80 | 85.55 | **31,941.80** | |
| | **Percent** | 2.60 | 34.07 | 63.07 | 0.27 | **100.00** | |

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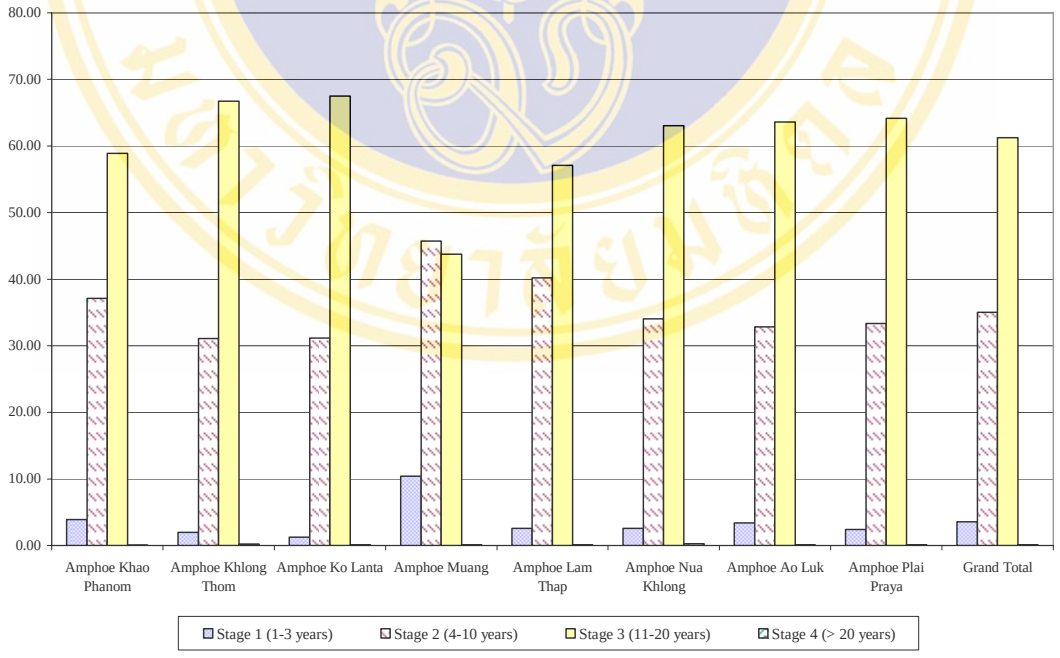
Table 4-3 The areas of each age class of oil palm plantation by using Expert System. (continued)

| Age (years) | | Stage 1 1-3 | Stage 2 4-10 | Stage 3 11-20 | Stage 4 > 20 | Grand Total | Percentage |
|---|---|---|---|---|---|---|---|
| Amphoe Ao Luk | $km^2$ | 6.69 | 64.50 | 124.93 | 0.27 | **196.38** | **22.36** |
| | Rais | 4,181.17 | 40,309.98 | 78,080.14 | 167.19 | **122,738.46** | |
| | Percent | 3.41 | 32.84 | 63.62 | 0.14 | **100.00** | |
| Amphoe Plai Praya | $km^2$ | 4.83 | 66.05 | 127.22 | 0.18 | **198.29** | **22.58** |
| | Rais | 3,020.82 | 41,282.68 | 79,514.53 | 112.06 | **123,930.09** | |
| | Percent | 2.44 | 33.31 | 64.16 | 0.09 | **100.00** | |
| Grand Total | $km^2$ | 31.50 | 307.56 | 538.04 | 1.12 | **878.23** | |
| | Rais | 19,690.62 | 192,227.56 | 336,277.72 | 700.34 | **548,896.23** | |
| | Percent | 3.59 | 35.02 | 61.26 | 0.13 | **100.00** | |

*Source: Analysis*




*Source: Analysis*

Figure 4-15 The comparison of percentage oil palm age class area in each amphoe of Krabi province by using Expert System

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The table 4-3 shown the result of age identification from expert classification that the total of oil palm plantation area is about 878.23 $km^2$ or 548,896.23 rai. Most of those are located in Amphoe Plai Praya, Amphoe Ao Luk, and Amphoe Khao Phanom, respectively. The majority of oil palm plantation stage is in stage 3 (productive stage), stage2 (intermediate stage), and stage 1 (young stage), respectively. In addition, it has compensation of oil palm plantation all amphoe in Krabi province.

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# CHAPTER V
# CONCLUSION AND DISCUSSION

## 5.1 Conclusion

This study is to apply geo-information technology with expert system in order to generate the knowledge base which used to identify age class of oil palm plantation. Landsat-5 TM imagery is main data source. The representation of vegetation index (Normalize Differentiate Vegetation Index: NDVI, Advance Vegetation Index: AVI), soil index (Bare Soil Index; BI), and Water Index (WI) were formulated by using imagery band ratio. Meanwhile, the rule base used in knowledge base was produced form regressions analysis. It was performed in order to formulate best fit equation for age class identification of oil palm by each index. The best suitable of equation were depicted by Coefficient of Determination ($R^2$).

The classified age classes of oil palm include 4 stages: Stage 1 or young stage (age of 1-3 years), Stage 2 or intermediate stage (age of 4-10 years), Stage 3 or productive stage (age of 10-20 years), and Stage 4 or mature stage (age of more than 20 years). The overall accuracy of expert classification is 63.11% which is satisfactory.

Moreover, the accuracy of comparison between expert classification and the maximum likelihood classification concluded that the overall accuracy of the expert classification is about 2.78% which higher than the maximum likelihood classification. Furthermore, it can be concluded the accuracy of each category from the expert classification is higher than one from the maximum likelihood classification.

Ultimately, by comparing with the result of maximum likelihood classification, the integrating of geo-information technologies with expert system can efficiency creates the age class classification of oil palm plantation. Therefore, the expert classification can duplicate human knowledge and provides a rules-based approach to

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image classification. Thus, it shows the expert classification that can be increased the classification accuracy.

## 5.2 Discussion

### 5.2.1 Result's Discussion

Due to several of oil palm plantation management in Krabi province, the growing of oil palm in each owner must not be the same. Even if oil palm has the same size and physical characteristics, they are not in the same age. So, it is very difficult to clearly distinguish them to their age.

Even though, the result form expert classification is better than those from maximum likelihood classification. The developed expert system can not exactly distinguish between stage 3 (productive stage) and stage 4 (mature state). It may be because the quality of sample point that use to generate the rule base or the limitation of non-linear regression equation and those mention reasons above that can not determent their differences.

### 5.2.2 Recommendation for Further Research

The expert system can increase the efficiency of age class identification of oil palm plantation; however, it is still facing various problems and limitations which point to further research to develop the better expert classification for age class of oil palm identification are as follows:

- The satellite imagery provided in this study is only the imagery from Landsat 5 TM. It can be used in knowledge-based system that created to use only in classification of age class identification of oil palm plantation in Krabi province. Nevertheless, its concept can be modified and applied to use with other site.
- High resolution of imagery (e.g., IKONOS, IRS, etc.) interesting with some GIS technique such as sieve, elimination, mean per zone, and etc., might

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provide good classification and more detail than low resolution of imagery but also be used with GIS technique.

- The research in term of multi-date analysis of specific smaller area can provide the better result than the large area because of many variations.
- The generating of expert system's rule is seriously concern. Especially, if perform it from statistics technique which has been depended on various variables such as the number of sample point, the quality of data, etc.
- The statistics technique such as multi-variants regression is the good solution to make the best fit for classification of oil palm.
- This research should be added with the details of GIS data (e.g., rainfall, soil water content, suitability, and etc.), the various image operations (e.g., Modified Soil-Adjusted Vegetation Index; MSAVI, Normalized Difference Water Index; NDWI, and etc.), shape analysis, and texture analysis, into the knowledge-based to identify age class of oil palm.
- Increasing of the models in the knowledge-based system, which created for image classification, will be time consuming for image processing.

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# APPENDIX

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# APPENDIX A
# RULE BASE'S STATISTICS

The number of 1039 point from field data was used to find out the best fit of age and each index including AVI (Advanced Vegetation Index), NDVI (Normalize Differentiated Vegetation Index), BI (Bare Soil Index), and WI (Water Index) by using statistics software, SPSS 12 for window.

The scatter plot of each index and age are shown by following;

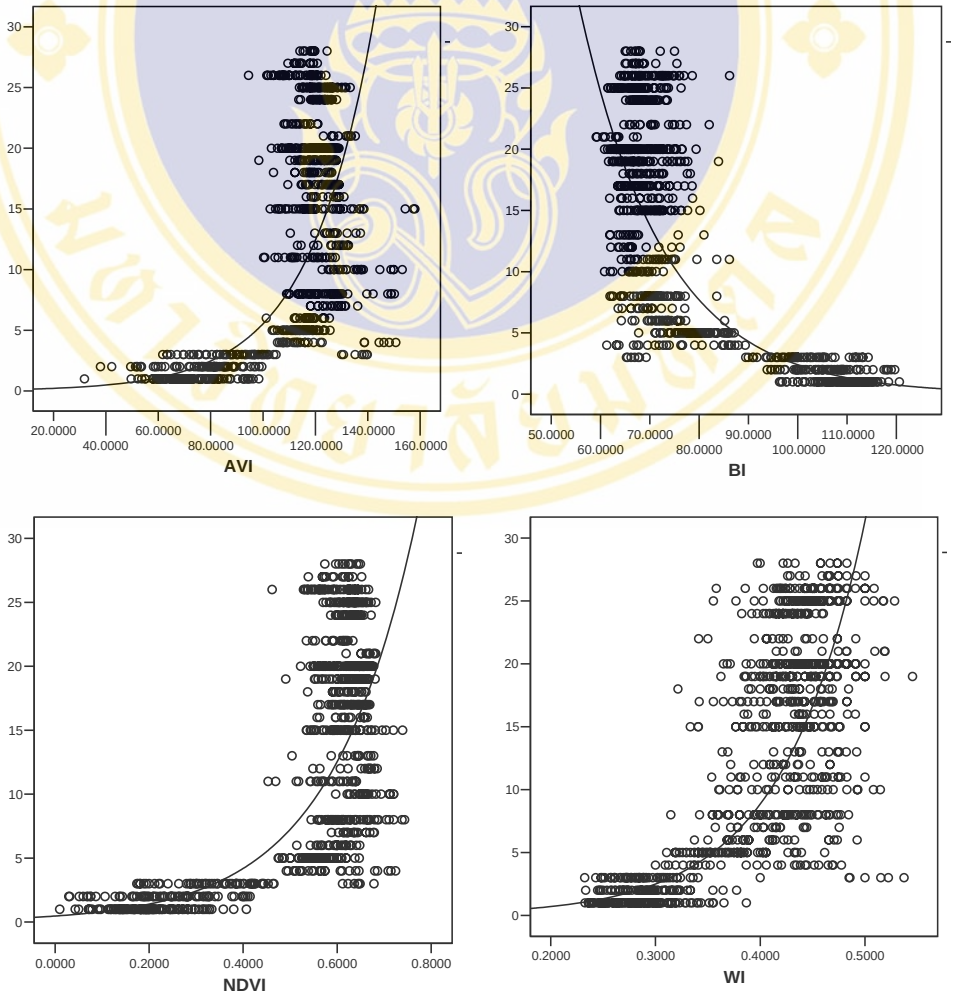


Figure A-1 The scatter plot of each index and age of oil palm

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Then, using curving estimate, that can be ,to generate the equation for rule base of expert classification. The important statistics value are show in table A-1

Table A – 1 Comparison among the indices by means of regression analysis

| | | Linear | Logarithmic | Inverse | Quadratic | Cubic | Compound | Power | S-curve | Growth | Exponential |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **AVI** | **R** | 0.5939 | 0.5993 | 0.5802 | 0.6141 | 0.6781 | 0.7731 | 0.7774 | 0.7518 | 0.7731 | 0.7731 |
| | **R Square** | 0.3527 | 0.3591 | 0.3367 | 0.3771 | 0.4598 | 0.5977 | 0.6044 | 0.5652 | 0.5977 | 0.5977 |
| | **Standard Error** | 7.1191 | 7.0838 | 7.2067 | 6.9869 | 6.5093 | 0.6920 | 0.6863 | 0.7194 | 0.6920 | 0.6920 |
| | | | | | | | | | | | |
| **NDVI** | **R** | 0.6826 | 0.6251 | 0.3221 | 0.6873 | 0.7075 | 0.8529 | 0.7940 | 0.4181 | 0.8529 | 0.8529 |
| | **R Square** | 0.4659 | 0.3907 | 0.1037 | 0.4724 | 0.5006 | 0.7274 | 0.6305 | 0.1748 | 0.7274 | 0.7274 |
| | **Standard Error** | 6.4665 | 6.9070 | 8.3770 | 6.4304 | 6.2590 | 0.5696 | 0.6632 | 0.9911 | 0.5696 | 0.5696 |
| | | | | | | | | | | | |
| **BI** | **R** | 0.7413 | 0.7471 | 0.7487 | 0.7517 | 0.7525 | 0.8864 | 0.8836 | 0.8759 | 0.8864 | 0.8864 |
| | **R Square** | 0.5496 | 0.5582 | 0.5605 | 0.5650 | 0.5662 | 0.7856 | 0.7808 | 0.7671 | 0.7856 | 0.7856 |
| | **Standard Error** | 5.9387 | 5.8816 | 5.8660 | 5.8386 | 5.8304 | 0.5052 | 0.5108 | 0.5265 | 0.5052 | 0.5052 |
| | | | | | | | | | | | |
| **WI** | **R** | 0.7394 | 0.7398 | 0.7318 | 0.7424 | 0.7437 | 0.8271 | 0.8372 | 0.8380 | 0.8271 | 0.8271 |
| | **R Square** | 0.5467 | 0.5473 | 0.5355 | 0.5511 | 0.5531 | 0.6840 | 0.7009 | 0.7022 | 0.6840 | 0.6840 |
| | **Standard Error** | 5.9574 | 5.9537 | 6.0304 | 5.9311 | 5.9178 | 0.6133 | 0.5967 | 0.5954 | 0.6133 | 0.6133 |

*Source: Analysis*



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# APPENDIX B
# SPECTRAL CHARACTERISTIC
# OF AGE CLASS OF OIL PALM

LANDSAT – 5 TM false color composition (4, 5, 3) of each age class, Krabi Province, can be classified as following (Table B-1).

Table B-1 LANDSAT - 5 TM false color composite imageries in each age class

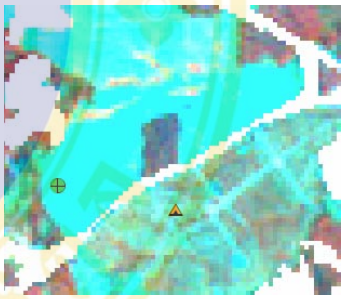
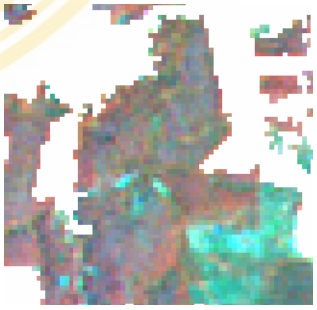
| Stage | Age | Topographic conditions | FCC band 453 (RGB) |
|---|---|---|---|
| 1 | Young Stage (age of 1-3 years) | |  |
| 2 | Intermediate Stage (age of 4-10 years) | |  |

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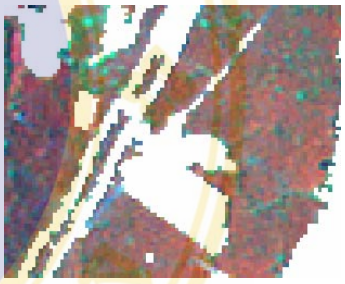
Table B-1 LANDSAT - 5 TM false color composite imageries in each age class (continued)

| Stage | Age | Topographic conditions | FCC band 453 (RGB) |
|---|---|---|---|
| 3 | Productive Stage (age of 10-20 years) | | |
| 4 | Mature Stage (age of more than 20 years) | |  |

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