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LAND SUITABILITY ANALYSIS BASED ON MANAGEMENT FOR RUBBER PLANTATION USING FUZZY LOGIC SYSTEM

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A Thesis Submitted in Partial Fulfillment of the Requirements for

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LAND SUITABILITY ANALYSIS BASED ON MANAGEMENT FOR RUBBER PLANTATION USING FUZZY LOGIC SYSTEM

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ประเทศไทยเป็นประเทศผู้ผลิตยางอันดับหนึ่งของโลก ปี พ.ศ. 2554 ซึ่งเป็นช่วงที่ยางมีราคาสูง ประเทศไทยสามารถผลิตยางได้ถึง 3.6 ล้านตัน หรือมีมูลค่ามากกว่า 4 แสนล้านบาท ปัจจุบันมีอัตราการผลิตมากกว่า 4 ล้านตันต่อปี แม้ขณะนี้ยางพาราจะมีราคาลดลงแต่ยังคงมีอัตราความต้องการมากขึ้นเรื่อยๆ เนื่องจากเป็นวัตถุดิบสำคัญทางอุตสาหกรรม ดังนั้นจึงควรมีการศึกษาและวางแผนรองรับการขยายพื้นที่เพาะปลูกในอนาคต ในการวิเคราะห์พื้นที่เหมาะสมในการปลูกยางจะต้องคำนึงถึงการบริหารจัดการร่วมด้วย บางพื้นที่แม้ว่าจะมีความเหมาะสมด้านทางกายภาพด้านคุณสมบัติดินหรือสภาพอากาศไม่ดีมากนัก แต่หากมีการบริหารจัดการสวนที่เหมาะสมก็อาจมีอัตราผลผลิตที่ดีได้ นอกจากนั้นยังพบว่าข้อมูลที่ใช้เป็นเกณฑ์สำหรับการวิเคราะห์ความเหมาะสมของพื้นที่มีความคลุมเครือและไม่เหมาะสมที่จะวิเคราะห์ด้วยวิธีการทั่วไปที่ใช้ข้อมูลแบบไม่ต่อเนื่อง งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อนำวิธีการ Mamdani's fuzzy logic มาใช้ประเมินพื้นที่เหมาะสมในการปลูกยางพารา ซึ่งปัจจัยที่นำมาวิเคราะห์จะถูกนำมาแปลงเป็นค่าระดับสมาชิกความคลุมเครือของความเหมาะสม และนำมารวมกันด้วยวิธีการของ Storie โดยแยกเป็นคุณสมบัติทางกายภาพของดิน (Kp) ทางเคมีของดิน (Ks) สภาพอากาศ (Kc) และปัจจัยทางด้านการบริหารจัดการ (Ma) คุณสมบัติแต่ละด้านนี้จะถูกนำมาจัดระดับสมาชิกความคลุมเครือของความเหมาะสมด้วยค่าทางสถิติ MIN, MEAN และ MAX และจัดองค์ประกอบร่วมกับระดับอัตราผลผลิตด้านน้ำยาง โดยข้อมูลด้านผลผลิตและการบริหารจัดการได้จากข้อมูลการสัมภาษณ์เกษตรกร จำนวน150 คน ผลการศึกษาพบว่าหากมีการจัดการสวนยางในระดับสูง (H) พื้นที่ศึกษาจะมีพื้นที่เหมาะสมในการปลูกยางพารา ระดับ S1, S2, S3, N เท่ากับ 2,091,501, 40,536, 6,636,763 และ 10,490,112 ไร่ ระดับปานกลาง (M) มีพื้นที่ 41,691, 165, 8,726,944 และ 10,490,112 ไร่ และ ระดับต่ำ (L) ไม่มีพื้นที่ระดับ S1 และ S2 มีพื้นที่ S3 และ N เท่ากับ 2,097,463 และ 17,161,449ไร่ ตามลำดับ และจากการตรวจสอบความถูกต้องเปรียบเทียบระหว่างอัตราผลผลิตที่ได้จากการวิเคราะห์ของ Mamdani's fuzzy logic กับผลผลิตจริง พบว่ายางพาราพันธุ์ RRIM 600 มีค่าสัมประสิทธิ์สหสัมพันธ์ (R^2) และ RMSE เท่ากับ 0.6039 และ 25.67 ตามลำดับ

สาขาวิชาการรับรู้จากระยะไกล	ลายมือชื่อนักศึกษา ______
ปีการศึกษา 2558	ลายมือชื่ออาจารย์ที่ปรึกษา ______
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ______

TAWATCHARAPONG WONGSGOON : LAND SUITABILITY ANALYSIS BASED ON MANAGEMENT FOR RUBBER PLANTATION USING FUZZY LOGIC SYSTEM. THESIS ADVISOR : ASST. PROF. SUNYA SARAPIROME, Ph.D. 164 PP.

FUZZY/FUZZY LOGIC/RUBBER/LAND SUITABILITY/ MAMDANI

Thailand is the world's largest natural rubber producer and exporter. The country produces more than 3 million metric tons of natural rubber annually, or more than 4 hundred billion baht in the year that the average annual price has reached the highest level (2011). Although the price has been declining for the last few years, prospects of the industry remain positive as natural rubber is an indispensable resource. Therefore, it should be studied and planned for future plantation expansion. In land suitability analysis for rubber plantation, plantation management has to be considered together with other factors. Although suitability levels of soil chemical and physical properties and climate of an area are low, productivity of the plantation can be high if plantation can be performed at a high level of management. Furthermore, data on suitability criteria are fuzzy and cannot be analyzed using general method fit for discrete data. This research therefore aims to use the Mamdani's fuzzy logic analysis method to evaluate land suitability for rubber plantation, clone RRIM 600, in Nakhon Ratchasima and Burirum provinces. Membership function of each criterion was developed based on crop requirement concluded from researches. From 150 samples collected from available data and interviewing of farmers, factors analyzed were converted into fuzzy membership levels of the suitability which were combined by means of Storie's method in 4 aspects: soil physical properties (Kp), soil chemical properties (Ks), climate (Kc), and plantation management (Ma). Each group of these factors was incorporated with a yield, all of which were classified by the suitability levels statistically to MIN, MEAN and MAX. The study found that if the plantation was managed in the high level (H), the suitability areas for rubber plantation in levels of S1, S2, S3 and N are 2,091,501, 40,536, 6,636,763, and 10,490,112 rai, respectively. If the plantation was managed in medium level (M), S1, S2, S3 and N are 41,691, 165, 8,726,944 and 10,490,112 rai respectively. If the plantations was managed in low level (L), there were no areas of S1 and S2 but 2,097,463 and 17,161,449 rai for S3 and N. According to the validating result of 32 samples to compare between the outputs from Mamdani's fuzzy logic analysis and the real outputs, it was found that these 2 outputs show linear regression relationship almost without under and over estimation (1:1) and with R^2 and RMSE of 0.6039, 25.67, respectively.

School of Remote Sensing | Student's Signature ____________

Academic Year 2015 | Advisor's Signature ____________

Co-Advisor's Signature ____________

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Tawatcharapong Wongsgoon

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LIST OF ABBREVIATIONS

ADS	Air Dried Sheets
AHP	Analytical Hierarchy Processing
CPD	Cooperative Promotion Department
DOA	The Department of Agriculture
Etc	Water Demand Of The Rubber Tree Calculated From Crop (Kc)
Eto	The Reference Crop Evapotranspiration
FAO	The Food and Agriculture Organization of the United Nations
FM	Fuzzy Membership Values
FMF	Fuzzy Membership Functions
Ih	The Index Of Humidity
IRSG	The International Rubber Study Group
MAR	Mean Annual Rainfall
MARD	Mean Annual Rainy Day
MCDA	Multi-Criteria Decision Analysis
MF	Membership Functions
MIMO	Multi-Input Multi-Output
MISO	Multi-Input Single-Output
PCM	Pairwise Comparison Matrices
RH	Relative Humidity
RMSE	Root Mean Squared Error

LIST OF ABBREVIATIONS (Continued)

RRIT	Rubber Research Institute of Thailand
SAW	Simple Additive Weighting
SS	Symbol of Soil Series
TOPSIS	Technique For Order Preference By Similarity Of Ideal Solution
VPD	The Vapor Pressure Deficit
WA	Weighted Average Method

CHAPTER I

INTRODUCTION

1.1 Background problem

Methods of MCDA such as sieve analysis, multiplication, Simple Additive Weighting (SAW), Analytical Hierarchy Processing (AHP) are related to evaluation of scores together with weights of criteria (Malczewski, 1999). In these methods, the criteria are classified based on suitability classes and converted to the same scale and then multiplied by the weight of each criterion. The classification can cause loss of accuracy in the interface between suitability classes (Baskoro, 2008). Besides, the determination of the weight for each factor is sometimes difficult and subjective (Malczewski, 2000 quoted in Qiu, Chastain, Zhou, Zhang and Sridharan, 2013) that can cause difficulties for interpretation and different decision making processes in the real world. For example, in the case that specified suitable mean annual rainfall for rubber cultivation is 1,350-2,500 mm, if the rainfall of most areas is 1,349 mm, it would immediately evaluate the area into an unsuitable class although rainfall 1,350 and 1,349 mm are virtually the same. Accordingly, it can cause an error of the analysis and may cause conflicts in implementation followed.

Moreover, these data models consisting of discrete, sharply bounded internally uniform entities that are used in land evaluation classifications, ignores important aspects of reality caused by internal inhomogeneity, short-range spatial variation, measurement error, complexity and imprecision. Considerable loss of information can occur when data that have been classified according to this model are retrieved or combined using the methods of simple Boolean algebra available in geographical information systems. To deal with data uncertainty may lead fuzzy set theory used, which is a generalization of Boolean algebra to situations where data are modeled by entities whose attributes have zones of gradual transition, rather than sharp boundaries, offers a useful alternative to existing methodology (Burrough, 1989).

To solve the problem mentioned above, the analysis methods of MCDA can be operated with fuzzy logic theory which is a method that can be properly used in a vague and uncertain data such as soil properties, climate, topography (Prasetyo, Hasiholan and Hartomo, 2012; Keshavarzi, Sarmadian, Heidari and Omid, 2010; Reshmidevi, Eldho and Jana, 2009; Baskoro, 2008; Jiang and Eastman, 2000; McBratney and Odeh, 1997). In addition, levels of suitability or preference can be inferenced by using the rules of the system defined by experts. Inferencing can be done by several methods such as traditional methods of Mamdani, Tsukamoto, Sugeno and Larsen (Siddique and Adeli, 2013; Phayung, 2013; MathWorks, 2012; Wang, 1997). These methods also provide results or answers of the analysis in various forms. Two standard forms are multi-input multi-output (MIMO) and multi-input single-output (MISO) (Passino and Stephen, 1998), such as the case that several physical factors are analyzed to find a suitable area for cultivation. Furthermore, these same factors can be used to find out productivity, growth rate and crop-type selection as well.

1.2 Problem / Opportunity Recognition

The latitudes suitable for rubber plantation indicate between 6 degrees north and 6 degrees south of the equator which are within Thailand, Malaysia and Indonesia which are the main countries of rubber producing countries. In Thailand, the southern part is the first rubber plantation which is appropriate for the environment. Areas of rubber cultivation also extend to new locations in the northeastern and northern parts of the country which locate at 14 to 20.5 degrees north. Many parts of these areas have a climatic conditions limit for rubber planting but can be exploited higher yields with an optimum level of management. Therefore, apart from other common criteria using in the previous studies, management criterion is added for suitability analysis in this study. This can lead to promoting some areas used to be ignored becoming suitable for plantation and resulted in increasing suitable area as a whole.

The International Rubber Study Group (IRSG) has forecasted that the demand of natural rubber in the world is growing steadily every year. By the year 2020, the estimated global demand will be 15.36 million tons because the automobile industry of China, which is a powerful economic country in the world, has been expanding by leaps and bounds. Natural rubber output worldwide is forecasted to reach 13.77 million metric tons in 2020. For this reason, it makes China, the world's largest consumer and one of the major rubber cultivation countries of the world such as Thailand, Indonesia, and Malaysia. Other countries in ASEAN such as Laos, Cambodia, Myanmar, and Vietnam recognize the importance and have promoted policy for rubber plantation continuously to meet the shortages that may occur. (Cooperative Promotion Department: CPD, 2015)

Laos has promoted the rubber plantation over 1.69 million rai, allowing foreign access for rubber cultivation in many areas around the country under the Agreement on Agriculture. Companies from Vietnam performed plantations in the south, from

Thailand performed plantations in the central region and businessmen from China performed plantations in the north.

Myanmar approved Malaysian investors in the cultivation of 0.88 million rai.

Cambodia approved investors from Malaysia, Vietnam, China and South Korea in the cultivation of 1.29 million rai.

In Thailand, the cabinet noticed and came to the conclusion on 26 May 2003 to approve the Ministry of Agricultural and Cooperatives to proceed with the project of growing the rubber tree for improving income and stability of the agriculturist in new planting areas such as the 1,000,000 rai project in the years 2004-2006, 700,000 rai for the Northeast and 300,000 rai for the North.

Such the mentioned policies motivate many departments in Thailand to conduct research to find suitable areas for growing rubber trees. Nevertheless, it is found that some studies result in different conclusions. According to some researches, there are significant differences as shown in Tables 1.1 and 1.2, particularly in index and yield ranging for classification that reflect the difference of class coverage areas.

Table 1.1 Studies of land suitability for growing rubber in the Northeast.

Researchers	Area (rai)			
	S1	S2	S3	N
1. Charat and Wasana (2010)	5,576,102	17,621,538	20,084,414	62,233,782
2. Somjate, Prasat and Prapat (2003)	-	19,314,052	5,843,731	-
3.Sathaporn and Charat (n.d.)	10,878,683	15,352,554	25,144,424	40,444,220

Table 1.2 Studies of land suitability for growing rubber in Buriram (BR) and UbonRatchatani (UB) Provinces.

Researchers		Area (rai)			
		S1	S2	S3	N
1. Charat and Wasana (2010)	BR	101,938	832,928	920,027	4,597,555
	UB	900,409	2,315,477	1,587,278	5,037,368
		(L1)	(L2)	(L3)	
2. Somjate, Prasat and Prapat (2546)	BR	-	474,970	1,020,454	-
	UB	-	128,100	382,189	-

Note: BR= Buriram, UB= Ubon Ratchatani

S1 = Highly suitable, S2 = Moderately suitable, S3 = Marginally suitable and N = Non-suitable

L1 = Air Dried Sheets (ADS) more than 400 kg/rai, L2 = ADS between 250-400 kg /rai, and L3 = ADS between 200-250 kg / rai (Marginal Land Suitability)

Arguments exist for which is the best practice for further planning. It seems to be hard to finalize and no effective or widely acceptable way is used to validate the results. This is either because the weights and scores used for index generation are more or less relied on low certainty of information and individual opinions, or some critical factors such as level of management might not be absolutely or systematically investigated and included in the analysis.

1.3 Objectives of the study

The objective of this research is to apply rules of fuzzy logic to multiple-criteria evaluation of land suitability for rubber plantation so as to overcome uncertain data and specifications. Mamdani's fuzzy inference method is proposed to be a proper rule development method for a study. Specific objectives are as follows:

1. To develop fuzzy membership functions and fuzzy rules of Mamdani's fuzzy inference method applied to land suitability classification based on management for rubber plantation to the Lower northeast region.

2. To apply the rules of Mamdani's fuzzy inference method to land suitability analysis for rubber plantation of Hevea clones RRIM 600 in Buriram and Nakhon Ratchasima provinces.

1.4 Basic assumptions

In this study, the accuracy of the fuzzy logic system is a result of rules which is derived from analysis of data collected otherwise.

1.5 Scope and limitations of the study

This study is conducted with fuzzy logic analysis in the following scopes and limitations:

1. The rubber species for this case study is RRIM 600.

2. The crop requirements selected and used in this study are reviewed from previous researches.

3. Due to data limitation in the study area, data used to develop rules (150 samples) are the data collected from the lower of northeast region where having the same characteristics and geographic domain. Data of 30 samples for validation are collected from Buriram and Nakhon Ratchasima provinces. The spatial distribution of samples is not quite representative for the whole region and study area because the

sampling had to be carried out from existing rubber plots which were not distributed well in the area.

4. A variety of plantation management criterion based on all farmers cannot be definitely investigated, so the research attempts to create land suitability maps in 3 scenarios based on expert opinions on the levels of the plantation management - High, Medium, and Low. These levels are finally applied to data collected.

5. The method of fuzzy rule development relies on an appropriate method for the study, which is Mamdani's fuzzy inference method.

6. An ADS per year is targeted attributes of land suitability maps generated.

7. Saline soil, wet land/flood plain, urban, and reserve areas are crucially barrier for rubber plantation, therefore they will be masked out using data mapped by the LDD.

1.6 Study areas

A study of land suitability analysis for rubber plantation using fuzzy logic theory can be used in decision making in areas, especially some of the areas that have not been used for rubber plantation, but required such as in Nakhon Ratchasima Province.

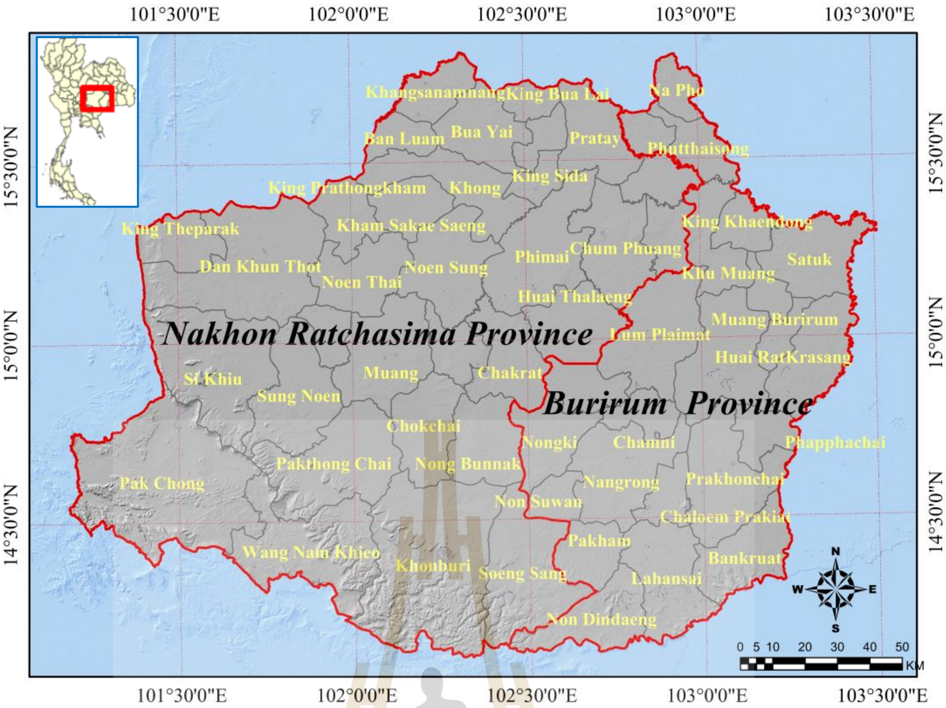


Figure 1.1 The study area.

1.6.1 Buriram

Buriram province is located in the lower part of the northeastern region of Thailand at Latitude: 14°15′N-14°45′N and Longitude: 102° 30′E-103°45′E (Figure 1.1), covers an area of 6,451,178 rai. A majority of people make their living through agriculture. The administration is subdivided to 23 amphoes, 188 tambols and 2,546 villages. The population is more than 1,566,740 (http://www.buriram.go.th; Department of Mineral Resources, Thailand, 2010).

For topographic characteristic of Buriram province, elevation of the area varies between 150 and 200 m above mean sea level (msl). The area is generally a part of Khorat plateau. Mountainous area covers about 25 % of the study area in the south, while undulating terrain and flat area cover about 60 % and 15 % of the area. The weather is tropical savannah climate with varying average annual rainfall between 1,000 and 1,400 mm. The annual average temperature is between 23 ^{o}C and 33 ^{o}C. The studied areas consist of 4,913,044 rai of Agricultural land, 625,630 rai of Forest land, 213,622 rai of Water Body, 411, 280 of Urban and Built-up land and 115,331 of Miscellaneous purposes. The rubber plantation area is about 210,233 rai or 4.27 % of Agricultural land area

1.6.2 Nakhon Ratchasima

Nakhon Ratchasima province has an area of 12, 808,728 rai divided into 32 amphoes, 287 tumbols, 3,743 villages. It locates on the Khorat Plateau, at latitude 15^{o} N and longitude 102^{o} E, with an elevation of 187 meters above mean sea level. Its population is about 2,591,000.

The weather of the province is quite hot in summer and cold in winter. An average temperature is 27.4 °C. An average relative humidity throughout the year is 71 %. An average rainfall throughout the year is 1,019.2 mm. The month with the most rainfall is September. An average wind speed is about 4-7 km/hr (1.1-1.9 m/s). The studied areas consist of 8,966,029 rai of agricultural lands, 2,299,964 rai of forests, 303,563 rai of water bodies, 843,632 rai of urbans and built-up lands and 541,405 rai of miscellaneous lands. The rubber plantation areas are about 41,157 rai or 0.46 % of agricultural areas. (http://www.nakhonratchasima.go.th; Department of Mineral Resources, Thailand, 2010).

In Buriram province, agriculturalists have concentrated on rubber planting because it helps reinforcing a better environment, retaining moisture in the soil, decreasing global warming, and causing social, economic and environmental benefits. It provides high and regular incomes, and generates stable rural employment. According to a record of the office of the Rubber Replanting Aid Fund in Burirum, farmers of more than 24,000 households have planted rubber in the area bigger than 240,000 rai, opened cut to more than 150,000 rai, and have produced more than 39,000 tons/year. An average income per household was around 286,000 baht/year. Each year, statistics showed that an average annual rubber plantation area has been increased 10 % (Office of the Rubber Replanting Aid Fun, 2013). Therefore, there should be a method to provide useful information that helps farmers in making appropriate decisions in selecting an area for planting rubber efficiently.

In Nakhon Ratchasima, a lot of people are interested in growing rubber. A number of farmers who want to plant rubber trees in Buriram also increases every year. Farmers in many areas of these provinces who plant sugarcane, cassava or rice are requiring planting the rubbers. The government organizations responsible for this issue are monitoring and assisting by providing information to support their decisions. Therefore, it is necessary to study all dimensions to make the right decision.

CHAPTER II

LITERATURE REVIEW

2.1 Concepts and theories of fuzzy

Fuzzy logic imitates the human's concept by simulating human language, judgment and common sense. Fuzzy was presented by a polish logician and philosopher Jan Lukasiewicz in 1920 titled "**On three-valued logic**". Later in 1965, Professor Lotfi Zadeh, who at that time was the head of the Electronic Engineering Sector, University of California, Berkeley, had published "Fuzzy Sets" which made Fuzzy Logic well known and popular afterwards (McBratney and Odeh, 1997; Agarwal, 1965; Wang, 1997). He mentioned that a decision-making in a fuzzy environment was meant to be a decision process in which the goals and/or the constraints, but not necessarily the system under control, were fuzzy in nature. This meant that the goals and/or the constraints constitute classes of alternatives whose boundaries were not sharply defined (Bellman and Zadeh, 1970).

In other words, we often use uncertain or vague concepts in human's thinking and language. Our thinking and language are not binary, i.e., black and white, zero or one, yes or no. In real life, we add much more variation to our judgments and classifications. These vague or uncertain concepts are said to be fuzzy. We encounter fuzziness almost everywhere in our everyday lives (Kainz, 2010). Accordingly, fuzzy logic theory has been used widely in many different purposes, so it should be used to assess land suitability in agriculture as well.

The fuzzy logic analysis method can be integrated with ambiguous data by considering the information in membership values which give details of the connection between two data classes. The analysis result does not lose accuracy in the interface of data; especially a continuous data such as Soil, Rain, slope, etc. The knowledge of an expert can be embedded in the rule base and membership function for the purpose of analysis as analyzed by experts. In addition, the analysis model using the conditional clause IF…. WILL, or IF …..THEN, rules can also integrate both quantitative and qualitative information together properly. Finally, the fuzzy logic and knowledge of an expert together as a system that so call "**Fuzzy Systems**".

2.1.1 Classical set and fuzzy set

Classical set or crisp set is a set where membership value of its members is only 0 or 1. For example, a set of male and female can be identified obviously. Mathematical model of a typical set as follows (Kainz, 2010; Sivanandam, Sumathi and Deepa, 2007)

$$\mu_A(x) = \begin{cases} 1, & x \in A \\ 0, & x \notin A \end{cases} \tag{2.1}$$

Where A is a set symbol of Crisp set, x is a set membership, and $\mu_A(x)$ is a membership function in set A of x.

Classical set theory is different from Fuzzy set theory. A classical set is defined by crisp boundaries, i.e., there is no uncertainty in prescription or location of the boundaries of the set. A fuzzy set, on the other hand, is prescribed by membership value; its boundaries are ambiguously specified. The boundaries look smooth because the values don't change immediately. The membership values of the fuzzy set are between 0 and 1. In the real world, there is not only the classical set but the fuzzy set which can be explained as follows (Kainz, 2010; Zimmermann, 2010).

X is not an empty set. Fuzzy set A can be characterized by a membership function.

$$\mu_{\underline{A}}(x) : X \rightarrow [0,1] \tag{2.2}$$

When $\mu_{\underline{A}}(x)$ is a membership function in set $\underline{A}$ of x. For each $x \in X$, Fuzzy set $\underline{A}$ can be defined by the following equation.

$$\underline{A} = \{ (x,\ \mu_{\underline{A}}(x)) \mid x \in X \} \tag{2.3}$$

When $\underline{A}$ is Fuzzy set $\underline{A}$, x is a set membership, $\mu_{\underline{A}}(x)$ is a membership function and X is a universe or population.

2.1.2 Membership function

Membership function is a function used to calculate membership value of a variable. Membership function has many forms, which may be asymmetrical or symmetrical forms. The commonly seen is a trapezoidal, triangular and Gaussian, which is the important part that affects the membership numbers of a variable as a function of different shapes. Figure 2.1 shows the following (Kainz, 2010; McBratney and Odeh, 1997; Mendel, 1995).

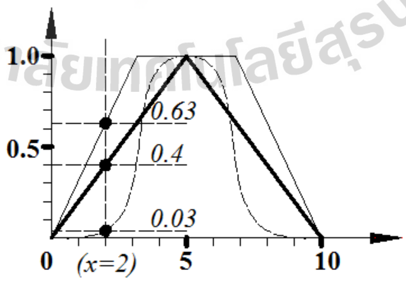


Figure 2.1 Forms of membership function.

Figure 2.1 shows that the variable x is equal to 2 if the value of a form membership function differently is trapezoidal, triangular and Gaussian will have value as different as it is 0.63, 0.4 and 0.03 respectively.

Moreover, the shape of the membership function also the decision maker's thinking and his decision, which will vary according to the definition of information systems, for example, the pattern of annual rainfall suitable for growing crops, which may be defined as a threshold of at least 1,250-3,000 mm/yr. We can make many types of membership function with different forms as following examples:

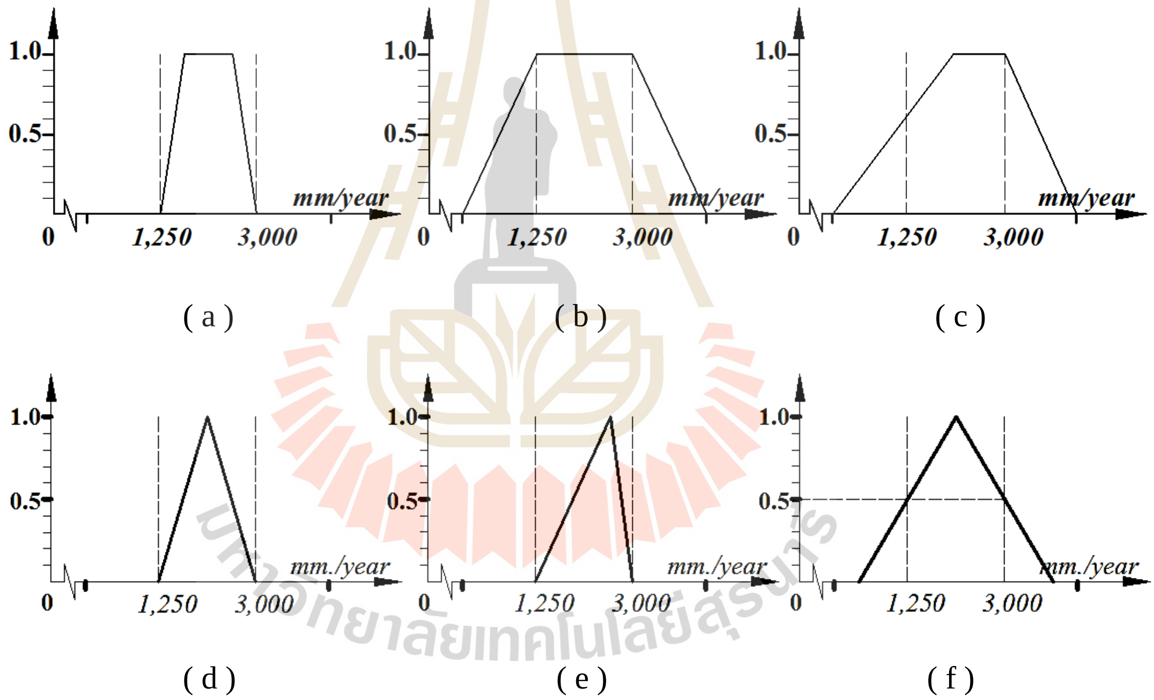


Figure 2.2 Different patterns of membership function in the same conditions.

Figure 2.2 shows that forms of membership function which are trapezoidal and triangular can be built into the membership function of annual rainfall suitable for growing crops and offers significant differences as shown in (a). Those experts have determined that the annual rainfall at 1,250 mm is a member of the annual rainfall in the planting equal to zero, and the amount of rainfall gradually increasing at 1,350-2,900 mm is regarded as the appropriate value in growing crops with a value equal to 1, and then gradually decreases until Zero when the annual rainfall is 3,000 mm. The annual rainfall is 1,250-3,000 mm can be used to generate membership functions for several forms as shown in Figure (b), (c), (d), (e) and (f) with different meaning.

2.1.3 Linguistic variable

In mathematics, variables usually assume numbers as values. A linguistic variable is a variable that assumes linguistic values which are words (linguistic terms). If, for example, we have the linguistic variable "height", the linguistic values for height could be "short", "average", and "tall". These linguistic values possess a certain degree of uncertainty or vagueness that can be expressed by a membership function to a fuzzy set.

Often, we modify a linguistic term by adding words like "very", "somewhat", "slightly", or "more or less" and arrive at expressions such as "very tall", "not short", or "somewhat average" (Kainz, 2010).

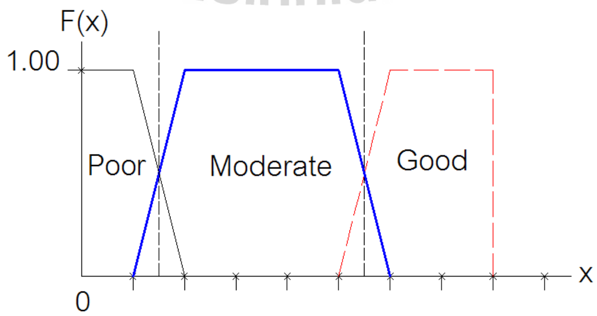


Figure 2.3 Linguistic variables.

In fuzzy set, linguistic variables allow us to know an attribute of what is described both in quality that represents the concepts and knowledge in human communication by using linguistic term and in quantity by using the membership function. Furthermore, these linguistic variables are defined in the class of criteria which are important in the interpretation of the fuzzy logic system, as shown in Figure 2.3.

Figure 2.3 shows that the criteria are classified to 3 classes, Poor, Moderate and Good, respectively, which are used in an inference process.

2.1.4 Operation of fuzzy set

Classical sets are fundamental operations that are generally known as Union, Intersection, Complement, and more. In this case fuzzy set will define these operations called "Standard fuzzy operations" as detailed below.

Considering two fuzzy sets A and B on the universe X, the following function theoretic operations of the set theoretic operations union, intersection and complement are defined for A and B on X (Zimmermann, 2010; Kainz, 2010; Wang, 1997):

- Union of Fuzzy set is OR operation by choosing the maximum value (Max) to be a result of the operation by the following equation,

$$\mu_{\underline{A} \cup \underline{B}}(X) = \text{Max}\,(\mu_{\underline{A}}(X), \mu_{\underline{B}}(X)) = \mu_{\underline{A}}(X) \cup \mu_{\underline{B}}(X). \qquad (2.4)$$

- Intersection of Fuzzy set is AND operation choosing the minimum value (Min) to be a result of the operation by the following equation,

$$\mu_{\underline{A} \cap \underline{B}}(X) = \text{Min}\,(\mu_{\underline{A}}(X), \mu_{\underline{B}}(X)) = \mu_{\underline{A}}(X) \cap \mu_{\underline{B}}(X). \qquad (2.5)$$

- Complement of Fuzzy set is an operation which the value of membership is deducted from the total membership by the following equation,

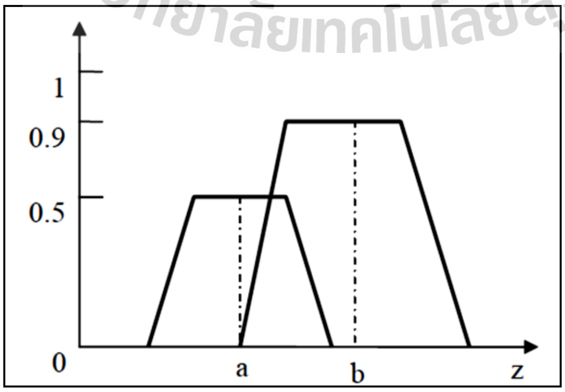
$$\mu_{\underset{\sim}{A}'}(X) = 1 - \mu_{\underset{\sim}{A}}(X). \quad (2.6)$$

2.1.5 Defuzzification

The weighted average (WA) method is the most frequently used in fuzzy applications since it is one of the more computationally efficient methods. Unfortunately, it is usually restricted to symmetrical output membership functions. It is given by the algebraic expression

$$Z^* = \frac{\sum_{i=1}^{N} \mu_C(Z_i) * Z_i}{\sum_{i=1}^{N} \mu_C(Z_i)} \quad (2.7)$$

where Σ denotes the algebraic sum and where Z_i is the centroid of each symmetric membership function. This method is shown in Figure 2.4. The WA method is formed by weighting each membership function in the output by its respective maximum membership value. As an example, the two functions shown in Figure 2.4 would result in the following general form for the defuzzified value:



$$Z^* = \frac{a(0.5)+b(0.9)}{0.5+0.9}$$

Figure 2.4 WA method of defuzzification (Ross, 2010).

2.1.6 Application of fuzzy set theory for land suitability analysis.

Fuzzy set theory has been used extensively for the analysis of land suitability. The theory is also applied together with other methods of MCDA and then enables new techniques in several ways such as: Fuzzy AHP, Fuzzy TOPSIS, etc. There are different purposes for assessment.

2.1.6.1 Ranking of alternatives

Ranking alternatives or assessing appropriate levels is related to goals and criteria values. The criteria values from linguistic variable are sometimes converted into fuzzy numbers. The membership functions (MF) can be specified by different parameters such as triangular MF specified by 3 parameters (l, m, u) or (a, b, c), trapezoidal MF specified by 4 parameters (a, b, c, d). Another characteristic of the rankings is a measure of membership number which is calculated directly from membership function. As a review of the studies of ranking of alternative, there are many forms which can be classified according to source of information created in the analysis below.

1) Converted into fuzzy number with linguistic variables; This process can be displayed as Figure 2.5.

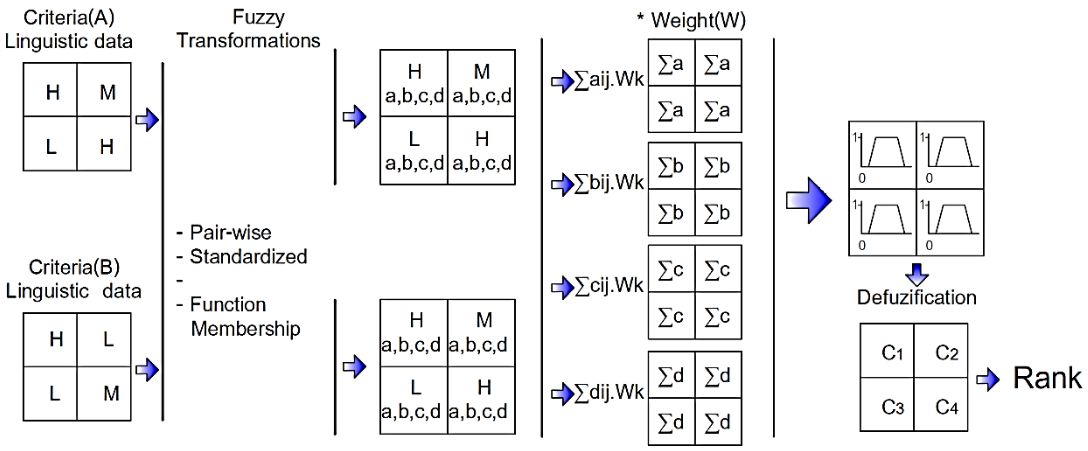


Figure 2.5 Summary of ranking of preference using fuzzy method.

Ranking of preference by Fuzzy Theory can be done by starting from defining levels of ambiguity using linguistic variables. If H is set for high, M is for medium and L is for low and they, then, are converted into the fuzzy numbers by considering the form of membership function such as trapezoidal be represented by a, b, c, and d. Next step is multiplying a, b, c and d of each pixel on criteria map, represented by a_{ij}, b_{ij}, c_{ij}, and d_{ij}, by their criterai weight (Wk, where k is a considered criterion). The outputs of a_{ij}.Wk, b_{ij}.Wk, c_{ij}.Wk, and d_{ij}.Wk are summing to Σa, Σb, Σc and Σd respectively which are used to define fuzzy numbers for difuzzification in order to find crisp values for ranking.

In addition, the linguistic variables can be transformed into a fuzzy number with pairwise comparison techniques by converting the crisp Pairwise Comparison Matrices (PCM) value (Saaty's scale) in the form of fuzzy PCM value (shown in Table 2.1).

Table 2.1 Conversion of crisp PCM fuzzy PCM.

Crisp PCM value	Fuzzy PCM value	Crisp PCM value	Fuzzy PCM value
1	(1,1,1),if diagonal (1, 1,3), otherwise	1/1	(1/1, 1/1, 1/1), if diagonal (1/3, 1,1), otherwise
2	(1, 2, 4)	1/2	(1/4,1/2, 1/1)
3	(1,3,5)	1/3	(1/5,1/3, 1/1)
5	(3, 5, 7)	1/5	(1/7, 1/5, 1/3)
7	(5,7,9)	1/7	(1/9, 1/7, 1/5)
9	(7,9,11)	1/9	(1/11, 1/9, 1/7)

Source: Prakash (2003).

2) Converted into fuzzy membership number with raw data. In

this process raw data are converted by calculating membership function correlated with conclusion data using correlation matrix described by Figure 2.6.

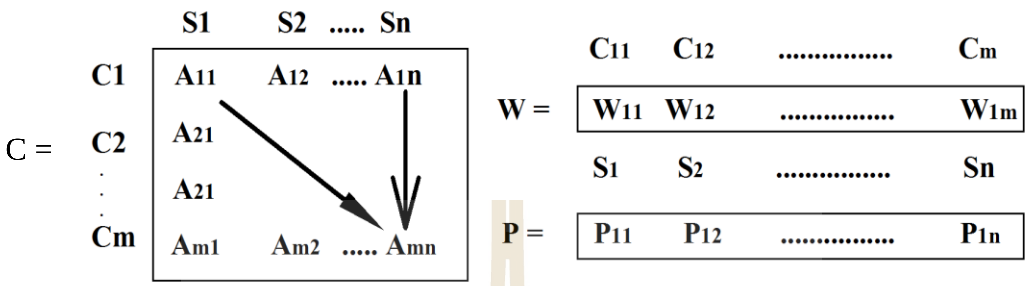


Figure 2.6 Correlation matrix.

In Figure 2.6, A membership matrix (C) is made up of the relationship between criteria(C1, C2, C3, …Cm) and suitability classes(S1, S2, S3, ….Sn) so it is called characteristic matrix; Matrix W is coefficient value matrix or weight matrix and Matrix P is result matrix. Following, we can find a mathematical model for this relationship.

$$P = W \circ C; \tag{2.8}$$

where " ◦ " is the fuzzy set operator (Max, Min, etc…).

These result matrixes of all cells of the study area are later defuzzied and ranked to be land suitability potential for rubber plantation.

2.1.6.2 Fuzzy logic control system

A general fuzzy controller consists of four modules (Klir and Yuan, 1995): a fuzzy rule base, a fuzzy inference engine, and fuzzification/ defuzzification modules. The interconnections between these modules and the controlled process are shown in Figure 2.7.

A fuzzy controller operates by repeating a cycle of the following four steps. First, measurements are taken of all variables that represent relevant conditions of the controlled process. Next, these measurements are converted into appropriate fuzzy sets to express measurement uncertainties. This step is called a fuzzification. The fuzzified measurements are then used by the inference engine to evaluate the control rules stored in the fuzzy rule base. The result of this evaluation is a fuzzy set (or several fuzzy sets) defined on the universe of possible actions. This fuzzy set is then converted, in the final step of the cycle, into a single (crisp) value (or a vector of values) that, in some sense, is the best representative of the fuzzy set (or fuzzy sets). This conversion is called a defuzzification. The defuzzified values represent actions taken by the fuzzy controller in individual control cycles (Klir and Yuan, 1995).

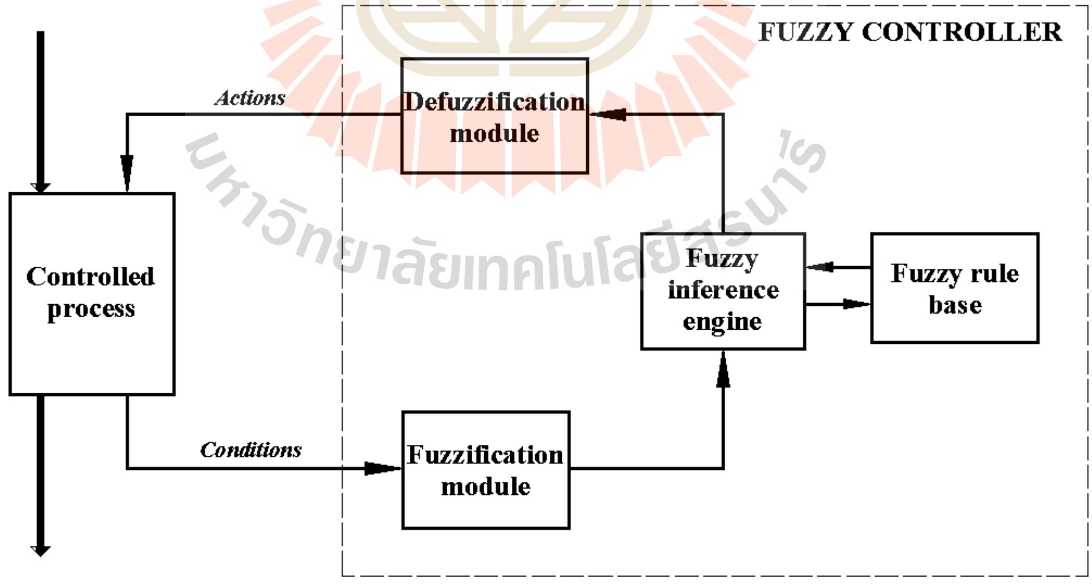


Figure 2.7 A general scheme of a fuzzy controller **(**Klir and Yuan, 1995).

2.1.7 Fuzzy logic systems and mamdani's fuzzy inference method

The fuzzy inference method has invented and developed in several ways. Among those methods, Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. The method employs the minimum operator to combine the sentences with "and" and exercises the maximum operator to combine the sentences with "or".

A Mamdani's Fuzzy Inference method is composed of the membership functions of the inputs, fuzzy if-then linguistic rules, and output membership functions (Grima, 1999 quoted in Ghehi, Jafari and Malekmohammadi, 2013; Alonso, n.d.). Several studies have used Mamdani's Fuzzy Inference method (Ghehi, Jafari and Malekmohammadi, 2013; Kansal and Kaur, 2013; Akgun, Sezer, Nefeslioglu, Gokceoglu and Pradhan, 2012). This method is one of the most appealing fuzzy methods to employ environmental assessments. The general fuzzy logic system can be depicted in Figure 2.8.

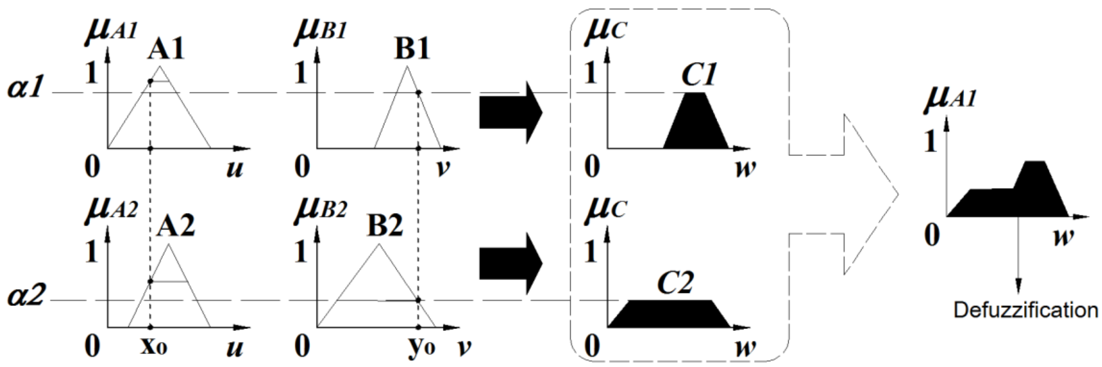


Figure 2.8 Fuzzy inference process (Phayung Meesad, 2013).

In Figure 2.8, Fuzzy Inference Process consists of criteria A and B where A is separated to 2 fuzzy sets, A1 and A2, and B is separated to 2 fuzzy sets, B1 and B2. After considering the relation of these two criteria, there are two rules of interpretation acquired. They are “If A=A1 and B=B1 then C=C1” and “If A=A2 and B=B2 then C=C2”. Then the system can be done by following procedures.

First, calculate α1 and α2 or the minimum membership number of the criteria considered of each rule (in this case, they are A and B).

$$\alpha 1 = A1(x_0) \cap B1\,(y_0) \tag{2.9}$$

$$\alpha 2 = A2(x_0) \cap B2\,(y_0) \tag{2.10}$$

Then, calculate α1 and α2 with the following equations. The output of each rule is $C_1^{'}$(w) and $C_2^{'}$ (w) respectively,

$$C_1^{'}(w) = (\alpha 1 \cap C1\,(w)) \tag{2.11}$$

$$C_2^{'}(w) = (\alpha 2 \cap C2\,(w)) \tag{2.12}$$

After that, combine the output of each rule.

$$C(w) = C_1^{'}(w) \cup C_2^{'}(w) = (\alpha 1 \cap C1(w)) \cup (\alpha 2 \cap C2(w)) \tag{2.13}$$

Finally, the output is converted to a suitable single value (Defuzzification). The data in the fuzzy form is converted to the sum value or the system controlling value.

2.1.8 Creating rules for the inference results

Creating rules for the inference process of Fuzzy logic systems can be conducted in 2 different ways.

2.1.8.1 Determined by experts

A specialist defines a relationship of the Criteria with results as many as possible in the IF-Will or Then rules where linguistic variables defined. Since these rules are general basic logic, there are not much different. For example, if they are cultivated in the area with good existing ground water and good soil, plants will yield well etc. It is important that professionals must understand about data range and corresponding language variables. Typically, basic criteria about these issues are configured out before.

As recommendations of the Rubber Research Institute of Thailand (2010) on rubber plantations: the rubber trees grow well in an environment where: rainfall is more than 1,250 mm/yr, the number of rainy days is 120-150 days, the dry season is not over 4 months, a temperature range is between 26-30 ^{o}C, an area slope is less than 35 %, a soil depth is more than 1 m, the type of soil is a clay loam soil or sandy soil without gravel or a layer of compacted shale, soil pH is between 4.5 and 5.5, it is located 0-200 meters above mean sea level (msl) and water drainage is good. By setting up a new sample, the linguistic variable rainfall data is shown in Table 2.2.

Table 2.2 The appropriate level of rainfall suitable for planting rubber.

Linguistic variables	Good	Medium	Poor	Non-suitable
Rainfall (mm./yr)	> 1,500	1,250-1,500	1,100-1,250	< 1,100

In the Table 2.2, the appropriate levels of rainfall for planting rubber are ranked into very good, medium, poor and not. All of these levels have the amount of rainfall placed on. Therefore, the specialist needs to understand the relationship of language and the values of the variables in these matches.

2.1.8.2 Analysis of sample data

In this approach, data are collected for representing a sample group such as a fuzzy set of output ADS which is classified to 3 classes of average ADS: very good, medium, and low representing ADS of over 290 kg/yr, 280-250 kg/yr and less than 200 kg/yr, respectively. Enough data collection of each group will need to be done. After data collection, the data will be analyzed in order to determine inference rules in the Fuzzy Logic system as following steps.

1. Classify information of premise data with scatter plot for the relationship between criteria values. For example, the scatter plots of the data about 3 classes of the conclusions, good (Δ), fair (o), and poor (×) and 3 premises of the criteria (Attribute 1, Attribute 2, Attribute 3) which have the result as in Figure 2.9. Figure 2.9 shows available relationship with 3 criteria: Attribute 1, Attribute 2 and Attribute 3 respectively which are scatter plotted to 9 cases: Attribute 1 and 1, Attribute 1 and 2, Attribute 1 and 3, Attribute 2 and 1, Attribute 2 and 2, Attribute 2 and 3, Attribute 3 and 1, Attribute 3 and 2 and finally Attribute 3 and 3. When considering, it is found that (the dashed lines show the division by the group for each dimension) Attribute 1 should be divided into 2 fuzzy sets {Low1, High1}, Attribute 2 should be divided into three fuzzy sets {Low2, Medium2, High2} and Attribute 3 should be divided into three fuzzy sets {Low3, Medium3, High3}.

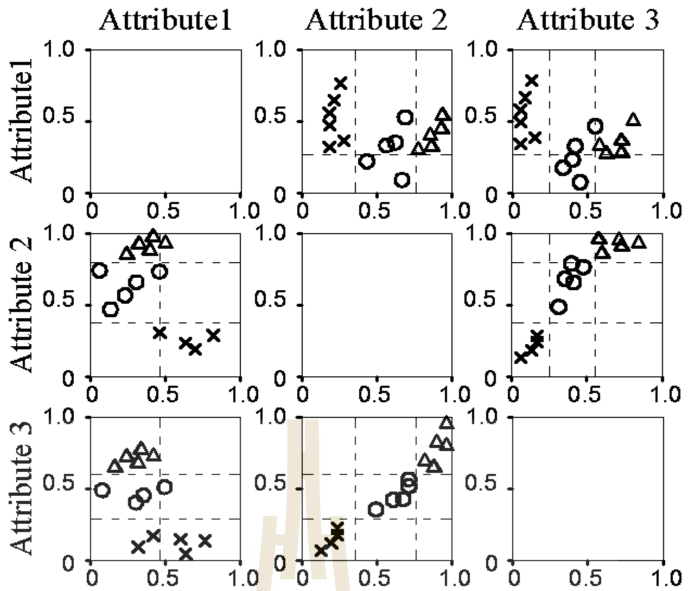


Figure 2.9 Scatter plots of good (Δ), fair (o) and poor (×) classes.

(Phayung Meesad, 2013)

2. Determine the appropriate values of the classes of criteria and then create the membership function.

3. Define membership function of the conclusion, such as the ADS product where good is more than 400 kg/yr, moderate is 400-250 kg/yr and poor is 250-200 kg/yr (Somjate, Prasat, and Prapat, 2003). The ambiguity in the connection between groups can be expressed as the Figure 2.10.

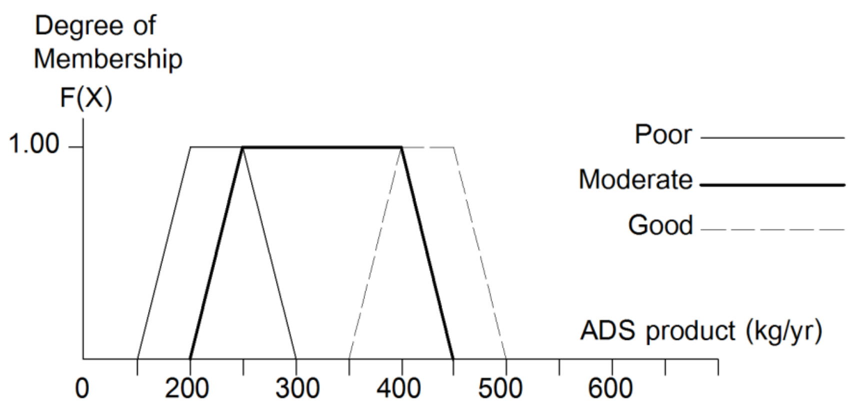


Figure 2.10 Function membership of rubber product.

Figure 2.10 shows 2 overlapping durations of the ADS product, 200-300 kg/yr and 350-450 kg/yr which are ambiguous. The rubber product from 200-300 kg/yr can be both poor class and moderate class and 350-450 kg/yr can be both moderate class and good class.

4. Convert the data into a symbol of Linguistic variable fuzzy sets and compared to the total collapse of redundant rules, for example, "1" refers to "Low", "2" refers to "Medium" and "3" refers to "High" as the example below.

From the Table 2.3 and 2.4 it can be seen that when converting the data from the raw data as a number representing the linguistic variable, then there will be some duplicate rows and collapse together with only 6 sets shown in the Table 2.4 on the right.

Table 2.3 Compared with data in fuzzy sets.

x1	*x2*	*x3*	*y*
1	1	1	1
2	1	1	1
2	1	1	1
2	1	1	1
2	1	1	1
1	2	2	2
1	2	2	2
1	2	2	2
1	2	2	2
2	2	2	2
2	3	3	3
1	3	3	3
1	3	3	3
1	3	3	3
1	3	3	3

Note: "1" is "Low", "2" is "Medium" and "3" is "High".

Table 2.4 Existing rules.

x1	*x2*	*x3*	*Y*	*Count*
1	1	1	1	1
2	1	1	1	4
1	2	2	2	4
2	2	2	2	1
2	3	3	3	1
1	3	3	3	4

Note: "1" is "Low", "2" is "Medium" and "3" is "High".

Fuzzy rules are shown in the following sentence.

Rule1: If x1 is Low and x2 is Low and x3 is Low, THEN y is Low

Rule2: If x1 is High and x2 is Low and x3 is Low, THEN y is Low

Rule3: If x1 is Low and x2 is Medium and x3 is Medium, THEN y is Medium

Rule4: If x1 is High and x2 is Medium and x3 is Medium, THEN y is Medium

Rule5: If x1 is High and x2 is High and x3 is High, THEN y is High

Rule6: If x1 is Low and x2 is High and x3 is High, THEN y is High

This study was designed to create rules based on two techniques which are experience of experts and phenomenal reality by considering the samples collected.

2.2 Previous researches of land suitability analysis for agriculture

Land suitability analysis methods for agriculture are generally done for the purpose of finding a result that indicates the priority or the suitability of choice such as highly suitable, moderately suitable, marginally suitable and not suitable by using criteria for making decision. They are Sieve analysis, Multiplication, SAW, AHP, TOPSIS, Fuzzy and combine multiple ways or hybrid methods such as Fuzzy TOPSIS, and Fuzzy AHP. Following are some examples of related researches.

2.2.1 Application of fuzzy set theory for land suitability analysis

The fuzzy Logic theory has been used in the study of Spatial analysis problems. Many researches have expressed that fuzzy set theory, which is a generalization of Boolean algebra to situations where data are modeled by entities whose attributes have zones of gradual transition, rather than sharp boundaries, offers a useful alternative to existing methodology. The Fuzzy logic theory has been applied to several studies in land suitability issues as following examples.

Goharnejad, Zare, Tahmasebi, Asadi, and Ebrahimi (2015) used Mamdani-type inference. They applied dataset of a rangeland in North-western Iran to check the generalization capability of the Mamdani model: the grazing capacity derived from the Mamdani-type inference was compared with traditional grazing capacity measured for these rangelands. The results showed that slope was the most important factor followed by forage production and soil resistance to erosion and water supply distances respectively. The RMSE and correlation coefficient of Mamdani model were minimized by 0.68 and 0.61, respectively.

Qiu et al. (2013) analyzed the distribution of kudzu in the conterminous United States by 3 fuzzy evaluation classic models including fuzzy logic pass / fail screening, graduated screening and weighted linear combination, except that they also presented a geometric average aggregation. The study showed the method for incorporating fuzzy suitability membership of environment factors in the modeling process. These fuzzy models also produced more informative fuzzy suitability maps. Through a defuzzification process, these fuzzy maps could be converted into conventional maps with clearly defined boundaries, suitable for use by individuals uncomfortable with fuzzy results.

Elaalem (2013) compared two approaches to land suitability evaluations; Parametric and Fuzzy AHP methods to model the opportunities for olive production in Jeffara Plain of Libya. The results of Fuzzy MCE showed that the majority of the study area was highly suitable for olive production, while the results obtained from using the parametric method showed that most of the study area was moderately suitable for olive production.

Keshavarzi et al. (2010) determined land suitability class in each land unit by using the matrix of land suitability (E) and calculating them after multiplying the characteristic matrix (R) in each land unit by the weights matrix (W). The weight contributions of individual characteristics to observed yield were determined by using the analytic hierarchy process (AHP). The results of this study indicated that the fuzzy method with higher correlation factor (R=0.91), had more accuracy and capability when predicting yield, since fuzzy set method considered the continual land changes and was more efficient in reflecting spatial variability of soil characteristic rather than Boolean's two-valued logic that overlooked a considerable section of useful information.

Maleki, Landi, Sayyad, Baninemeh and Zareian (2010) studied on application of fuzzy logic to land suitability for irrigated wheat to determine the quantitative impact of land qualities on irrigated wheat production, using fuzzy set (FS) theory. The theory was applied and compared with conventional Parametric-Stories (PS) method in a land suitability assessment for irrigated wheat production for two different regions. Those two methods' performances were evaluated by comparing the relationships between observed yields and calculated land indices. Results showed that, for both regions, land suitability indices produced by FS method showed higher correlation with observed yields than those produced by conventional PS method. The coefficients of determination (R^2) between land suitability indices and observed irrigated wheat yield using FS and PS methods were, in Sardasht-Behbahan, 0.89 and 0.84, respectively. The same result, but with the sharp difference between two methods, were obtained in Neiriz-Fars-plain using FS (R^2=0.80) compared to PS method (R^2=0.34). Therefore, it could be calculated even in situations where conventional methods could not well estimate crop yield. The fuzzy method could improve the quality of land suitability assessment.

Reshmidevi, Eldho and Jana (2009) adopted Mamdani implication method and developed it in Geographic Information System (GIS) environment to assess the land suitability pertaining to the specified crop with a fuzzy rule-based inference system, considering both land potential and surface water potential. This approach was proposed in this study in which the attributes were systematically classified into different groups to estimate the intermediate suitability indices. Weighted linear aggregation method and Yager's aggregation method were used for estimating the aggregated effect of the attributes in each group and the results are compared. Further, the rule-base was developed by using the intermediate land suitability indices. The model was applied to a subwatershed of Gandheshwari area in West Bengal (India). The input attributes were prepared in raster map format in the GIS environment by using ERDAS IP ver. 9.1 and the output was generated in the form of thematic map showing the suitability of each cell (20 m x 20 m) for the selected crop. For the land suitability evaluation problem in the case study area, Yager's aggregation method found more appropriate than the commonly used weighted linear aggregation method. From the analysis, 23 % of the existing paddy fields were found less suitable/not suitable for paddy due to the poor surface water potential or unsuitable terrain conditions of the area. The method, integrated with GIS, was found efficient in handling large amount of attribute information, and was useful in the land suitability assessment in agricultural watersheds.

Kurtener, Torbert and Krueger (2008) performed Evaluation of Agricultural Land Suitability with Application of Fuzzy Indicators. Composite fuzzy indicator gave the opportunity to obtain a weighted average estimation of land suitability across all of the attributes. It was found that further development of this fuzzy indicator tool would be advantageous for application in future studies for elaboration of problem-oriented research.

Braimoh, Vlek and Stei (2004) evaluated for Land suitability index of Maize Based on Fuzzy Set in Northern Ghana. The assessment used data from a random sampling across the study area with 120 series and then assessed the Membership number and multiplied by the weight. The results were used to evaluate the relationship Interpolated land suitability which showed a high correlation (R^2= 0.87) with observed maize yield at the village level.

Prakash (2003) used the fuzzy AHP technique to implement the analysis of suitability of the Rice crop in the Doiwala Block of the Dehradun District, Uttataranchal, India. It was found that Fuzzy AHP performed better than rest of AHP, Ideal Vector Approach (IVA).

Ahamed, Rao and Murthy (2000) studied 9 parameters (eight of soil and one of topography). Suitability analysis was carried out by fuzzy membership classification with weighing factors including relative importance of the soil parameters governing the crop productivity. The weight was obtained from the traditional approach, pairwise comparison method. The approach was also found to be advantageous to determine the crops of highest suitability for a given area, so that decisions could be made to grow appropriate crops and derive optimum production.

Ranst, Tang, Groenemans and Sinthurahat(1996) used relationships between membership values of criteria and a latex yield to determine the weight of criteria in application of fuzzy logic to land suitability for rubber production in peninsular Thailand.

The proposed method differed from the usual technical land evaluation procedures by (1) the use of an explicit weight for the effect of each land quality on crop performance, and (2) the way for combining the evaluation of land qualities into a final land suitability class or land suitability index. The methodology was tested by comparing the estimated yields and land indices calculated by fuzzy set theory with those obtained by conventional procedures: (1) Maximum limitation method; (2) Parametric-Stories method, and (3) Multiple linear regressions. In the last approach the land index was replaced by the predicted relative yield from multiple regressions on the various land qualities. The results obtained with the latter method were in better agreement (R^2=0.89) with the observed yields as compared to those obtained with the other three methods: maximum limitation (R^2=0.19); Parametric-Stories method (R^2= 0.81); multiple linear regression (R^2=0.81).

Baja, Ramli and Jayadi (n.d.) assessed the suitability of the land by using fuzzy logic theory in the evaluation of the factors taken into consideration the suitability and combined them by using a convex combination function to produce a join membership function (JMF) of all attributes , Y as follows:

$$JMF(\mathrm{Y}) = \sum_{i=1}^{n} \lambda i . MF(xi), \tag{2.14}$$

where λi was a weighting factor for the *i* th land property x, and *MF(xi)* denoted a membership grade for the *i* th land property x.

The result of this research showed that the coefficient of correlation of the result and existing corn yield was relatively low (R=0.61). They discovered that it was due to differences in land management in each point of sampling. Land management could give very different crop yields although the land areas had relatively the same level of suitability. These identified difficulties of validation against crop yields. It was almost impossible to precisely find out different areas or farms of the same crop types with the same land management practices.

It can be seen that application of fuzzy set theory for land suitability analysis can take many forms, which is similar to that of the land suitability classes to assess form of the membership value of criteria multiplied by the weight. The results of the study in the form of index numbers of land suitable level can indicate the relationship of the land suitability level.

2.2.2 Other models and methods

Sutus Dansakulpon, Somyot Sinturahut (1999) defined rubber plantation areas in the south by assessing land, togethered with remote sensing techniques and geographic information factors including rubber production from soil suitability index and climate in the areas for evaluation of terrain. The survey found that about 5.7 million rai of the rubber plantation area was in suitable areas, around 1.2 million rai of the rubber plantation area was in medium level and about 3.5 million rai of the rubber plantation area was not in recommended areas.

Surajit and Suwat (2011) combined layers of climate and soil data by Storie's Method in the evaluation identified a potential land for rubber plantation in Ubon Ratchathani. The percentages of lands suitable for growing rubber were 23,32,29,13 and 3 for Paradise appropriate, reasonable, moderate, space suits, and unsuitable respectively. The suitable areas were in the west, north and south of the province where the average rainfall was more than 1,600 mm/yr.

Charat and Wasana (2010) used geographic information systems and developed spatial model to evaluate land suitability for rubber plantation in Northeast

Thailand. The land suitability evaluation based on the Food and Agriculture Organization of the United Nations [FAO] concept of land evaluation was conducted by an overlaying analysis of land qualities. The overlay operation with a multiplication of the factor rating as defined criteria provided the suitability classes of land. The result indicated that the suitability area was approximately 5,576,102, 17,621,538, 20,084,414 and 62,233,782 rai for highly suitable, moderately suitable, marginally suitable and unsuitable levels respectively.

Somjate Phathumintra et al. (2003) from Rubber Research Institute, Department of Agriculture evaluated potential areas for growing rubber trees by considering factors that affected productivity, and using a model of developed rubber production including factors of climate, soil conditions and the suitability of the physical factors and provided 3 appropriate levels. They found that there was not any area in an optimum level or L1 where potential for rubber production was higher than 400 kg/rai/yr., but 19,314,052 rai were in suitable level L2 where the potential for rubber production was higher than 250-400 kg/rai/yr., and 5,843,731 rai were in L3 which was a limited space and the potential for rubber production was under 250 kg/rai/yr.

Somjate Phathumintra and Pramote Suwanmongkhon (1987) evaluated suitability of soils and climates in the Northeast. The results showed that the area planted rubber level 2 (L2) which was expected to yield 258-386 kg/rai/yr. was 299,996 rai, the area planted rubber level 3 (L3) which was expected to yield 125-258 kg/rai/yr. was 9,462,859 rai and the area planted rubber level 4 (L4) which was expected to yield less than 125 kg/rai/yr. was 6,513,000 rai.

Sathaporn and Charat (n.d.) adopted geographic information systems and developed spatial model to evaluate land suitability for rubber plantation in the Northeast of Thailand as Charat Mongkolsawat and Wasana Putklang (2010). The result showed that suitability area was approximately 10,878,683, 15,352,554, 25,144,424 and 40,444,220 rai for highly suitable, moderately suitable, marginally suitable and unsuitable levels respectively.

2.3 Synthesis of the research approach and study orientation

2.3.1 Using fuzzy logic method for decision making

According to the review, the Fuzzy logic theory can be applied in two aspects: ranking of preference (as appeared in 2.1.6.1) and estimation of the system (as appeared in 2.1.6.2). This study requires result for rubber plant land suitability in terms of productivity. This kind of result expresses more objective and certain information. Therefore, fuzzy logic control system is selected to use as the research procedure.

Fuzzy logic control system is the system using knowledge-based or IF-THEN rules. For example, if the rules of the management of the crop is IF irrigation is good, and fertilization is excellent, THEN growth will be good; IF irrigation is medium and fertilization is medium, THEN growth will be moderate; IF irrigation is low and fertilization is low, THEN growth will be low and etc. The inference is done in all rules and results from all the rules are transformed to be the crisp value by defuzzification. This fuzzy analysis can be reorganized to incorporate with spatial data as flow diagram shown in Figure 2.11.

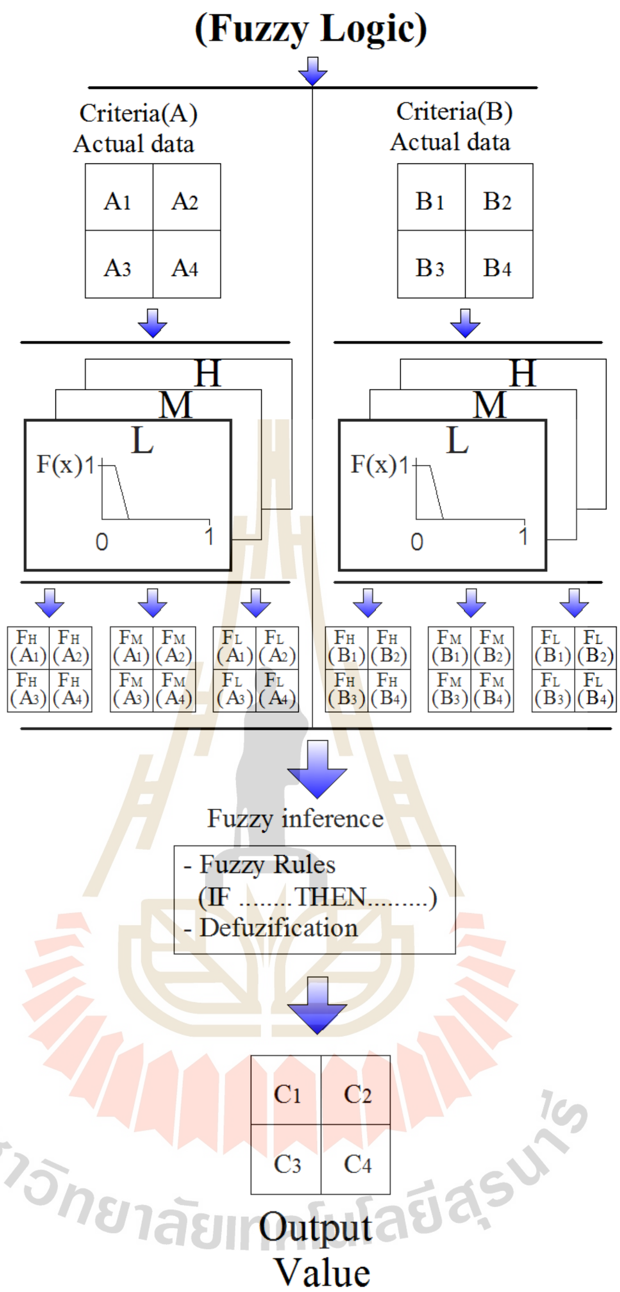


Figure 2.11 Spatial data analysis using fuzzy logic theory.

In Figure 2.11, actual criteria data A and B are input data containing fuzzy classes (H, M, and L for High, Medium, and Low) available in membership for determining process. These membership values are used in the inference by rules developed, and their results are combined before defuzzification. The final output is obtained as an estimating value of the system represented by crisp number.

2.3.2 Study orientation

1. Criteria used are similar to the previous studies. The difference in this study is to incorporate management criteria into land suitability analysis. The classification of management level as input into the system relies on expert opinion while the generation of land suitability maps relies on scenarios of management set up.

2. Criteria used, which always contain data with uncertainty, are classified in form of fuzzy sets using fuzzy membership functions developed in this study before applying in the decision rules.

3. The specific decision rules for incorporating fuzzy sets of criteria are developed in form of conditions based on actual data synthesis to achieve economic land suitability maps.

4. Mamdani's fuzzy inference is applied to incorporate results from decision rules. The basic criteria combining operation of this process is fuzzy intersection or minimization. The result reflects the conservative consideration that provides more economical confidence for its further use.

5. Validation is planned to operate using data from the survey visiting as many representative sites as possible.

CHAPTER III

RESEARCH PROCEDURE

Research procedure can be generalized as a flow chart shown in Figure 3.1

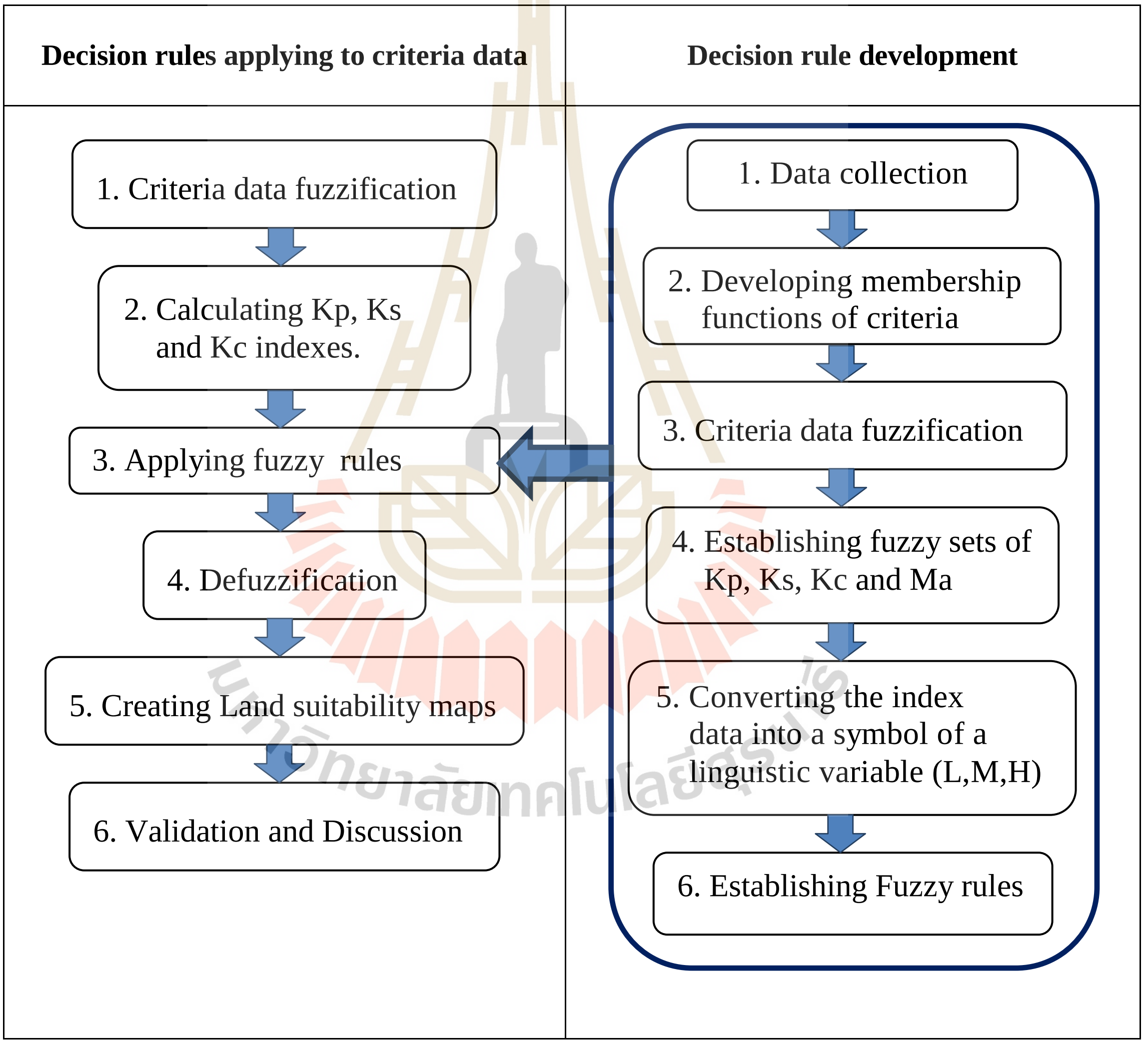


Figure 3.1 Flow chart of the research procedure**.**

The flow chart shows the process from the Decision rule development, which is explained in Section 3.3. After system rules acquired, the land suitability analysis for rubber plantation can be performed by calculating maps of Criteria to find fuzzy number from fuzzy membership function of each criterion, then calculating Kp, Ks and Kc indexes by aggregating with Storie's method, applying Kp, Ks and Kc to the acquired fuzzy rules in order to find outputs of each management level- high, medium or low. Next step is defuzzification. The results of this step are amount of ADS per year of each pixel which are used for creating land suitability maps in 3 scenarios. Last step is validation and discussion.

3.1 Criteria selection

Rubber plantations can provide good yields or not, depending on 3 major factors: clones of rubber trees, environment, and management. The environment and management are factors that must be considered together. This study took the studies related to the optimum levels of criteria of Saichai Suchartgul, Somsak Maneepong, and Montree Issarakrisila (2012); Somjate Pratummintra (2000), and the Department of Agriculture (DOA, 2012) to determine membership functions.

3.1.1 Soil conditions

Soil conditions which were taken into land suitability assessment for rubber plantation were categorized as follows.

1) Physical Properties

- Soil texture

Soil suitable for rubber plantation should contain not less than 35 % clay, so that it can retain moisture and absorb nutrients well. It should also be composed of more than 30 % sand, so that it can be well ventilated. It can be classified as Clay (C), Clay Loam (CL), Loam (L) and Sandy Loam (SL).

- Effective soil depth

The suitable depth of rubber root should be more than 1 meter over gravel, solid rock, or lateritic layer. This will allow rubber root penetration. A good soil depth helps the plant to tide over the drought season more efficiently as moisture stored.

- Soil slope

Rubber planting areas should be a flat surface or less than 35 degrees of slope. Rubber planting in areas with high slope can cause leaching of the soil surface and if there is very heavy rainfall over several days, it may cause landslides easily.

- Soil drainage

Rubber trees should be planted in an area with well drained. Well drained soils are essential for optimum growth and yield of rubber plants. In marshy areas, owing to poor physical properties and waterlogged conditions, growth of rubber is always found to be very poor.

- Flood period

Rubber trees, less than 4 years old, endure flooding for up to 5-10 days. The rubbers, over 5 years old, endure the flooding for about 2 weeks to 2 months. Nevertheless, areas without flood disturbance are strongly recommended. In addition, a groundwater level should be deeper than 1 meter and the area should not be paddy field or marsh.

2) Chemical Properties

According to the related studies, chemical properties of soil should have suitable macronutrients of soil for rubber planting: Phosphorus (P) of 10-20 mg/kg, Potassium (K) of 40-80 mg/kg, and Organic matter (OM) of 1.0-2.6 % and pH of 4.5-5.5 with non-saline condition.

3.1.2 Climate

Zoning suitable for rubber plantation is mostly determined by rainfall. Southern area is beginning of the rubber plantation in Thailand, with mean annual rainfall (MAR) between 1,800-5000 mm in the number of mean annual rainy days (MARD) between 159-227 days. In addition, in the eastern part of Thailand, MAR is between 1,200-5,000 mm with a number of MARD is between 119-227 days. If the MAR is low, it will affect rubber growth, survival rates and yield.

- The average annual rainfall

A rubber tree grows well in areas with regularly raining throughout the year. The optimum MAR should be 1,800-2,500 mm. The most popular areas of rubber plantation of Thailand are in the South and East where MAR exceeds 1,800 mm. However, potential of areas with MAR lower than 1,800 mm as in the Northeast and North can be considered as well.

- Dry season

When entering the dry season, the rainfall is less than the water demand of the rubber. If dry period is longer than 3 months, it will affect the growth of rubber trees which can be determined by the index of humidity (*Ih*). If the *Ih* is < 0.5, it indicates that the month is too dry. If *Ih* is > 1, it indicates that the volume of water exceeds demand in that month. The *Ih* values can be calculated by the equation below.

$$Ih = R / ETc \tag{3.1}$$

R is monthly rainfall.

ETc is water demand of the rubber tree calculated from crop coefficient multiplied by the reference crop evapotranspiration (ETo) with Penman-Monteith approach.

- Loss of tapping days

Loss of tapping days due to heavy rain is not as a major problem of rubber plantation in the northeastern region, but drought severity can cause low latex because high temperature and low humidity can indicated the vapor pressure deficit (*VPD*). If *VPD* is greater than 11 mbar, the latex will stop very quickly after tapping (Ninane, 1985, quoted in Somjate, 2000). *VPD* is calculated by the Equation 3.2.

$$VPD = \left(1.00 - \left(\frac{RH}{100}\right)\right) * p^{sat}(T) \tag{3.2}$$

As the equation, *VPD* can be calculated from Relative Humidity (*RH*) and saturated vapor pressure of water (P^{sat}) in kPa (10 mbar) at temperature (*T*) in °K.

- Temperature regime

Rubbers with normal growth can be tapped at the age of about 6 years. Optimum temperature is 24-28 °C on the area with elevation less than 200 m above mean sea level. The rubbers grow 6 months more slowly than normal for every increasing 100 m of the elevation. Every increase of 100 m elevation can cause the temperature to decrease by 0.5 °C.

- Wind speed

The wind can cause damages to the rubber trees. Rubber plantation areas should have an average wind speed less than 1 m/s. The wind speed between 2-3 m/s can affect the growth and latex product.

Accordingly, all factors would be reclassified to affect specifically for the immature period (growth before tapping) and mature period (rubber product) as shown in Table 3.1.

Table 3.1 Crop requirements for rubber plantation.

Crop requirements
Soil conditions
1) Physical Properties
- Soil structure
- Effective soil depth
- Soil slope
- Soil drainage
- Flood period
2) Chemical Properties
- N, P, K, pH
- Saline soil
Climate factors
- The Average annual rainfall
- Dry season
- Losses of tapping days
- Temperature regime
- Wind speed

3.1.3 Management of rubber plantation

Plantation management is a factor that makes a successful planting. Rubber can grow faster and be tapped in good timing depending on the following management.

1) Replacement planting

Rubber replacement should be conducted as soon as possible if dead rubber trees are found. Replacement should use a rubber of similar size. If the rubbers are planted more than 2 years, replacement planting should not be performed because they will grow too much differently. Moreover, it should be planted in early rainy season.

2) Pruning

Pruning stems of the rubbers provide appropriate trunk area to make a high quantity of latex. It also increases total leaf area and increase stem size.

3) Plantation maintenance during dry season

- To retain moisture in soil, straw or crop residues can be used to cover 5-10 cm around the rubber stem.

- To protect sunburn in dry season, a solution of lime mixed with water in a ratio of 1:2 can be applied on the base of rubber stem.

- To protect the rubber trees from fire, protection path and plant debris cleaning should be conducted not less than 3 m from the rubbers.

4) Fertilizing

Both organic and chemical fertilizers should be applied. Organic fertilizer is helpful in improving soil structure; provides macronutrients and micronutrients to the soil. Chemical fertilizer provides micronutrients. Fertilizer grade needs to be considered based on age and type of soil. A suitable period of fertilization is when planting has suitable soil moisture.

- Fertilizing in immature period.

DOA recommended fertilizer for the rubber trees in the Northeast as shown in Table 3.2.

- Fertilizing in a mature period

DOA (2012) recommended 2 types of fertilizers for the rubber trees in a mature period grade 29-5-18 for all soil types, and the fertilizer based on N, P and

K in the soil.

Table 3.2 Fertilizer for rubber in the Northeast.

Age	Clay Loam (kg/rai/yr) Fertilizer grade 20-10-12	Sandy Loam(kg/rai/yr) Fertilizer grade 20-10-17
1	18	23
2	26	31
3	27	32
4	27	37
5	31	43
6	31	50

5) Weeding

Weeds should be eliminated to increase growing rates of the rubber trees.

6) Planting legume cover crops in the rubber tree planting area

Legume cover crops can increase soil organic matter, improve soil structure, maintain moisture in the soil and prevent erosion of the soil. This makes rubber trees grow faster and higher yield.

7) Rubber tapping

The rubber production can be exploited when the circumference of the trunk at 150 cm is 50 cm. The factors that are important to support higher yields of latex are as follows:

- Depth of tapping

Tapping should be done as close as the cambium of rubber bark. Cutting too deep can damage the regenerate bark which effects to tapping.

- The number of rubber trees tapped per day

A number of rubber trees that can be tapped exploited depend on the size of the rubber trees, length of creases, characteristic of the area, and expertise of tappers. In cutting S/2 d2, one man can tap 450-500 trees per day or in cutting S/3 d/2, one man can tap 650-700 trees a day. Overload rubber tapping can cause the rubber trees damaged.

- Tapping time

Tapping can be conducted from night to morning. Yields are not much different. Experiments of tapping in different time showed that latex harvested in the morning period, 6:00-8:00, was around 4-5 % less than latex harvested during 3:00-6:00.

- Bark consumption

Tapping a thick or thin bark does not affect the yield of the latex. But the thick trees bark can make shorter tapping life.

- Sharpness of a knife

Rubber latex can flow better and a little shell is consumed if a sharp knife is used.

Mapping on suitable area for rubber plantation in the past usually considered physical factors only while the level of plantation management was not taken into consideration due to its difficulty on evaluation. In practice, this leads to the presence of conflicts. For example, some areas with good physical factors but low plantation management provide a low yield; conversely, some areas with poor physical factors but high plantation management provide higher yield. This is because differences in plantation management. The better management of course provides the higher yield.

3.2 Development of membership functions of criteria

The development or selection of a suitable membership function of a fuzzy set is one of the most important activities in fuzzy logic. It is a responsibility of a user to select a function which is the best representation of the fuzzy concept to be modeled. The following criteria are valid for all membership functions.

In fuzzy logic analysis system, a fuzzy number can be configured by estimating from actual data in the past or average values defined by experts. They will be then used to create a membership function. This process is a key of thinking methods and a solution of fuzzy systems. There are usually several kinds of shapes of the function such as triangular, trapezoidal, Gaussian, bell-shaped, smooth, Z-membership, positive linear, negative linear and sigmoidal (Yanar, 2003; Phayung Meesad, 2013). In this study, the shapes and the upper and the lower critical bounds of the membership function are selected based on characteristics of criteria data.

The bounds of a fuzzy set of each factor is determined from research reports. For example, Rubber Research Institute of Thailand (RRIT, 2010) proposed that the rubber trees grow well in an average temperature, between 26-30 °C, throughout the year while Pramote Suwanmongkon, et al. (1984) proposed that the annual average temperature should be between 24-27 °C. This information is ambiguous by nature. Accordingly, when considering the temperature, the range of 24-27 °C is recognized synchronization of the two studies. Therefore, fuzzy membership function can be established from this observation as shown in Figure 3.2.

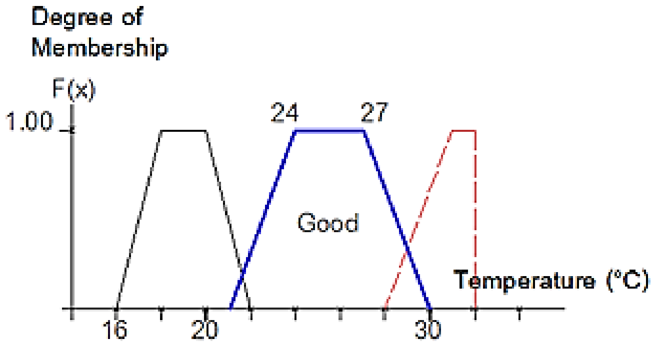


Figure 3.2 Membership functions of temperature regimes.

3.3 Decision Rule Development

Rules of fuzzy logic systems in this study were developed by synthesizing sample data collected from the field investigation (150 samples for this case). The sequence of the approach is shown in Figure 3.1.

3.3.1 Data collection: Data used to create rules of Mamdani's fuzzy inference were collected by interviewing owners of the rubber plantations together with physical and chemical information from the locations on soil maps.

3.3.2 Developing the membership functions of Criteria: Determine the membership functions of criteria were developed from crop requirement information of the DOA and related researches.

3.3.3 Criteria data fuzzification: The data collected were calculated to find suitability scores of the memberships of criteria.

3.3.4 Establish Kp, Ks, Kc and Ma indexes: Criteria at each sample point were characterized and identified that the number of criteria was too big. To reduce the number of criteria, they were grouped and transformed to be physical soil (Kp) chemical soil (Ks), weather (Kc) and plantation management (Ma) indexes by identifying fuzzy membership of each criterion and combing by Stories's method in the same group. Those groups of criteria including index of plantation management (Ma) were used as premise criteria to create rules for inferencing ADS by the fuzzy logic system.

Verheye (n.d.), National Science Foundation Flanders/Belgium and Geography Department University Gent, Belgium mentioned that systems might differ in the factors including both in terms of nature and amount of parameters and in their mathematical manipulation. Three main kinds of manipulation were recognized: additive, multiplicative and complex functions. The best-known parametric system for rating the quality of the land was the Storie index. The Stories's method was described by the following Equation 3.3, where R was a percentage of the suitability of the factors used in the assessment.

$$\frac{\prod_{i=1}^{n} R_i}{100^{n-1}} \tag{3.3}$$

3.3.5 Convert the indexes data into a symbol of linguistic variables (L, M, H): values of Kp, Ks, Kc and latex product were represented by linguistic variables (L, M, H) with statistics of data.

3.3.6 Establish Fuzzy rules: Summarize rules used in Mamdani's fuzzy inference.

3.4 Decision rules applying to criteria data

Assessment of land suitability for growing rubber trees with fuzzy logic systems were conducted by determining the criteria influencing the growth which was related to the physical factors of the area as mentioned in the section 3.1.1 and interpreting the rules created in section 3.3. Various input data and procedures involved were shown in Figure 3.3.

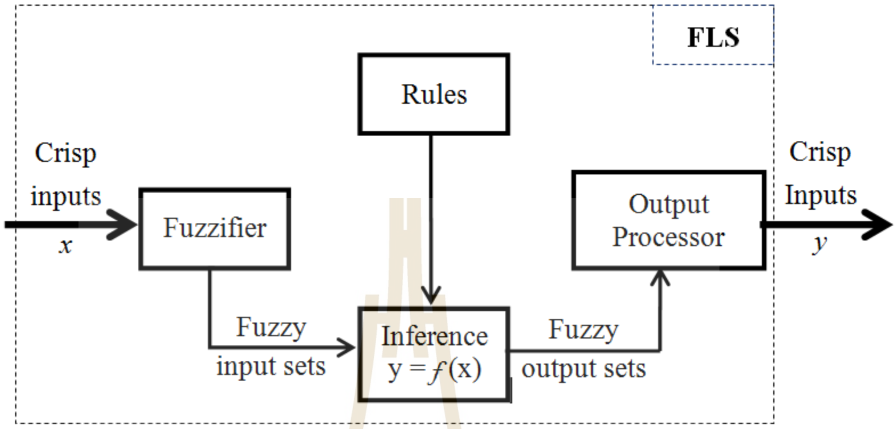


Figure 3.3 Interpreting the Fuzzy Inference Diagram (Mendel, 2001).

The Figure 3.3 showed data import process starting from crisp inputs to perform fuzzification to find membership level of the data in a different class defined by the linguistic variable. Then the result was forwarded to the interpretation (inference) step by rules created in the system. The final step was the Output Processor. The outputs of each rule were put together and transferred to crisp outputs by defuzzification.

3.5 Defuzzification

The last step in the fuzzy inference process was defuzzification. Fuzziness helped evaluating the rules, but the final output of a fuzzy system had to be a crisp value. The input for the defuzzification process was the aggregate of fuzzy set and the output was a single number.

There were several defuzzification methods, but the most popular and scientific one was the WA (see 2.1.5). This was to find the point where a vertical line would slice the aggregate set into two equal masses.

3.6 Land suitability maps

In this study, land suitability maps of rubber plantation of 3 scenarios (High, Medium, and Low) of plantation management were acquired based on application of decision rules developed (see Appendix B). A set of land suitability maps were in form of GIS rater layers of which all cells contained ADS production per year. These maps were simplified to be 3 classes of suitability, high, medium, and low, for each plantation management scenario.

3.7 Validation

There were 30 samples from field investigation used for validation by comparing ADS to the model result.

To check the validity of the results of this study, accuracy by the Root Mean Square Error (RMSE) was used to measure the difference between the results of ADS analyzed by Mamdani's fuzzy logic system and the 30 samples of actual data collected from the field. If RMSE was close to 0, the yield predicted by Mamdani's fuzzy logic system was close to the yield actually observed. The individual differences were also called residuals, and the RMSE served to aggregate them into a single measure of predictive power using Equation 3.4.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{mod,i})^2}{n}} \qquad (3.4)$$

The RMSE of a model prediction with respect to the estimated variable X_{mod} was defined as the square root of the mean squared error: where X_{obs} was observed ADS and X_{mod} was ADS predicted at time *i*.

The coefficient of determination, R^2, was estimated from the relationship of 30 samples of observed and modeled ADSs. The grahic presentation could tell that the relationship was over or under estimation when they were compared. The R^2 presented the better relationship of them when its value was closer to 1. It was a measure that how good one variable was predictable or correctable from the other variable. R^2 could be estimated using Eqation 3.5.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}, \tag{3.5}$$

where *y* was observed ADS and *f* was modeled ADS, n was a number of samples, and $\bar{y}$ was average of observed ADS.

CHAPTER IV

RESULTS AND VALIDATION

The results of land suitability analysis for rubber plantation using fuzzy logic in Buriram and Nakhon Ratchasima provinces are shown as follows.

4.1 Criteria data fuzzification

The crop requirements for rubber plantation are shown in Table 4.1. The fuzzy membership functions (FMF) were used to calculate the fuzzy membership and values of Kp, Ks, and Kc were defined as shown in Figures 4.1 to 4.12 and Tables 4.2 and 4.3. The higher fuzzy membership of a criterion indicated the more suitability for rubber plantation. The functions were developed to estimate suitable membership or score responding to optimum, lower and upper critical characteristic of crop requirements.

Table 4.1 Crop requirements for rubber plantation (modified after Saichai Suchartgul, Somsak Maneepong, and Montree Issarakrisila (2012); Somjate Pratummintra (2000), and DOA, (2012).

1. Soil conditions	Unit	Lower Critical	Optimum	Upper Critical
a) Physical properties (Kp)				
- Soil texture				
a) %sand	%	14	35-70	100
b) %clay	%	14	30-65	86

Table 4.1 Crop requirements for rubber plantation (Continued).

1.Soil conditions	Unit	Lower Critical	Optimum	Upper Critical
- Soil slope	%	0	0-8	35
- Effective soil depth	m.	md	d, vd	vd
- Soil drainage	-	vpd	wd	ex
- Flood Area	-	-	Mask out	-
b) Chemical properties (Ks)				
- OM	%	0	>1.5	-
- P	Mg/kg	0	>15.0	-
- K	Mg/kg	0	>60.0	-
- pH	-	3	4.5-5.5	7.5
- Saline soil	-	-	Mask out	-
2. Climate factors (Kc)	Unit	Lower Critical	Optimum	Upper Critical
- The average annual rainfall	mm.	900	1,800-2,500	4,000
- Dry season	Months	0	0-3	8
- Losses of tapping days(*VPD*)	kPa	0	0-1	6
- Temperature regime	C^o	15	24-28	38
- Wind speed	m/s	0	0-1	3

Note: md: moderately deep, d: deep , vd: very deep.

vpd: very poorly drained, pd: poorly drained, spd: somewhat poorly drained,

mw: moderately well drained, wd: well drained, ex: excessively drained.

4.1.1 Membership function of soil physical properties (Kp)

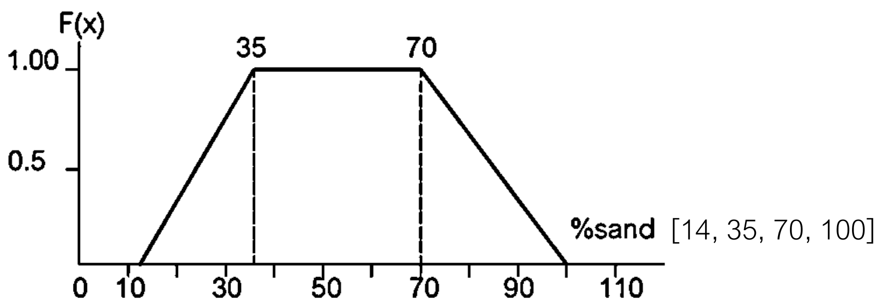


Figure 4.1 FMF of percentage of sand.

Figure 4.1 shows that the membership score 1 is assigned to the optimum range (35-70 %) of sand, while a percentage of sand in lower range at 14 and in the upper range at 100 are classified as a critical value and is assigned to be 0. This related to a textural classes of soil, drainage properties, water and nutrient storage.

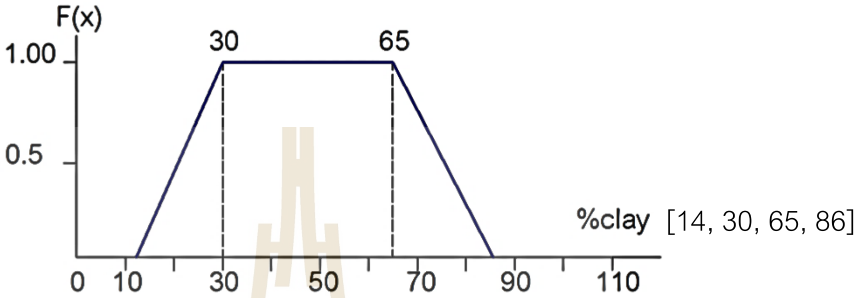


Figure 4.2 FMF of percentage of clay.

Figure 4.2 shows that the membership score 1 is assigned to the optimum range (30-65 %) of clay, while a percentage of clay, which is lower than 14 % and higher than 86 % are considered as a critical value. These relate to textural properties, drainage class, water and nutrient use efficiency.

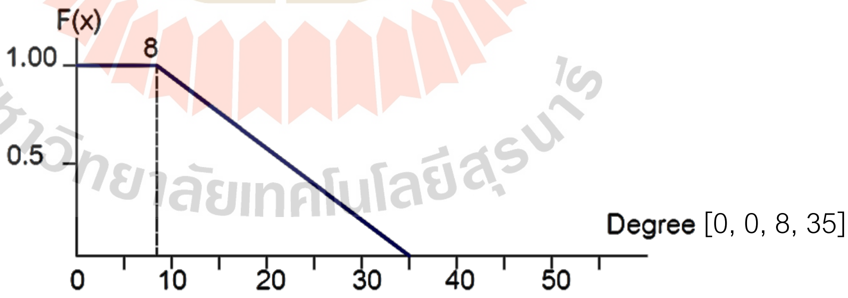


Figure 4.3 FMF of soil slope.

Figure 4.3 shows the suitable slope is 0-8 and scored to be 1. The suitability score is lower when the slope is more than 8. The land with the slope higher than 35 is scored as 0, because in the forestry's law it is considered as conservation area and crop is not allowed to cultivate.

Table 4.2 Membership values of soil depth properties.

Effective soil depth	Very deep, Deep	Moderately deep	Shallow, Very shallow
	1.0	0.5	0

As discussed in 3.1.1, the effective soil depth can be scored based on its fuzzy classes as shown in Table 4.2. Drainage of soil can be affected not only by percent of clay and sand but also by organic matter content and colloidal materials in soil (Yong, 2001). The suitability score can be assigned based on its fuzzy classes as shown in Table 4.3.

Table 4.3 Membership values of drainage.

Drainage	Well	Moderately	Somewhat Poorly	Poorly	Very poorly
	1.0	0.95	0.85	0.6	0.45

4.1.2 Membership function of soil chemical properties (Ks)

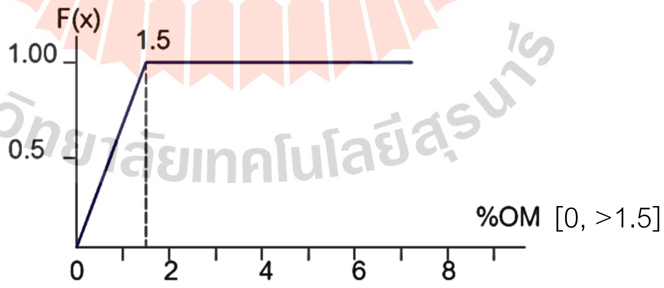


Figure 4.4 FMF of organic matter (OM).

OM refers to all types of organic matter in the soil consisting of organic nitrogen compounds, organic phosphorus compounds and other compounds. High volume of OM makes the soil have high capability in cation exchange and in water absorption. The OM is important in holding of particles. Figure 4.4 shows that the suitability score is 1 for area with percentages of OM more than 1.5. The score will reduce from 1 to 0 when OM content is grading from less than 1.5 to 0.

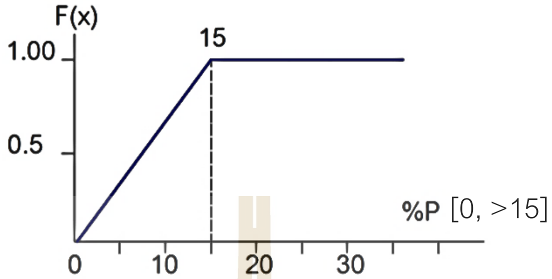


Figure 4.5 FMF of phosphorus (P).

Phosphorus (P) content is another key nutrient in enhancing growth of rubber trees during the years of immaturity until they are able to tap, particularly during the initial stages of establishment when the rubber trees are able to produce only a limited root system. Figure 4.5 shows that the suitable percentage of P is more than 15 and scored to be 1. The score is grading from 1 to 0 when P content is reducing from less than 15 to 0.

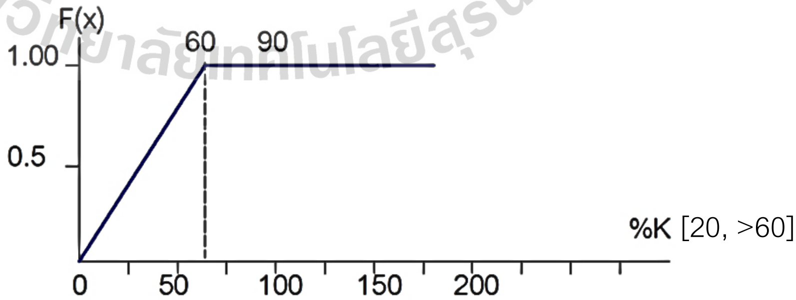


Figure 4.6 FMF of potassium (K).

Potassium (K) is one of the most important major nutrients for growth and yield of rubber trees. Figure 4.6 shows that the suitable percentage of K is more than

60 and scored to be 1. The score is grading from 1 to 0 when K content is reducing from less than 60 to 0.

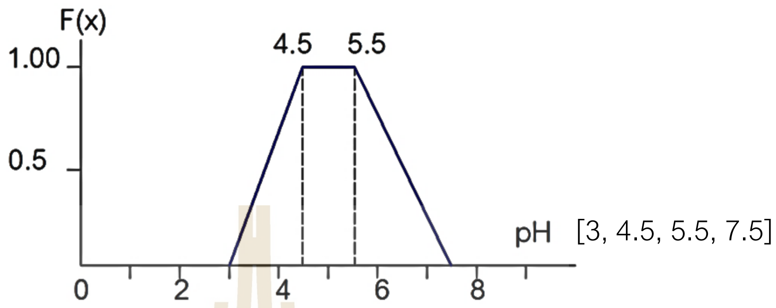


Figure 4.7 FMF of pH.

Appropriate pH of soil help plants absorbing nutrients. Rubber trees grow well in the soil with the pH 4.5-5.5 as shown in Figure 4.7. The score 1 is assigned for the optimum range (4.5-5.5). Out of this range, the score is reducing from 1 to 0 when it is closer to lower and upper critical pH.

4.1.3 Membership function of climate factors (Kc)

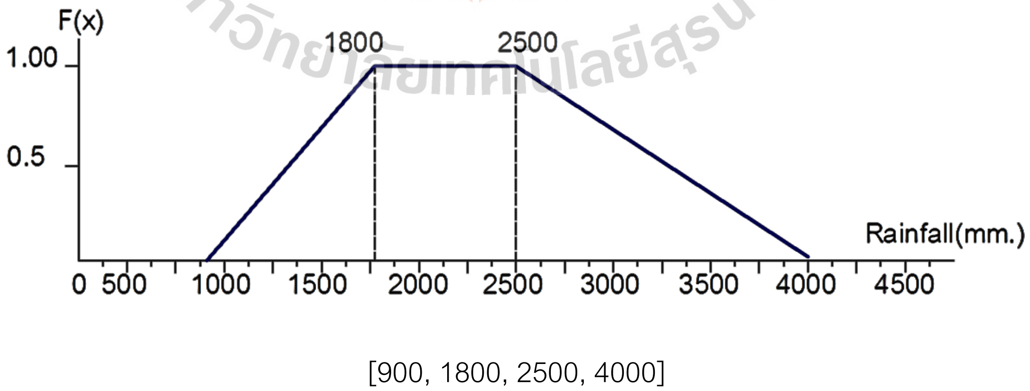


Figure 4.8 FMF of average annual rainfalls.

Figure 4.8 shows that optimum average annual rainfall for rubber plantation is 1,800-2,500 mm. The area with an average annual rainfall over 4,000 mm would have lower tapping days. The area with average annual rainfall lower than 1,800 mm can be still good for plantation but must not lower than 1,000 mm, the lower critical rainfall that can cause long drought period, slow growth, sun burnt, epidemic disease, and finally lower yield.

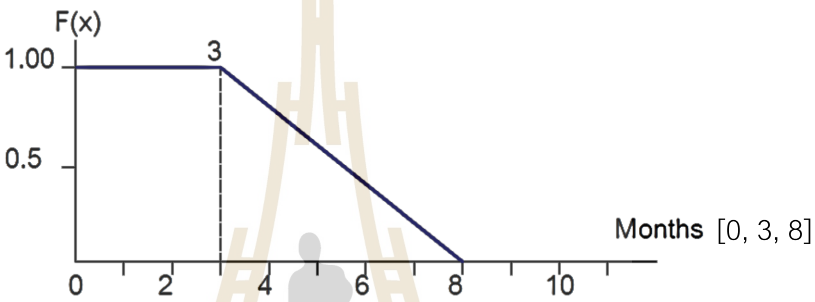


Figure 4.9 FMF of the number of dry months when $Ih < 0.5$.

Figure 4.9 shows that area with a drought period or a month which $Ih < 0.5$ should be not more than 3 months in a year, this assigned a score as 1 and degrading to 0 when number of dry months is more than 3 months, when a number of dry month reach to 8 months, then it consider as a critical and a given score is 0.

Figure 4.10 FMF of the number of months when *VPD* > 11mbar.

Figure 4.10 shows a number of month that *VPD* is higher than 11 mbar, which affect to flow of latex, will be less than 1 month then a given score is 1. On the other hand, the number of month which *VPD* is higher than 11 mbar is more than 6 months, a given score is 0. The interpreting score between 1-0 will be done for the area, with the number of month that has a *VPD* higher than 11 mbar.

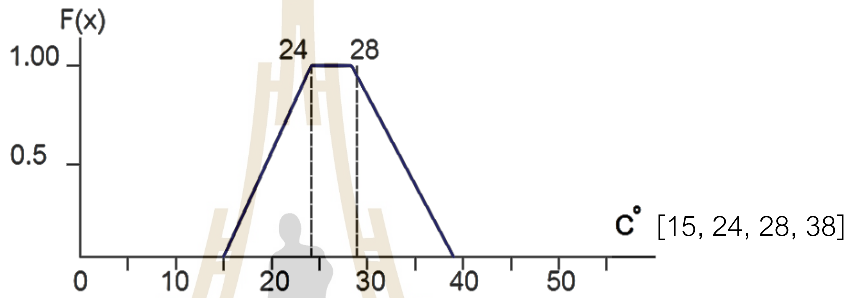


Figure 4.11 FMF of average temperatures.

Figure 4.11 shows that optimum average temperature for rubber plantation is 24-28 ^{o}C and scored as 1. The area with the average temperature under 15 ^{o}C and overr 40 ^{o}C can cause slow growth and too low latex.

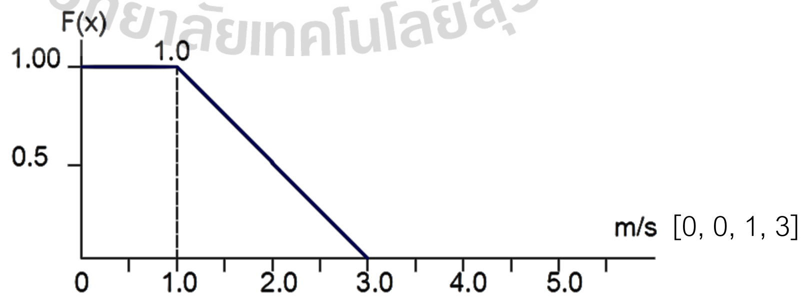


Figure 4.12 FMF of average wind speed.

Figure 4.12 shows that area with wind speeds less than 1 m/s should be scored as 1 and grading to 0 when it is higher than 1 to upper critical speed of 3 m/s.

4.1.4 Membership function of rubber plantation management (Ma)

Plantation management is an important factor that makes successful planting. The rubber trees grow faster and can be tapped earlier with better management. Results from interviews with farmers about the management of rubber plantation have been brought to the scoring criteria in Table 4.4.

1) Replacement planting

In this study, data collected were only from farmlands in which the number of rubber trees planted was more than 80 %, so this factor was not taken into consideration.

2) Pruning

Pruning when the rubber trees are young is a preparation of a proper tapping area of the trunks. The trees can have more area for tapping without branches or nodes and can increase their trunk diameter. In this study, pruning the rubber trees at the age of 2-3 years was determined based on the amount of pruning.

3) Plantation maintenance during dry season

The rubber plantation management during dry season involves plantation maintenance in order to keep moisture in the soil during the dry season by watering the rubber trees when needed or supporting the rubber trees to get enough water for growing. In this study, water providing methods during the dry season were considered, such as irrigation by pumping water from a water source or a truck, or a water supply system etc.

4) Fertilizing

In this study, the suitability regarding fertilizers in rubber plantations was considered in criteria about types of the fertilizer, mature or immature, duration of fertilization, the number and the amount of fertilizers based on the instruction manual for rubber cultivation of the Department of Agriculture.

5) Weed control

Weeds are a serious problem in rubber production because they compete with the rubber trees for nutrients, space, light and water as these are needed by the rubbers. Some weeds also encourage pests and diseases by acting as alternate host. In addition, they may cause disturbance in water management when the population of the weeds is high. Due to these reasons, they are responsible for reduced yield and need planned eradication. The weeds can be controlled either by mechanical or chemical methods. Regularly controlling the weeds in the rubber plantations from the beginning of planting to the tapping time, especially during the rainy season when the weeds grows fast, can make high-yielding ADS. In this study, the suitability regarding weed control in rubber plantation was considered in the number of weeding in a year.

6) Planting a cover crop in the rubber planting area

On some rubber plantations which have a problem to provide water to the rubber trees during the dry season, cover crops, especially in the summer time, is necessary. In this study, the managements of rubber plantations with and without cover crops were considered.

7) Rubber tapping

The collected data showed that most farmers had been introduced to each other about the appropriate time for tapping the rubbers in order to allow much ADS exudes. Different tapping systems provide different amount of ADS. This study used the tapping systems, recommended by DOA in an academic document in 2012, for scoring the suitability of rubber tapping. The best tapping system gave a score of 1. The lowest score was 0.5. There was not any score less than 0.5 because DOA introduced only the systems which could provide satisfied amount of ADS as shown in Table 4.4.

Table 4.4 Scoring membership values of managed rubber plantations.

Management Factors	Scoring Criteria				
	0.1	0.3	0.5	0.8	1.0
Dry Season (DS)	-	-	Rain	Rain and sometimes watering	Good source of watering
Pruning (PR)	No	1 times/year	2 times/yr	3 times/yr	Always
Fertilizing (FR)					
- Immature period	No	Sometimes	2 times/yr	3 times/yr	DOA*
- Mature period	No	Sometimes	2 times/yr	3 times/yr	DOA*
- Quantity	-	Uncertainly	-	-	DOA*
Weeding (WD)	No	Sometimes	2 times/yr	>2times/yr	Always
Cover crops (CC)	No	-	Sometimes	-	Yes
Rubber tapping systems (TP)	-	-	S/2 d1 2d/3, S/3 d1 2d/3, S/3 d2	S/2 d2	S/2 d3

Note: “ - ” not existing,

DOA* : Recommendations of the Department of Agricultural, Thailand;

S/3 2d/3 is a one third-spiral cut with a tapping frequency of two days out of three;

S/3 d2 is a one third-spiral cut with a tapping frequency of once two days;

S/2 2d/3 is a half- spiral cut with a tapping frequency of two days out of three;

S/2 d2 is a half- spiral cut with a tapping frequency of once in two days;

S/2 d3 is a half- spiral cut with a tapping frequency of once in three days.

4.2 Decision rule development

An important part of the analysis is to determine suitable areas for planting rubber trees by means of Fuzzy logic system. The system rules were developed based on the collected field data. To achieve the goal of this research, 150 samples were collected for simulating a model as shown in Figure 4.13. On the other hand 30 samples were collected for model validation in the lower northeastern region as shown in Figure 4.40.

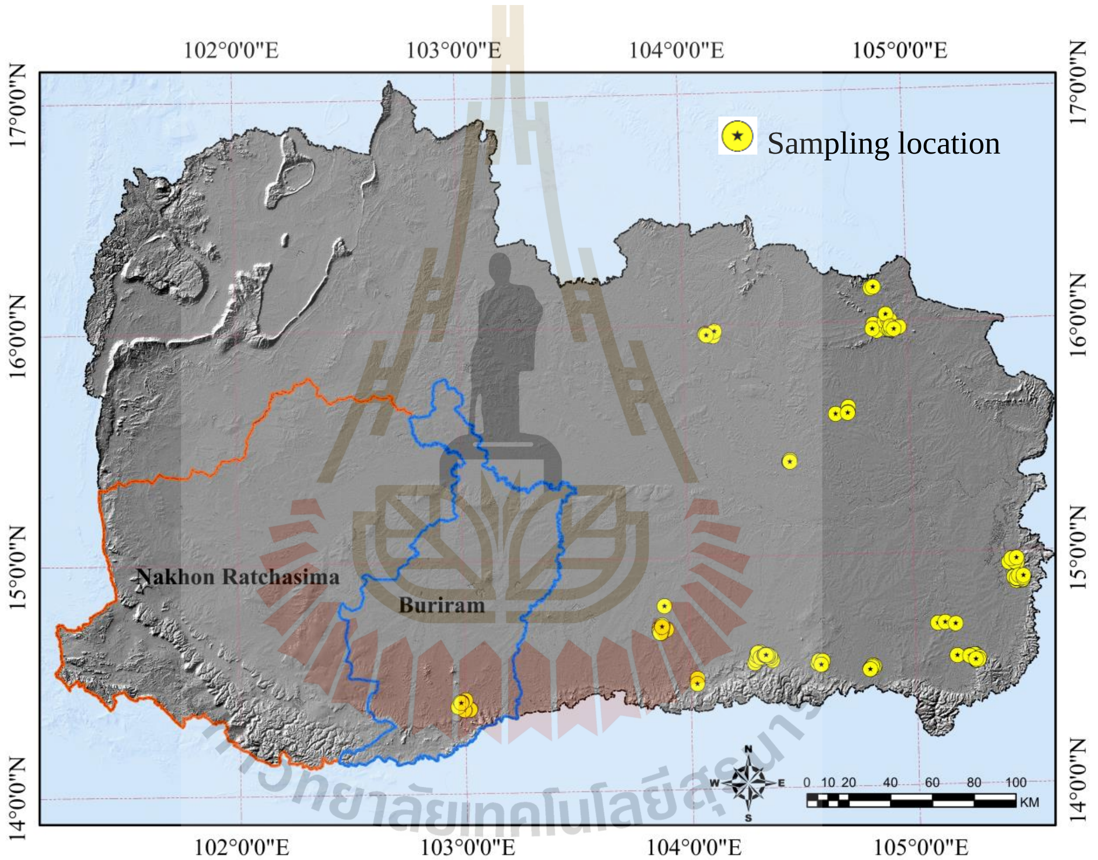


Figure 4.13 Samples points for simulating model.

The consideration to create the system rules can be divided into 6 parts.

4.2.1 Soil physical properties (Kp)

According to an interpreting of the collected data concerning to physical properties of soil and topography, the results are shown in Table 4.5.

Table 4.5 The collected data concerning soil physical properties.

Samp. No.	Location (UTM zone 48N)			SS	Soil physical properties				
	X	Y	Z		Sand (%)	Clay (%)	Soil Depth	Slope (%)	Drainage
1	286467	1588945	251	Kt	55.95	27.34	d	2.2	mw
2	286738	1589065	243	Kt	55.95	27.34	d	3.5	mw
3	286472	1588884	245	Kt	55.95	27.34	d	0.8	mw
4	283927	1588532	252	Kt	55.95	27.34	d	3.4	mw
5	283695	1588782	261	Kt	55.95	27.34	d	4.8	mw
6	284424	1593474	211	Kt	55.95	27.34	d	0.3	mw
7	281687	1591192	240	Kt	55.95	27.34	d	2.9	mw
8	280870	1590362	243	Kt	55.95	27.34	d	4.6	mw
9	282186	1592487	243	Kt	55.95	27.34	d	0.7	mw
10	282477	1592487	230	Kt	55.95	27.34	d	3.5	mw
11	282270	1592491	230	Kt	55.95	27.34	d	0.8	mw
12	282062	1592547	232	Kt	55.95	27.34	d	1.4	mw
13	282307	1592145	243	Kt	55.95	27.34	d	1.2	mw
14	406286	1764067	156	Kt	55.95	27.34	d	0.0	mw
15	403434	1765215	162	Kt	55.95	27.34	d	2.5	mw
16	403382	1764892	158	Kt	55.95	27.34	d	3.5	mw
17	406963	1764778	160	Kt	55.95	27.34	d	1.7	mw
18	407272	1764041	175	Kt	55.95	27.34	d	2.9	mw
19	407901	1766309	166	Yt	51.38	19.70	d	2.6	wd
20	403970	1764565	165	Re	64.79	21.83	vd	2.0	spd
21	427982	1610990	208	Kt	55.95	27.34	d	1.2	mw
22	427966	1610920	193	Kt	55.95	27.34	d	1.8	mw
23	428186	1611078	198	Kt	55.95	27.34	d	2.2	mw
24	428969	1610960	193	Kt	55.95	27.34	d	3.1	mw
25	428144	1611430	201	Kt	55.95	27.34	d	1.7	mw
26	430534	1609726	192	Kt	55.95	27.34	d	1.7	mw
27	430039	1610711	186	Kt	55.95	27.34	d	1.0	mw
28	477812	1603514	185	Kt	55.95	27.34	d	0.0	mw
29	479907	1604127	182	Ub	78.36	5.55	d	2.1	mw
30	479910	1604170	186	Kt	55.95	27.34	d	1.7	mw
31	479888	1604134	189	Ng	86.03	3.17	vd	2.0	spd-mw
32	479898	1604093	178	Kt	55.95	27.34	d	2.7	mw
33	479889	1604160	180	Kt	55.95	27.34	d	2.0	wd-spd
34	479899	1604117	185	Kt	55.95	27.34	d	2.1	mw
35	479873	1604728	185	Kt	55.95	27.34	d	1.7	mw
36	479871	1604826	190	Kt	55.95	27.34	d	2.0	mw
37	479065	1604966	182	Kt	55.95	27.34	d	1.2	mw
38	478885	1604355	186	Kt	55.95	27.34	d	0.5	mw
39	477986	1603134	189	Kt	55.95	27.34	d	3.9	mw
40	477923	1603206	188	Kt	55.95	27.34	d	2.0	mw
41	422965	1607656	232	Re	64.79	21.83	d	2.1	mw

Table 4.5 The collected data concerning soil physical properties (Continued).

Samp. No.	Location (UTM zone 48N)			SS	Soil physical properties				
	X	Y	Z		Sand (%)	Clay (%)	Soil depth	Slope (%)	Drainage
42	423578	1609098	223	Re	64.79	21.83	d	3.8	mw
43	424841	1612319	187	Kt	55.95	27.34	vd	3.2	spd
44	424853	1612391	189	Kt	55.95	27.34	vd	0.8	spd
45	424189	1612174	192	Kt	55.95	27.34	vd	3.8	spd
46	425636	1612694	193	Re	64.79	21.83	d	2.5	mw
47	425841	1611803	190	Kt	55.95	27.34	d	0.7	mw
48	424116	1611190	198	Kt	55.95	27.34	d	2.6	mw
49	424551	1612451	183	Kt	55.95	27.34	vd	1.7	spd
50	454918	1606098	204	Kt	55.95	27.34	d	4.8	mw
51	454924	1606031	200	Kt	55.95	27.34	d	7.2	mw
52	425669	1610228	216	Kt	55.95	27.34	d	0.3	mw
53	429135	1610604	194	Kt	55.95	27.34	vd	0.8	wd
54	427620	1611216	206	Kt	55.95	27.34	d	2.1	mw
55	427840	1611362	199	Kt	55.95	27.34	d	5.5	mw
56	429111	1611337	190	Kt	55.95	27.34	d	2.4	mw
57	428347	1611281	200	Kt	55.95	27.34	d	0.8	mw
58	453600	1607946	226	Kt	55.95	27.34	d	3.1	mw
59	455298	1607783	198	Kt	55.95	27.34	d	0.3	mw
60	454496	1606094	192	Bb	66.33	12.08	d	1.7	mw
61	377922	1625317	167	Kt	55.95	27.34	d	3.8	mw
62	378423	1623221	173	Kt	55.95	27.34	d	1.0	mw
63	379113	1624790	176	Kt	55.95	27.34	d	2.0	mw
64	377754	1624125	175	Bb	66.33	12.08	md	1.5	mw-spd
65	378372	1623020	175	Kt	55.95	27.34	d	1.4	mw
66	378487	1623179	179	Kt	55.95	27.34	d	2.4	mw
67	380655	1625194	167	Bb	66.33	12.08	d	3.6	mw
68	381316	1624694	174	Kt	55.95	27.34	md	3.0	mw-spd
69	379427	1626311	158	Kt	55.95	27.34	d	2.7	mw
70	378314	1623363	174	Kt	55.95	27.34	d	0.5	mw
71	378799	1624346	180	Re	64.79	21.83	d	2.6	mw
72	395160	1600326	201	Kt	55.95	27.34	md	2.6	mw-spd
73	380464	1635858	164	Kt	55.95	27.34	d	1.4	mw
74	379022	1626424	161	Kt	55.95	27.34	d	0.0	mw
75	395441	1600839	218	Kt	55.95	27.34	d	2.9	mw
76	395300	1598401	218	Rn	37.70	20.90	md	2.3	mw-spd
77	378316	1623106	174	Re	64.79	21.83	vd	1.8	spd
78	379242	1626807	160	Re	64.79	21.83	d	1.1	mw
79	379092	1626007	164	Rn	37.70	20.90	d	1.0	mw
80	483790	1767563	194	Ng	86.03	3.17	d	6.2	mw
81	485255	1764433	189	Ng	86.03	3.17	d	1.5	mw
82	483247	1765364	198	Kt	55.95	27.34	d	1.2	mw

Table 4.5 The collected data concerning soil physical properties (Continued).

Samp. No.	Location (UTM zone 48N)			SS	Soil physical properties				
	X	Y	Z		Sand (%)	Clay (%)	Soil depth	Slope (%)	Drainage
83	490073	1765888	180	Kt	55.95	27.34	d	1.0	spd
84	495050	1765520	181	Re	64.79	21.83	vd	3.4	spd
85	492332	1766260	177	Kt	55.95	27.34	vd	1.2	spd
86	491631	1769394	175	Kt	55.95	27.34	d	3.2	spd
87	489686	1772168	166	Bbc	66.33	12.08	d	1.4	wd-spd
88	491510	1764729	187	Kt	55.95	27.34	d	0.7	wd-spd
89	491372	1764835	181	Re	64.79	21.83	d	0.0	mw
90	482825	1784853	203	Kt	55.95	27.34	d	3.4	mw
91	484151	1785401	202	Re	64.79	21.83	d	1.4	wd-spd
92	491903	1766285	176	Kt	55.95	27.34	d	3.1	mw
93	528602	1606126	205	Ci	18.15	68.54	vd	3.0	spd
94	528580	1606398	207	Ci	18.15	68.54	vd	1.0	spd
95	527971	1607085	199	Ng	86.03	3.17	d	4.2	mw
96	526390	1608550	184	Kt	55.95	27.34	d	2.6	mw
97	525156	1608669	180	Ng	86.03	3.17	md	2.1	mw-spd
98	528174	1606970	203	Kt	55.95	27.34	d	3.4	mw
99	525768	1608414	188	Kt	55.95	27.34	vd	2.1	spd
100	525953	1608662	181	Kt	55.95	27.34	vd	0.8	spd
101	528211	1608977	202	Ci	18.15	68.54	vd	1.7	spd
102	525700	1608480	189	Ci	18.15	68.54	d	2.0	mw
103	549924	1643824	172	Kt	55.95	27.34	vd	1.1	spd
104	551871	1644392	183	Kt	55.95	27.34	d	0.8	mw
105	551474	1644030	173	Kt	55.95	27.34	vd	1.7	wd
106	550836	1645116	175	Re	64.79	21.83	vd	2.9	wd
107	551460	1645644	192	Kt	55.95	27.34	vd	2.9	wd
108	550650	1644079	184	Kt	55.95	27.34	d	0.3	wd-spd
109	548511	1644130	167	Kt	55.95	27.34	d	1.2	mw
110	548395	1644714	169	Kt	55.95	27.34	d	1.4	wd-spd
111	548440	1644829	172	Bt	76.7	17.30	d	2.0	mw
112	519460	1608908	162	Kt	55.95	27.34	d	2.0	mw
113	510656	1624505	163	Kt	55.95	27.34	d	0.0	mw
114	514076	1624905	163	Kt	55.95	27.34	vd	1.7	wd
115	549256	1652632	177	Kt	55.95	27.34	vd	1.9	wd
116	545165	1652612	196	Kt	55.95	27.34	vd	2.7	wd
117	548874	1651905	185	Ng	86.03	3.17	d	3.4	mw
118	547933	1652794	180	Ng	86.03	3.17	d	2.6	mw
119	546408	1654267	179	Ng	86.03	3.17	d	1.7	mw
120	548841	1654557	192	Ng	86.03	3.17	vd	0.0	spd
121	464574	1725374	131	Ng	86.03	3.17	d	3.5	mw
122	470516	1725988	144	Ng	86.03	3.17	d	2.1	mw
123	441862	1703430	135	Kt	55.95	27.34	d	3.2	mw

Table 4.5 The collected data concerning soil physical properties (Continued).

Samp. No.	Location (UTM zone 48N)			SS	Soil physical properties				
	X	Y	Z		Sand (%)	Clay (%)	Soil depth	Slope (%)	Drainage
124	441884	1703199	122	Kt	55.95	27.34	d	2.1	mw
125	442034	1703312	133	Kt	55.95	27.34	d	2.3	mw-spd
126	442044	1703339	131	Ng	86.03	3.17	vd	3.0	spd
127	442008	1703315	132	Kt	55.95	27.34	d	2.4	mw
128	442075	1703409	129	Ng	86.03	3.17	d	2.2	mw
129	442295	1703916	126	Re	64.79	21.83	d	1.1	mw
130	528017	1606997	198	Re	64.79	21.83	d	5.0	mw
131	548466	1644679	180	Kt	55.95	27.34	d	0.8	mw
132	547423	1645542	164	Yt	51.38	19.70	d	2.6	wd-spd
133	519147	1624071	151	Kt	55.95	27.34	d	1.2	wd-spd
134	442106	1703157	126	Kt	55.95	27.34	d	1.7	wd-spd
135	529576	1606975	246	Ng	86.03	3.17	d	3.4	wd-spd
136	529659	1606867	239	Re	64.79	21.83	d	2.6	wd-spd
137	529455	1607376	230	Ci	18.15	68.54	d	2.1	wd-spd
138	551464	1644155	179	Ci	18.15	68.54	d	1.8	wd-spd
139	550639	1644747	175	Re	64.79	21.83	d	2.4	mw
140	530084	1607482	239	Re	64.79	21.83	d	2.6	mw
141	528227	1609091	198	Re	64.79	21.83	d	0.3	mw
142	527768	1609114	188	Ng	86.03	3.17	d	1.2	mw
143	525433	1608485	175	Kt	55.95	27.34	d	1.2	mw
144	529980	1607672	232	Kt	55.95	27.34	d	1.5	wd-spd
145	529623	1606714	226	Bb	66.33	12.08	d	1.0	mw
146	528334	1606878	206	Kt	55.95	27.34	d	0.7	wd-spd
147	548586	1644836	174	Ci	18.15	68.54	vd	2.0	spd
148	549689	1646155	172	Re	64.79	21.83	vd	0.8	spd
149	551885	1645130	194	Kt	55.95	27.34	d	2.2	mw
150	551941	1646064	175	Kt	55.95	27.34	d	0.0	Wd
				Min	18.15	3.17		0.00	
				Mean	58.60	25.26		2.17	
				Max	86.03	68.54		7.20	

Note: Soil Depth: md = moderately deep (100-125 cm), d = deep (125-150 cm) ,

vd = very deep (>150 cm)

Drainage: pd = poorly drained, spd = somewhat poorly drained,

mw = moderately well drained, wd= well drained

The soil physical data showed that the average percentage of sand was

58.69 %, the average percentage of clay was 24.91 %, the average percentage of soil slope was 2.2 %, soil depths were moderately deep to very deep soil, and soil drainage was classified as moderately well, somewhat poorly drained and well drained, respectively. Moreover, it was found that none of the rubber tree was planted in an area at risk from flooding. It meant that the suitable level of these kinds of data was in high group of the crop requirements (in Table 4.1). Therefore, it was defined into two groups of fuzzy sets as medium (M) and High (H).

4.2.2 Soil chemical properties (Ks)

Analytical results of the data concerning the soil chemical properties in the sample rubber plantations can be expressed in Table 4.6.

Table 4.6 The collected data concerning chemical properties.

Samp.	Location (UTM zone 48N)			Soil chemical properties			
No.	X	Y	Z	OM (%)	P (ppm.)	K (ppm.)	pH
1	286467	1588945	251	0.52	4.52	11.28	4.75
2	286738	1589065	243	0.52	4.52	11.28	4.75
3	286472	1588884	245	0.52	4.52	11.28	4.75
4	283927	1588532	252	0.52	4.52	11.28	4.75
5	283695	1588782	261	0.52	4.52	11.28	4.75
6	284424	1593474	211	0.52	4.52	11.28	4.75
7	281687	1591192	240	0.52	4.52	11.28	4.75
8	280870	1590362	243	0.52	4.52	11.28	4.75
9	282186	1592487	243	0.52	4.52	11.28	4.75
10	282477	1592487	230	0.52	4.52	11.28	4.75
11	282270	1592491	230	0.52	4.52	11.28	4.75
12	282062	1592547	232	0.52	4.52	11.28	4.75
13	282307	1592145	243	0.52	4.52	11.28	4.75
14	406286	1764067	156	0.52	4.52	11.28	4.75
15	403434	1765215	162	0.52	4.52	11.28	4.75
16	403382	1764892	158	0.52	4.52	11.28	4.75
17	406963	1764778	160	0.52	4.52	11.28	4.75
18	407272	1764041	175	0.52	4.52	11.28	4.75
19	407901	1766309	166	0.72	2.47	33.28	5.22
20	403970	1764565	165	1.67	4.37	45.29	5.23
21	427982	1610990	208	0.52	4.52	11.28	4.75

Table 4.6 The collected data concerning chemical properties (Continued).

Samp. No.	Location (UTM zone 48N)			Soil chemical properties			
	X	Y	Z	OM (%)	P (ppm.)	K (ppm.)	pH
22	427966	1610920	193	0.52	4.52	11.28	4.75
23	428186	1611078	198	0.52	4.52	11.28	4.75
24	428969	1610960	193	0.52	4.52	11.28	4.75
25	428144	1611430	201	0.52	4.52	11.28	4.75
26	430534	1609726	192	0.52	4.52	11.28	4.75
27	430039	1610711	186	0.52	4.52	11.28	4.75
28	477812	1603514	185	0.52	4.52	11.28	4.75
29	479907	1604127	182	0.52	4.52	11.28	4.75
30	479910	1604170	186	0.31	1.2	10.72	5.34
31	479888	1604134	189	0.52	4.52	11.28	4.75
32	479898	1604093	178	0.17	1.64	17.26	6.31
33	479889	1604160	180	0.52	4.52	11.28	4.75
34	479899	1604117	185	0.52	4.52	11.28	4.75
35	479873	1604728	185	0.52	4.52	11.28	4.75
36	479871	1604826	190	0.52	4.52	11.28	4.75
37	479065	1604966	182	0.52	4.52	11.28	4.75
38	478885	1604355	186	0.52	4.52	11.28	4.75
39	477986	1603134	189	0.52	4.52	11.28	4.75
40	477923	1603206	188	0.52	4.52	11.28	4.75
41	422965	1607656	232	0.52	4.52	11.28	4.75
42	423578	1609098	223	1.67	4.37	45.29	5.23
43	424841	1612319	187	1.67	4.37	45.29	5.23
44	424853	1612391	189	1.67	4.37	45.29	5.23
45	424189	1612174	192	0.52	4.52	11.28	4.75
46	425636	1612694	193	0.52	4.52	11.28	4.75
47	425841	1611803	190	0.52	4.52	11.28	4.75
48	424116	1611190	198	1.67	4.37	45.29	5.23
49	424551	1612451	183	0.52	4.52	11.28	4.75
50	454918	1606098	204	0.52	4.52	11.28	4.75
51	454924	1606031	200	0.52	4.52	11.28	4.75
52	425669	1610228	216	1.14	7.4	24.02	5.13
53	429135	1610604	194	0.52	4.52	11.28	4.75
54	427620	1611216	206	0.52	4.52	11.28	4.75
55	427840	1611362	199	0.52	4.52	11.28	4.75
56	429111	1611337	190	0.52	4.52	11.28	4.75
57	428347	1611281	200	0.52	4.52	11.28	4.75
58	453600	1607946	226	0.52	4.52	11.28	4.75
59	455298	1607783	198	0.52	4.52	11.28	4.75
60	454496	1606094	192	0.52	4.52	11.28	4.75
61	377922	1625317	167	0.52	4.52	11.28	4.75
62	378423	1623221	173	0.52	4.52	11.28	4.75
63	379113	1624790	176	0.55	1.27	75.1	5.09

Table 4.6 The collected data concerning chemical properties (Continued).

Samp.	Location (UTM zone 48N)			Soil chemical properties			
No.	X	Y	Z	OM (%)	P (ppm.)	K (ppm.)	pH
64	377754	1624125	175	0.52	4.52	11.28	4.75
65	378372	1623020	175	0.52	4.52	11.28	4.75
66	378487	1623179	179	0.52	4.52	11.28	4.75
67	380655	1625194	167	0.55	1.27	75.1	5.09
68	381316	1624694	174	0.52	4.52	11.28	4.75
69	379427	1626311	158	0.52	4.52	11.28	4.75
70	378314	1623363	174	0.52	4.52	11.28	4.75
71	378799	1624346	180	0.55	1.27	75.1	5.09
72	395160	1600326	201	0.52	4.52	11.28	4.75
73	380464	1635858	164	0.52	4.52	11.28	4.75
74	379022	1626424	161	0.52	4.52	11.28	4.75
75	395441	1600839	218	0.55	1.27	75.1	5.09
76	395300	1598401	218	1.67	4.37	45.29	5.23
77	378316	1623106	174	0.52	4.52	11.28	4.75
78	379242	1626807	160	0.52	4.52	11.28	4.75
79	379092	1626007	164	0.52	4.52	11.28	4.75
80	483790	1767563	194	0.52	4.52	11.28	4.75
81	485255	1764433	189	0.52	4.52	11.28	4.75
82	483247	1765364	198	0.32	1.66	33.83	5.02
83	490073	1765888	180	1.67	4.37	45.29	5.23
84	495050	1765520	181	1.67	4.37	45.29	5.23
85	492332	1766260	177	0.32	1.66	33.83	5.02
86	491631	1769394	175	0.17	1.64	17.26	6.31
87	489686	1772168	166	0.17	1.64	17.26	6.31
88	491510	1764729	187	0.52	4.52	11.28	4.75
89	491372	1764835	181	0.52	4.52	11.28	4.75
90	482825	1784853	203	0.17	1.64	17.26	6.31
91	484151	1785401	202	0.52	4.52	11.28	4.75
92	491903	1766285	176	1.67	4.37	45.29	5.23
93	528602	1606126	205	1.67	4.37	45.29	5.23
94	528580	1606398	207	0.52	4.52	11.28	4.75
95	527971	1607085	199	0.52	4.52	11.28	4.75
96	526390	1608550	184	0.55	1.27	75.1	5.09
97	525156	1608669	180	0.52	4.52	11.28	4.75
98	528174	1606970	203	1.67	4.37	45.29	5.23
99	525768	1608414	188	1.67	4.37	45.29	5.23
100	525953	1608662	181	1.67	4.37	45.29	5.23
101	528211	1608977	202	0.52	4.52	11.28	4.75
102	525700	1608480	189	1.67	4.37	45.29	5.23
103	549924	1643824	172	0.52	4.52	11.28	4.75
104	551871	1644392	183	1.14	7.4	24.02	5.13
105	551474	1644030	173	1.14	7.4	24.02	5.13

Table 4.6 The collected data concerning chemical properties (Continued).

Samp. No.	Location (UTM zone 48N)			Soil chemical properties			
	X	Y	Z	OM (%)	P (ppm.)	K (ppm.)	pH
106	550836	1645116	175	1.14	7.4	24.02	5.13
107	551460	1645644	192	0.17	1.64	17.26	6.31
108	550650	1644079	184	0.52	4.52	11.28	4.75
109	548511	1644130	167	0.17	1.64	17.26	6.31
110	548395	1644714	169	0.52	4.52	11.28	4.75
111	548440	1644829	172	0.52	4.52	11.28	4.75
112	519460	1608908	162	0.52	4.52	11.28	4.75
113	510656	1624505	163	1.14	7.4	24.02	5.13
114	514076	1624905	163	1.14	7.4	24.02	5.13
115	549256	1652632	177	1.14	7.4	24.02	5.13
116	545165	1652612	196	0.52	4.52	11.28	4.75
117	548874	1651905	185	0.52	4.52	11.28	4.75
118	547933	1652794	180	0.52	4.52	11.28	4.75
119	546408	1654267	179	1.67	4.37	45.29	5.23
120	548841	1654557	192	0.52	4.52	11.28	4.75
121	464574	1725374	131	0.52	4.52	11.28	4.75
122	470516	1725988	144	0.52	4.52	11.28	4.75
123	441862	1703430	135	0.52	4.52	11.28	4.75
124	441884	1703199	122	0.27	1.25	52.01	4.92
125	442034	1703312	133	1.67	4.37	45.29	5.23
126	442044	1703339	131	0.52	4.52	11.28	4.75
127	442008	1703315	132	0.52	4.52	11.28	4.75
128	442075	1703409	129	0.52	4.52	11.28	4.75
129	442295	1703916	126	0.52	4.52	11.28	4.75
130	528017	1606997	198	0.52	4.52	11.28	4.75
131	548466	1644679	180	0.17	1.64	17.26	6.31
132	547423	1645542	164	0.17	1.64	17.26	6.31
133	519147	1624071	151	0.17	1.64	17.26	6.31
134	442106	1703157	126	0.17	1.64	17.26	6.31
135	529576	1606975	246	0.17	1.64	17.26	6.31
136	529659	1606867	239	0.17	1.64	17.26	6.31
137	529455	1607376	230	0.17	1.64	17.26	6.31
138	551464	1644155	179	0.52	4.52	11.28	4.75
139	550639	1644747	175	0.52	4.52	11.28	4.75
140	530084	1607482	239	0.52	4.52	11.28	4.75
141	528227	1609091	198	0.52	4.52	11.28	4.75
142	527768	1609114	188	0.52	4.52	11.28	4.75
143	525433	1608485	175	0.17	1.64	17.26	6.31
144	529980	1607672	232	0.52	4.52	11.28	4.75
145	529623	1606714	226	0.17	1.64	17.26	6.31
146	528334	1606878	206	1.67	4.37	45.29	5.23

Table 4.6 The collected data concerning chemical properties (Continued).

Samp.	Location (UTM zone 48N)			Soil chemical properties			
No.	X	Y	Z	OM (%)	P (ppm.)	K (ppm.)	pH
147	548586	1644836	174	1.67	4.37	45.29	5.23
148	549689	1646155	172	0.52	4.52	11.28	4.75
149	551885	1645130	194	0.72	2.47	33.28	5.22
150	551941	1646064	175	0.52	4.52	11.28	4.75
			Min	0.17	1.20	10.72	4.75
			Mean	0.65	4.13	19.60	5.01
			Max	1.67	7.40	75.10	6.31

The soil chemical data showed that the average percentage of Organic Matter (OM) was 0.60 %, the average of Phosphorus (P) was 4.10 ppm, and the average of Potassium (K) was 17.96 ppm. That meant that the suitability level of these kinds of data was in a low group of the crop requirements (in Table 4.1). And The average of pH was 4.97 which were close to the most suitable value. Therefore, in this study, fuzzy sets of Ks were divided into two groups: Low (L) and Medium (M).

4.2.3 Climate properties (Kc)

Analytical results of the data concerning the climate in the sample rubber plantations can be expressed in Table 4.7.

Table 4.7 The collected data concerning climate.

Samp.	Location (UTM zone 48N)			Climate properties				
No.	X	Y	Z	Rainfall (mm/yr)	*Ih* (Months)	*VPD* (mbar)	T ^{o}C	Wind (m/s)
1	286467	1588945	251	1228	4.9	3.1	27.1	0.93
2	286738	1589065	243	1229	4.9	3.1	27.1	0.93
3	286472	1588884	245	1228	4.9	3.1	27.1	0.93
4	283927	1588532	252	1224	4.9	3.1	27.1	0.93
5	283695	1588782	261	1224	4.9	3.1	27.1	0.93
6	284424	1593474	211	1222	4.9	3.1	27.1	0.93
7	281687	1591192	240	1219	4.9	3.1	27.1	0.93

Table 4.7 The collected data concerning climate (Continued).

Samp. No.	Location (UTM zone 48N)			Climate properties				
	X	Y	Z	Rainfall (mm/yr)	*Ih* (Months)	*VPD* (mbar)	T ^{o}C	Wind (m/s)
8	280870	1590362	243	1219	4.9	3.1	27.1	0.93
9	282186	1592487	243	1219	4.9	3.1	27	0.93
10	282477	1592487	230	1220	4.9	3.1	27	0.93
11	282270	1592491	230	1219	4.9	3.1	27	0.93
12	282062	1592547	232	1219	4.9	3.1	27	0.93
14	406286	1764067	156	1420	5.6	3.0	27	1.18
15	403434	1765215	162	1415	5.6	3.0	27	1.18
16	403382	1764892	158	1414	5.6	3.0	27	1.18
17	406963	1764778	160	1421	5.6	3.0	27	1.18
18	407272	1764041	175	1421	5.6	3.0	27	1.18
19	407901	1766309	166	1423	5.6	3.0	27	1.18
20	403970	1764565	165	1416	5.6	3.0	27	1.18
21	427982	1610990	208	1390	5.1	3.1	27.1	1.23
22	427966	1610920	193	1390	5.1	3.1	27.1	1.23
23	428186	1611078	198	1390	5.1	3.1	27.1	1.23
24	428969	1610960	193	1391	5.1	3.1	27.1	1.23
25	428144	1611430	201	1391	5.1	3.1	27.1	1.23
26	430534	1609726	192	1392	5.1	3.1	27.1	1.23
27	430039	1610711	186	1392	5.1	3.1	27.1	1.23
28	477812	1603514	185	1392	5.1	3.1	27.1	1.23
29	479907	1604127	182	1392	5.1	3.1	27.1	1.23
30	479910	1604170	186	1438	5.4	3.1	27.1	1.39
31	479888	1604134	189	1440	5.4	3.1	27.1	1.39
32	479898	1604093	178	1440	5.4	3.1	27.1	1.39
33	479889	1604160	180	1440	5.4	3.1	27.1	1.39
34	479899	1604117	185	1440	5.4	3.1	27.1	1.39
35	479873	1604728	185	1440	5.4	3.1	27.1	1.39
36	479871	1604826	190	1440	5.4	3.1	27.1	1.39
37	479065	1604966	182	1441	5.4	3.1	27.1	1.39
38	478885	1604355	186	1441	5.4	3.1	27.1	1.39
39	477986	1603134	189	1441	5.4	3.1	27.1	1.39
40	477923	1603206	188	1440	5.4	3.1	27.1	1.39
41	422965	1607656	232	1438	5.4	3.1	27.1	1.39
42	423578	1609098	223	1438	5.4	3.1	27.1	1.39
43	424841	1612319	187	1384	5.1	3.1	27.1	1.23
44	424853	1612391	189	1384	5.1	3.1	27.1	1.23
45	424189	1612174	192	1385	5.1	3.1	27.1	1.23
46	425636	1612694	193	1388	5.1	3.1	27.1	1.23
47	425841	1611803	190	1388	5.1	3.1	27.1	1.23
48	424116	1611190	198	1388	5.1	3.1	27.1	1.23
49	424551	1612451	183	1,389	5.1	3.1	27.1	1.23
50	454918	1606098	204	1,389	5.1	3.1	27.1	1.23

Table 4.7 The collected data concerning climate (Continued).

Samp. No.	Location (UTM zone 48N)			Climate properties				
	X	Y	Z	Rainfall (mm/yr)	*Ih* (Months)	*VPD* (mbar)	T °C	Wind (m/s)
51	454924	1606031	200	1,387	5.1	3.1	27.1	1.23
52	425669	1610228	216	1,388	5.1	3.1	27.1	1.23
53	429135	1610604	194	1,423	5.3	3.1	27.1	1.34
54	427620	1611216	206	1,424	5.3	3.1	27.1	1.34
55	427840	1611362	199	1,424	5.3	3.1	27.1	1.34
56	429111	1611337	190	1,388	5.1	3.1	27.1	1.23
57	428347	1611281	200	1,391	5.1	3.1	27.1	1.23
58	453600	1607946	226	1,390	5.1	3.1	27.1	1.23
59	455298	1607783	198	1,390	5.1	3.1	27.1	1.23
60	454496	1606094	192	1,391	5.1	3.1	27.1	1.23
61	377922	1625317	167	1,391	5.1	3.1	27.1	1.23
62	378423	1623221	173	1,424	5.3	3.1	27.1	1.34
63	379113	1624790	176	1,426	5.3	3.1	27.1	1.34
64	377754	1624125	175	1,423	5.3	3.1	27.1	1.34
65	378372	1623020	175	1,380	4.6	3.0	27.1	1.13
66	378487	1623179	179	1,378	4.6	3.0	27.1	1.13
67	380655	1625194	167	1,379	4.6	3.0	27.1	1.13
68	381316	1624694	174	1,379	4.6	3.0	27.1	1.13
69	379427	1626311	158	1,378	4.6	3.0	27.1	1.13
70	378314	1623363	174	1,378	4.6	3.0	27.1	1.13
71	378799	1624346	180	1,378	4.6	3.0	27.1	1.13
72	395160	1600326	201	1,379	4.7	3.0	27.2	1.13
73	380464	1635858	164	1,378	4.7	3.0	27.2	1.13
74	379022	1626424	161	1,380	4.6	3.0	27.2	1.13
75	395441	1600839	218	1,378	4.6	3.0	27.1	1.13
76	395300	1598401	218	1,378	4.6	3.0	27.1	1.13
77	378316	1623106	174	1,379	4.6	3.0	27.1	1.13
78	379242	1626807	160	1,365	4.9	3.1	27.1	1.13
79	379092	1626007	164	1,384	4.6	3.0	27.2	1.13
80	483790	1767563	194	1,379	4.6	3.0	27.1	1.13
81	485255	1764433	189	1,380	4.6	3.0	27.2	1.13
82	483247	1765364	198	1,365	4.9	3.1	27.1	1.13
83	490073	1765888	180	1,364	4.9	3.1	27.1	1.13
84	495050	1765520	181	1,378	4.6	3.0	27.1	1.13
85	492332	1766260	177	1,380	4.6	3.0	27.2	1.13
86	491631	1769394	175	1,380	4.6	3.0	27.2	1.13
87	489686	1772168	166	1,512	5.6	3.1	26.8	1.18
88	491510	1764729	187	1,513	5.6	3.1	26.8	1.23
89	491372	1764835	181	1,512	5.6	3.1	26.8	1.23
90	482825	1784853	203	1,516	5.6	3.1	26.8	1.23
91	484151	1785401	202	1,515	5.6	3.1	26.8	1.18
92	491903	1766285	176	1,516	5.6	3.1	26.8	1.18

Table 4.7 The collected data concerning climate (Continued).

Samp. No.	Location (UTM zone 48N)			Climate properties				
	X	Y	Z	Rainfall (mm/yr)	*Ih* (Months)	*VPD* (mbar)	T ^{o}C	Wind (m/s)
93	528602	1606126	205	1,519	5.6	3.1	26.8	1.23
94	528580	1606398	207	1,517	5.6	3.1	26.8	1.23
95	527971	1607085	199	1,517	5.6	3.1	26.8	1.23
96	526390	1608550	184	1,517	5.6	3.1	26.8	1.18
97	525156	1608669	180	1,516	5.6	3.1	26.8	1.18
98	528174	1606970	203	1,517	5.6	3.1	26.8	1.23
99	525768	1608414	188	1,517	5.6	3.1	26.8	1.23
100	525953	1608662	181	1,517	5.6	3.1	26.8	1.23
101	528211	1608977	202	1,519	5.6	3.1	26.8	1.23
102	525700	1608480	189	1,511	5.6	3.1	26.7	1.13
103	549924	1643824	172	1,512	5.6	3.1	26.7	1.13
104	551871	1644392	183	1,517	5.6	3.1	26.8	1.23
105	551474	1644030	173	1,518	5.6	3.1	26.8	1.23
106	550836	1645116	175	1,490	5.5	3.1	27.1	1.39
107	551460	1645644	192	1,490	5.5	3.1	27.1	1.39
108	550650	1644079	184	1,491	5.5	3.1	27.1	1.39
109	548511	1644130	167	1,492	5.5	3.1	27.1	1.39
110	548395	1644714	169	1,492	5.5	3.1	27.1	1.44
111	548440	1644829	172	1,491	5.5	3.1	27.1	1.39
112	519460	1608908	162	1,492	5.5	3.1	27.1	1.44
113	510656	1624505	163	1,492	5.5	3.1	27.1	1.44
114	514076	1624905	163	1,492	5.5	3.1	27.1	1.39
115	549256	1652632	177	1,492	5.5	3.1	27.1	1.44
116	545165	1652612	196	1,513	5.6	3.1	27.1	1.49
117	548874	1651905	185	1,513	5.6	3.1	27.1	1.49
118	547933	1652794	180	1,512	5.6	3.1	27.1	1.44
119	546408	1654267	179	1,512	5.6	3.1	27.1	1.44
120	548841	1654557	192	1,513	5.6	3.1	27.1	1.49
121	464574	1725374	131	1,513	5.6	3.1	27.1	1.49
122	470516	1725988	144	1,513	5.6	3.1	27.1	1.49
123	441862	1703430	135	1,513	5.6	3.1	27.1	1.49
124	441884	1703199	122	1,514	5.6	3.0	27.1	1.49
125	442034	1703312	133	1,514	5.6	3.0	27.1	1.49
126	442044	1703339	131	1,513	5.6	3.1	27.1	1.49
127	442008	1703315	132	1,492	5.5	3.1	27.1	1.44
128	442075	1703409	129	1,506	5.6	3.0	27.1	1.49
129	442295	1703916	126	1,507	5.6	3.0	27.1	1.49
130	528017	1606997	198	1,518	5.7	3.0	27.1	1.49
131	548466	1644679	180	1,520	5.7	3.0	27.1	1.49
132	547423	1645542	164	1,517	5.7	3.0	27.1	1.49
132	547423	1645542	164	1,517	5.7	3.0	27.1	1.49
133	519147	1624071	151	1518	5.7	3.0	27.1	1.49

Table 4.7 The collected data concerning climate (Continued).

Samp. No.	Location (UTM zone 48N)			Climate properties				
	X	Y	Z	Rainfall (mm/yr)	*Ih* (Months)	*VPD* (mbar)	T ^{o}C	Wind (m/s)
134	442106	1703157	126	1520	5.7	3.0	27.1	1.49
135	529576	1606975	246	1519	5.7	3.0	27.1	1.49
136	529659	1606867	239	1513	5.7	3.0	27.1	1.49
137	529455	1607376	230	1522	5.7	3.0	27	1.49
138	551464	1644155	179	1520	5.7	3.0	27.1	1.49
139	550639	1644747	175	1520	5.7	3.0	27.1	1.49
140	530084	1607482	239	1490	5.6	3.0	27.1	1.44
141	528227	1609091	198	1490	5.6	3.0	27.1	1.44
142	527768	1609114	188	1490	5.6	3.0	27.1	1.44
143	525433	1608485	175	1490	5.6	3.0	27.1	1.44
144	529980	1607672	232	1490	5.6	3.0	27.1	1.44
145	529623	1606714	226	1490	5.6	3.0	27.1	1.44
146	528334	1606878	206	1490	5.6	3.0	27.1	1.44
147	548586	1644836	174	1490	5.6	3.0	27.1	1.44
148	549689	1646155	172	1491	5.5	3.1	27.1	1.39
149	551885	1645130	194	1514	5.6	3.0	27.1	1.49
150	551941	1646064	175	1515	5.6	3.0	27.1	1.49
			Min	1219	4.60	3.00	26.70	0.93
			Mean	1430	5.28	3.07	27.06	1.27
			Max	1522	5.70	3.10	27.20	1.49

The climate data showed that the average of the average annual rainfall was 1,435 mm, the average of dry season periods was 5.3 months, the average of periods when *VPD* more than 11 was 3.1 months and the average of temperature regime was 27.1, and the average wind speed was 1.29. Accordingly, it meant that the suitability level of these kinds of data was in a low group of the crop requirements (in Table 4.1). Therefore, in this study, fuzzy sets of Ks were divided into two groups: Low (L) and Medium (M).

4.2.4 Rubber plantation management (Ma)

Analysis results of the data concerning the management factors in the sample rubber plantations based on scoring criteria which were determined in 4.1.4

and Table 4.4 can be expressed in Table 4.8. These indexes of management factors were combined and fuzzified for further rule development (see Appendix B).

Table 4.8 The collected data concerning management factors.

Samp. No.	Location(UTM zone 48N)			Management factors					
	X	Y	Z	DS	PR	FR	WD	CC	TP
1	286467	1588945	251	0.5	0.5	0.8	0.8	0.5	0.8
2	286738	1589065	243	0.5	0.5	0.8	0.8	0.8	0.8
3	286472	1588884	245	0.5	0.5	0.8	0.8	0.5	0.8
4	283927	1588532	252	0.5	0.8	0.8	0.5	0.5	0.8
5	283695	1588782	261	0.5	0.8	0.8	0.8	0.8	0.8
6	284424	1593474	211	0.5	1.0	0.9	0.8	0.5	0.8
7	281687	1591192	240	0.5	1.0	1.0	1.0	0.8	0.8
8	280870	1590362	243	0.5	0.3	0.4	1.0	0.5	0.8
9	282186	1592487	243	0.5	0.3	0.4	0.8	0.5	0.8
10	282477	1592487	230	0.5	0.8	0.8	0.5	0.5	0.8
11	282270	1592491	230	0.5	0.8	0.9	0.8	0.8	0.8
12	282062	1592547	232	1.0	0.3	0.5	0.5	0.7	0.8
13	282307	1592145	243	0.5	0.3	0.4	1.0	0.5	0.8
14	406286	1764067	156	0.5	1.0	0.6	1.0	0.5	0.8
15	403434	1765215	162	0.5	0.8	0.7	0.8	0.8	0.8
16	403382	1764892	158	0.5	0.3	0.8	0.5	0.8	0.8
17	406963	1764778	160	0.5	0.3	0.8	0.8	0.5	0.8
18	407272	1764041	175	0.5	1.0	0.9	0.8	0.8	0.8
19	407901	1766309	166	0.5	0.8	1.0	0.8	0.7	0.8
20	403970	1764565	165	0.5	0.8	0.9	0.8	0.7	0.8
21	427982	1610990	208	0.5	0.8	0.8	0.8	0.7	0.8
22	427966	1610920	193	0.5	0.5	0.8	0.8	0.5	1.0
23	428186	1611078	198	0.5	0.5	0.8	1.0	0.5	0.8
24	428969	1610960	193	0.5	0.8	0.8	0.8	0.5	1.0
25	428144	1611430	201	0.5	1.0	0.8	0.8	0.5	0.8
26	430534	1609726	192	1.0	0.8	0.8	0.8	0.5	0.8
27	430039	1610711	186	0.5	0.8	0.8	0.8	0.8	1.0
28	477812	1603514	185	0.5	1.0	0.8	1.0	0.8	0.8
29	479907	1604127	182	0.5	0.5	0.6	0.5	0.5	0.8
30	479910	1604170	186	0.5	0.8	0.6	0.8	0.5	0.8
31	479888	1604134	189	0.5	0.8	0.8	0.5	0.5	0.8
32	479898	1604093	178	0.5	0.8	0.7	0.8	0.7	0.8
33	479889	1604160	180	0.5	0.8	0.8	1.0	0.5	0.8
34	479899	1604117	185	0.5	0.8	0.8	0.8	0.5	0.8
35	479873	1604728	185	0.5	0.5	0.8	0.8	0.5	0.8
36	479871	1604826	190	0.5	0.5	0.8	0.8	0.7	0.8

Table 4.8 The collected data concerning management factors (Continued).

Samp.	Location(UTM zone 48N)			Management factors					
No.	X	Y	Z	DS	PR	FR	WD	CC	TP
37	479065	1604966	182	0.5	0.5	0.7	0.5	0.7	0.8
38	478885	1604355	186	0.5	0.8	0.8	0.8	0.5	0.8
39	477986	1603134	189	0.5	0.8	0.4	0.5	0.5	0.8
40	477923	1603206	188	0.5	0.8	0.6	0.8	0.5	0.8
41	422965	1607656	232	0.5	1.0	0.8	1.0	0.8	0.8
42	423578	1609098	223	0.5	0.8	0.8	1.0	0.7	0.8
43	424841	1612319	187	0.5	0.5	0.8	0.5	0.7	0.8
44	424853	1612391	189	0.5	0.5	0.8	0.5	0.7	0.8
45	424189	1612174	192	0.5	0.8	0.8	0.8	0.7	0.8
46	425636	1612694	193	0.5	0.8	0.9	0.8	0.7	0.8
47	425841	1611803	190	0.5	0.8	0.9	0.8	0.7	0.8
48	424116	1611190	198	0.5	0.8	0.9	0.8	0.7	0.8
49	424551	1612451	183	1.0	0.3	0.8	0.8	0.7	0.8
50	454918	1606098	204	1.0	0.5	0.9	1.0	0.7	0.8
51	454924	1606031	200	1.0	0.8	0.9	0.8	0.8	0.8
52	425669	1610228	216	0.5	0.3	0.8	0.5	0.5	0.8
53	429135	1610604	194	0.5	0.8	0.8	0.5	0.5	0.8
54	427620	1611216	206	0.5	0.3	0.4	1.0	0.5	0.8
55	427840	1611362	199	0.5	0.3	0.7	1.0	0.5	0.8
56	429111	1611337	190	0.5	0.8	0.8	0.5	0.5	0.8
57	428347	1611281	200	0.5	0.3	0.9	0.5	0.8	0.8
58	453600	1607946	226	0.5	1.0	0.6	1.0	0.5	0.8
59	455298	1607783	198	0.5	0.5	0.8	1.0	0.7	0.8
60	454496	1606094	192	1.0	1.0	0.8	0.8	0.5	0.8
61	377922	1625317	167	1.0	1.0	0.8	1.0	0.8	0.8
62	378423	1623221	173	0.5	0.3	0.8	0.5	0.5	0.8
63	379113	1624790	176	0.5	0.5	0.7	0.5	0.8	0.8
64	377754	1624125	175	0.5	0.3	0.6	0.5	0.8	0.8
65	378372	1623020	175	0.5	0.3	0.5	0.8	0.5	0.8
66	378487	1623179	179	0.5	0.5	0.9	0.5	0.8	0.8
67	380655	1625194	167	0.5	0.8	0.9	0.8	0.8	0.8
68	381316	1624694	174	0.5	0.8	0.8	0.5	0.7	0.8
69	379427	1626311	158	0.5	0.3	0.8	0.8	0.5	0.8
70	378314	1623363	174	0.5	0.3	0.8	0.5	0.5	0.8
71	378799	1624346	180	0.5	0.8	0.8	0.8	0.7	0.8
72	395160	1600326	201	0.5	0.8	0.9	0.8	0.5	0.8
73	380464	1635858	164	0.5	0.5	0.9	0.5	0.5	0.8
74	379022	1626424	161	0.5	0.8	0.8	0.5	0.8	0.8
75	395441	1600839	218	0.5	0.3	0.9	0.8	0.5	0.8
76	395300	1598401	218	0.5	0.3	0.9	1.0	0.5	0.8
77	378316	1623106	174	0.5	0.5	0.8	0.5	0.8	0.8
78	379242	1626807	160	1.0	1.0	0.8	0.8	0.8	0.8

Table 4.8 The collected data concerning management factors (Continued).

Samp. No.	Location(UTM zone 48N) X	Y	Z	Management factors DS	PR	FR	WD	CC	TP
79	379092	1626007	164	0.5	0.3	0.8	0.8	0.8	0.8
80	483790	1767563	194	1.0	1.0	0.8	0.8	0.8	0.8
81	485255	1764433	189	0.5	0.5	0.9	0.5	0.7	0.8
82	483247	1765364	198	0.5	0.5	0.8	0.8	0.5	0.8
83	490073	1765888	180	0.5	0.8	0.9	1.0	0.8	0.8
84	495050	1765520	181	0.5	1.0	0.9	0.8	0.7	0.8
85	492332	1766260	177	0.5	0.5	0.9	0.8	0.7	0.8
86	491631	1769394	175	0.5	0.8	0.7	0.8	0.7	0.8
87	489686	1772168	166	0.5	1.0	0.8	0.5	0.5	0.8
88	491510	1764729	187	0.5	1.0	0.6	0.8	0.8	0.8
89	491372	1764835	181	0.5	1.0	0.8	0.8	0.5	0.8
90	482825	1784853	203	1.0	0.5	0.8	0.8	0.7	1.0
91	484151	1785401	202	0.5	0.8	0.9	0.8	0.7	0.8
92	491903	1766285	176	0.5	0.5	0.6	0.8	0.7	0.8
93	528602	1606126	205	0.5	0.8	0.8	0.8	0.8	0.8
94	528580	1606398	207	0.5	0.3	0.8	0.8	0.8	0.8
95	527971	1607085	199	0.5	0.5	1.0	1.0	0.5	0.8
96	526390	1608550	184	0.5	0.8	0.6	1.0	0.8	0.8
97	525156	1608669	180	0.5	0.3	0.8	0.8	0.5	0.8
98	528174	1606970	203	0.5	0.5	0.8	0.8	0.5	0.8
99	525768	1608414	188	0.5	1.0	0.8	1.0	0.8	0.8
100	525953	1608662	181	0.5	0.8	0.8	0.5	0.8	0.8
101	528211	1608977	202	0.5	0.8	0.6	0.8	0.7	0.8
102	525700	1608480	189	0.5	0.8	0.8	0.5	0.8	0.8
103	549924	1643824	172	0.5	0.5	0.8	0.8	0.8	0.8
104	551871	1644392	183	0.5	0.8	0.9	0.8	0.5	0.8
105	551474	1644030	173	0.5	0.3	0.9	1.0	0.5	0.8
106	550836	1645116	175	0.5	0.8	0.8	0.8	0.7	0.8
107	551460	1645644	192	0.5	0.5	0.8	0.5	0.8	0.8
108	550650	1644079	184	0.5	0.5	0.8	0.5	0.8	0.8
109	548511	1644130	167	0.5	0.5	0.8	0.8	0.8	0.8
110	548395	1644714	169	0.5	0.3	0.6	0.8	0.8	0.8
111	548440	1644829	172	0.5	0.8	0.8	0.8	0.5	0.8
112	519460	1608908	162	0.5	0.8	0.8	0.5	0.7	1.0
113	510656	1624505	163	0.5	0.5	0.9	0.8	0.8	1.0
114	514076	1624905	163	1.0	0.5	0.8	0.8	0.7	0.8
115	549256	1652632	177	0.5	0.3	0.4	0.8	0.5	0.8
116	545165	1652612	196	0.5	1.0	0.9	1.0	0.5	0.8
117	548874	1651905	185	0.5	1.0	0.9	1.0	0.5	0.8
118	547933	1652794	180	0.5	0.3	0.8	0.8	0.5	0.8
119	546408	1654267	179	0.5	0.8	0.9	0.8	0.5	0.8
120	548841	1654557	192	1.0	0.8	0.9	0.8	0.8	0.8

Table 4.8 The collected data concerning management factors (Continued).

Samp.	Location(UTM zone 48N)			Management factors					
No.	X	Y	Z	DS	PR	FR	WD	CC	TP
121	464574	1725374	131	0.5	0.5	0.9	0.8	0.7	0.8
122	470516	1725988	144	0.5	0.3	0.8	0.8	0.5	1.0
123	441862	1703430	135	0.5	0.3	1.0	0.8	0.5	0.8
124	441884	1703199	122	0.5	0.3	0.6	0.8	0.5	0.8
125	442034	1703312	133	0.5	0.5	0.8	0.5	0.5	0.8
126	442044	1703339	131	0.5	0.3	0.7	0.5	0.5	0.8
127	442008	1703315	132	0.5	0.3	0.9	0.5	0.5	0.8
128	442075	1703409	129	0.5	0.5	0.9	0.5	0.5	0.8
129	442295	1703916	126	0.5	0.5	0.8	0.5	0.5	0.8
130	528017	1606997	198	0.5	0.3	0.7	0.5	0.5	0.8
131	548466	1644679	180	0.5	0.3	0.6	0.8	0.8	0.8
132	547423	1645542	164	0.5	0.3	0.8	0.8	0.8	0.8
133	547423	1645542	164	1.0	0.5	0.8	0.8	0.5	0.8
134	519147	1624071	151	0.5	0.3	0.6	0.8	0.5	0.8
135	442106	1703157	126	0.5	0.8	0.8	0.8	0.5	0.8
136	529576	1606975	246	0.5	0.8	0.8	0.8	0.7	0.8
137	529659	1606867	239	0.5	0.3	0.8	0.8	0.5	0.8
138	529455	1607376	230	0.5	0.3	0.9	0.5	0.5	0.8
139	551464	1644155	179	0.5	0.8	0.8	0.8	0.7	1.0
140	550639	1644747	175	0.5	0.3	0.8	0.5	0.5	0.8
141	528227	1609091	198	0.5	1.0	0.8	1.0	0.8	0.8
142	527768	1609114	188	0.5	0.8	0.7	1.0	0.5	0.8
143	525433	1608485	175	1.0	0.5	0.8	0.8	0.5	0.8
144	529980	1607672	232	1.0	0.8	0.8	0.8	0.5	0.8
145	529623	1606714	226	0.5	0.8	0.8	0.8	0.5	0.8
146	528334	1606878	206	0.5	0.8	0.8	0.8	0.7	0.8
147	548586	1644836	174	0.5	0.8	0.8	0.5	0.8	0.8
148	549689	1646155	172	0.5	0.5	0.8	0.8	0.8	0.8
149	551885	1645130	194	0.5	0.5	0.8	0.8	0.8	0.8
150	551941	1646064	175	0.5	0.8	0.5	0.8	0.8	0.8

Note: DS is Dry Season, PR is Pruning, FR is Fertilizing, WD is Weeding, CC is Cover crop, TP is Rubber tapping systems.

4.2.5 Rubber product

Regarding to the collected data, it was found that the average yield of ADS around 191 kg/rai/year, the minimum around 124 kg/rai/year and the maximum around 288 kg/rai/year. Therefore, the fuzzy sets of the ADS can be determined as shown in Figure 4.14.

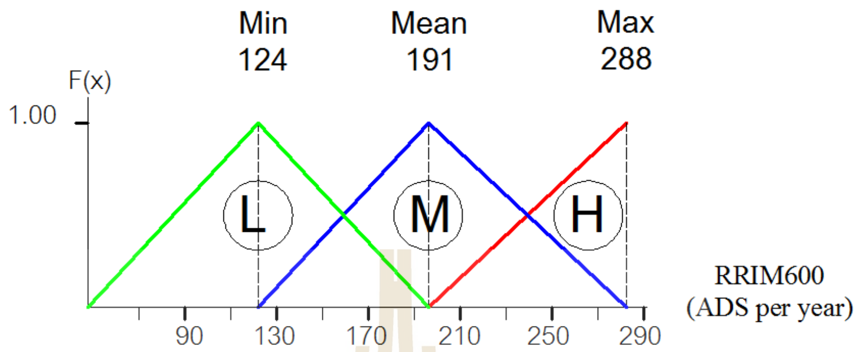


Figure 4.14 Fuzzy sets of ADS per year (RRIM600).

4.2.6 Results of rules analysis

In this study, system rules were created mainly based on 150 samples of the data of RRIM600 clone rubbers due to this clone of rubbers being grown so extensively in the lower northeastern region that made the data more reliable, easier to collect and enough to the study.

In data analysis done in sections 4.2.1, 4.2.2, and 4.2.3, each factor were calculated from the membership function in 4.1.1, 4.1.2, and 4.1.3 and combined by means of Storie's method for Kp, Ks and Kc along with calculation for finding minimum, mean and maximum values.

The Min, Mean and Max values acquired were taken into account to find the values used to determine Fuzzy classes and represent linguistic variables of the data.

Table 4.9 showed that the minimum, mean, and maximum values of Kp, Ks, Kc, and Ma were 0.00, 67.80 and 83.38, 0.24, 4.87 and 21.99, 12.75, 15.87 and 20.52, and 1.92, 11.49 and 49.07, respectively. Fuzzy classes of Kp (a), Ks (b), Kc (c) and Ma(d) could be determined as shown in Figure 4.15.

Table 4.9 Field data analysis results.

Samp. No	Kp		Ks		Kc		Ma		ADS (kg/yr)	
1	79.21	H	1.96	L	13.11	L	6.13	L	183	M
2	79.21	H	1.96	L	13.15	L	9.81	M	148	L
3	79.21	H	1.96	L	13.11	L	6.13	L	205	M
4	79.21	H	1.96	L	12.95	L	6.13	L	181	M
5	79.21	H	1.96	L	12.95	L	15.70	M	137	L
6	79.21	H	1.96	L	12.87	L	14.93	M	136	L
7	79.21	H	1.96	L	12.75	L	32.00	H	280	H
8	79.21	H	1.96	L	12.75	L	2.40	L	190	M
9	79.21	H	1.96	L	12.75	L	1.92	L	189	M
10	79.21	H	1.96	L	12.79	L	6.13	L	165	M
11	79.21	H	1.96	L	12.75	L	19.11	M	147	L
12	79.21	H	1.96	L	12.75	L	4.20	L	165	M
13	79.21	H	1.96	L	12.79	L	2.40	L	217	M
14	79.21	H	1.96	L	15.14	L	12.00	M	138	L
15	79.21	H	1.96	L	15.00	L	13.65	M	147	L
16	79.21	H	1.96	L	14.97	L	3.68	L	167	M
17	79.21	H	1.96	L	15.17	L	3.68	L	223	M
18	79.21	H	1.96	L	15.17	L	23.89	H	283	H
19	35.64	M	4.41	L	15.23	L	16.73	M	194	M
20	41.59	M	21.99	M	15.03	L	11.95	M	214	M
21	79.21	H	1.96	L	16.21	M	13.74	M	155	L
22	79.21	H	1.96	L	16.21	M	7.67	L	217	M
23	79.21	H	1.96	L	16.21	M	8.33	L	144	L
24	79.21	H	1.96	L	16.24	M	12.27	M	210	M
25	79.21	H	1.96	L	16.24	M	13.33	M	162	M
26	79.21	H	1.96	L	16.28	M	19.63	M	173	M
27	79.21	H	1.96	L	16.28	M	19.63	M	169	M
28	79.21	H	1.96	L	16.28	M	26.67	H	279	H
29	0.00	M	1.96	L	16.28	M	3.00	L	138	L
30	79.21	H	0.29	L	14.51	L	7.68	L	191	M
31	0.00	M	1.96	L	14.57	L	6.13	L	163	M
32	79.21	H	0.24	L	14.57	L	11.95	M	232	M
33	77.12	H	1.96	L	14.57	L	12.27	M	182	M
34	79.21	H	1.96	L	14.57	L	9.81	M	192	M
35	79.21	H	1.96	L	14.57	L	6.13	L	208	M
36	79.21	H	1.96	L	14.57	L	8.59	L	217	M
37	79.21	H	1.96	L	14.59	L	4.67	L	228	M
38	79.21	H	1.96	L	14.59	L	9.81	M	204	M

Table 4.9 Field data analysis results (Continued).

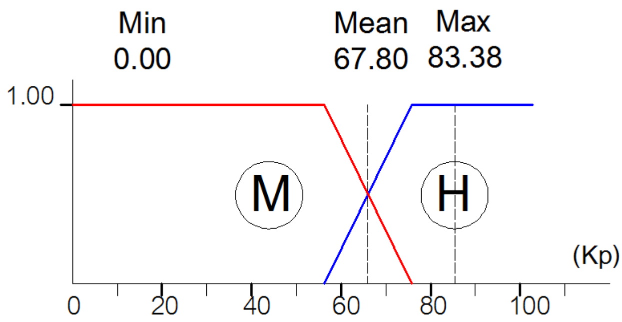
Samp. No	Kp		Ks		Kc		Ma		ADS (kg/yr)	
39	79.21	H	1.96	L	14.59	L	3.20	L	164	M
40	79.21	H	1.96	L	14.57	L	7.68	L	160	M
41	46.49	M	1.96	L	14.51	L	8.00	L	208	M
42	46.49	M	21.99	M	14.51	L	17.17	M	174	M
43	70.87	H	21.99	M	16.01	M	5.83	L	220	M
44	70.87	H	21.99	M	16.01	M	5.83	L	230	M
45	70.87	H	1.96	L	16.04	M	13.74	M	250	H
46	46.49	M	1.96	L	16.14	M	16.73	M	228	M
47	79.21	H	1.96	L	16.14	M	16.73	M	231	M
48	79.21	H	21.99	M	16.14	M	16.73	M	252	H
49	70.87	H	1.96	L	16.18	M	10.30	M	152	L
50	79.21	H	1.96	L	16.18	M	26.13	H	257	H
51	79.21	H	1.96	L	16.11	M	38.23	H	288	H
52	79.21	H	14.96	M	16.14	M	2.30	L	143	L
53	83.38	H	1.96	L	15.11	L	6.13	L	232	M
54	79.21	H	1.96	L	15.14	L	19.20	M	180	M
55	79.21	H	1.96	L	15.14	L	4.00	L	157	M
56	79.21	H	1.96	L	16.14	M	6.13	L	140	L
57	79.21	H	1.96	L	16.24	M	14.93	M	160	M
58	79.21	H	1.96	L	16.21	M	12.00	M	190	M
59	79.21	H	1.96	L	16.21	M	10.73	M	203	M
60	0.00	M	1.96	L	16.24	M	24.53	H	225	M
61	79.21	H	1.96	L	16.24	M	49.07	H	284	H
62	79.21	H	1.96	L	15.14	L	2.50	L	220	M
63	79.21	H	3.87	L	15.19	L	5.33	L	159	M
64	0.00	M	1.96	L	15.11	L	2.88	L	131	L
65	79.21	H	1.96	L	20.35	M	2.40	L	124	L
66	79.21	H	1.96	L	20.26	M	7.47	L	226	M
67	0.00	M	3.87	L	20.30	M	19.11	M	229	M
68	37.52	M	1.96	L	20.30	M	8.59	L	140	L
69	79.21	H	1.96	L	20.26	M	3.68	L	232	M
70	79.21	H	1.96	L	20.26	M	2.30	L	140	L
71	46.49	M	3.87	L	20.26	M	13.74	M	220	M
72	37.52	M	1.96	L	19.71	M	11.95	M	143	L
73	79.21	H	1.96	L	19.66	M	4.67	L	165	M
74	79.21	H	1.96	L	20.35	M	9.81	M	171	M
75	79.21	H	3.87	L	20.26	M	4.48	L	227	M
76	19.41	M	21.99	M	20.26	M	5.60	L	131	L
77	41.60	M	1.96	L	20.30	M	6.13	L	149	L
78	46.49	M	1.96	L	17.37	M	39.25	H	225	M
79	40.97	M	1.96	L	20.52	M	5.89	L	144	L
80	0.00	M	1.96	L	20.30	M	39.25	H	232	M

Table 4.9 Field data analysis results (Continued).

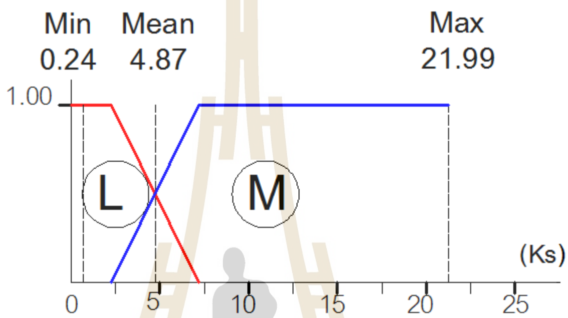
Samp. No	Kp		Ks		Kc		Ma		ADS (kg/yr)	
81	0.00	M	1.96	L	20.35	M	6.53	L	139	L
82	79.21	H	1.35	L	17.37	M	6.13	L	224	M
83	70.87	H	21.99	M	17.33	M	23.89	H	240	H
84	41.60	M	21.99	M	20.26	M	20.91	H	198	M
85	70.87	H	1.35	L	20.35	M	10.45	M	170	M
86	70.87	H	0.24	L	20.35	M	11.95	M	236	M
87	0.00	M	0.24	L	17.23	M	7.67	L	160	M
88	77.12	H	1.96	L	16.78	M	15.36	M	240	H
89	46.49	M	1.96	L	16.75	M	12.27	M	190	M
90	79.21	H	0.24	L	16.86	M	21.47	H	250	H
91	45.27	M	1.96	L	17.31	M	16.73	M	224	M
92	79.21	H	21.99	M	17.34	M	6.72	L	222	M
93	13.97	M	21.99	M	16.95	M	15.70	M	188	M
94	13.97	M	1.96	L	16.89	M	5.89	L	136	L
95	0.00	M	1.96	L	16.89	M	10.00	M	136	L
96	79.21	H	3.87	L	17.37	M	15.36	M	164	M
97	0.00	M	1.96	L	17.34	M	3.68	L	126	L
98	79.21	H	21.99	M	16.89	M	6.13	L	143	L
99	70.87	H	21.99	M	16.89	M	24.53	H	238	M
100	70.87	H	21.99	M	16.89	M	9.81	M	240	H
101	13.97	M	1.96	L	16.95	M	10.75	M	225	M
102	15.61	M	21.99	M	17.67	M	9.81	M	162	M
103	70.87	H	1.96	L	17.70	M	9.81	M	248	H
104	79.21	H	14.96	M	16.89	M	11.95	M	200	M
105	83.38	H	14.96	M	16.92	M	18.67	M	235	M
106	48.94	M	14.96	M	15.30	L	13.74	M	185	M
107	83.38	H	0.24	L	15.30	L	6.13	L	200	M
108	77.12	H	1.96	L	15.33	L	6.13	L	203	M
109	79.21	H	0.24	L	15.36	L	9.81	M	187	M
110	77.12	H	1.96	L	14.88	L	4.61	L	200	M
111	15.22	M	1.96	L	15.33	L	9.81	M	218	M
112	79.21	H	1.96	L	14.88	L	10.73	M	200	M
113	79.21	H	14.96	M	14.88	L	14.93	M	288	H
114	83.38	H	14.96	M	15.36	L	18.67	M	275	H
115	83.38	H	14.96	M	14.88	L	1.92	L	190	M
116	83.38	H	1.96	L	14.32	L	18.67	M	180	M
117	0.00	M	1.96	L	14.32	L	18.67	M	179	M
118	0.00	M	1.96	L	14.77	L	13.33	M	141	L
119	0.00	M	21.99	M	14.77	L	11.95	M	136	L
120	0.00	M	1.96	L	14.32	L	38.23	H	179	M
121	0.00	M	1.96	L	14.32	L	10.45	M	162	M
122	0.00	M	1.96	L	14.32	L	4.60	L	144	L

Table 4.9 Field data analysis results (Continued).

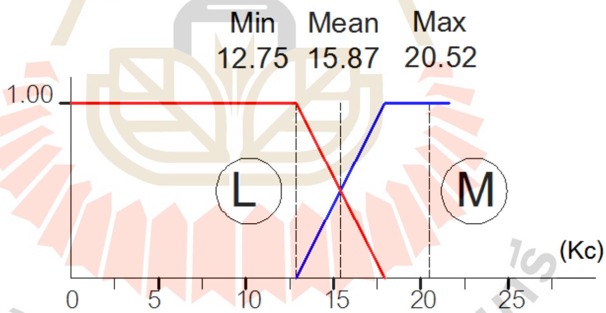
Samp. No	Kp		Ks		Kc		Ma		ADS (kg/yr)	
123	79.21	H	1.96	L	14.32	L	16.00	M	203	M
124	79.21	H	1.28	L	14.83	L	2.88	L	188	M
125	75.04	H	21.99	M	14.83	L	3.83	L	166	M
126	0.00	M	1.96	L	14.32	L	2.00	L	142	L
127	79.21	H	1.96	L	14.88	L	2.80	L	229	M
128	0.00	M	1.96	L	14.64	L	4.67	L	137	L
129	46.49	M	1.96	L	14.67	L	4.17	L	139	L
130	46.49	M	1.96	L	14.31	L	2.00	L	169	M
131	79.21	H	0.24	L	14.36	L	4.61	L	128	L
132	32.97	M	0.24	L	14.29	L	5.89	L	193	M
133	77.12	H	0.24	L	14.31	L	13.33	M	213	M
134	77.12	H	0.24	L	14.36	L	2.72	L	143	L
135	0.00	M	0.24	L	14.33	L	9.81	M	204	M
136	45.27	M	0.24	L	14.19	L	13.74	M	200	M
137	15.20	M	0.24	L	14.40	L	3.68	L	141	L
138	15.20	M	1.96	L	14.36	L	2.80	L	143	L
139	46.49	M	1.96	L	14.36	L	17.17	M	168	M
140	46.49	M	1.96	L	14.73	L	7.67	L	128	L
141	46.49	M	1.96	L	14.73	L	26.67	H	223	M
142	0.00	M	1.96	L	14.73	L	10.67	M	230	M
143	79.21	H	0.24	L	14.73	L	12.27	M	130	L
144	77.12	H	1.96	L	14.73	L	21.33	H	275	H
145	0.00	M	0.24	L	14.73	L	9.81	M	147	L
146	77.12	H	21.99	M	14.73	L	13.74	M	275	H
147	13.97	M	21.99	M	14.73	L	9.81	M	222	M
148	41.60	M	1.96	L	15.33	L	9.81	M	171	M
149	79.21	H	4.41	L	14.83	L	9.81	M	221	M
150	83.38	H	1.96	L	14.86	L	10.24	M	170	M
min =	0.00		0.24		12.75		1.92		124	
mean=	67.80		4.87		15.87		11.49		191	
max=	83.38		21.99		20.52		49.07		288	



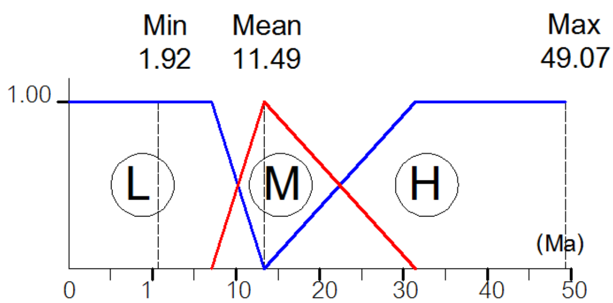
(a) Fuzzy classes of Kp.



(b) Fuzzy classes of Ks.



(c) Fuzzy classes of Kc.



(d) Fuzzy classes of Ma.

Figure 4.15 Fuzzy sets of Kp, Ks, Kc and Ma.

Fuzzy classes of Kp, Ks, Kc, and Ma factors were 2, 2, 2 and 3, respectively. When all the components were arranged, there were 2x2x2x3 = 24 system rules for ADS analysis which was classified by different classes of the management. From 150 samples, the rules were developed and selected based on frequency experienced in sample analysis shown in Table 4.10-4.12. According to the concept of Mamdani's fuzzy logic, one set of fuzzy class of Kp, Ks, Kc, and Ma could finally have only one class of ADS. Therefore, the low frequency class of ADS for a certain set of fuzzy class of Kp, Ks, Kc, and Ma was declined to meet the requirement of the concept. Frequencies shown in these tables were only the majority of ADS class for a certain set of fuzzy class of Kp, Ks, Kc, and Ma.

Table 4.10 Selected rules for ADS analysis of low rubber plantation management.

	Kp	Ks	Kc	Ma	ADS	Frequency
1	H	L	L	L	M	25
2	H	L	M	L	M	6
3	H	M	L	L	M	2
4	H	M	M	L	M	3
5	M	L	L	L	L	8
6	M	L	M	L	L	7
7	M	M	L	L	L*	-
8	M	M	M	L	L	1

Table 4.11 Selected rules for ADS analysis of medium rubber plantation management.

	Kp	Ks	Kc	Ma	ADS	Frequency
1	H	L	L	M	M	12
2	H	L	M	M	M	13
3	H	M	L	M	H	3
4	H	M	M	M	H	4
5	M	L	L	M	M	9
6	M	L	M	M	M	6
7	M	M	L	M	M	4
8	M	M	M	M	M	2

Table 4.12 Selected rules for ADS analysis of high rubber plantation management.

	Kp	Ks	Kc	Ma	ADS	Frequency
1	H	L	L	H	H	3
2	H	L	M	H	H	5
3	H	M	L	H	H*	-
4	H	M	M	H	H	2
5	M	L	L	H	M	2
6	M	L	M	H	M	3
7	M	M	L	H	M*	-
8	M	M	M	H	M	1

Note: “ * ” no case can be extracted from available data. Therefore, the ADS is obtained from expert’s opinion.

“ - ” not existing.

4.3 The analysis results of the soil properties of the study areas

According to the study of a soil series map of the Land Development Department (Figure 4.17), the study areas were divided into 7 categories: soil units of totally about 18,587,647 rai, Slope Complex, Alluvial Complex, Rubble land, and Urban and Water Areas which were uncultivable areas of totally about 2,543,908 rai, as shown in Figure 4.16 and Table 4.13.

Table 4.13 Category of study area related to soil mapping.

	Category	**Areas(rai)**
1	Soil units	18,587,674
2	Slope Complex	1,869,988
3	Alluvial Complex	435,500
4	Rubble land	19,727
5	Urban	56,515
6	Water Areas	162,178
	Sum	**19,261,593**

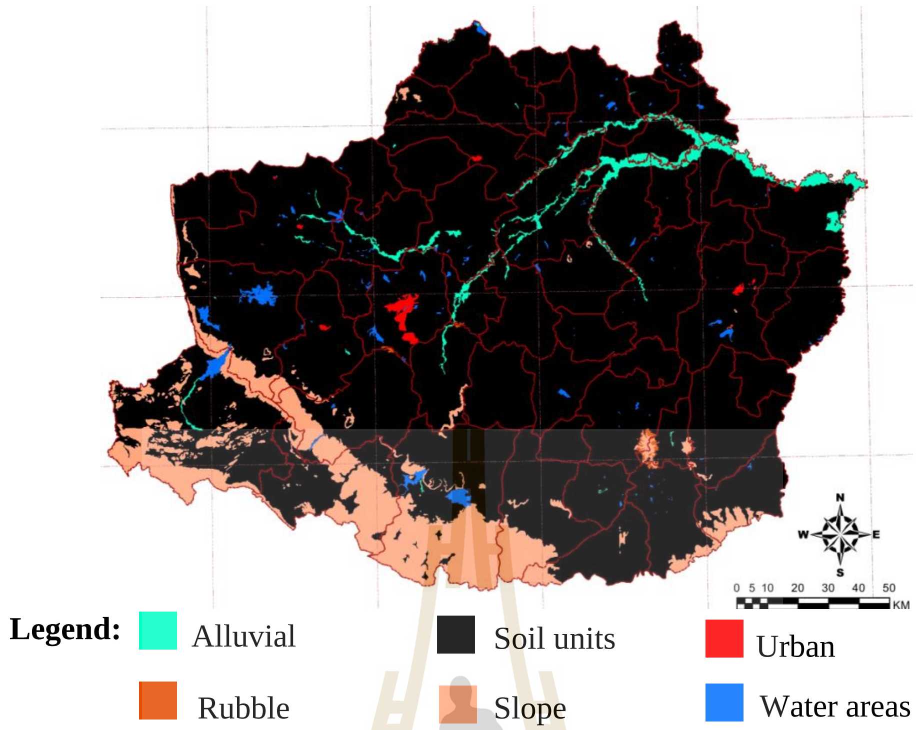


Figure 4.16 Category of study area related to soil mapping.

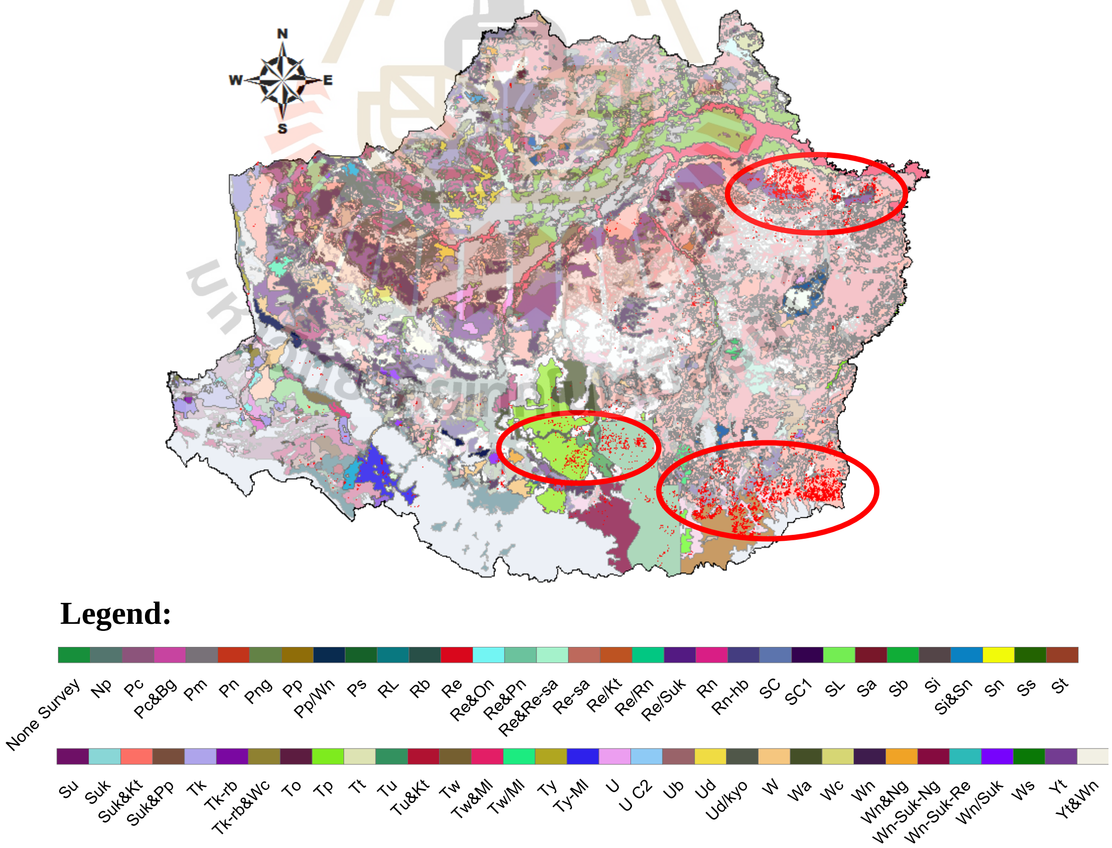


Figure 4.17 Soil series map.

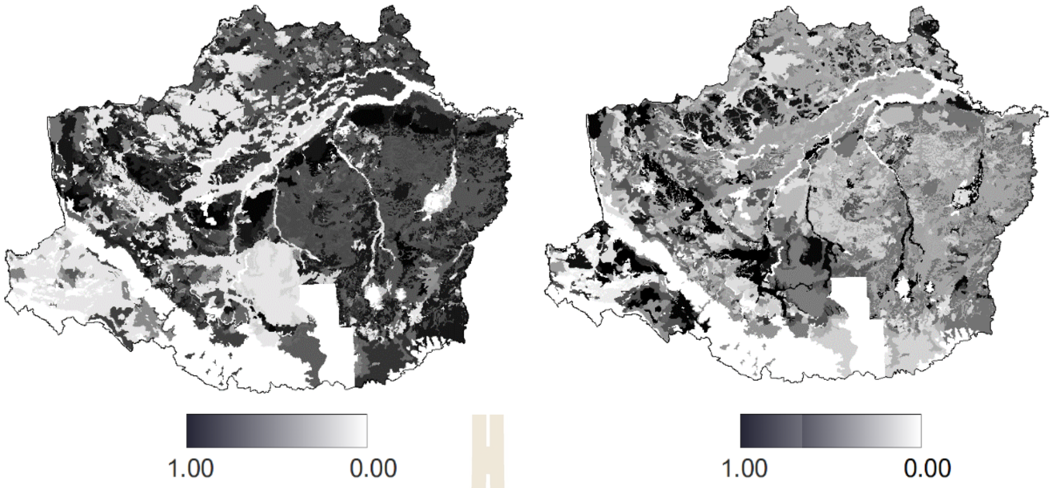
After overlaying Soil Series maps and rubber plantation area, it was found that most of the rubber plantations were shown in three parts (in red circles). In 3 districts, Khaendong, Satuk, and Khu Muang, in an upper part of Buriram, soil series were Khorat series (Kt), Yasothon series (Yt), Satuek series (Suk), and Warin series (Wn). In 4 districts, Pakhum, Non Dindaeng, Lahansai and Bankruat, in a lower part of Buriram, soil series were Satuek series (Suk), Khorat series (Kt), and Nam Phong series (Ng). The boundaries of the left lower part of Buriram Province: Non Suwan and Nongki districts, and Nakhon Ratchasima Province: Soeng Sang, Khonburi and Nong bunnak districts, soil series consist of Chok Chai series (Ci), Surin series (Su), and Ci / Su soil units.

4.4 The analysis results of the physical soil properties

4.4.1 Soil texture

Soil suitable for rubber plantation should contain clay not less than 35 % so that it can retain moisture and absorb nutrients well. It should be also composed of sand more than 30 % so that it can be well ventilated. It should be classified as Clay (C), Clay Loam (CL), Loam (L), and Sandy Loam (SL).

Fuzzy membership values (FM) of the suitability of the mixture of sand, and clay can be calculated as the results in Figure 4.18.



(a) FM of suitability of sand. (b) FM of suitability of clay.

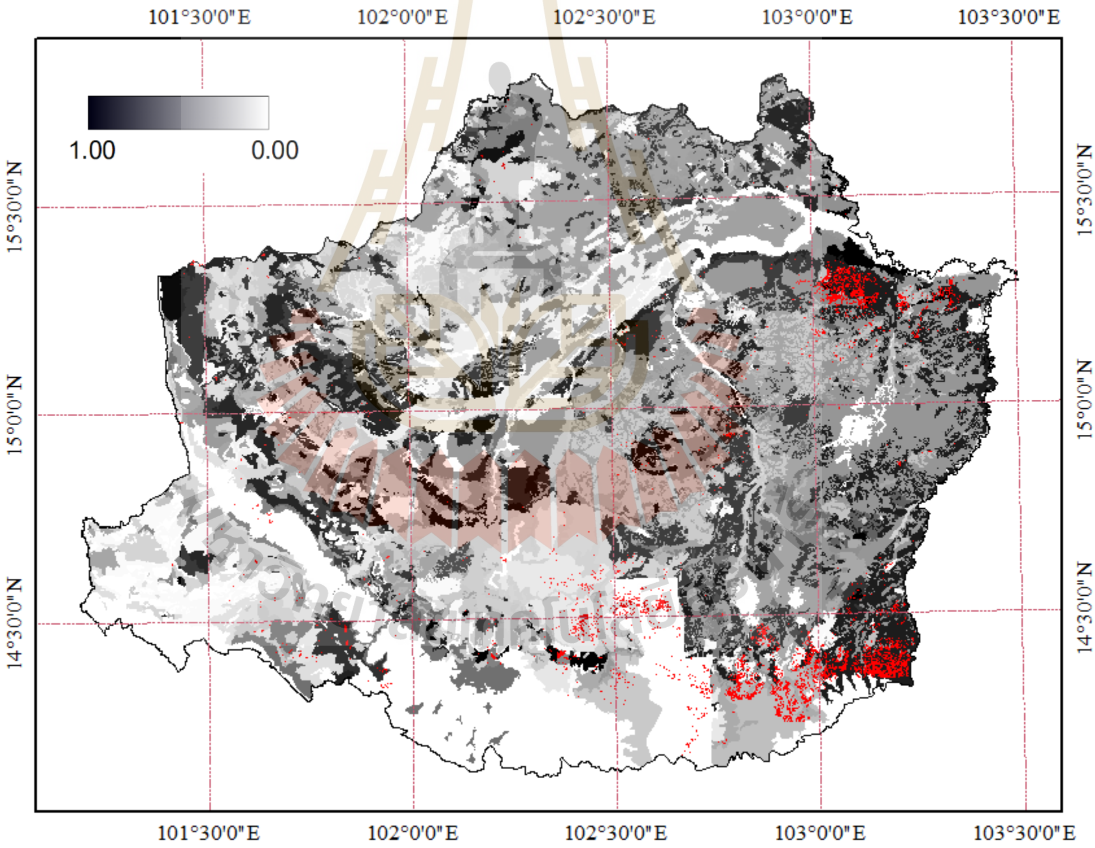


Figure 4.18 The Aggregation of FM of sand and clay.

According to the data of the soil in the study area about the composition of sand (a) and clay (b), after calculating FM of the suitability of the soil characteristics together with the combination by Storie’s method, it was found that the suitability score of soil for rubber plantation is high. This kind of soil was found in the long-established rubber plantation area which was the eastern part of Buriram Province and found scattered throughout Nakhon Ratchasima Province.

4.4.2 Soil slope

Rubber planting areas should have a flat surface or a slope less than 35 degrees. Rubber planting in areas with high slope can cause leaching of the soil surface and if there is very heavy rainfall over several days, it may cause landslides easily. It is found that, in Buriram and Nakhon Ratchasima, most areas are plain and high slope in a mountain range.

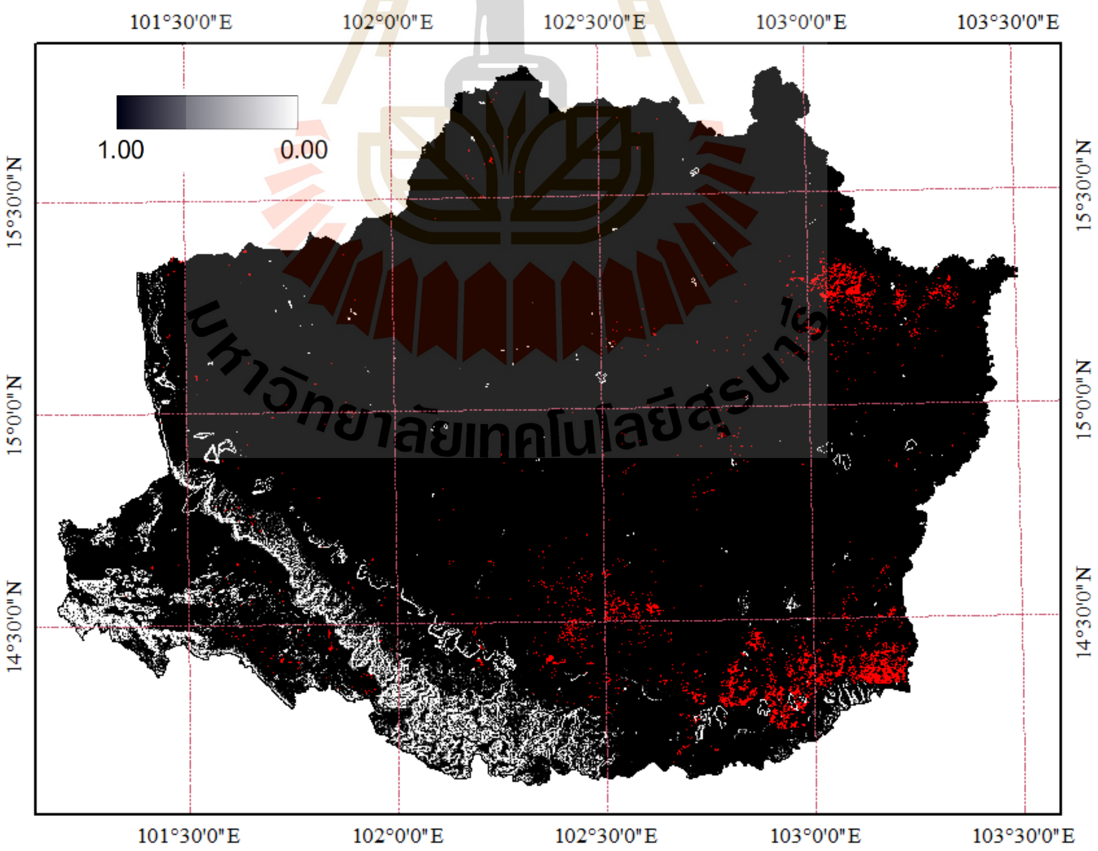


Figure 4.19 Map showing FM of suitability of soil slope.

The southern parts of the study area were less suitable. The FM values of the suitability related to these criteria are shown in Figure 4.19.

4.4.3 Effective soil depth

The depth of suitable soil from the surface should not have been less than 1 meter over gravel, solid rock, or lateritic layer. This allowed rubber root penetration. After calculating the FM of suitability of soil depth, it was found that the suitable areas were in the upper area and the area stretching along the southwest side of the study area. The suitability was high and began to decline when the area getting close to the mountain range as shown in Figure 4.20.

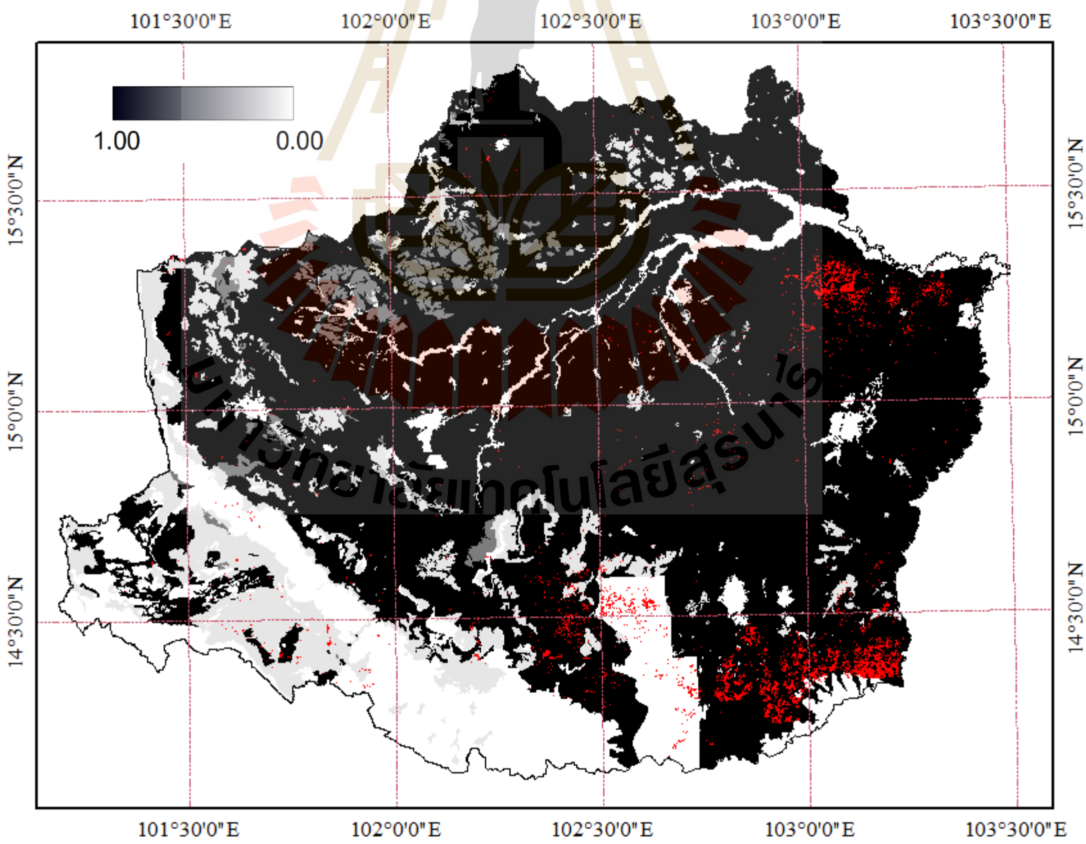


Figure 4.20 Map showing FM of suitability of effective soil depth and traditional rubber planting area (rad dots).

4.4.4 Soil drainage

Rubber trees should be planted in an area with well drainage and groundwater level should deeper than 1 meter and should not be paddy field or marsh. After, considering drainage of soils in the study area, the result of FM is shown in Figure 4.21.

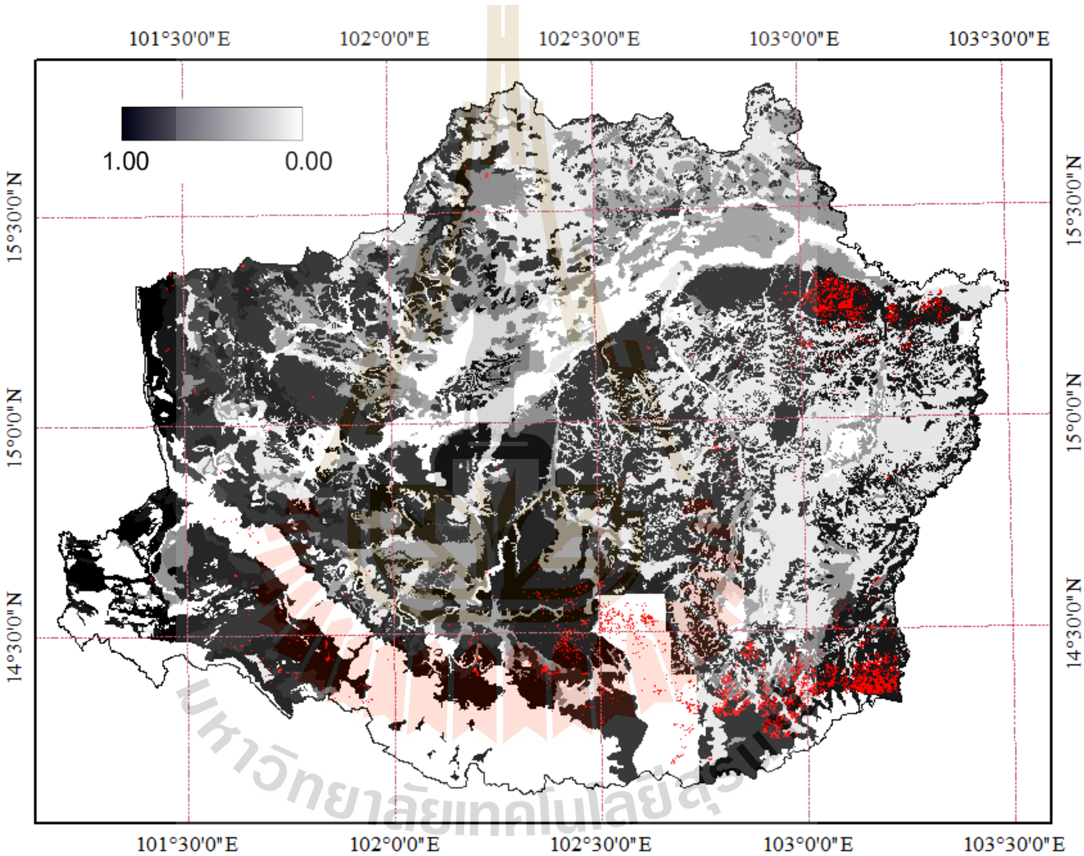


Figure 4.21 Map showing FM of suitability of soil drainage.

4.4.5 Flood period

Rubbers should not be grown in flooded areas because it may cause root rot. In this study, a flood map was created based on the map of the Land Development Department (Figure 4.22) for supplementing the analysis where FM of a flooded area was 0 and FM of the area outside a flood zone was 1. It could be seen that the traditional rubber planting areas (Red dots) were mostly not in the flood zone.

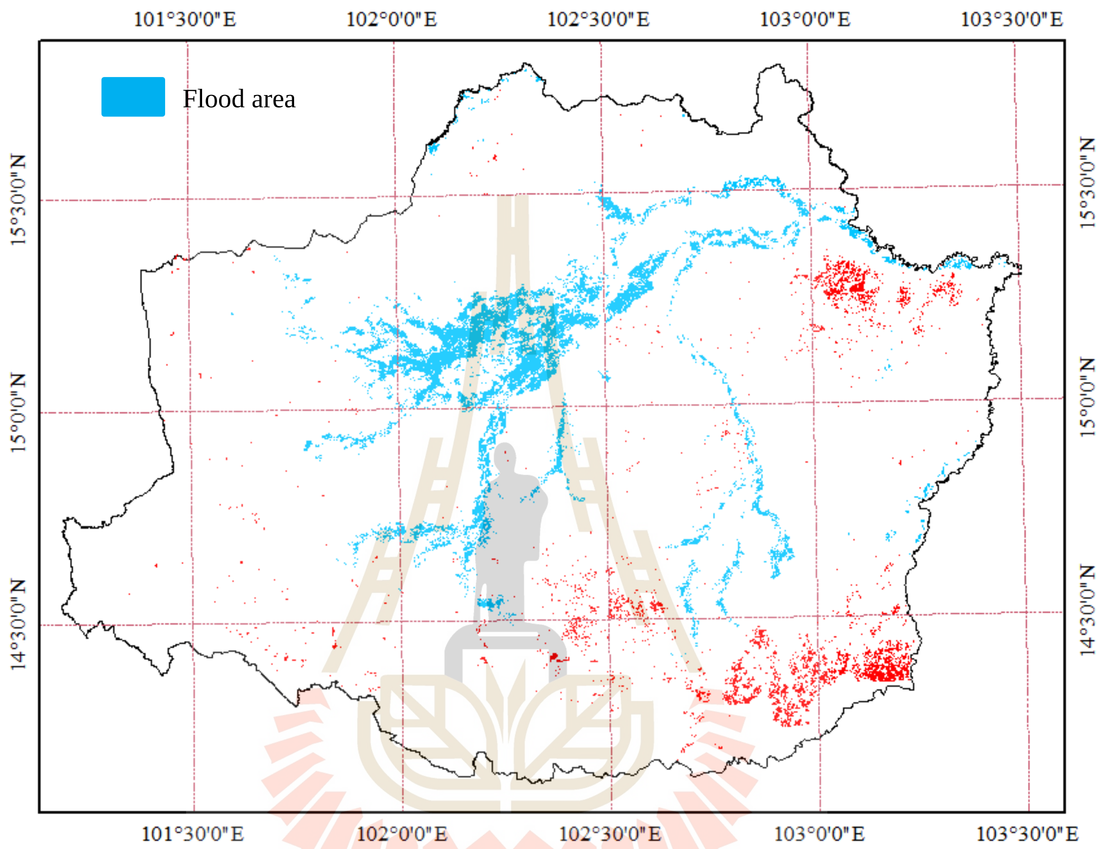


Figure 4.22 Map showing flood (FM=0) and non-flood (FM=1) areas and traditional rubber plantation area.

4.4.6 Aggregation of soil physical factors (Kp) for appropriate rubber plantation

After combining the FM values of sand, clay, soil depth, soil drainage, and flooding condition, it was found that Buriram and Nakhon Ratchasima, except water, forests and urban, had land suitability of rubber plantation area summarized in the Figure 4.23.

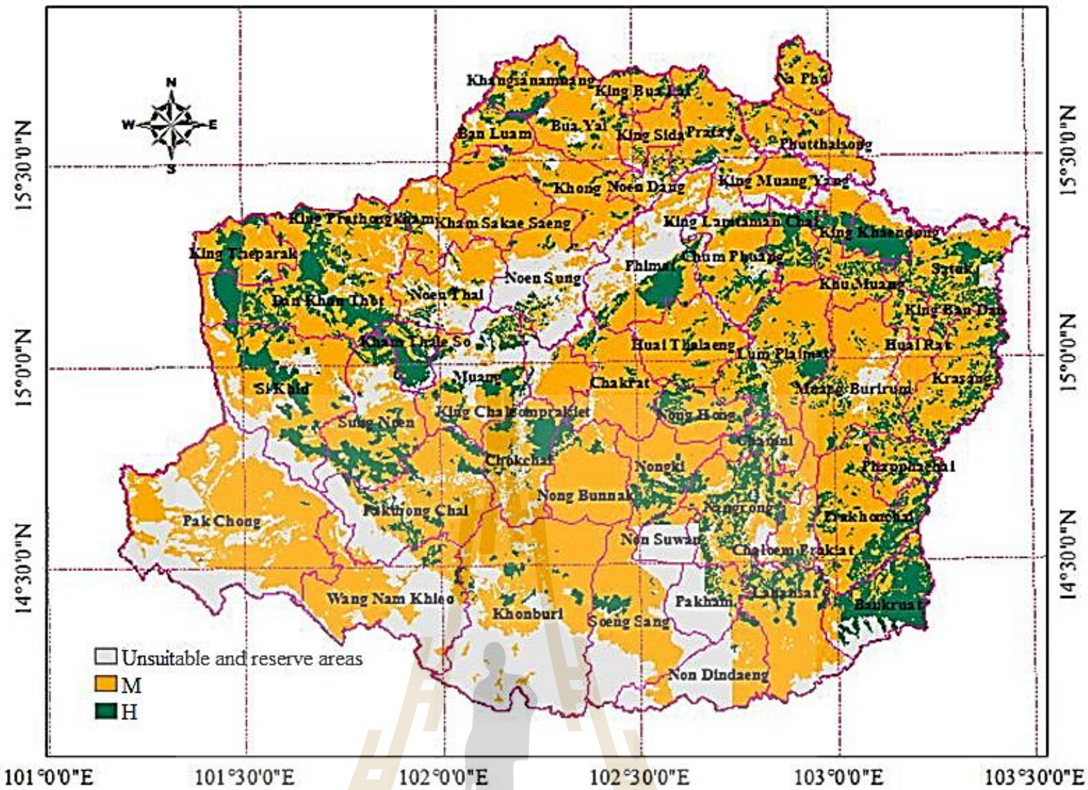


Figure 4.23 Land suitability for rubber plantation based on soil physical properties.

The map above showed land suitability for rubber plantation based on soil physical property which was mostly in Low level (Yellow) and partly in medium level (Green) distributed throughout the area.

4.5 The analysis results of the chemical properties

After using the soil series maps for analyzing the suitability of chemical properties, a map showing suitability of each factor was created as shown below.

4.5.1 OM

According to an analysis of percentages of organic matter (OM) of each soil series, it was found that the percentage of OM suitable for rubber plantation of the traditional rubber planting areas in the Buriram was at a low level. And in areas with a moderate percentage of OM in the southern part which was a piedmont plateau in Pak Chong, Nong Boonmak, Khonburi and the areas nearby riverbanks. After calculation of the FM, the map could be displayed as shown in Figure 4.24.

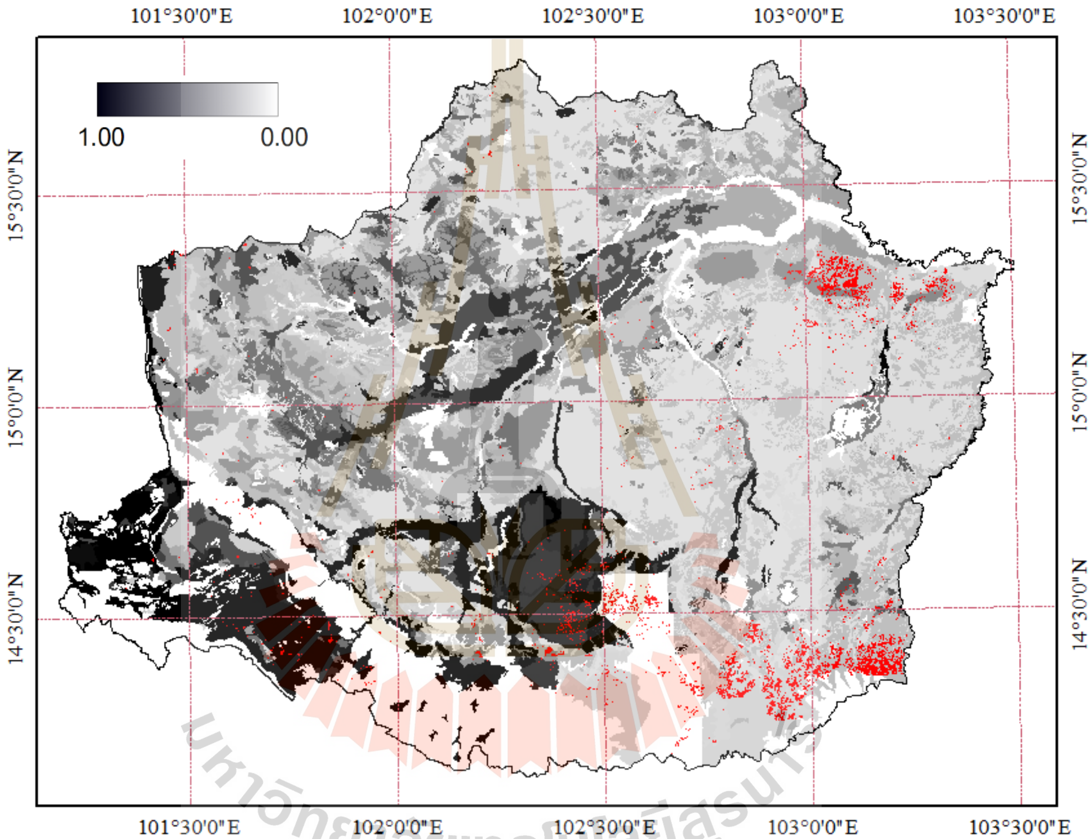


Figure 4.24 FM of organic matter quantity in the soil.

4.5.2 Phosphorus in the Soil

After determining the FM of the suitability of Phosphorus in the soil, it was found that areas with the suitability at medium (M) and low (L) levels were scattered throughout the study area. Accordingly, the areas could be displayed in the map below (Figure 4.25).

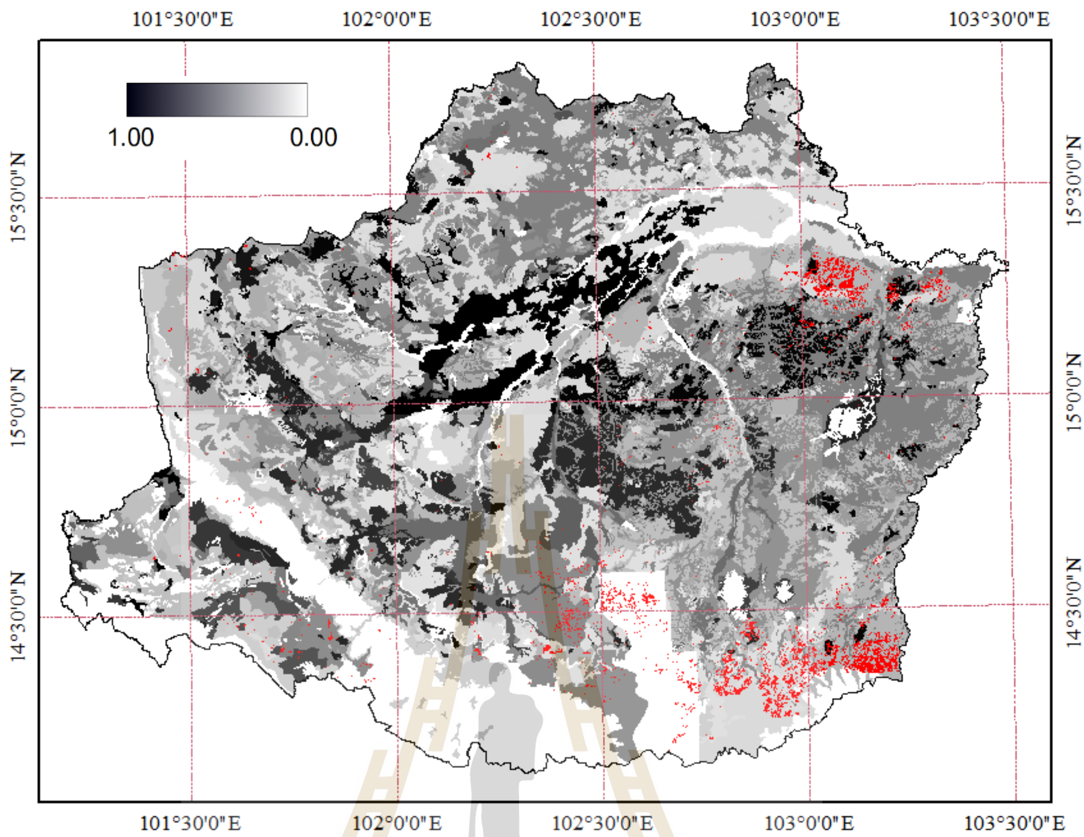


Figure 4.25 FM of phosphorus quantity in the soil.

4.5.3 Potassium in the Soil

After determining the FM of the suitability of Potassium in the soil, it was found that most areas with the suitability for rubber plantation at low level (L) were scattered throughout Buriram Province and most areas with the suitability for rubber plantation at medium level (M) were scattered throughout Nakhon Ratchasima Province. Accordingly, the areas could be displayed in Figure 4.26.

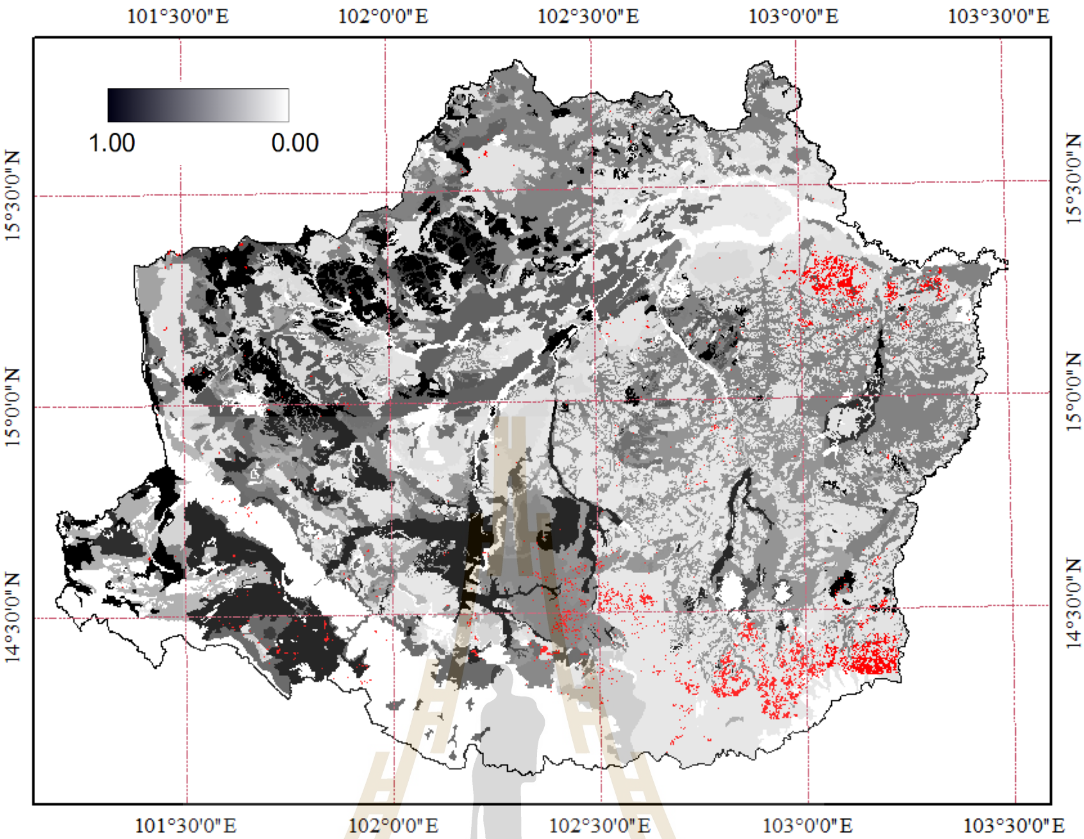


Figure 4.26 FM of potassium quantity in the soil.

4.5.4 pH

After determining the FM of the suitability of pH of the soil, it was found that high FM distributed throughout most areas. Anyway, in the current, most of rubber plantations have got medium FM as displayed in the map below (Figure 4.27).

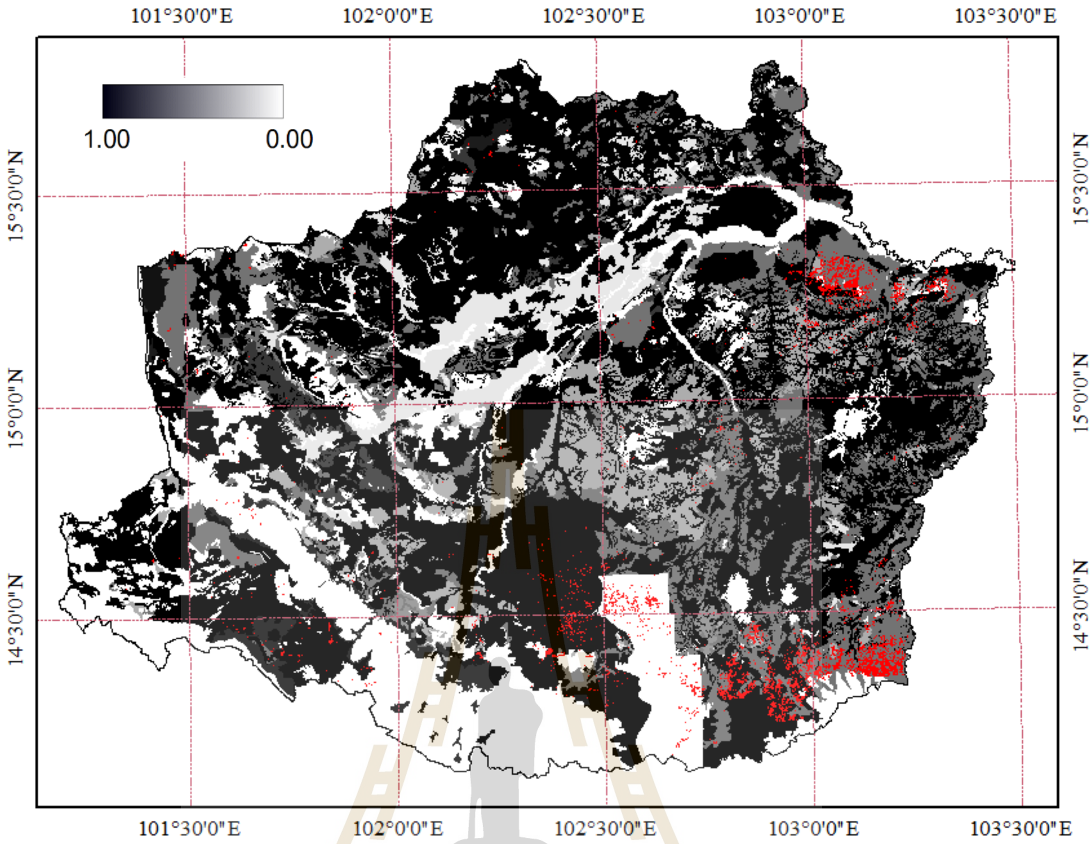


Figure 4.27 FM of pH of the soil.

4.5.5 Soil Salinity

Rubbers should not be planted in a saline soil. In this study, the soil salinity map of LDD was used for supplementing the analysis. FM of the area where salt was detected was 0 and the FM of the area in where salt was not detected was 1. The results are shown in Figure 4.28. It can be seen that most of rubber plantations (Red dots) were not in the saline soils.

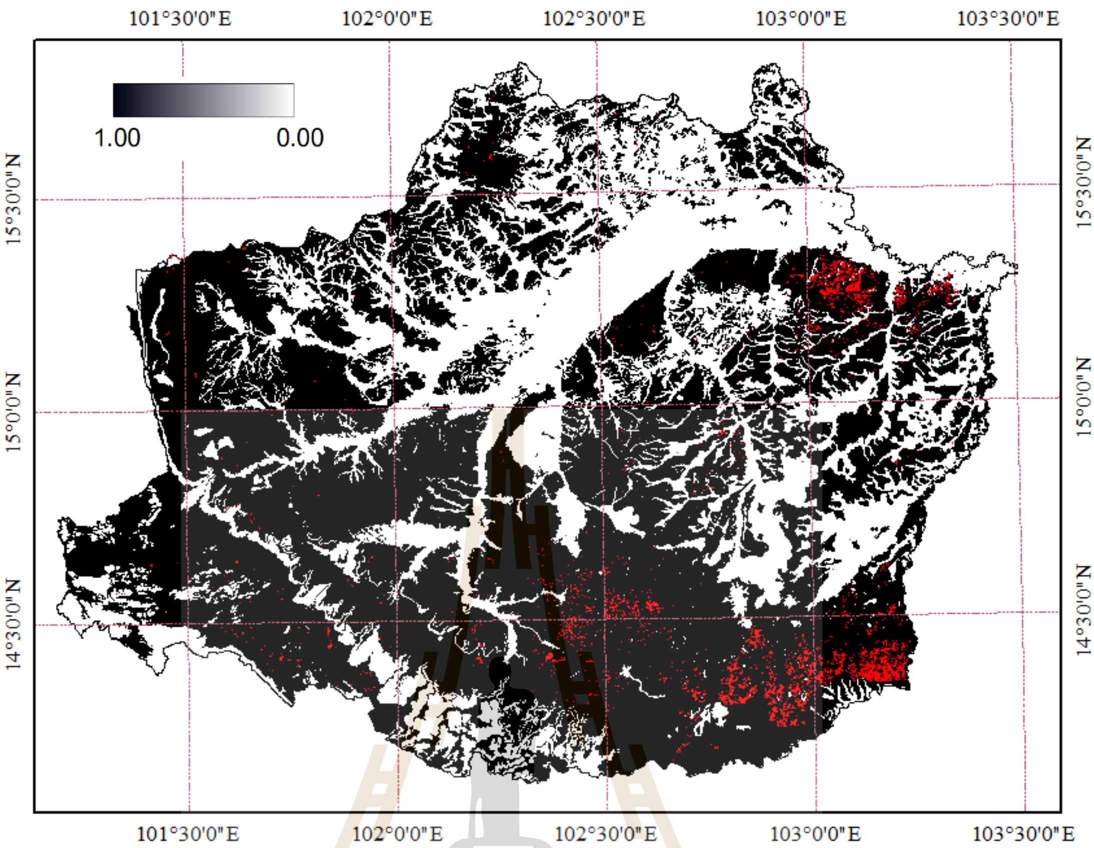


Figure 4.28 FM of saline soils.

4.5.6 Aggregation of soil chemical factors (Ks) for appropriate rubber plantation

After combining soil chemical factors: the FM values of the organic matter, Phosphorus quantity, Potassium quantity, pH of soil, and soil salinity, it was found that Buriram and Nakhon Ratchasima Provinces, excluding water, forests and urban, had land suitability for rubber plantation as shown in Figure 4.29.

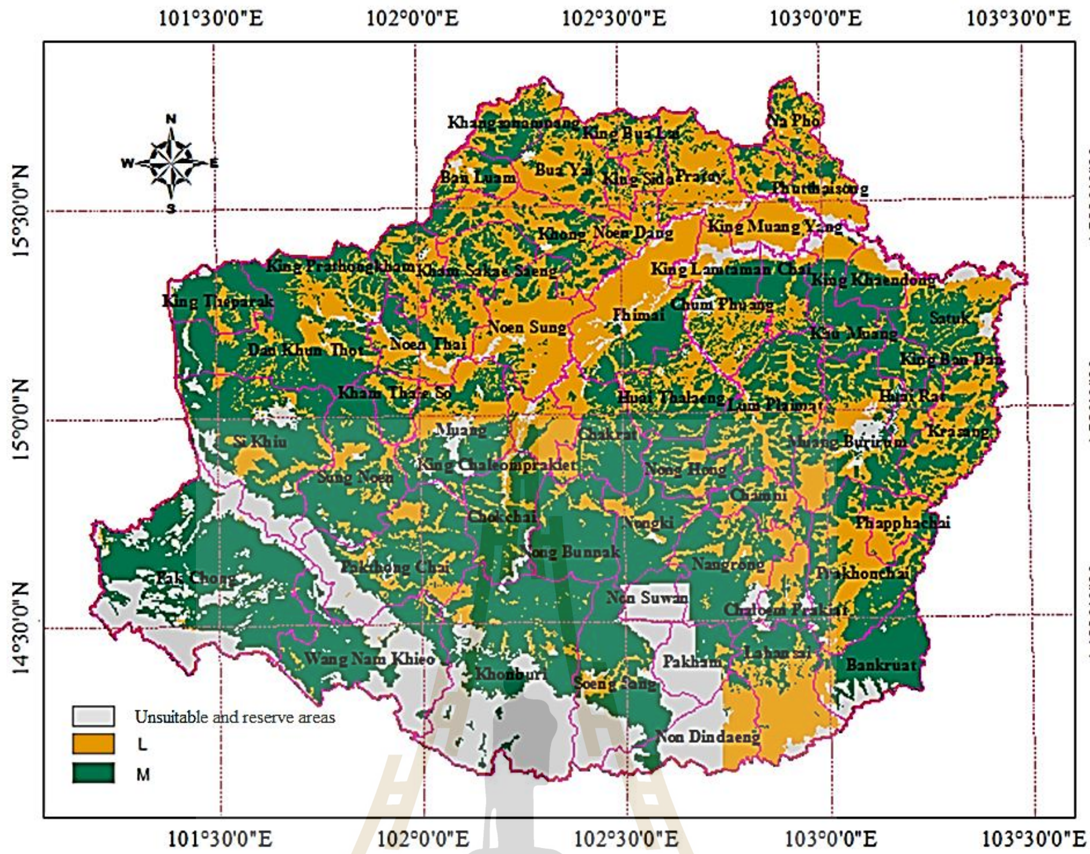


Figure 4.29 Land suitability for rubber plantation by soil chemical factors.

The map above showed land suitability for rubber plantation based on soil chemical property which was mostly in medium level (Green) and partly in Low level (Yellow) distributed throughout the area.

4.6 The Analysis Results of the Climate Properties

The data, average annual rainfall, raining days, dry season, losses of tapping days, temperature regime and wind speed used in the analysis are from 9 weather stations (Figure 4.30) among the study area. These data can be displayed in Table 4.14 to 4.18.

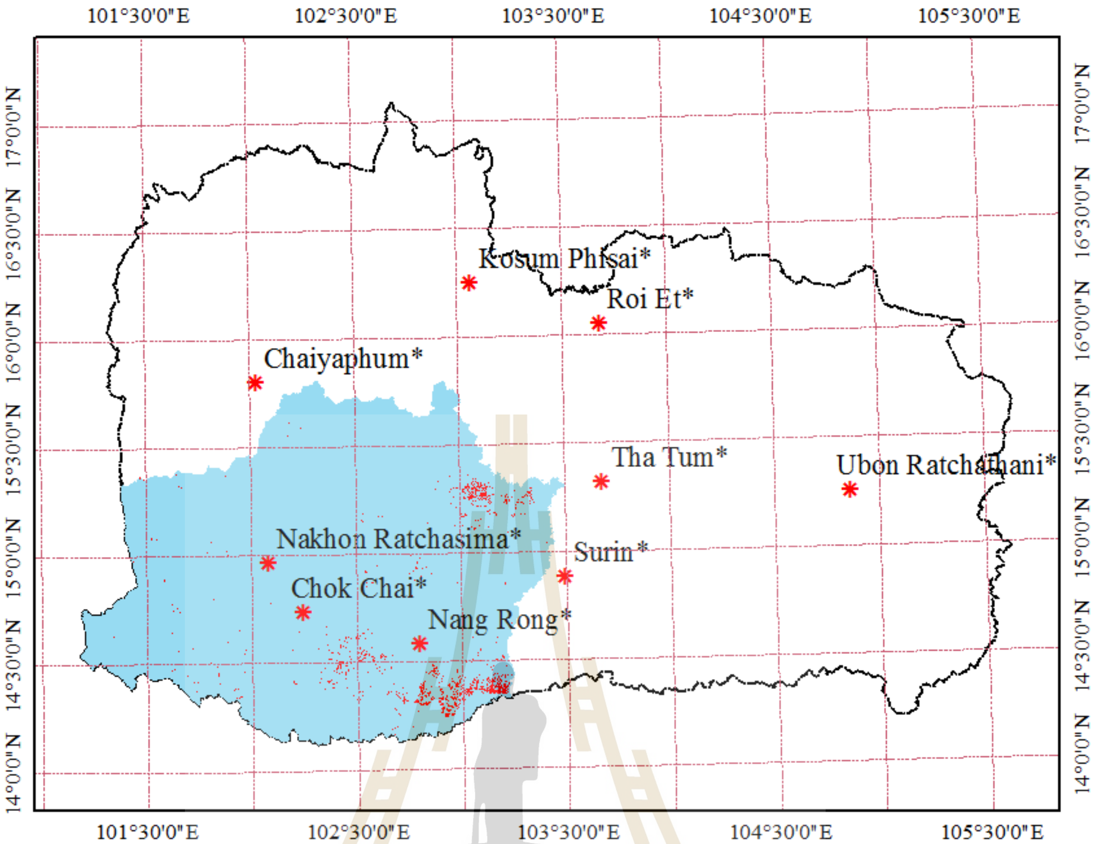


Figure 4.30 Weather stations in the study area

Table 4.14 Rainfall in different months.

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM
Kosum Phisai	3.5	15	51.8	89	161.5	177.8	160	231.9	240.6	111.4	18.1	3.1	1263.7
Chaiyaphum	4.5	14.3	51.3	92.6	140.2	137.6	110.4	196.2	230	137	19	4.1	1137.2
Roi Et	3.6	19.2	41.2	75.9	186.1	223.5	195.9	252.2	219.8	107.3	15.2	2.1	1342.0
Ubon Ratchathani	2	15.4	30.5	86.8	208.6	240.2	254.4	303.3	293.8	123.1	22.6	1	1581.7
Nakhon Ratchasima	8.2	16.1	37.1	72.2	154.1	104.5	120.9	157.2	228.3	146.3	23.9	2.7	1071.5
Chok Chai	4	14.8	37.5	81.3	149	107.3	118.9	153.5	211.6	164.3	29.4	3.2	1074.8
Surin	5.6	11.5	45.6	93.3	179.8	204.7	221.3	256.2	255.4	128.2	28.7	1.9	1432.2
Tha Tum	5.1	16.1	44.2	86.7	172.3	206.1	218.2	227.9	263	126.3	21	1	1387.9
Nang Rong	4.7	19.6	47.9	81.6	166.6	129.7	148	181.7	239.6	133.9	37.2	3.4	1193.9

Table 4.15 Drought in different months (* is *Ih* <0.5 : drought).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ih <0.5
Kosum Phisai	0.02*	0.08*	0.27*	0.46*	0.83	0.91	0.82	1.19	1.23	0.57	0.09*	0.02*	6
Chaiyaphum	0.02*	0.07*	0.26*	0.47*	0.72	0.71	0.57	1.01	1.18	0.70	0.10*	0.02*	5
Roi Et	0.02*	0.10*	0.21*	0.39*	0.95	1.15	1.00	1.29	1.13	0.55	0.08*	0.01*	6
Ubon Ratchathani	0.01*	0.08*	0.16*	0.45*	1.07	1.23	1.30	1.56	1.51	0.63	0.12*	0.01*	6
Nakhon Ratchasima	0.04*	0.08*	0.19*	0.37*	0.79	0.54	0.62	0.81	1.17	0.75	0.12*	0.01*	5
Chok Chai	0.02*	0.08*	0.19*	0.42*	0.76	0.55	0.61	0.79	1.09	0.84	0.15*	0.02*	5
Surin	0.03*	0.06*	0.23*	0.48*	0.92	1.05	1.13	1.31	1.31	0.66	0.15*	0.01*	4
Tha Tum	0.03*	0.08*	0.23*	0.44*	0.88	1.06	1.12	1.17	1.35	0.65	0.11*	0.01*	5
Nang Rong	0.02*	0.10*	0.25*	0.42*	0.85	0.67	0.76	0.93	1.23	0.69	0.19*	0.02*	5

Table 4.16 Losses of tapping days (* is *VPD*>11).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	*VPD*>11
Kosum Phisai	8.8	11*	13.2*	13.7*	9.8	8.8	8.2	6.8	5.9	7.2	8.7	8.7	3
Chaiyaphum	11.8*	14*	16.2*	15.3*	10.4	9.7	9.1	7.8	6.9	8.6	10.8	10.9	4
Roi Et	10	12.2*	14.9*	14.7*	10.8	9.4	8.8	7.5	7	8.1	9.4	9.5	3
Ubon Ratchathani	10.6	12.8*	15.1*	14.4*	10	8.1	7.6	6.6	6.6	7.8	9.4	9.4	3
Nakhon Ratchasima	10.9	13.5*	15.5*	14.4*	10.9	11.3	10.6	9.5	7.3	7.4	9.4	9.9	3
Chok Chai	10.1	12.5*	13.6*	13.3*	9.9	10.2	9.6	8.6	6.5	6.6	8	8.7	3
Surin	10.5	12.9*	14.6*	13.8*	9.5	8.1	7.5	6.6	5.8	6.7	8.7	9.3	3
Tha Tum	9.5	11.9*	14.6*	14.8*	10.3	9.3	8.2	7.3	5.9	7.1	8.8	8.8	3
Nang Rong	9.4	11.7*	12.8*	12.4*	9.1	9	8	7.5	5.8	6.2	7.6	8.4	3

Table 4.17 Temperature regime.

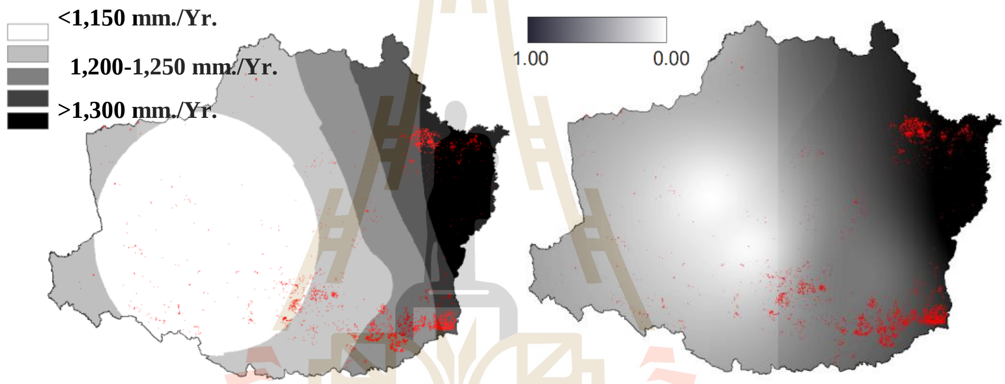
ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Mean
Kosum Phisai	23.7	25.8	28.4	30.1	29.3	29	28.6	28	27.7	27.1	25.3	23.5	27.21
Chaiyaphum	24.2	26.7	28.8	30	28.9	28.5	28	27.6	27.3	27	25.6	23.8	27.20
Roi Et	23.3	25.7	28.2	29.8	29	28.7	28.3	27.9	27.5	26.7	24.9	22.9	26.91
Ubon Ratchathani	24.2	26.5	28.9	30	29	28.4	28	27.6	27.4	26.8	25.4	23.7	27.16
Nakhon Ratchasima	24.3	26.9	28.9	30	29.1	29.1	28.6	28.1	27.4	26.7	25.4	23.6	27.34
Chok Chai	24.4	26.5	28.5	29.6	28.8	28.7	28.3	27.9	27.3	26.6	25.1	23.6	27.11
Surin	24.1	26.6	28.7	29.8	28.8	28.3	27.9	27.6	27.3	26.7	25.3	23.6	27.06
Tha Tum	24	26.2	28.7	30.4	29.5	29.1	28.6	28.2	27.7	27	25.4	23.7	27.38
Nang Rong	24.3	26.4	28.4	29.5	28.8	28.6	28.1	27.8	27.2	26.5	25	23.6	27.02

Table 4.18 Wind speed (* is Wind speed >1 m/s).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Mean
Kosum Phisai	0.9	1.0	1.1*	1.0	1.0	1.2*	1.3*	1.2*	0.7	0.9	1.1*	1.2*	1.1*
Chaiyaphum	0.8	0.8	0.9	0.9	0.8	1.0	1.1*	1.0	0.6	0.8	1.0	1.0	0.9
Roi Et	1.0	1.0	1.0	1.0	1.0	1.3*	1.4*	1.3*	0.8	1.0	1.2	1.2	1.1*
Ubon Ratchathani	1.8*	1.6*	1.6*	1.5*	1.6*	1.9*	1.9*	1.9*	1.3*	1.9*	2.8*	2.8*	1.9*
Nakhon Ratchasima	0.8	0.8	0.9	0.9	0.9	1.2*	1.2*	1.1*	0.7	1.0	1.2*	1.1*	1.0
Chok Chai	0.7	0.8	1.0	0.9	0.8	1.1*	1.2*	1.1*	0.7	0.8	1.0	0.9	0.9
Surin	1.1	1.0	1.1*	1.1*	1.1*	1.3*	1.3*	1.3*	0.8	1.2*	1.5*	1.5*	1.2*
Tha Tum	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.5	0.8	1.2*	1.2*	0.8
Nang Rong	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.6	1.0	1.3*	1.2*	0.8

4.6.1 The Average Annual Rainfall

An analysis of the average annual rainfall of the study areas showed that the average annual rainfall of the areas in the eastern part of Buriram where traditional rubber planting areas (red dots) were found ranged from 1,250 to more than 1,300 mm which was suitable for growing rubbers. Nevertheless, in Nakhon Ratchasima, the rainfall was low, so it was less suitable for planting rubbers. After calculating, the FM are shown in Figure 4.31.

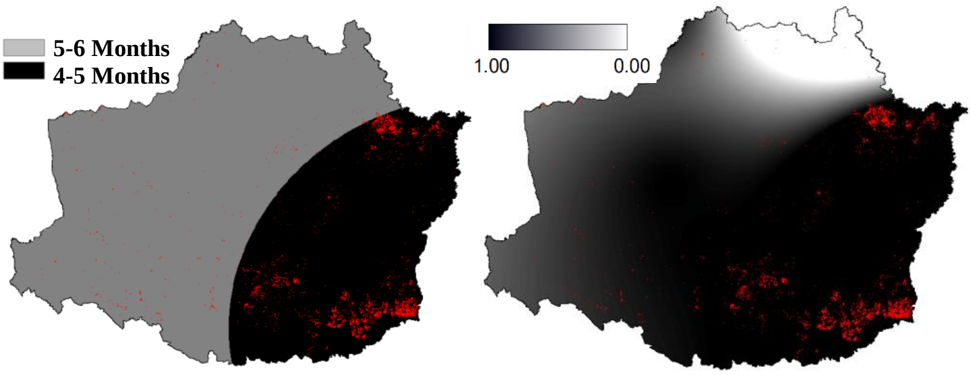


(a) Average rainfall (30 years). (b) The FM of suitability of rainfall.

Figure 4.31 Average rainfall (30 years) and the FM of suitability of rainfall.

4.6.2 Dry Season

According to the function when the *Ih* is <0.5, it indicates that the month is too dry, the analysis of the index of humidity (*Ih*) of the study areas showed that the dry season of most of the areas in Nakhon Ratchasima lasted 5-6 months, which was unsuitable for growing rubber. Moreover, the dry season in Buriram lasting 4-5 months was low suitability for growing rubbers. The areas in Red dots were the traditional rubber planting areas. After calculating, the FM is shown in the Figure 4.32.

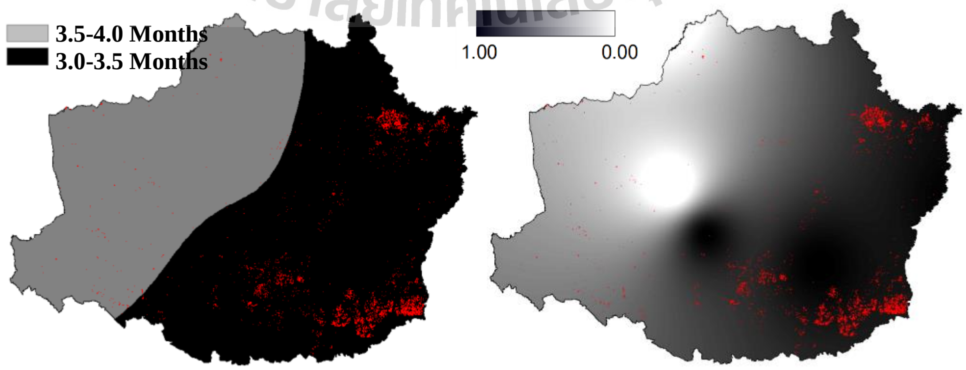


(a) The Distribution of drought months. (b) FM of dry season.

Figure 4.32 The distribution of drought months and FM of dry season.

4.6.3 Losses of Tapping Days

The analysis of the vapor pressure deficit (*VPD*) based on the function when the *VPD*> 11 kPa in any month, the rubber trees do not yield in the month or the tapping rubber does not provide good yield. It is found that the *VPD* of most areas of Nakhon Ratchasima and Buriram during a dry season was more than 11 on average up to 3-3.5 months, which was considered as a rubber-tapping break. Therefore, it did not affect losses of tapping days. After calculating, the FM is shown in the Figure 4.33.

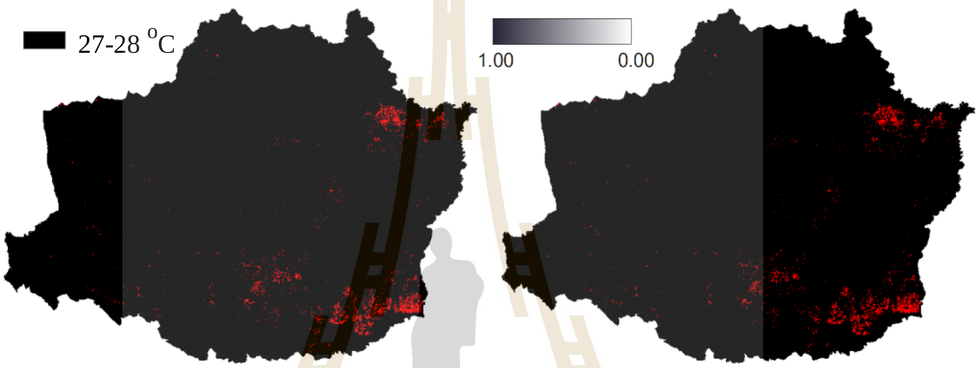


(a) Number of months unable to tap. (b) the FM of months unable to tap.

Figure 4.33 Number and FM of months unable to tap.

4.6.4 Temperature Regime

The analysis of temperature was based on the function that if any month had a temperature range between 26-30 °C, that month was suitable for rubber cultivation. The study area had an average temperature of 27-28 °C, which is considered suitable for rubber cultivation. After calculating, the FM is shown in Figure 4.34.

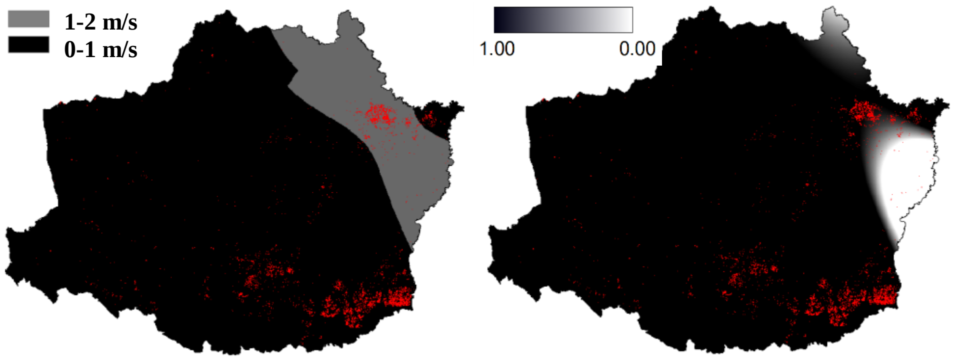


(a) Temperature regime. (b) The FM of temperature regime.

Figure 4.34 Temperature regime and its FM.

4.6.5 Wind Speed

Based on the function of wind speed analysis, the wind speed suitable for planting rubbers was less than 1 m/s. It was found that most of the study area had an average wind speed of less than 1 m/s and the areas in the upper Buriram had high wind speed affected the growth and ADS product. After calculating, the FM is shown in Figure 4.35.



(a) Wind speed. (b) The FM of wind speed.

Figure 4.35 Wind speed and its FM.

4.6.6 Aggregation of climate factors (Kc) for appropriate rubber plantation

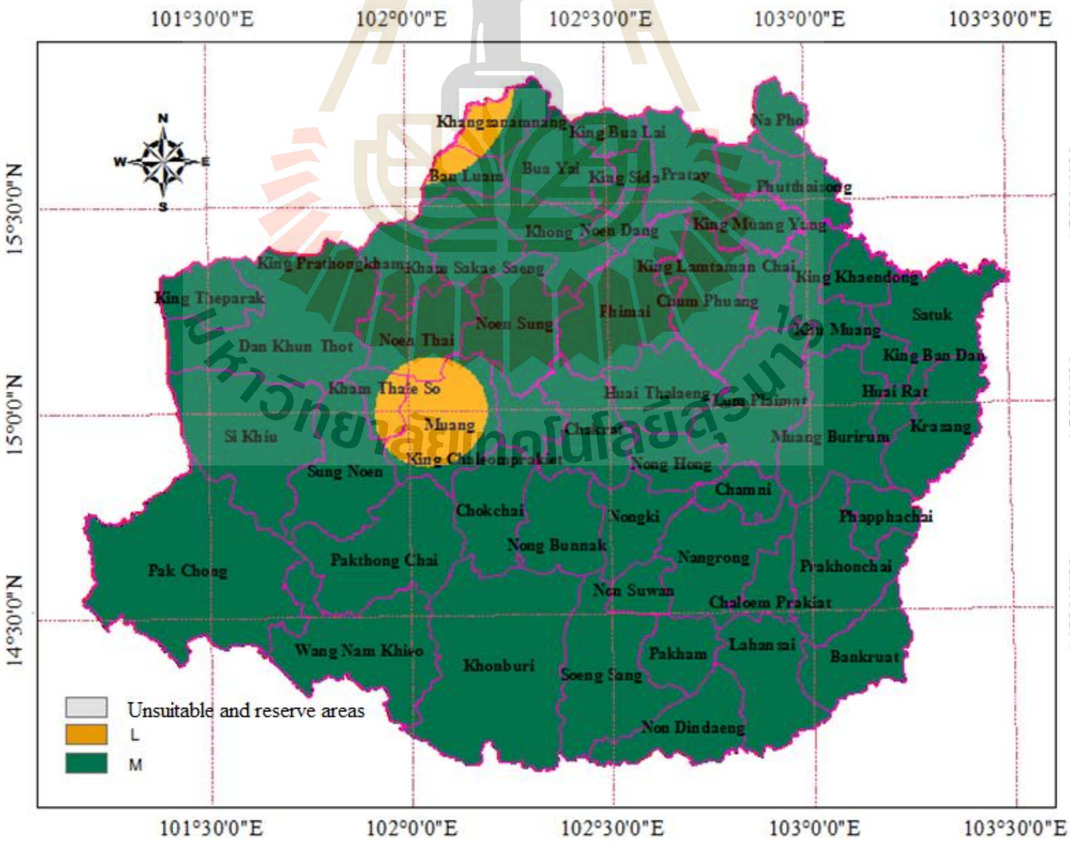


Figure 4.36 Land suitability for rubber plantation by climate factors.

After combining all FM data of the climate factors of the study areas: the average annual rainfall, the dry season, losses of tapping days, the temperature regime, and the wind speed, it was found that Buriram and Nakhon Ratchasima except water, forests, and urban, had land suitability for rubber plantation as summarized in Figure 4.36. The map showed land suitability for rubber plantation based on climate factor which was mostly in medium level (Green) and partly in Low level (Yellow) concentrated in the central of Nakhon Ratchasima.

4.7 Application of fuzzy rules for estimating ADS of RRIM 600 clone

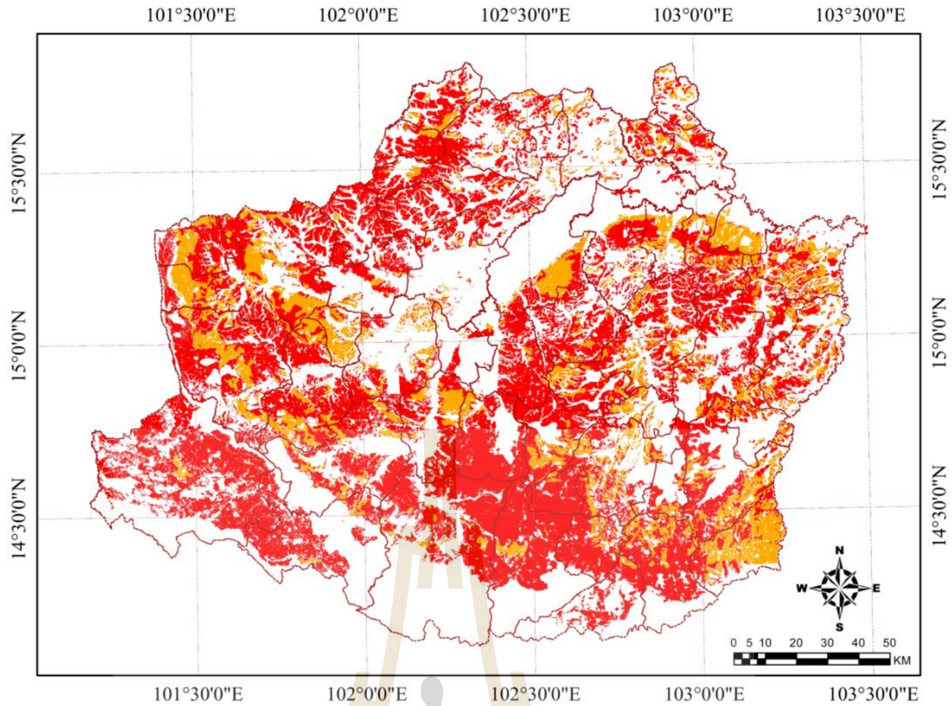
4.7.1 The overall study results

After analyzing the data on soil physical and chemical characteristics, climate and management of the rubber plantation areas, fuzzy rules of RRIM 600 clone were applied to create land suitability maps of Buriram and Nakhon Ratchasima in 3 scenarios (low, medium, and high) of plantation management. A set of land suitability maps was in a form of raster base with a cell size of 40x40 m of which all cells contained ADS per year. By applying fuzzy rules of Mamdani's fuzzy inference, land suitability maps of rubber plantation of 3 scenarios (low, medium, and high) of plantation management were created as shown in Figures 4.38-4.40. These maps demonstrate the potential of the rubber production. The suitability levels of the plantations were divided into 3 classes based on ADS productivity on the third year of tapping. There were S1 for a high suitability which the ADS yield was between 250-300 Kg/rai/yr, S2 for a medium suitability which the ADS yield was between 200- 250 Kg/rai/yr , S3 for a low suitability which the ADS yield was 150-200 Kg/rai/yr and N for a non-suitable area such as areas of saline soil, wetland/flood plain, urban, and reserve area. N for low management included area with ADS less than 150 Kg/rai/yr (S4). But S4 areas did not exist when medium and high levels of management were applied.

Table 4.19 and Figure 37 to 39 showed that the suitability levels of the areas with low management were in S3, S4 and N classes. Once high and medium levels of management were applied, S3 area was reduced and S1 was increased while S2 had less positive effect. It indicated that management level was very important. When its level was changed, the area was able to immediately transform from S3 to S1, with less grading through S2.

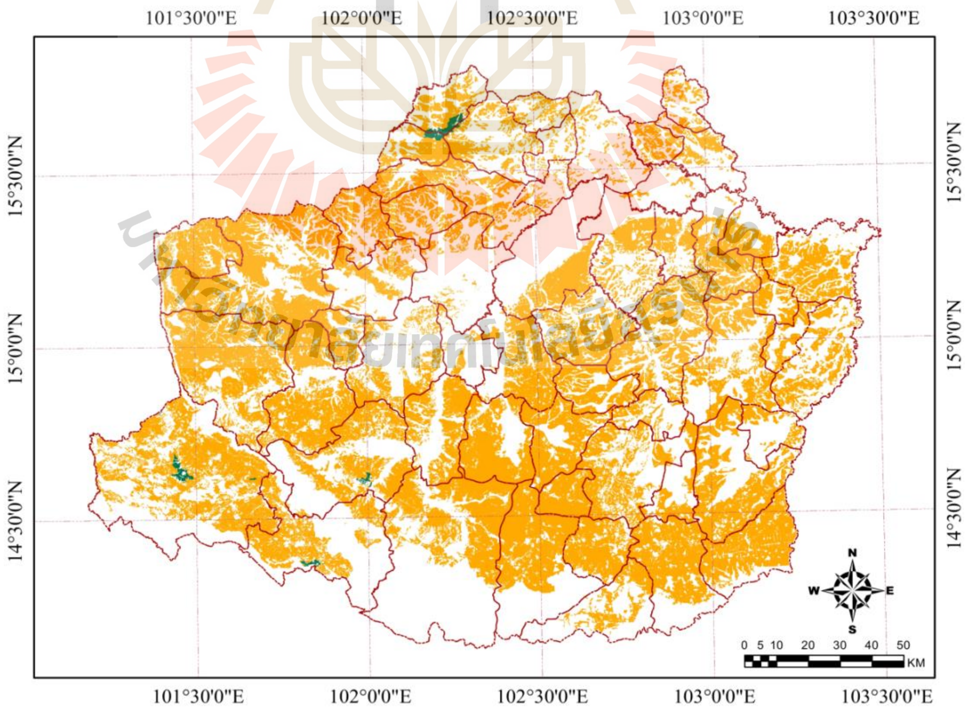
Table 4.19 Summary of suitable areas of RRIM600 rubber plantation in the study areas

	Management Levels		
Suitability Levels (kg/rai/yr)	High	Medium	Low
250-300 (S1)	2,091,501	41,691	-
200-250 (S2)	40,536	165	-
150-200 (S3)	6,636,763	8,726,944	2,097,463
100-150 (N+S4)	10,490,112	10,490,112	17,161,449
Sum	19,258,912	19,258,912	19,258,912



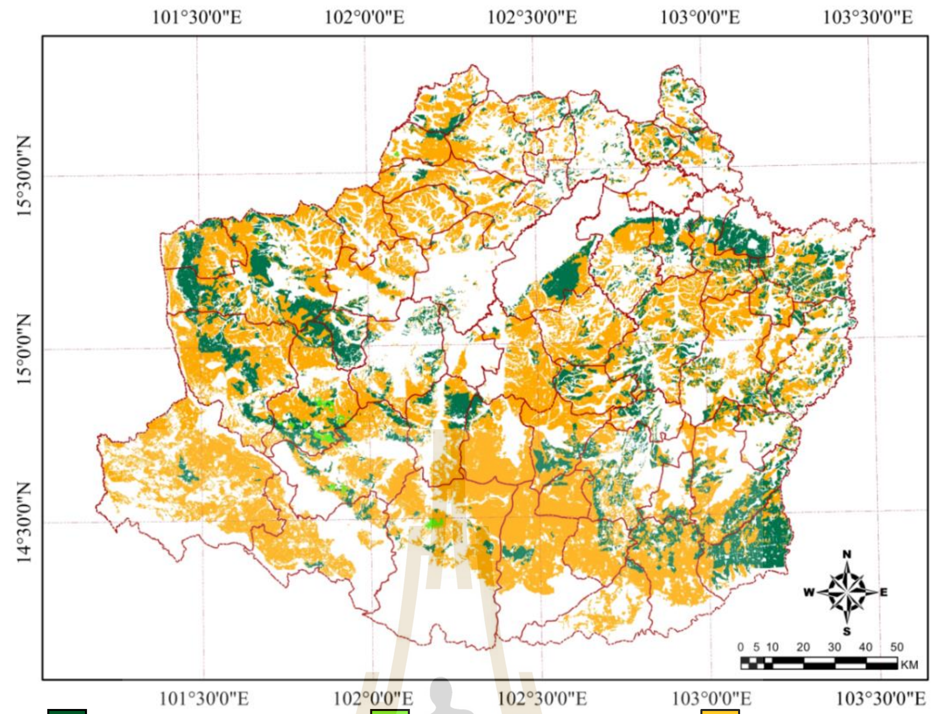
Legend: S3 = 150-200 kg/rai/yr. S4 = 100-150 kg/rai/yr. N = Non-suittable areas.

Figure 4.37 ADS product on low rubber plantation management (L).



Legend: S1= 250-300 kg/rai/yr. S2= 200-250 kg/rai/yr. S3= 150-200 kg/rai/yr.
S4= 100-150 kg/rai/yr. N = Non- suitable areas.

Figure 4.38 ADS product based on medium management (M).



Legend: S1= 250-300 kg/rai/yr. S2= 200-250 kg/rai/yr. S3= 150-200 kg/rai/yr.
S4= 100-150 kg/rai/yr. N = Non- suitable areas.

Figure 4.39 ADS product based on high management (H).

4.7.2 Suitability area based on districts

Suitable area based on suitability classes and levels of management of districts of Buriram and Nakorn Ratchasima provinces are shown in the Tables 4.20 and 4.21 respectively.

Table 4.20 Suitable areas for rubber plantation of Buriram province.

Buriram	Low Management(L)				Medium Management(M)				High Management(H)			
	S1	S2	S3	N	S1	S2	S3	N	S1	S2	S3	N
BanDan	-	-	172,120	175,520	-	-	64,013	42,549	18,888	17	45,070	42,587
Bankruat	-	-	15,068	93,711	-	-	253,713	93,927	172,030	117	81,457	94,036
BanMaiChaiphot	-	-	17,581	130,621	-	-	52,293	56,486	15,056	10	37,179	56,534
ChaloemPrakiat	-	-	24,746	124,654	-	-	54,260	93,942	17,581	13	36,638	93,970
Chamni	-	-	9,429	99,736	-	-	47,099	102,301	24,736	9	22,292	102,363
HuaiRat	-	-	48,716	225,398	-	-	51,296	57,869	9,415	6	41,842	57,903
Khaendong	-	-	18,905	87,657	-	-	75,061	85,770	67,212	5	7,834	85,780
KhuMuang	-	-	67,217	93,614	-	-	147,724	126,390	48,692	26	98,897	126,498
Krasang	-	-	49,314	340,429	-	-	141,567	248,176	49,258	38	92,051	248,396
Lahansai	-	-	56,495	370,580	-	-	261,079	165,996	56,473	26	204,514	166,062
LumPlaimat	-	-	69,990	445,304	-	-	279,677	235,617	69,927	46	209,495	235,826
MuangBuriram	-	-	47,951	472,863	-	-	232,811	288,003	47,895	33	184,716	288,169
Nangrong	-	-	83,650	393,178	-	-	234,711	242,117	83,623	32	150,814	242,359
NaPho	-	-	18,261	113,517	-	-	40,958	90,820	18,239	10	22,649	90,880
NonDindaeng	-	-	6,062	337,488	-	-	98,589	244,961	6,057	9	92,519	244,964
NongHong	-	-	38,564	157,567	-	-	122,823	73,308	38,547	15	84,189	73,380
Nongki	-	-	47,813	230,071	-	-	203,362	74,522	47,807	19	155,459	74,599
NonSuwan	-	-	5,685	118,920	-	-	113,429	11,176	5,685	5	107,729	11,186
Pakham	-	-	18,011	201,262	-	-	165,243	54,030	18,004	7	147,165	54,097
Phapphachai	-	-	20,066	144,516	-	-	44,599	119,983	20,052	12	24,464	120,055
Phutthaisong	-	-	12,572	183,386	-	-	52,768	143,190	12,559	9	40,175	143,215
Prakhonchai	-	-	106,653	417,299	-	-	295,800	228,153	106,581	60	188,955	228,357
Satuk	-	-	84,367	303,033	-	-	171,673	215,727	84,326	45	87,041	215,988
Sum	**-**	**-**	**1,039,236**	**5,260,325**	**-**	**-**	**3,204,548**	**3,095,013**	**1,038,645**	**570**	**2,163,143**	**3,097,204**

Table 4.21 Suitable areas for rubber plantation of Nakorn Ratchasima province.

Nakorn Ratchasima	LowManagement(L)				MediumManagement(M)				HighManagement(H)			
	S1	S2	S3	N	S1	S2	S3	N	S1	S2	S3	N
BanLuam	-	-	10,489	127,860	7,162	-	77,234	53,954	10,484	1,222	72,655	53,988
BuaLai	-	-	15,910	298,277	-	-	38,277	71,799	9,067	2	29,152	71,855
BuaYai	-	-	10,398	339,340	2,384	-	107,799	204,004	15,907	4	94,203	204,073
Chakrat	-	-	53,511	287,143	-	-	191,598	158,141	10,390	13	181,168	158,168
Chaleomprakiet	-	-	25,587	377,619	-	-	21,871	154,178	3,665	30	18,141	154,213
Chokchai	-	-	212,532	655,068	-	-	183,743	156,911	53,484	671	129,496	157,003
ChumPhuang	-	-	19,560	314,404	257	-	123,784	279,165	25,583	9	98,400	279,214
DanKhunThot	-	-	1,467	210,208	6	-	535,806	331,788	212,423	1,044	322,119	332,015
HuaiThalaeng	-	-	58,295	71,419	-	-	179,160	154,804	19,552	77	159,493	154,842
KhamSakaeSaeng	-	-	21,478	177,728	-	-	109,259	102,415	1,467	-	107,779	102,429
KhamThaleSo	-	-	17,897	1,151,003	-	-	71,208	58,506	58,301	9	12,808	58,596
Khangsanamnang	-	-	17,780	387,832	13,286	-	79,503	106,417	21,471	6	71,298	106,431
Khonburi	-	-	9,068	101,008	-	-	385,158	783,741	16,283	7,804	361,009	783,804
Khong	-	-	3,668	172,381	-	-	182,344	223,268	17,772	255	164,274	223,311
LamtamanChai	-	-	38,197	127,450	-	-	75,217	90,431	38,191	8	36,967	90,482
Muang	-	-	1,673	165,662	-	-	143,685	333,444	43,226	843	99,462	333,597
MuangYang	-	-	3,612	213,634	-	-	13,340	153,996	1,671	1	11,655	154,008
NoenDang	-	-	4,431	109,827	-	-	19,830	84,060	4,518	4	15,260	84,108
NoenSung	-	-	47,588	182,322	-	-	54,809	376,011	8,699	9	46,013	376,099
NoenThai	-	-	43,238	433,891	-	-	113,690	227,949	15,297	3	98,326	228,014
NongBunnak	-	-	4,520	99,370	-	-	238,086	105,421	16,897	8	221,154	105,448
PakChong	-	-	8,704	422,115	11,572	-	524,376	699,938	12,000	6	523,916	699,964
PakthongChai	-	-	15,301	326,338	3,622	-	263,536	361,383	51,588	5,650	209,815	361,489
Phimai	-	-	16,910	326,597	-	-	142,164	414,783	73,154	13	68,940	414,840
Pratay	-	-	12,007	1,223,879	-	-	44,422	291,147	19,729	13	24,591	291,236
Prathongkham	-	-	52,257	576,285	-	-	115,498	101,748	3,613	1	111,855	101,777

Table 4.21 Suitable areas for rubber plantation of Nakorn Ratchasima province (Continued).

Nakorn Ratchasima	LowManagement(L)				MediumManagement(M)				HighManagement(H)			
	S1	S2	S3	N	S1	S2	S3	N	S1	S2	S3	N
Sida	-	-	73,168	483,779	-	-	22,331	91,926	4,427	6	17,871	91,953
SiKhiu	-	-	19,740	315,830	-	-	444,402	284,319	113,963	26	330,309	284,423
SoengSang	-	-	113,982	614,739	-	-	314,933	276,516	19,117	4	295,769	276,559
SungNoen	-	-	19,115	572,333	-	-	322,319	154,482	90,474	22,042	209,704	154,581
Theparak	-	-	93,161	383,640	-	-	160,545	69,364	47,579	18	112,893	69,419
WangNamKhieo	-	-	12,982	652,143	3,421	165	226,607	434,932	12,864	168	217,125	434,968
SUM	**-**	**-**	**1,058,227**	**11,901,124**	**41,711**	**165**	**5,526,534**	**7,390,941**	**1,052,856**	**39,967**	**4,473,620**	**7,392,908**

4.8 Validation and discussion

To validate the resulting suitability map, RMSE was applied to comparing the modeled results from Mamdani's fuzzy logic system with 30 samples of observation from the field in the same positions (Figure 4.40). Graphic presentation of the linear relationship of the modeled results and observations can indicate the trending that the results are either over or under estimation or neither. R^2 or the coefficient of determination can indicate how good the relationship of 2 variables is, based on this number of samples.

Table 4.22 lists fuzzy indexes, i.e. KP, KS, KC, and Ma, and modeled and observed ADS of 30 samples. Minimum, maximum, and average of modeled ADS are 124, 288, and 191 respectively. By comparing modeled and observed ADS, the RMSE was estimated and resulted as 25.67. The graphic presentation showing a linear relationship of these 2 variables is plotted as shown in Figure 4.41. The graphic presentation shows that the relationship is very close to 1:1. It means that over or under estimation correction is not required for the modeled results. The R^2 of this relationship is 0.6039 and indicates that the relationship is fairly acceptable.

From the validation it can be discussed that there is no requirement for over or under estimation correction for the modeled results. For example, if the modeled ADS is 200 kg/rai/yr, it can be directly incorporate with RMSE to provide the approximate range of ADS as 200±25.67.

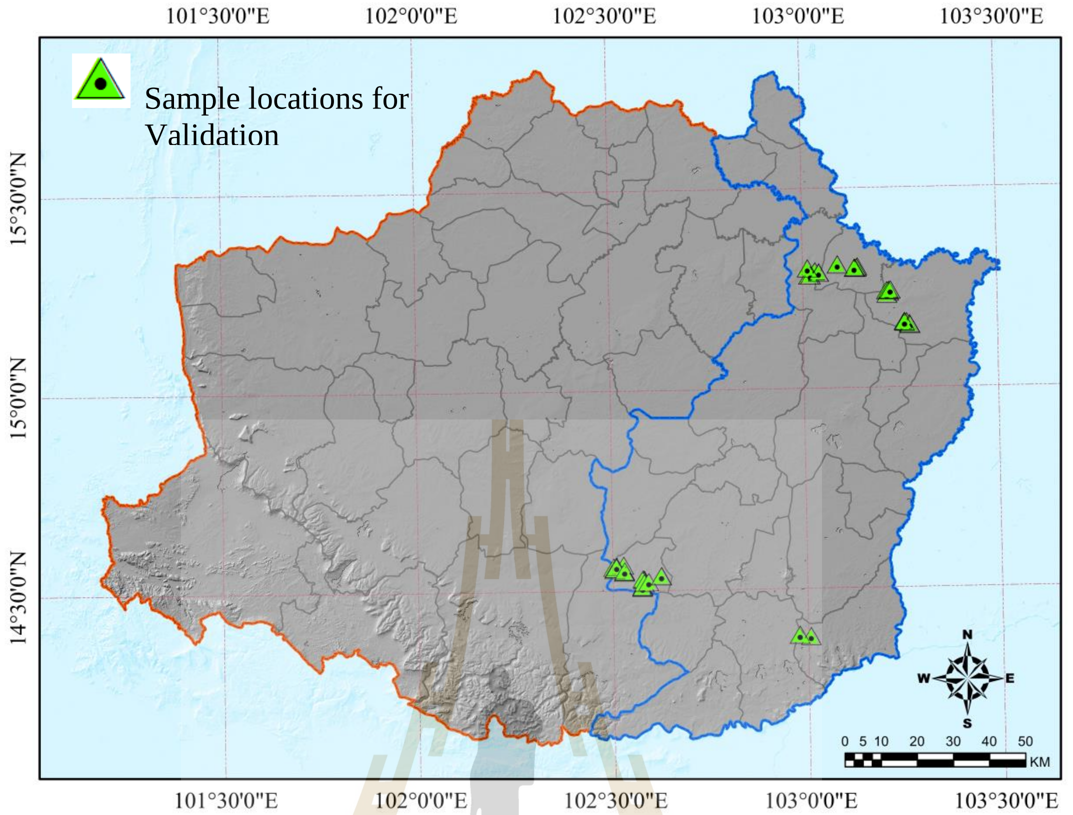


Figure 4.40 Spatial distribution of samples for validation.

Table 4.22 Field data for validation.

Samp. No.	UTM zone 48 X	UTM zone 48 Y	UTM zone 48 Z	Kp	Ks	Kc	Ma	ADS. obs.	ADS mod.
1	238827	1607519	265	100.00	12.20	10.92	6.13	215	191
2	238988	1607563	271	100.00	12.20	10.56	9.81	196	191
3	238568	1607678	308	100.00	12.20	10.52	6.13	191	191
4	238436	1605455	300	100.00	12.20	10.56	6.13	222	191
5	238469	1605401	291	83.38	1.96	10.56	15.70	212	234
6	238900	1606579	284	83.38	1.96	10.56	14.93	225	227
7	240137	1606863	278	100.00	12.20	10.68	32.00	254	288
8	284789	1590763	231	27.93	1.25	12.57	2.40	147	124
9	300090	1692727	151	83.38	1.96	15.90	1.92	200	191
10	299879	1692426	160	83.38	1.96	15.86	6.13	238	191
11	299472	1692346	171	83.38	1.96	15.86	19.11	281	262
12	299344	1692398	176	83.38	1.96	15.82	4.20	207	191
13	233553	1609885	267	100.00	12.20	10.17	2.40	175	191
14	233524	1609643	270	100.00	12.20	10.17	12.00	193	196
15	287177	1690598	184	83.38	1.96	14.39	13.65	243	213

Table 4.22 Field data for validation (Continued).

Samp.	UTM zone 48							ADS.	ADS
No.	X	Y	Z	Kp	Ks	Kc	Ma	obs.	mod.
16	233333	1611592	248	100.00	12.20	10.09	3.68	210	191
17	231486	1610799	251	100.00	12.20	9.90	3.68	224	191
18	230877	1610443	249	100.00	12.20	9.86	23.89	264	288
19	231415	1611310	256	100.00	12.20	9.90	16.73	193	245
20	314169	1676653	182	83.38	1.96	18.96	11.95	208	196
21	312796	1677301	165	83.38	1.96	18.83	13.74	189	214
22	312877	1677117	172	37.29	4.40	18.83	7.67	161	124
23	289457	1691330	174	83.38	1.96	15.10	8.33	239	191
24	233600	1609991	275	100.00	12.20	10.17	12.27	178	199
25	243693	1608393	260	100.00	12.20	10.87	13.33	221	210
26	243765	1608399	261	100.00	12.20	10.90	19.63	240	275
27	309104	1686075	153	37.29	4.40	17.73	19.63	228	205
28	294661	1693422	162	83.38	1.96	15.48	26.67	288	288
29	286374	1692556	163	83.38	1.96	14.87	3.00	210	191
30	281687	1591192	240	83.38	1.96	12.16	7.68	194	191
								R^2 = 0.6039	
								RMSE = 25.67	

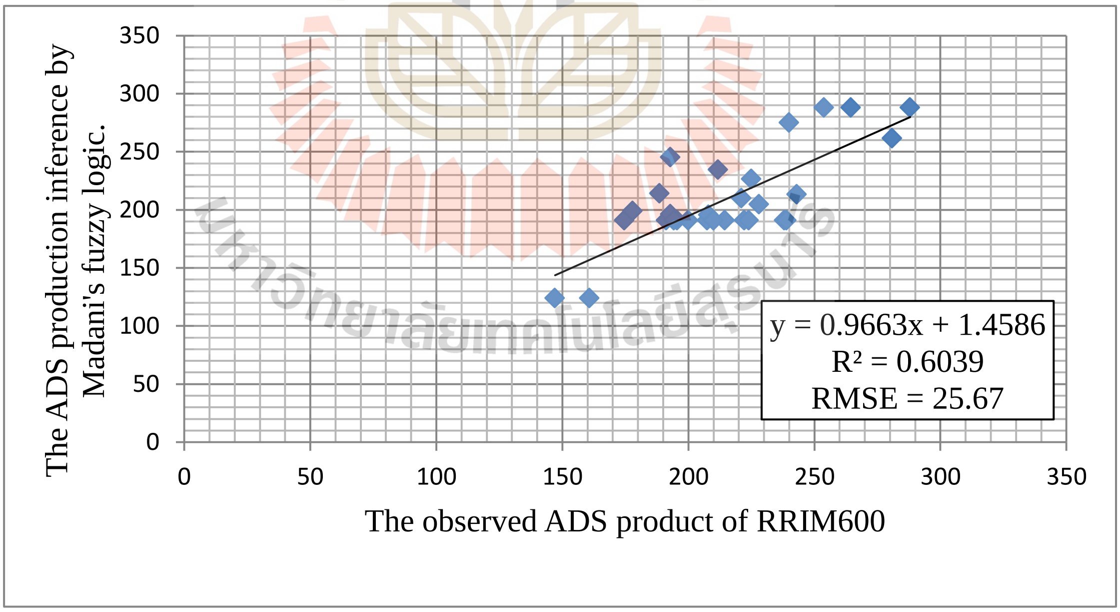


Figure 4.41 The comparison of ADS products from PRIM 600 by Madani's fuzzy logic inference value and the observed ADS product in the field.

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CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The 3 main factors, which affect to rubber production, are rubber clones, environment, and plantation management. Normally, farmers should select rubber clones and field management for rubber plantations based on the recommendations of the Department of Agriculture (DOA, 2012). The environment factors, which are considered as limitations, vary depending on the climate characteristics of each area. Nevertheless, according to the study, the relationship between the environment and field management of the cultivated area affected directly to rubber production, especially when a farmer applied field management based on recommendation of the DOA. The suitable criteria and guide for plantation management that used in this study, are mainly based on selections from previous researches and the DOA's recommendations. The analytical results can provide rules or logic of the system describing the fuzzy appearance of those phenomena.

In this studied, 150 datasets were collected in the lower northeastern region of Thailand and consisted of soil properties, climate and field managements. These were used to analyze and create rules of Mamdani's fuzzy logic system as shown in Table 4.9 to 4.12.

Plantation managements performed in general rubber plantations are regularly pruning during the trees are young, properly fertilizing about 2 times a year with the amount of 50 kg/rai/time, weeding 2 times/yr, mulching the rubber trees especially the dry season, tapping the rubbers with an appropriate method, etc. as introduced in section 3.1.3. After scoring each plantation management (Table 4.4 in section 4.1.4) and aggregating them by using Stories method, the results are plantation management index consisting of 3 levels (high, medium, and low). According to the plantation management index in the study areas, it is found that, in low level of plantation management, there is not an area in the suitability levels S1and S2 but there are 2,097,463 rai in the suitability level S3 (150-200 kg/rai/yr) and 17,161,449 rai in the suitability level N (100-150 kg/rai/yr). Moreover, in medium level of plantation management, there are 41,691 rai in the suitability level S1 (250-300 kg/rai/yr), 165 rai in the suitability level S2 (200-250 kg/rai/yr), 8,726,944 rai in the suitability level S3 (150-200 kg/rai/yr), and 10,490,112 rai in the suitability level N (100-150 kg/rai/yr). In addition, in high level of plantation management, there are 2,091,501 rai in the suitability level S1 (250-300 kg/rai/yr), 40,536 rai in the suitability level S2 (200-250 kg/rai/yr), 6,636,763 rai in the suitability level S3 (150-200 kg/rai/yr), and 10,490,112 rai in the suitability level N (100-150 kg/rai/yr).

Validation of the accuracy of results from the Mamdani Fuzzy Logic analysis system was performed with 30 sets of the field data. The result shows that the RMSE of latex product are 0.6039, R^2 for RRIM600. In conclusion, the study results can serve the designed objectives of this study.

5.2 Recommendations

Recommendations for further studies include:

(1) The results of this study confirm that the yield of rubber plantation is directly related to the level of plantation management. If the plantation management recommended by the DOA is performed, that plantation can provide a higher yield. However, to obtain equal product, the plantation on area with higher suitability of soil physical and chemical properties spend lower cost of the management than the plantation on area with lower suitability of soil physical and chemical properties. Therefore, in a future study, the cost of plantation management in each level should be estimated so that it can be used as an important economic factor for marginal profit determination. Particularly when the lowest market price of ADS can be expected, the system can assign which area can be economic for rubber plantation by economically considering which suitability class of the land fit to which cost level of management. In addition, to serve the policy which requires more plantation area, the area becoming more suitable when higher level or higher cost of management is applied is the target to be chosen. To serve management in farming level, the specific land can be improved by selective practice based on information of Kp, Ks, and Kc provided as the result of the study.

(2) In this study, some rules are still missing. That is because of limitations of the data collected. Therefore, to make Mamdani’s Fuzzy Logic analysis system more comprehensive for analyzing the suitability of rubber plantation, it is necessary to find these missing rules in future studies.

(3) Most of the farmers did not record the information systematically, so it is difficult to collect an actual latex yield. Most of these kind of data used in this study are obtained from the estimation of the farmer. Accordingly, some tolerances can occur in the analysis. Therefore, in future studies, the determination of the specific

rubber plantations to be studied and a systematic and ongoing data collection are required in order to obtain the highest accurate data.

(4) There are many factors related to the productivity of latex such as tapping methods, a tapping time, an experience in tapping, a size of the rubber tree, etc. For being more complete, in future studies, bringing up these factors and adjusting the yields correspondingly in the same conditions.

(5) Tools that aid in ArcGIS application for automatically analyzing rubber plantation suitability by Mamdani's fuzzy logic should be developed.

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APPENDICES

APPENDIX A

FUZZY LOGIC AND APPLICATIONS IN GIS

Analysis procedures of land suitability for rubber plantation using ArcGIS of this research are as follows:

1. Create criterion maps in Raster format.

2. Calculate Fuzzy membership of each criterion map. For example, the Figure shows rainfall is considered suitable when it is 1,000-2,500 mm. The features meeting the criterion are represented as a fuzzy set with linear membership types. The Fuzzy membership of criterion maps can be calculated by using Fuzzy membership tool in ArcGIS 10 as shown in Figure 1 and 2.

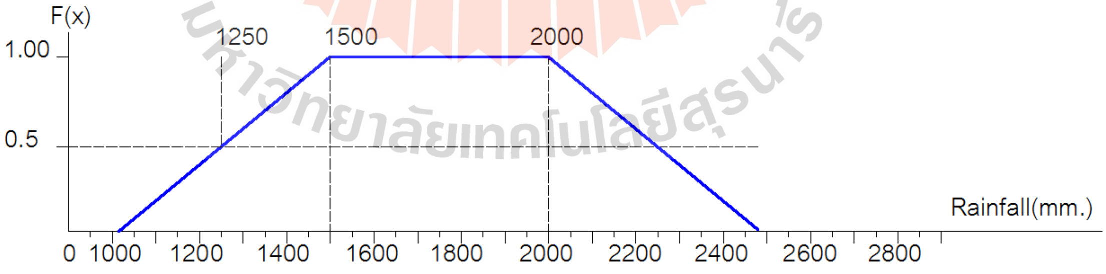

Figure 1 Membership function of rainfall.

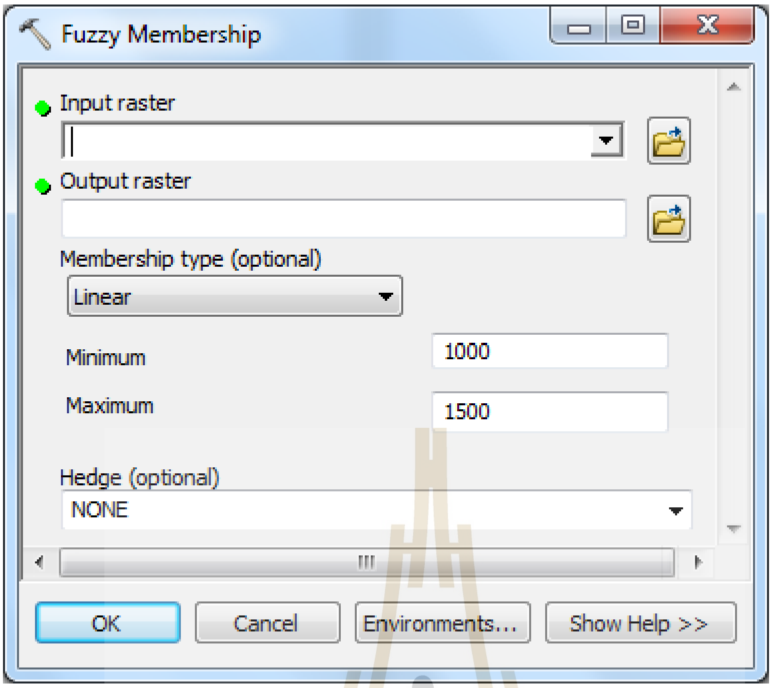

Figure 2 Using Fuzzy membership tools in Fuzzy membership calculation.

3. Calculate the Fuzzy memberships of each criterion and aggregate the outputs to index Maps (Kp,Ks,Kc,M)

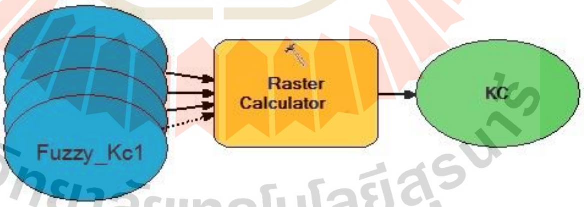

Figure 3 The aggregation of Fuzzy membership of each criterion by raster calculator tool in ArcGIS 10

4. Use index Maps to calculate Fuzzy memberships of each Fuzzy class (L, M, U). For example, in the calculation of the Fuzzy membership of Kc index of each Fuzzy class, the membership functions are determined in L and M of Kc as shown in Figure 3.

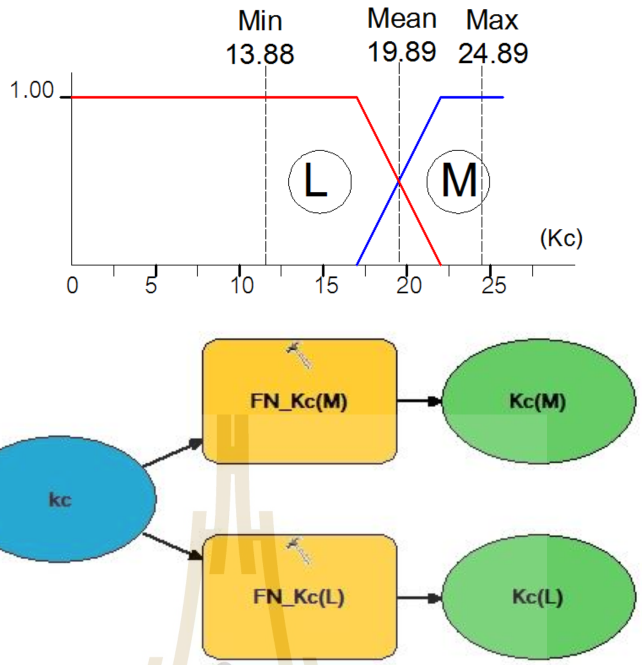

Figure 4 Fuzzy memberships calculation of each Fuzzy class of Kc index.

5. Apply the membership values to every rule. For example, Rule16 in the plantation management class is M: Output_R16 = min (Kc, Ks, Kc) shown in Figure 4.

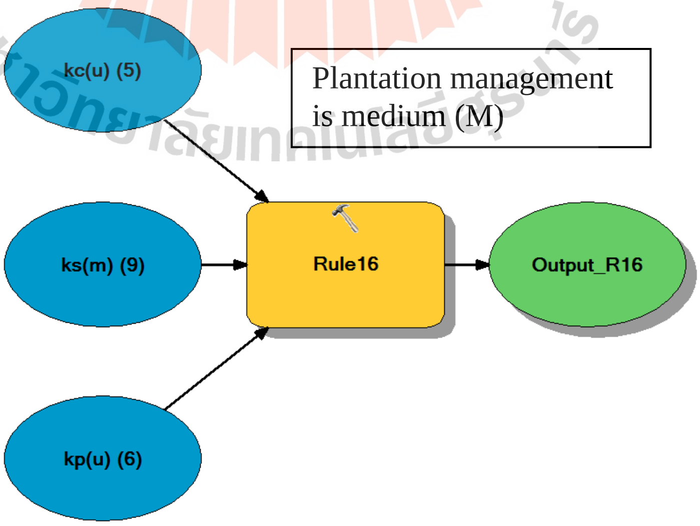

Figure 5 The calculation to find the outputs of the rules.

6. Calculate latex product by applying every rule output in defuzzification. For example, after getting the outputs of each rule, they are classified into Class U, Class M and Class L. Then, each class is overlain to find the maximum by Fuzzy overlaying tool. Next, the maximum is multiplied by an average yield of each class, and the results are combined and divided by the combination results of the maximum of each class by the Raster calculator Tool as shown in Figure 5.

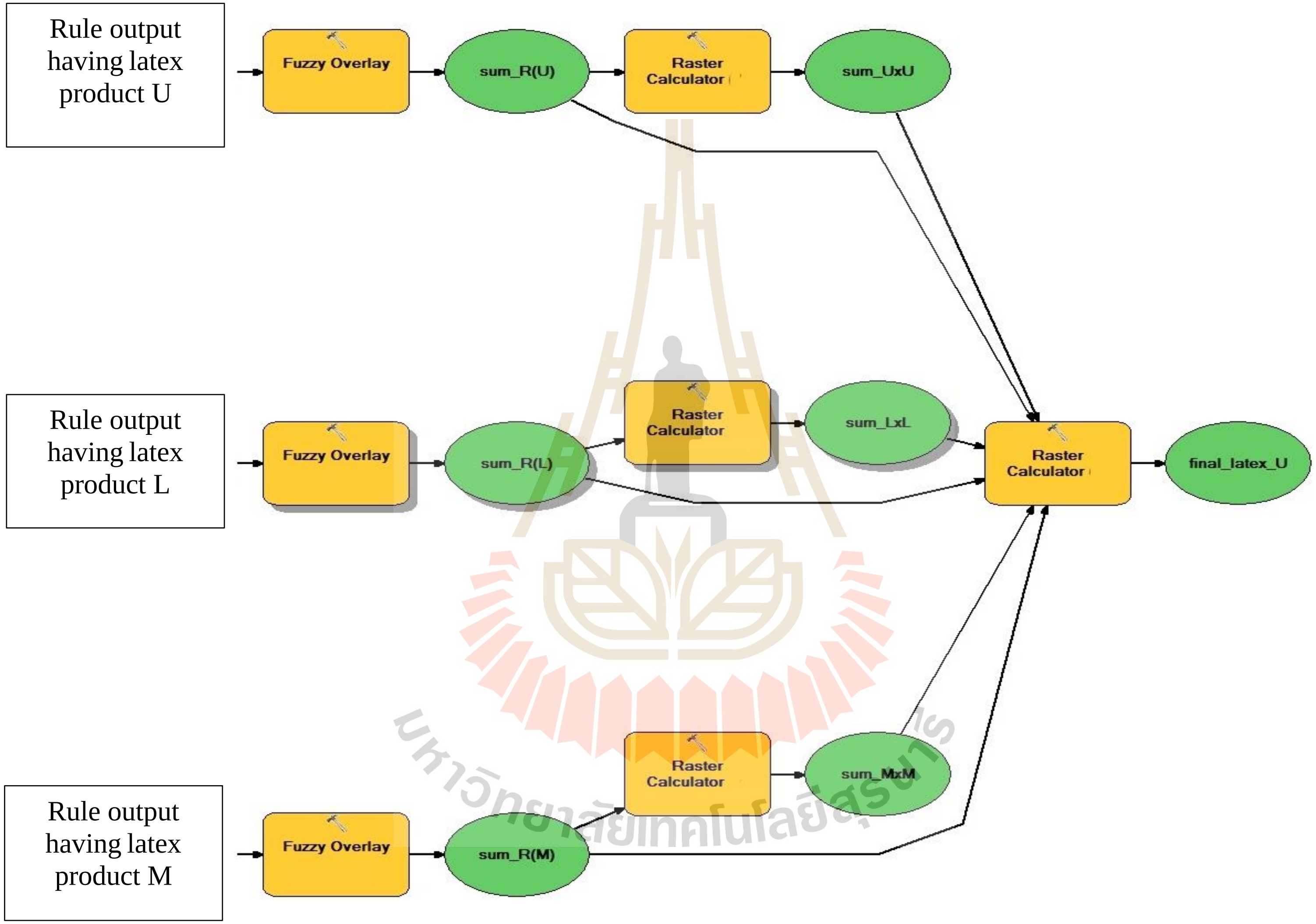

Figure 6 The calculation of Latex product in ArcGIS.

APPENDIX B

PLANTATION MANAGEMENT DATA

Analysis results of the data concerning the management factors in the sample rubber plantations based on scoring criteria determined in Table 1 can be expressed in Table 2. These indexes of the management factors are fuzzified and combined by using Storie's Method.

Table 1 Scoring membership values of the managed rubber plantations.

Management Factors	Scoring Criteria				
	0.1	0.3	0.5	0.8	1.0
Dry Season	-	-	Rain	Rain and sometimes watering	Good source of watering
Pruning	No	1 times/year	2 times/yr	3 times/yr	Always
Fertilizing					
- Immature period	No	Sometimes	2 times/yr	3 times/yr	Based on DOA
- Mature period	No	Sometimes	2 times/yr	3 times/yr	Based on DOA
- Quantity	-	Uncertainly	-	-	Based on DOA
Weeding	No	Sometimes	2 times/yr	>2times/yr	Always
Cover crops	No	-	Sometimes	-	Yes
Rubber tapping systems	-	-	S/2 d1 2d/3, S/3 d1 2d/3, S/3 d2	S/2 d2	S/2 d3

Note: " - " not existing, DOA is the Department of Agricultural, Thailand;

S/3 d1 2d/3 is a one third-spiral cut with a tapping frequency of two days out of three;

S/3 d2 is a one third-spiral cut with a tapping frequency of once two days;

S/2 d1 2d/3 is a half- spiral cut with a tapping frequency of two days out of three;

S/2 d2 is a half- spiral cut with a tapping frequency of once two days;

S/2 d3 is a half- spiral cut with a tapping frequency of once three days.

Data collection and plantation management are defined and described as shown in Table 2.

Table 2 Symbols and descriptions.

Criteria	Symbol	Description
Dry Season	1	Rain
	2	Rain and sometimes watering
	3	Watering and Good source
Pruning (Times/Yr.)	1	No pruning
	2	2-3 times/year
	3	>3 times/year
	4	Always
Fertilizing		
- Immature / Mature period	1	Sometimes
	2	2 times/year
	3	3 times/year
	4	Based on DOA.
- Quantity	1	Uncertainly
	2	Based on DOA.
Weeding (Times/Yr.)	1	Always
	2	2 times/year
	3	3 times/year
	>3	Always
Cover crops	1	No
	2	Sometimes
	3	Yes
Rubber tapping systems	1	S/2 d2
	2	S/2 d1 2d/3
	3	S/3 d2
	4	S/3 d1 2d/3

Table 3 Plantation management data.

Samp.	**Dry season**		**Pruning (T/Yr.)**		**Fertilizing**							**Weeding (T/Yr.)**		**Cover crops**		**Tapping systems**		**Ma**
No.		***FV1***		***FV2***	**Im.M**	**Mat**	**Vol.**	*F1*	*F2*	*F3*	***FV3***		***FV4***		***FV5***		***FV6***	
1	1	0.5	2	0.5	3	2	1	0.8	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	6.13
2	1	0.5	2	0.5	3	2	1	0.8	0.5	1.0	0.8	3	0.8	3	1.0	4	0.8	12.27
3	1	0.5	2	0.5	3	2	1	0.8	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	6.13
4	1	0.5	2	0.8	3	2	1	0.8	0.5	1.0	0.8	2	0.5	2	0.5	4	0.8	6.13
5	1	0.5	2	0.8	3	2	1	0.8	0.5	1.0	0.8	3	0.8	3	1.0	4	0.8	19.63
6	1	0.5	5	1.0	4	>2	1	1.0	0.8	1.0	0.9	3	0.8	2	0.5	4	0.8	14.93
7	1	0.5	5	1.0	4	>2	1	1.0	1.0	1.0	1.0	3	0.8	3	1.0	4	0.8	32.00
8	1	0.5	1	0.3	1	2	2	0.3	0.5	0.3	0.4	>3	1.0	2	0.5	4	0.8	2.20
9	1	0.5	1	0.3	2	2	2	0.5	0.5	0.3	0.4	3	0.8	2	0.5	4	0.8	2.08
10	1	0.5	3	0.8	3	2	1	0.8	0.5	1.0	0.8	2	0.5	2	0.5	4	0.8	6.13
11	1	0.5	3	0.8	>2	2	1	0.8	0.8	1.0	0.9	3	0.8	3	1.0	4	0.8	22.19
12	3	1.0	1	0.3	2	2	2	0.5	0.8	0.3	0.5	2	0.5	2	0.5	4	0.8	3.20
13	1	0.5	1	0.3	2	2	2	0.5	0.5	0.3	0.4	>3	1.0	2	0.5	4	0.8	2.60
14	1	0.5	4	1.0	1	2	1	0.3	0.5	1.0	0.6	>3	1.0	2	0.5	4	0.8	12.00
15	1	0.5	3	0.8	2	2	1	0.5	0.5	1.0	0.7	3	0.8	3	1.0	4	0.8	17.07
16	1	0.5	1	0.3	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	3	1.0	4	0.8	5.00
17	1	0.5	1	0.3	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	4.00
18	1	0.5	4	1.0	>2	>2	1	1.0	0.8	1.0	0.9	3	0.8	3	1.0	4	0.8	29.87
19	1	0.5	3	0.8	4	>2	1	1.0	1.0	1.0	1.0	3	0.8	2	0.5	4	0.8	12.80
20	1	0.5	3	0.8	3	2	1	0.8	0.8	1.0	0.9	3	0.8	2	0.5	4	0.8	11.09
21	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	10.67
22	1	0.5	2	0.5	4	>2	2	1.0	1.0	0.3	0.8	3	0.8	2	0.5	1	1.0	7.67
23	1	0.5	2	0.5	3	2	1	0.8	0.5	1.0	0.8	>3	1.0	2	0.5	4	0.8	7.67
24	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	1	1.0	13.33
25	1	0.5	4	1.0	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	13.33
26	2	1.0	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	21.33
27	1	0.5	3	0.8	>2	2	1	0.8	0.5	1.0	0.8	3	0.8	3	1.0	1	1.0	24.53

Table 3 Plantation management data (Continued).

Samp.	Dry season		Pruning (T/Yr.)		Fertilizing							Weeding (T/Yr.)		Cover crops		Tapping systems		Ma
No.		***FV1***		***FV2***	**Im.M**	**Mat**	**Vol.**	*F1*	*F2*	*F3*	***FV3***		***FV4***		***FV5***		***FV6***	
28	1	***0.5***	4	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	>3	***1.0***	3	***1.0***	4	***0.8***	***33.33***
29	1	***0.5***	2	***0.5***	>2	2	2	*1.0*	*0.5*	*0.3*	***0.6***	2	***0.5***	2	***0.5***	4	***0.8***	***3.00***
30	1	***0.5***	5	***0.8***	>2	2	2	*1.0*	*0.5*	*0.3*	***0.6***	3	***0.8***	2	***0.5***	4	***0.8***	***7.68***
31	1	***0.5***	3	***0.8***	2	2	1	*0.5*	*0.8*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***6.13***
32	1	***0.5***	3	***0.8***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	3	***0.8***	2	***0.5***	4	***0.8***	***8.53***
33	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	>3	***1.0***	2	***0.5***	4	***0.8***	***13.33***
34	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
35	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***6.67***
36	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***6.67***
37	1	***0.5***	2	***0.5***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	2	***0.5***	2	***0.5***	4	***0.8***	***3.33***
38	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
39	1	***0.5***	3	***0.8***	2	2	2	*0.5*	*0.5*	*0.3*	***0.4***	2	***0.5***	2	***0.5***	4	***0.8***	***3.47***
40	1	***0.5***	3	***0.8***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	3	***0.8***	2	***0.5***	4	***0.8***	***7.68***
41	1	***0.5***	4	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	>3	***1.0***	3	***1.0***	4	***0.8***	***33.33***
42	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	>3	***1.0***	2	***0.5***	4	***0.8***	***13.33***
43	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***4.17***
44	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***4.17***
45	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
46	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***11.95***
47	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***11.95***
48	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***11.95***
49	2	***1.0***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***8.00***
50	2	***1.0***	2	***0.5***	>2	2	1	*0.8*	*1.0*	*1.0*	***0.9***	>3	***1.0***	2	***0.5***	4	***0.8***	***18.67***
51	2	***1.0***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	3	***1.0***	4	***0.8***	***47.79***
52	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***2.50***
53	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***6.67***
54	1	***0.5***	1	***0.3***	2	2	2	*0.5*	*0.5*	*0.3*	***0.4***	>3	***1.0***	2	***0.5***	4	***0.8***	***2.60***

Table 3 Plantation management data (Continued).

Samp. No.	Dry season		Pruning (T/Yr.)		Fertilizing							Weeding (T/Yr.)		Cover crops		Tapping systems		Ma
		FV1		***FV2***	**Im.M**	**Mat**	**Vol.**	*F1*	*F2*	*F3*	***FV3***		***FV4***		***FV5***		***FV6***	
55	1	***0.5***	1	***0.3***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	>3	***1.0***	2	***0.5***	4	***0.8***	***4.00***
56	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***6.67***
57	1	***0.5***	1	***0.3***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	3	***1.0***	4	***0.8***	***5.60***
58	1	***0.5***	5	***1.0***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	>3	***1.0***	2	***0.5***	4	***0.8***	***12.00***
59	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	>3	***1.0***	2	***0.5***	4	***0.8***	***8.33***
60	2	***1.0***	4	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***26.67***
61	3	***1.0***	4	***1.0***	2	2	1	*0.5*	*0.8*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***49.07***
62	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***2.50***
63	1	***0.5***	2	***0.5***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	2	***0.5***	3	***1.0***	4	***0.8***	***6.67***
64	1	***0.5***	1	***0.3***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	2	***0.5***	3	***1.0***	4	***0.8***	***3.60***
65	1	***0.5***	1	***0.3***	2	2	2	*0.5*	*0.8*	*0.3*	***0.5***	3	***0.8***	2	***0.5***	4	***0.8***	***2.56***
66	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	3	***1.0***	4	***0.8***	***9.33***
67	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	3	***1.0***	4	***0.8***	***23.89***
68	1	***0.5***	2	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***6.67***
69	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***4.00***
70	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***2.50***
71	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
72	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***11.95***
73	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	2	***0.5***	4	***0.8***	***4.67***
74	1	***0.5***	2	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	3	***1.0***	4	***0.8***	***13.33***
75	1	***0.5***	1	***0.3***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***4.48***
76	1	***0.5***	1	***0.3***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	>3	***1.0***	2	***0.5***	4	***0.8***	***5.60***
77	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	3	***1.0***	4	***0.8***	***8.33***
78	2	***1.0***	4	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***26.67***
79	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***8.00***
80	3	***1.0***	5	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***26.67***
81	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	2	***0.5***	4	***0.8***	***4.67***

Table 3 Plantation management data (Continued).

Samp.	Dry season		Pruning (T/Yr.)		Fertilizing							Weeding (T/Yr.)		Cover crops		Tapping systems		Ma
No.		FV1		FV2	Im.M	Mat	Vol.	F1	F2	F3	FV3		FV4		FV5		FV6	
82	1	0.5	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	6.67
83	1	0.5	3	0.8	>2	>2	1	0.8	1.0	1.0	0.9	>3	1.0	3	1.0	4	0.8	29.87
84	1	0.5	4	1.0	>2	>2	1	0.8	1.0	1.0	0.9	3	0.8	2	0.5	4	0.8	14.93
85	1	0.5	2	0.5	>2	>2	1	0.8	1.0	1.0	0.9	3	0.8	2	0.5	4	0.8	7.47
86	1	0.5	4	0.8	2	2	1	0.5	0.5	1.0	0.7	3	0.8	2	0.5	4	0.8	8.53
87	1	0.5	4	1.0	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	2	0.5	4	0.8	8.33
88	1	0.5	4	1.0	>2	2	2	1.0	0.5	0.3	0.6	3	0.8	3	1.0	4	0.8	19.20
89	1	0.5	4	1.0	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	13.33
90	2	1.0	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	1	1.0	16.67
91	1	0.5	3	0.8	>2	>2	1	0.8	1.0	1.0	0.9	3	0.8	2	0.5	4	0.8	11.95
92	1	0.5	2	0.5	1	2	1	0.3	0.5	1.0	0.6	3	0.8	2	0.5	4	0.8	4.80
93	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	3	1.0	4	0.8	21.33
94	1	0.5	1	0.3	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	3	1.0	4	0.8	8.00
95	1	0.5	2	0.5	>2	>2	1	1.0	1.0	1.0	1.0	>3	1.0	2	0.5	4	0.8	10.00
96	1	0.5	3	0.8	1	2	1	0.3	0.5	1.0	0.6	>3	1.0	3	1.0	4	0.8	19.20
97	1	0.5	1	0.3	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	4.00
98	1	0.5	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	6.67
99	1	0.5	4	1.0	>2	2	1	1.0	0.5	1.0	0.8	>3	1.0	3	1.0	4	0.8	33.33
100	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	3	1.0	4	0.8	13.33
101	1	0.5	3	0.8	1	2	1	0.3	0.5	1.0	0.6	3	0.8	2	0.5	4	0.8	7.68
102	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	3	1.0	4	0.8	13.33
103	1	0.5	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	3	1.0	4	0.8	13.33
104	1	0.5	5	0.8	>2	>2	1	0.8	1.0	1.0	0.9	3	0.8	2	0.5	4	0.8	11.95
105	1	0.5	1	0.3	>2	2	1	1.0	0.5	1.0	0.8	>3	1.0	2	0.5	4	0.8	5.00
106	1	0.5	3	0.8	>2	2	1	1.0	0.5	1.0	0.8	3	0.8	2	0.5	4	0.8	10.67
107	1	0.5	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	3	1.0	4	0.8	8.33
108	1	0.5	2	0.5	>2	2	1	1.0	0.5	1.0	0.8	2	0.5	3	1.0	4	0.8	8.33

Table 3 Plantation management data (Continued).

Samp. No.	Dry season		Pruning (T/Yr.)		Fertilizing							Weeding (T/Yr.)		Cover crops		Tapping systems		Ma
		FV1		***FV2***	**Im.M**	**Mat**	**Vol.**	*F1*	*F2*	*F3*	***FV3***		***FV4***		***FV5***		***FV6***	
109	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***13.33***
110	1	***0.5***	1	***0.3***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	3	***0.8***	3	***1.0***	4	***0.8***	***5.76***
111	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
112	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	1	***1.0***	***8.33***
113	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	3	***1.0***	1	***1.0***	***18.67***
114	2	***1.0***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***13.33***
115	1	***0.5***	1	***0.3***	2	2	2	*0.5*	*0.5*	*0.3*	***0.4***	3	***0.8***	2	***0.5***	4	***0.8***	***2.08***
116	1	***0.5***	5	***1.0***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	>3	***1.0***	2	***0.5***	4	***0.8***	***18.67***
117	1	***0.5***	4	***1.0***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	>3	***1.0***	2	***0.5***	4	***0.8***	***18.67***
118	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***4.00***
119	1	***0.5***	3	***0.8***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***11.95***
120	2	***1.0***	3	***0.8***	>2	2	1	*0.8*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***39.25***
121	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	3	***0.8***	2	***0.5***	4	***0.8***	***7.47***
122	1	***0.5***	1	***0.3***	3	2	1	*0.8*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	1	***1.0***	***4.60***
123	1	***0.5***	1	***0.3***	>2	>2	1	*1.0*	*1.0*	*1.0*	***1.0***	3	***0.8***	2	***0.5***	4	***0.8***	***4.80***
124	1	***0.5***	1	***0.3***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	3	***0.8***	2	***0.5***	4	***0.8***	***2.88***
125	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***4.17***
126	1	***0.5***	1	***0.3***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	2	***0.5***	2	***0.5***	4	***0.8***	***2.00***
127	1	***0.5***	1	***0.3***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	2	***0.5***	4	***0.8***	***2.80***
128	1	***0.5***	2	***0.5***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	2	***0.5***	4	***0.8***	***4.67***
129	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***4.17***
130	1	***0.5***	1	***0.3***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	2	***0.5***	2	***0.5***	4	***0.8***	***2.00***
131	1	***0.5***	1	***0.3***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	3	***0.8***	3	***1.0***	4	***0.8***	***5.76***
132	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***8.00***
133	1	***1.0***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***13.33***
134	1	***0.5***	1	***0.3***	1	2	1	*0.3*	*0.5*	*1.0*	***0.6***	3	***0.8***	2	***0.5***	4	***0.8***	***2.88***
135	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***

Table 3 Plantation management data (Continued).

Samp. No.	Dry season		Pruning (T/Yr.)		Fertilizing							Weeding (T/Yr.)		Cover crops		Tapping systems		Ma
		FV1		***FV2***	**Im.M**	**Mat**	**Vol.**	*F1*	*F2*	*F3*	***FV3***		***FV4***		***FV5***		***FV6***	
136	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
137	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***4.00***
138	5	***0.5***	1	***0.3***	>2	>2	1	*0.8*	*1.0*	*1.0*	***0.9***	2	***0.5***	2	***0.5***	4	***0.8***	***2.80***
139	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	1	***1.0***	***13.33***
140	1	***0.5***	1	***0.3***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	2	***0.5***	4	***0.8***	***2.50***
141	1	***0.5***	4	***1.0***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***26.67***
142	1	***0.5***	3	***0.8***	2	2	1	*0.5*	*0.5*	*1.0*	***0.7***	>3	***1.0***	2	***0.5***	4	***0.8***	***10.67***
143	2	***1.0***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***13.33***
144	2	***1.0***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***21.33***
145	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***10.67***
146	1	***0.5***	3	***0.8***	3	2	1	*0.8*	*0.5*	*1.0*	***0.8***	3	***0.8***	2	***0.5***	4	***0.8***	***9.81***
147	1	***0.5***	3	***0.8***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	2	***0.5***	3	***1.0***	4	***0.8***	***13.33***
148	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***13.33***
149	1	***0.5***	2	***0.5***	>2	2	1	*1.0*	*0.5*	*1.0*	***0.8***	3	***0.8***	3	***1.0***	4	***0.8***	***13.33***
150	1	***0.5***	3	***0.8***	>2	2	2	*0.8*	*0.5*	*0.3*	***0.5***	3	***0.8***	3	***1.0***	4	***0.8***	***13.65***
																	Min	*2.000*
																	Aver.	*11.297*
																	Max	*49.067*

Note: FV 1 to 6 are Fuzzy Values of the criteria. Im.M is immature trees. Mat is mature trees. Ma is a management index.

APPENDIX C

HOW TO CALCULATE VPD

The vapor pressure deficit (*VPD*) is calculated by the Equation

$$VPD = \left(1.00 - \left(\frac{RH}{100}\right)\right) * p^{sat}(T)$$

where, *RH* is Relative Humidity

P^{sat} is saturated vapor pressure of water in *kPa* at temperature (*T*) in °*K*. calculated by the Equation

$P^{sat}(T) = 0.6108 \exp[7.5T/(237.3+T)]$

T in Table 4 and *RH* in Table 5 can be calculated to find *VPD* as in Table 6 and 7.

Table 4 Mean temperature for the 30 year period. (°C).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC_
Kosum Phisai*	23.7	25.8	28.4	30.1	29.3	29	28.6	28	27.7	27.1	25.3	23.5
Chaiyaphum*	24.2	26.7	28.8	30	28.9	28.5	28	27.6	27.3	27	25.6	23.8
Roi Et*	23.3	25.7	28.2	29.8	29	28.7	28.3	27.9	27.5	26.7	24.9	22.9
Ubon Ratchathani*	24.2	26.5	28.9	30	29	28.4	28	27.6	27.4	26.8	25.4	23.7
Nakhon Ratchasima*	24.3	26.9	28.9	30	29.1	29.1	28.6	28.1	27.4	26.7	25.4	23.6
Chok Chai*	24.4	26.5	28.5	29.6	28.8	28.7	28.3	27.9	27.3	26.6	25.1	23.6
Surin*	24.1	26.6	28.7	29.8	28.8	28.3	27.9	27.6	27.3	26.7	25.3	23.6
Tha Tum*	24	26.2	28.7	30.4	29.5	29.1	28.6	28.2	27.7	27	25.4	23.7
Nang Rong*	24.3	26.4	28.4	29.5	28.8	28.6	28.1	27.8	27.2	26.5	25	23.6

Table 5 Relative humidity for the 30 year period (*RH*).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC_
Kosum Phisai*	70	67	66	68	76	78	79	82	84	80	73	70
Chaiyaphum*	61	60	59	64	74	75	76	79	81	76	67	63
Roi Et*	65	63	61	65	73	76	77	80	81	77	70	66
Ubon Ratchathani*	65	63	62	66	75	79	80	82	82	78	71	68
Nakhon Ratchasima*	64	62	61	66	73	72	73	75	80	79	71	66
Chok Chai*	67	64	65	68	75	74	75	77	82	81	75	70
Surin*	65	63	63	67	76	79	80	82	84	81	73	68
Tha Tum*	68	65	63	66	75	77	79	81	84	80	73	70
Nang Rong*	69	66	67	70	77	77	79	80	84	82	76	71

Table 6 Relative humidity for the 30 year period (*RH*).

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC_
Kosum Phisai*	0.88	1.1	1.32	1.37	0.98	0.88	0.82	0.68	0.59	0.72	0.87	0.87
Chaiyaphum*	1.18	1.4	1.62	1.53	1.04	0.97	0.91	0.78	0.69	0.86	1.08	1.09
Roi Et*	1	1.22	1.49	1.47	1.08	0.94	0.88	0.75	0.7	0.81	0.94	0.95
Ubon Ratchathani*	1.06	1.28	1.51	1.44	1	0.81	0.76	0.66	0.66	0.78	0.94	0.94
Nakhon Ratchasima*	1.09	1.35	1.55	1.44	1.09	1.13	1.06	0.95	0.73	0.74	0.94	0.99
Chok Chai*	1.01	1.25	1.36	1.33	0.99	1.02	0.96	0.86	0.65	0.66	0.8	0.87
Surin*	1.05	1.29	1.46	1.38	0.95	0.81	0.75	0.66	0.58	0.67	0.87	0.93
Tha Tum*	0.95	1.19	1.46	1.48	1.03	0.93	0.82	0.73	0.59	0.71	0.88	0.88
Nang Rong*	0.94	1.17	1.28	1.24	0.91	0.9	0.8	0.75	0.58	0.62	0.76	0.84

ST_NAME	JUN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC_
Kosum Phisai*	8.8	11	13.2	13.7	9.8	8.8	8.2	6.8	5.9	7.2	8.7	8.7
Chaiyaphum*	11.8	14	16.2	15.3	10.4	9.7	9.1	7.8	6.9	8.6	10.8	10.9
Roi Et*	10	12.2	14.9	14.7	10.8	9.4	8.8	7.5	7	8.1	9.4	9.5
Ubon Ratchathani*	10.6	12.8	15.1	14.4	10	8.1	7.6	6.6	6.6	7.8	9.4	9.4
Nakhon Ratchasima*	10.9	13.5	15.5	14.4	10.9	11.3	10.6	9.5	7.3	7.4	9.4	9.9
Chok Chai*	10.1	12.5	13.6	13.3	9.9	10.2	9.6	8.6	6.5	6.6	8	8.7
Surin*	10.5	12.9	14.6	13.8	9.5	8.1	7.5	6.6	5.8	6.7	8.7	9.3
Tha Tum*	9.5	11.9	14.6	14.8	10.3	9.3	8.2	7.3	5.9	7.1	8.8	88
Nang Rong*	9.4	11.7	12.8	12.4	9.1	9	8	7.5	5.8	6.2	7.6	8.4

APPENDIX D

HOW TO CALCULATE THE INDEX OF HUMIDITY (IH)

The index of humidity (*Ih*) is calculated by the Equation

$$Ih = R \,/\, ETc$$

where, *R* is monthly rainfall

ETc is water demand of the rubber tree calculated by the Equation

$$ETc = Kc{*}ETo$$

Where, Kc is Crop Coefficient with Penman-Monteith approach

ETo is the reference crop evapotranspiration

Table 7 KC of the rubber recommended by Royal Irrigation Department (RID, 2554).

	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec_
Kc	0.65	0.86	1.13	1.35	1.56	1.29	1.2	0.93	0.63	0.52	0.52	0.52

ETo is calculated by the Penman-Monteith approach. The FAO Penman-Monteith equation (Allen et al., 1998) is given by:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where ETo is reference evapotranspiration [mm day-1],

R_n net radiation at the crop surface [MJ m-2 day-1],

G soil heat flux density [MJ m-2 day-1],

T mean daily air temperature at 2 m height [°C],

u_2 wind speed at 2 m height [m s-1],

e_s saturation vapour pressure [kPa],

e_a actual vapour pressure [kPa],

e_s-e_a saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa °C-1],

γ psychrometric constant [kPa °C-1].

However, ETo can be calculated by ETo calculator software developed by the Land and Water Division of FAO which can be downloaded from http://www.fao.org/nr/water/eto.html. Its main function is to calculate the reference of evapotranspiration (ETo) according to FAO standards. The ETo calculator assesses ETo from meteorological data by means of the FAO Penman-Monteith equation. This method has been selected by FAO as the reference because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

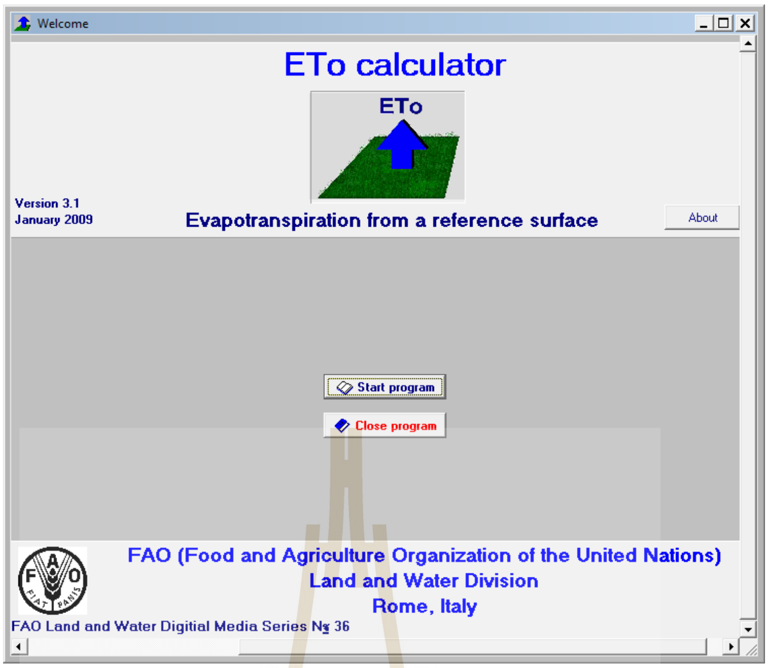

Figure 7 ETo calculator software.

In this study, an average maximum temperature (Tmax), an average minimum temperature (Tmin), an average maximum relative humidity (RHmax), an average minimum relative humidity (RHmin), and an average Wind speed (u(x)) are taken into the consideration to calculate ETo as the results shown in Tables 8 to 16

Table 8 Kosum Phisai (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31.4	16.7	90	46	1.8	3.3
2	33.7	19.7	87	44	2	4
3	35.7	22.5	85	45	2.1	4.6
4	36.8	24.7	86	47	2	4.9
5	35.2	24.9	91	56	2	4.6
6	34.2	24.9	91	60	2.4	4.4
7	33.6	24.6	92	62	2.6	4.3
8	33	24.3	94	66	2.3	4.1
9	32.6	23.8	96	66	1.4	3.7
10	32.2	22.7	93	60	1.7	3.5
11	31.6	19.9	91	51	2.1	3.3
12	30.5	16.7	91	47	2.3	3.2

Table 9 Chaiyaphum (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31	18.5	81	40	1.5	3.1
2	33.7	20.9	80	38	1.6	3.8
3	35.7	23.1	80	38	1.8	4.5
4	36.4	24.9	83	43	1.7	4.8
5	34.6	25	89	53	1.5	4.3
6	33.5	24.9	90	56	2	4.2
7	32.9	24.5	90	58	2.1	4.1
8	32.3	24.3	92	61	2	3.9
9	32	24.1	94	62	1.2	3.6
10	31.6	23.4	90	58	1.6	3.3
11	30.9	21.2	84	48	2	3.2
12	29.9	18.5	82	42	1.9	3

Table 10 Roi Et (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	30.3	17.2	85	41	1.9	3.2
2	32.6	19.8	82	40	1.9	3.8
3	34.7	22.7	80	40	2	4.4
4	35.7	24.8	83	44	2	4.7
5	34.2	25	89	54	1.9	4.3
6	33.1	25.2	90	59	2.6	4.1
7	32.4	25	90	61	2.7	4
8	31.7	24.8	91	65	2.5	3.7
9	31.4	24.5	93	65	1.5	3.4
10	31.1	23	90	59	1.9	3.3
11	30.5	20.1	87	50	2.4	3.3
12	29.3	17.3	85	44	2.4	3.1

Table 11 Ubon (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31.7	17.5	87	41	3.5	3.9
2	34	19.9	84	41	3.2	4.5
3	35.8	22.5	81	41	3.2	5.1
4	36.4	24.4	84	46	3	5.2
5	34.7	24.5	90	55	3.1	4.7
6	33.3	24.4	92	61	3.6	4.4
7	32.6	24.2	92	63	3.6	4.2
8	31.9	23.9	93	66	3.7	4
9	31.8	23.7	94	65	2.6	3.7
10	31.8	22.5	91	60	3.7	3.8
11	31.4	20.3	87	52	5.4	4
12	30.6	17.8	87	46	5.4	4

Table 12 Nakhon Ratchasima (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	30.7	18.5	85	42	1.6	3.2
2	33.6	21	83	39	1.5	3.8
3	35.6	23.2	82	39	1.7	4.5
4	36.5	24.9	84	43	1.7	4.8
5	35	25	88	52	1.8	4.5
6	34.4	25.1	87	53	2.3	4.4
7	33.8	24.7	88	54	2.3	4.3
8	33.2	24.5	90	57	2.2	4.1
9	32.2	24	93	61	1.4	3.7
10	31	23.2	92	60	1.9	3.3
11	30.1	21.1	88	53	2.3	3.1
12	29.3	18.3	85	45	2.2	3

Table 13 Chok Chai (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31	17.6	88	43	1.3	3.2
2	33.5	20.2	86	40	1.6	3.9
3	35.2	22.6	85	42	1.9	4.5
4	35.9	24.4	86	46	1.8	4.7
5	34.5	24.8	90	55	1.6	4.3
6	33.9	24.9	89	55	2.2	4.3
7	33.4	24.5	89	56	2.3	4.2
8	32.8	24.3	90	58	2.2	4.1
9	32	23.9	94	63	1.3	3.6
10	30.9	23	94	62	1.5	3.2
11	30.1	20.5	91	54	1.9	3.1
12	29.4	17.5	89	47	1.8	3

Table 14 Surin (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31.2	18.1	87	41	2.1	3.4
2	33.5	20.6	85	40	2	4
3	35.4	23	83	41	2.2	4.6
4	36	24.9	86	46	2.1	4.8
5	34.5	24.9	91	55	2.2	4.4
6	33.4	24.9	92	59	2.6	4.2
7	32.7	24.6	93	62	2.6	4
8	32.2	24.4	94	65	2.5	3.9
9	31.7	24.2	96	67	1.6	3.5
10	31.1	23.3	93	63	2.3	3.3
11	30.8	20.8	89	53	2.9	3.4
12	30	18.1	87	46	3	3.3

Table 15 Tha Tum (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31.1	17.6	87	45	1.4	3.2
2	33.6	20.3	84	42	1.4	3.8
3	35.6	23	82	43	1.3	4.4
4	36.6	25.1	84	45	1.3	4.6
5	34.9	25.1	89	55	1.3	4.3
6	33.7	25.1	90	60	1.6	4.1
7	33	24.8	91	63	1.6	3.9
8	32.3	24.6	92	66	1.5	3.7
9	31.8	24.2	94	68	0.9	3.5
10	31.2	23.2	91	63	1.6	3.3
11	30.7	20.7	88	54	2.4	3.2
12	29.9	17.8	87	49	2.3	3.1

Table 16 Nang Rong (Thailand) - monthly data: January – December.

Month	Tmax Co	Tmin Co	RHmax %	RHmin %	u(x) knot	ETo mm/day
1	31.2	17.5	90	44	1.5	3.3
2	33.9	20.1	88	41	1.4	3.9
3	35.7	22.4	88	43	1.3	4.5
4	36.4	24.1	90	46	1.3	4.7
5	34.8	24.5	92	55	1.3	4.4
6	34.1	24.5	92	57	1.5	4.2
7	33.5	24.2	93	59	1.5	4.1
8	33	24	94	61	1.5	4
9	32.1	23.7	96	66	1.2	3.6
10	30.9	23	95	64	1.9	3.3
11	30.2	20.5	91	55	2.6	3.2
12	29.6	17.6	90	48	2.4	3.2

ETc in Table17 can be calculated from Kc in Table 7 and ETo in Tables 8 to 16. The results of the calculation of *Ih* are shown in Table 19.

Table 17 Water demand of the rubber (ETc) monthly data: January - December (mm/day).

Station_name	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec_
Kosum Phisai*	2.1	3.4	5.2	6.6	7.2	5.7	5.2	3.8	2.3	1.8	1.7	1.7
Chaiyaphum*	2.0	3.3	5.1	6.5	6.7	5.4	4.9	3.6	2.3	1.7	1.7	1.6
Roi Et*	2.1	3.3	5.0	6.3	6.7	5.3	4.8	3.4	2.1	1.7	1.7	1.6
Ubon Ratchathani*	2.5	3.9	5.8	7.0	7.3	5.7	5.0	3.7	2.3	2.0	2.1	2.1
Nakhon Ratchasima*	2.1	3.3	5.1	6.5	7.0	5.7	5.2	3.8	2.3	1.7	1.6	1.6
Chok Chai*	2.1	3.4	5.1	6.3	6.7	5.5	5.0	3.8	2.3	1.7	1.6	1.6
Surin*	2.2	3.4	5.2	6.5	6.9	5.4	4.8	3.6	2.2	1.7	1.8	1.7
Tha Tum*	2.1	3.3	5.0	6.2	6.7	5.3	4.7	3.4	2.2	1.7	1.7	1.6
Nang Rong*	2.1	3.4	5.1	6.3	6.9	5.4	4.9	3.7	2.3	1.7	1.7	1.7

Table 18 Monthly rainfall data: January - December (mm).

Station_name	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec_	Sum
Kosum Phisai*	3.5	15	51.8	89	161.5	177.8	160	231.9	240.6	111.4	18.1	3.1	1264
Chaiyaphum*	4.5	14.3	51.3	92.6	140.2	137.6	110.4	196.2	230	137	19	4.1	1137
Roi Et*	3.6	19.2	41.2	75.9	186.1	223.5	195.9	252.2	219.8	107.3	15.2	2.1	1342
Ubon Ratchathani*	2	15.4	30.5	86.8	208.6	240.2	254.4	303.3	293.8	123.1	22.6	1	1582
Nakhon Ratchasima*	8.2	16.1	37.1	72.2	154.1	104.5	120.9	157.2	228.3	146.3	23.9	2.7	1072
Chok Chai*	4	14.8	37.5	81.3	149	107.3	118.9	153.5	211.6	164.3	29.4	3.2	1075
Surin*	5.6	11.5	45.6	93.3	179.8	204.7	221.3	256.2	255.4	128.2	28.7	1.9	1432
Tha Tum*	5.1	16.1	44.2	86.7	172.3	206.1	218.2	227.9	263	126.3	21	1	1388
Nang Rong*	4.7	19.6	47.9	81.6	166.6	129.7	148	181.7	239.6	133.9	37.2	3.4	1194

Table 19 Drought in different months (* is Ih<0.5 : drought).

Station_name	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec_	Sum_Ih<0.5
Kosum Phisai*	0.05*	0.16*	0.32*	0.45*	0.73	1.04	1.00	1.96	3.44	1.97	0.35*	0.06*	6
Chaiyaphum*	0.07*	0.16*	0.33*	0.48*	0.67	0.85	0.72	1.74	3.38	2.58	0.38*	0.08*	6
Roi Et*	0.06*	0.21*	0.27*	0.40*	0.89	1.41	1.32	2.36	3.42	2.02	0.30*	0.04*	6
Ubon Ratchathani*	0.03*	0.14*	0.17*	0.41*	0.92	1.41	1.63	2.63	4.20	2.01	0.36*	0.02*	6
Nakhon Ratchasima*	0.13*	0.18*	0.24*	0.37*	0.71	0.61	0.76	1.33	3.26	2.75	0.49*	0.06*	6
Chok Chai*	0.06*	0.16*	0.24*	0.43*	0.72	0.64	0.76	1.30	3.11	3.19	0.61	0.07*	5
Surin*	0.08*	0.12*	0.28*	0.48*	0.84	1.26	1.49	2.28	3.86	2.41	0.54	0.04*	5
Tha Tum*	0.08*	0.18*	0.29*	0.47*	0.83	1.30	1.50	2.14	3.98	2.37	0.42*	0.02*	6
Nang Rong*	0.07*	0.21*	0.30*	0.43*	0.78	0.80	0.97	1.58	3.52	2.52	0.75	0.07*	5

APPENDIX E

INTERVIEW

แบบสอบถามเพื่อการวิจัย
ด้านการบริหารจัดการสวนยางพารา

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คำชี้แจง: แบบสอบถามนี้จัดทำขึ้นเพื่อใช้เก็บรวบรวมข้อมูลการวิจัยเกี่ยวกับ การดูแลจัดการสวนยางพาราของเกษตรกร ที่ส่งผลต่อการให้ผลผลิต

1. ชื่อ-นามสกุล **นาย บุญมา ฉัตรรัมย์**
2. ตำแหน่งปลูกยาง • หมู่บ้าน 8 ตำบล **ร่อนทอง** อำเภอ **สตึก** จังหวัด **บุรีรัมย์**
3. พันธุ์ยางที่ปลูก • RRIM600 จำนวน..................(ไร่)....................(ต้น), เปิดกรีดแล้ว....................(ต้น)
   • RRIT251 จำนวน.................. (ไร่)....................(ต้น), เปิดกรีดแล้ว...................(ต้น)
   • อื่นๆ................ จำนวน.................ไร่.................ต้น, เปิดกรีดแล้ว....................(ต้น)
4. การเจริญเติบโต • อายุต้นยางปัจจุบัน.............(ปี) • ขนาดเส้นรอบลำต้นปัจจุบัน..................ซ.ม.
   • ต้นยางโตได้ขนาดรอบลำต้น 50(ซ.ม.)เมื่อ.............. (ปี) (วัดสูงจากพื้นดิน 1.50 เมตร)
5. ผลผลิตโดยเฉลี่ย (พ.ศ.2556)
   • ยางแผ่น.............(กก./วัน) • น้ำยางสด..............(กก./วัน) • ยางก้อนถ้วย..............(กก./วัน)
6. จำนวนวันกรีดโดยประมาณ (พ.ศ.2556) ....(วัน)
7. ระบบการกรีดยาง
   7.1. ระบบกรีด ○1/2ลำต้น 1วัน เว้น1วัน ○1/2ลำต้น 2วัน เว้น 1วัน
   ○1/3ลำต้น 1วัน เว้น1วัน ○1/3ลำต้น 2 วัน เว้น1วัน
   7.2. เวลากรีดทั่วไป ....
8. **การดูแลต้นยาง (ช่วงอายุยาง 1-5 ปี)**
   8.1. จำนวนต้นที่ตายในแปลง ....(ต้น) ปลูกซ่อม........................... (ต้น)
   8.2. ระบบการให้น้ำในฤดูแล้ง ○ไม่มี ○มีระบบประปา ○รถบรรทุกน้ำ
   8.3. แต่งกิ่ง.............(ครั้ง/ปี)
   8.4. คลุมโคนต้นหน้าแล้ง ○คลุม ○ไม่คลุม ○บางครั้ง
   8.5. ใส่ปุ๋ย • เคมี.............(ครั้ง/ปี) ปริมาณที่ใส่............. (ก.ก./ไร่ / ครั้ง)
   • ปุ๋ยอินทรีย์.............(ครั้ง/ปี) ปริมาณที่ใส่............. (ก.ก./ไร่ / ครั้ง)
   8.6. กำจัดวัชพืช.............(ครั้ง/ปี)
9. **การดูแลต้นยาง ช่วงกรีด (ปัจจุบัน)**
   9.1. ใส่ปุ๋ย • เคมี.............(ครั้ง/ปี) ปริมาณที่ใส่............. (ก.ก./ไร่ / ครั้ง)
   • ปุ๋ยอินทรีย์.............(ครั้ง/ปี) ปริมาณที่ใส่............. (ก.ก./ไร่ / ครั้ง)
   9.2. ระบบการให้น้ำในฤดูแล้ง ○ไม่มี ○มีระบบประปา ○รถบรรทุกน้ำ

ขอกราบขอบพระคุณทุกท่าน
ทุกคำตอบของท่านจะมีคุณค่าต่องานศึกษาวิจัยทางวิชาการ
ขอให้คุณความดีนี้ส่งผลให้ท่านและครอบครัว ประสบแต่ความสุขความเจริญยิ่งขึ้นไป

APPENDIX F

PHOTOS FROM FIELD SURVEY

Figure 8 Pictures showing the plantations with high level of management.

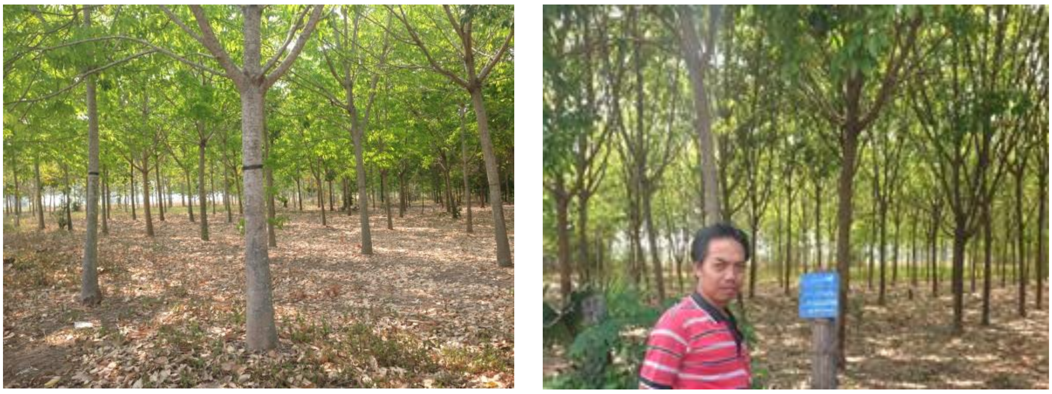

Figure 9 Pictures showing the plantations with medium level of management.

Figure 10 Pictures showing the plantations with medium level of management (continued).

Figure 11 Pictures showing the plantations with low level of management.

Figure 12 Field equipment.

Figure 13 Expert and farmer interviewing.

Figure 11 Expert and farmer interviewing (Continued).

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Publications and Presentations

Sunya Sarapirome and Tawatcharapong Wongsgoon. (2011). Land suitability assessment for rubber plantation using TOPSIS in Burirum, Thailand. In Proceedings of the 32nd Asian Conference on Remote Sensing 2011, Oct 03 -07. Taipei, Taiwan.