Land Suitability Analysis Based on Management for Rubber Plantation Using Mamdani's Fuzzy Inference System

Wongsagoon, T.,[1] Sarapirome, S.[2] and Pratummintra, S.[3]
School of Remote Sensing, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand, E-mail :tawatcharapong@gmail.com,[1] sunyas@g.sut.ac.th,[2] and spratummin@yahoo.com[3]

Abstract
Thailand is the world's largest natural rubber producer and exporter. The most important factor in gaining higher productivity is plantation management. This research, therefore, aims to use Mamdani's fuzzy inference system (FIS) to evaluate land suitability based on rubber plantations in Nakhon Ratchasima and Buriram provinces. The system is comprised by developing fuzzy membership functions of criteria, estimating criterion group indexes of soil physical and chemical properties, climate, and plantation management, establishing and applying fuzzy rules to agglomerating fuzzy classes of indexes and air-dried rubber sheet productivity, and defuzzifying to attain crisp productivity and generate land suitability maps of different management levels. The agglomeration was raster-based analysis using GIS facilities. The study proved that the productivity was strongly dependent on the levels of plantation management. Higher application levels resulted in higher yields. The study was validated by the use of 30 samples, the relationship of modeled results and observed data was about 1:1 and the RMSE was 25.67 kg/rai/year.

1. Introduction

The rubber plantation that provides a high yield consists of 3 main factors: rubber clones, environment, and plantation management (*Ma*). Normally, farmers should select varieties of rubbers and *Ma* methods appropriately as recommended by the Department of Agriculture (DOA, 2012). The environment is considered as limitations varying on nature of each area. Nevertheless, according to the survey, the relationship that can affect the yield is more influenced by the relationship between the environment of the cultivated area and the *Ma* of farmer. In the past, suitable area for rubber plantation was mapped based on only physical factors without considering the level of *Ma* due to its difficulty on evaluation. In practice, this led to the presence of conflicts. For example, some areas with poor physical factors but high *Ma* possibly provided higher yield. The better management of course provides the higher yield.

Furthermore, in land suitability analysis (*LSA*), Multi-Criteria Decision Analysis (*MCDA*) such as Sieve Analysis, Multiplication, Simple Additive Weighting (*SAW*), Analytical Hierarchy Processing (*AHP*), etc. was widely used. These methods are related to weight and score evaluation of criteria (Malczewski, 1999 and_Prakash, 2003). The classification could cause loss of accuracy in the interface between suitability classes (Baskoro, 2008). Besides, weighting and scoring each criterion was so often difficult and subjective (Qiu et al., 2013) that could cause difficulties on interpretation and decision making in the real world. For example, in case that specified suitable mean annual rainfall for rubber cultivation was 1,350-2,500 mm, if the rainfall of most areas was 1,349 mm, it would immediately evaluate the area into an unsuitable class although rainfall 1,350 and 1,349 mm were virtually the same. Plus, characteristics of spatial data and their distributions as criteria for the analysis are actually not completely deterministic or stable as well.

To solve the problem mentioned above, the study aims to operate *MCDA* for mapping suitable land for rubber plantation using Mamdani's *FIS* (Mamdani and Assilian, 1975) which is the method that can be properly applied to scoring and agglomerating vague and uncertain spatial data such as soil properties, climate, and topography affecting crop requirement (Prasetyo et al., 2012, Ranst et al., 1996, Keshavarzi et al., 2010, Reshmidevi et al., 2009, Baskoro, 2008, Jiang and Eastman, 2000 and McBratney and Odeh, 1997). For more practical achievement, *Ma* as a group of criteria was also added to incorporate with physical criteria in the system. Nakhon Ratchasima and Buriram Province in the northeastern Thailand (Figure 1), where in the historic record had low potential for rubber plantation, were chosen for this study.

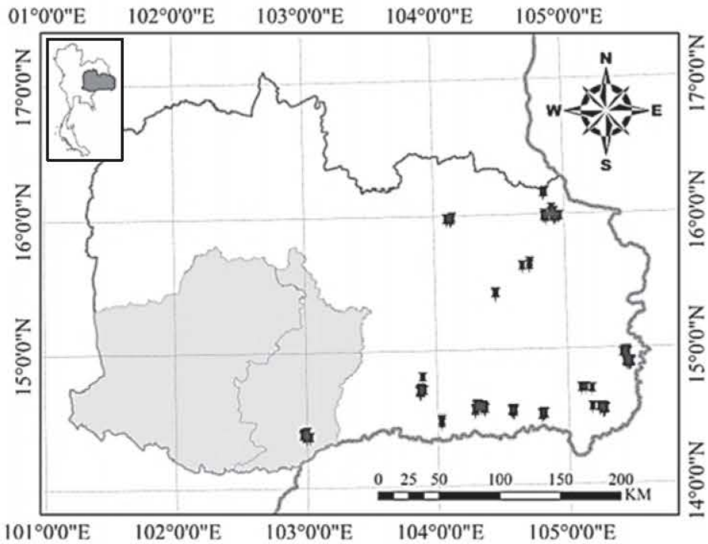


Figure 1: Study area and sampling locations

Table 1: Crop requirements (modified after Saichai et al., (2012), Pratummintra (2000) and DOA, (2012))

1. Soil conditions	Unit	L	Op	U
a) Physical properties (*Kp*)				
- Soil structure				
a) %sand	%	14	35-70	100
b) %clay	%	14	30-65	86
- 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	L	Op	U
- 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°	15	24-28	38
- Wind speed	m/s	0	0-1	3

Note:
L: Lower critical, Op: Optimum, U: Upper critical
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.

2. Material and Methods

The study procedure can be generalized by applying Mamdani's *FIS* to land suitability assessment for rubber plantation as a flow chart shown in Figure 2.

Processes of the system for *LSA* consist of calculating maps of criteria to find fuzzy membership values (*FMV*) of raster cells using developed fuzzy membership functions (*FMF*) of each spatial criterion, combining criteria and converting to be fuzzy linguistic classes (*FLC*) for groups of criteria, establishing fuzzy rules (*FR*) from field samples, applying them to raster cells, and then defuzzifying result to be crisp rubber productivity (in term of air-dried rubber sheet (ADS)) indicating land suitability in different levels of management. The operations are raster-based analysis using facilities of ArcMap™.

2.1 Criteria Data Collection

The accuracy of agricultural land evaluation depends on the significance of the chosen land qualities with respect to their effects on crop production. The crop requirement for rubber plantation in this study was gathered from the studies of Saichai et al.,)2000(and DOA) 2012 (and shown in Table 1 .Groups of criteria for *LSA* could be extracted from the table to be soil physical and chemical properties, and climate factors .

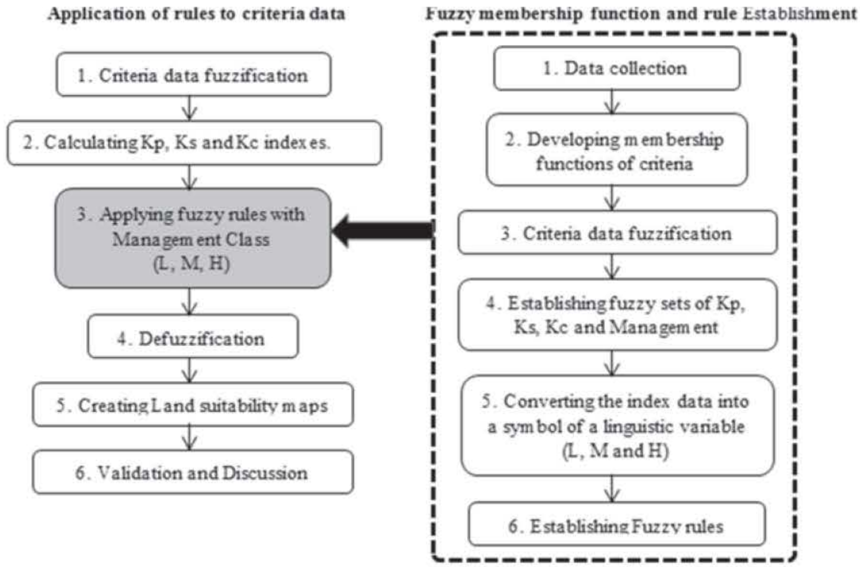


Figure 2: Flow chart of the research procedure

Table 2: Scoring membership values of management factors in rubber plantations

Management Factors	Scoring Criteria				
	0.1	0.3	0.5	0.8	1.0
1. Dry Season	-	-	Rain	Rain and sometimes watering	Good source of watering
M. Pruning	No	1 times/year	2 times/yr	3 times/yr	Always
3. 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 Based on DOA
- Quantity	-	Uncertainly	-	-	
4. Weeding	No	Sometimes	2 times/yr	>2 times/yr	Always
5. Cover crops	No	-	Sometimes	-	Yes
6. 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 in 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 in two days;
S/2 d3 is a half- spiral cut with a tapping frequency of once in three days.

Plant management was added to fulfil a list of criteria influencing land suitability assessment. Then, data samples used to establish *FR* of Mamdani's *FIS* were collected on location basis. The sampling locations were limited on availability and distribution of existing rubber plantation plots in the lower northeastern region where sharing the common geographic and geologic characteristics with the study area.

Physical properties of any sampling location such as soil texture, effective soil depth, soil slope, soil drainage and flood period and chemical properties such as N ,P, K, pH and saline soil were extracted from soil series map and information of the Land Development Department (LDD))2002 .(Climate factors such as average annual rainfall, dry season duration, losses of tapping days) as indicated by the vapor pressure deficit (*VPD*)(, temperature regime and wind speed of a sampling location were gathered from The Thai Meteorological Department (TMD). *Ma*, the most important criterion that can influence a degree of successful planting as shown in Table 2, was collected by interviewing owners of the rubber plots.

The *Ma* covers proper practice and frequency with good timing of replacement planting, pruning, maintenance during dry season, fertilizing, weeding removal, planting legume cover crops, and rubber taping to obtain the best amount of *ADS*.

2.2 Developing Fuzzy Membership Function (FMF)

In this study, the shapes of the *FMF* were selected based on characteristics of criteria data. For example, *FMF* in form of trapezoidal was applied to suitable pH which appears in range while monotonically increasing form was applied to organic matter which appears only lower limit. Some criteria with qualitative characteristics and apparent in descriptive class such as soil depth and soil drainage were scored from 0 to 1 for each class.

Scoring membership values for *Ma* was designed based on proper practice and its frequency of implementation. The higher score indicates better management of a certain activity. The scoring of rubber tapping is referred to the DOA (2012) who introduces only the systems that can provide satisfied amount of *ADS*. The lowest score is therefore not less than 0.5 as shown in Table 2.

However, too many criteria for suitability assessment can cause excessive difficulty on *FR* establishment .To reduce a number of criteria, they were set to be 4 groups of soil physical properties (*Kp*), soil chemical properties (*Ks*), climate factors (*Kc*), and management (*Ma*). Scores or fuzzy membership values (*FMV*) of criteria in every group were combined as a criterion group index using Stories's method which Verheye,)2009 (suggested to be the best known method for rating the quality of the land .The method is described by the following Equation 1, where *R* is a percentage of the suitability of the factors used in the assessment and *n* is a number of factors .The number of multiplications of factors is *n-1*.

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

Equation 1

To apply Mamdani's *FIS* successfully, *FLC* of criterion group indexes and *ADS* (in the third year of tapping) were required. From collected samples, the maximum, average, and minimum values of them were estimated to generate functions converting them to be classes of *L* (low), *M* (medium), and *H* (high) for further *FR* establishment.

2.3 Fuzzy Rule Establishment

Table 3(a) shows an example of establishing if-then *FR* .In this case, '*x1*', '*x2*', and '*x3* 'are input of criteria in terms of *FLC* suitability while '*y* 'is *ADS* as output in *FLC* rubber product .There are some duplicate sets in the same fuzzy rules of data collected which were finally collapsed to be a set for a rule)Table 3(b)). A number of duplicated sets for each rule is expressed as a count number of that rule.

2.4 Criteria Agglomeration Using Decision Rules

For a given cell in a map of criterion group, it can fall into more than one established *FR* if only a group of its fall into more than one *FLC*. Agglomeration of criterion classes in a rule is performed using 'minimum' or 'intersect' operator while 'maximum' or 'union' operator is used for agglomeration of all *FR*. Figure 3 displays the agglomerations of each *FR* and all *FR*. *A1, A2 and B1, B2* are *FLC* of input criteria *A* and *B*, respectively. *C1* and *C2* are *FLC* of output criterion *C*. The μ is fuzzy membership of each criterion. x_0 and y_0 are input variables of criteria *A* and *B* of a given cell. A criterion herein can be any group of criteria in the study. The process results in aggregated set of classes which requires further defuzzification. In the study *A* and *B* were groups of criteria (*Kp*, *Ks*, *Kc*, and *Ma*) and criterion *C* was *ADS*.

Table 3: Data in fuzzy sets from collected samples (a) and created rules (b).

(a)

	R1	R2	R2	R2	R2	R3	R3	R3	R3	R4	R5	R6	R6	R6	R6
x1	L	M	M	M	M	L	L	L	L	M	M	L	L	L	L
x2	L	L	L	L	L	M	M	M	M	M	H	H	H	H	H
x3	L	L	L	L	L	M	M	M	M	M	H	H	H	H	H
y	L	L	L	L	L	M	M	M	M	M	H	H	H	H	H

(b)

	R1	R2	R3	R4	R5	R6
x1	L	M	L	M	M	L
x2	L	L	M	M	H	H
x3	L	L	M	M	H	H
y	L	L	M	M	H	H
Count	1	4	4	1	1	4

Note: "*L*" is "Low", "*M*" is "Medium" and "*H*" is "High".

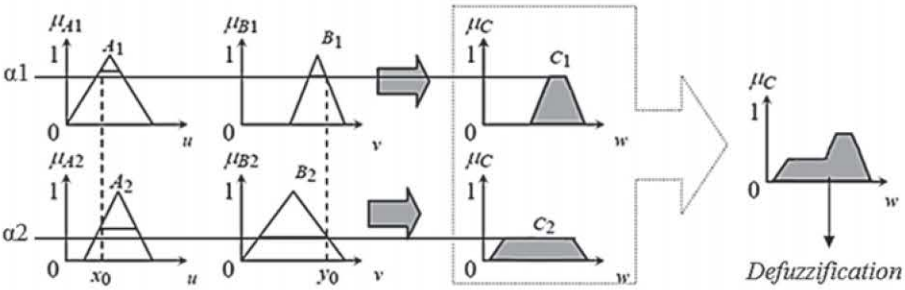


Figure 3: Agglomeration of criteria fuzzy classes of rules (Phayung Meesad, 2013)

2.5 Defuzzification of ADS

The last step in the fuzzy inference process is defuzzification of aggregated set of *ADS*. The final output of the fuzzy system has to be a crisp value of *ADS*. The weighted average (*WA*) method is a defuzzification that was used by finding a point where a vertical line slices the aggregate set into two equal masses. It is given by the algebraic expression as:

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

Equation 2

where Σ denotes the algebraic sum and Z_i is the centroid of each symmetric *FMF*.

2.6 Validation

To validate the results, the Root Mean Square Error (*RMSE*) is used to distinguish between the results of *ADS* analyzed by Mamdani's *FIS* and the 30 samples of actual data collected from the fields with corresponding locations. If *RMSE* is close to 0, the yield predicted by the system is close to the yield actually observed. The individual differences are also called residuals, and the *RMSE* is served to aggregate and average them to be a single measure of predictive power using Equation 3.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obsi} - X_{modi})^2}{n}}$$

Equation 3

The *RMSE* of a model prediction is defined as the square root of the mean squared error where X_{obs} is observed *ADS* and X_{mod} is *ADS* predicted at time *i*, *n* is a number of samples. The coefficient of determination, R^2, is estimated from the relationship of 30 samples of observed and modeled *ADS*s. The graphic presentation can tell whether the prediction is over or under estimation when they are compared. The R^2 presents a better prediction when its value is closer to 1. It measures how predictable or correctable one variable is, comparing to other variables. R^2 can be estimated by using Equation 4.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(X_{obs,i} - X_{mod,i}\right)^2}{\sum_{i=1}^{n}\left(X_{obs,i} - \overline{X}_{mod,i}\right)^2}$$

Equation 4

where X_{obs} is observed *ADS* and X_{mod} is modeled *ADS*, *n* is a number of samples, and $\overline{X}_{mod}$ is an average of observed *ADS*.

3. Result and Discussion

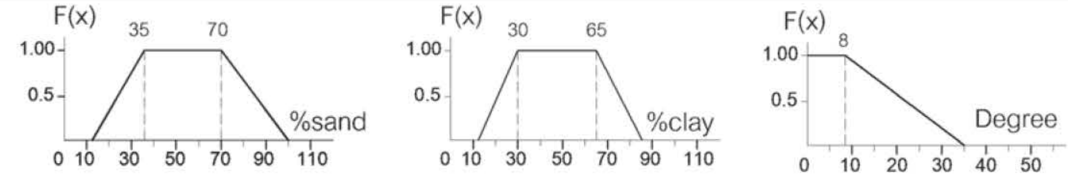
3.1 Sampling Locations

The system rules were established based on the collected field data. Difficulty of field data collection on *ADS* productivity and plantation management really occurred due to less systematic records of farmers together with availability and distribution limitations of existing rubber plots in the study area and the region. Therefore, the sampling locations could not be confined only in the study area but extending to the rest of the region where having the same geographic and geologic characteristics. Nonetheless, to achieve the goal of this research, after serious screening, 150 samples were able to be collected for simulating a model and 30 samples for result validation. The sample locations are displayed in Figure 1.

3.2 Developed Membership Functions

The *FMF* used to calculate the *FMV* of criteria of *Kp*, *Ks*, and *Kc* were defined as shown in Figures 4(a)-4(c). The higher *FMV* of any criterion indicates the more suitability for rubber plantation of the land. Table 2 shows a list of management factors and scoring of their *FMV*. Summation of all factor scores in a sample location represents the membership value of the *Ma*.

(a)



[14, 35, 70, 100] a) *FMF* of % sand

[14, 30, 65, 86] b) *FMF* of % clay

[0, 0, 8, 35] c) *FMF* of soil slope

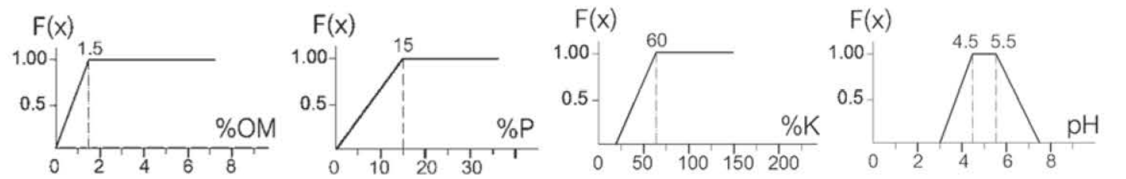
Effective soil depth	Very deep, Deep	Moderately deep	Shallow, Very shallow
	1.0	0.5	0

d) Membership values of soil depth properties

Soil drainage	Well	Moderately	Somewhat Poorly	Poorly	Very poorly
	1.0	0.95	0.85	0.6	0.45

e) Membership values of soil drainage

(b)



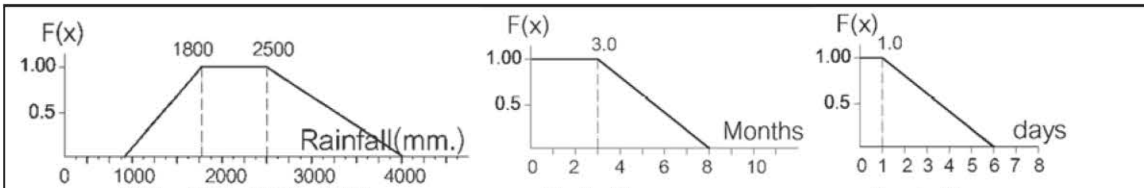
[0, >1.5] a) *FMF* of OM

[0, >15] b) *FMF* of P

[0, >60] c) *FMF* of K

[3, 4.5, 5.5, 7.5] d) *FMF* of pH

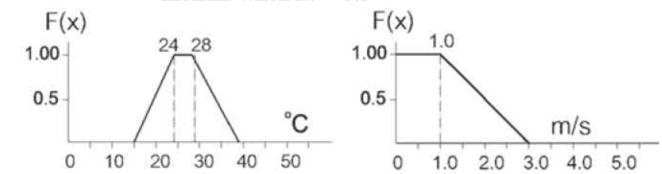
(c)



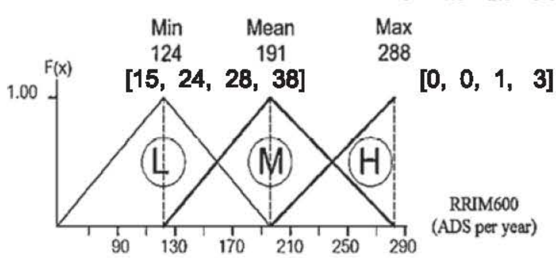
[900, 1800, 2500, 4000] a) *FMF* of average annual rainfalls

[0, 3, 8] b) *FMF* of the number of months when $Ih < 0.5$

[0, 1, 6] c) *FMF* of the number of months when $VPD > 11$mbar

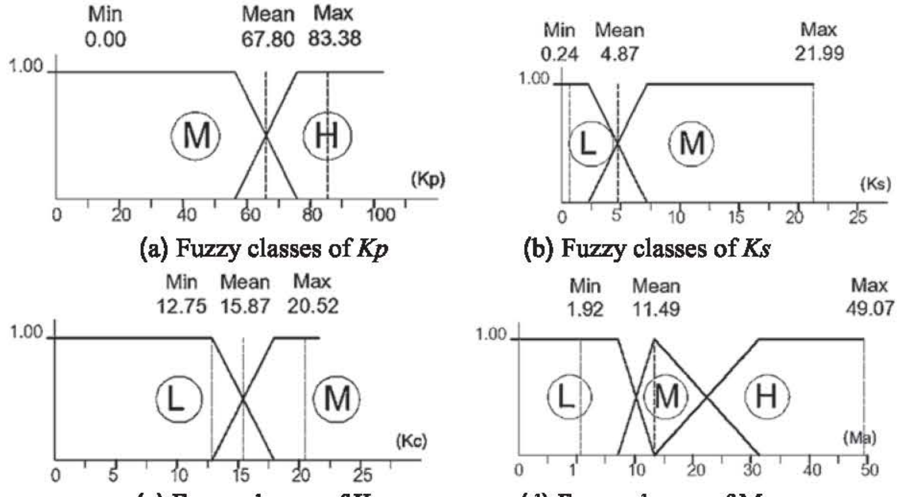


[15, 24, 28, 38] [0, 0, 1, 3]



d) *FMF* of average temperatures e) *FMF* of average wind speed f) fuzzy classes of *ADS* productivity

Figure 4: Membership functions of (a) soil physical properties (*Kp*), (b) soil chemical properties (*Ks*), (c) soil climate factors (*Kc*), and fuzzy classes of *ADS* productivity



(a) Fuzzy classes of *Kp* (b) Fuzzy classes of *Ks* (c) Fuzzy classes of Kc (d) Fuzzy classes of Ma

Figure 5: Fuzzy classes of *Kp*, *Ks*, *Kc* and *Ma*

Table 4: Selected rules for *ADS* analysis of rubber plantation management

	Rubber Plantation Management																	
	Low						Medium						High					
	Kp	*Ks*	*Kc*	*Ma*	*ADS*	*Count*	*Kp*	*Ks*	*Kc*	*Ma*	*ADS*	*Count*	*Kp*	*Ks*	*Kc*	*Ma*	*ADS*	*Count*
1	H	L	L	L	M	25	H	L	L	M	M	12	H	L	L	H	H	3
2	H	L	M	L	M	6	H	L	M	M	M	13	H	L	M	H	H	5
3	H	M	L	L	M	2	H	M	L	M	H	3	H	M	L	H	H*	-
4	H	M	M	L	M	3	H	M	M	M	H	4	H	M	M	H	H	2
5	M	L	L	L	L	8	M	L	L	M	M	9	M	L	L	H	M	2
6	M	L	M	L	L	7	M	L	M	M	M	6	M	L	M	H	M	3
7	M	M	L	L	L*	-	M	M	L	M	M	4	M	M	L	H	M*	-
8	M	M	M	L	L	1	M	M	M	M	M	2	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.

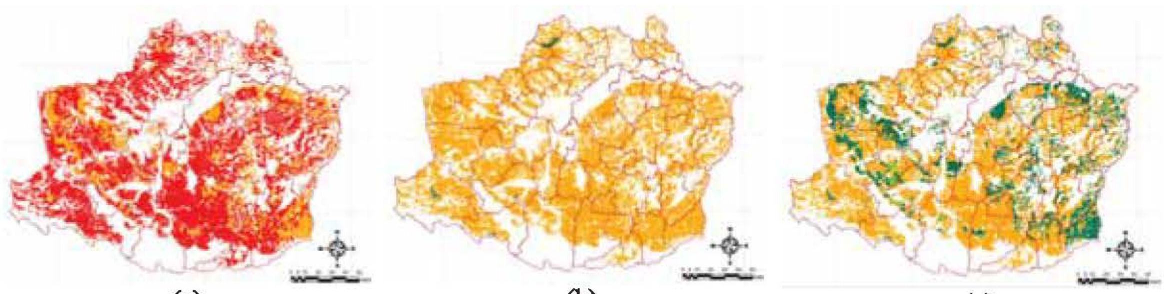
3.3 Established Fuzzy Rules

Regarding to the field data, the maximum, average, and minimum yields of *ADS* were 288, 191 and 124 kg/rai/year respectively and used to determine the *FLC*s or classes of the *ADS* as shown in Figure 4(c). The *FMV* of each criterion was calculated using a corresponding function mentioned above and then combined by Storie's method to obtain *Kp*, *Ks*, *Kc* and *Ma*. Their minimum, mean, and maximum values are 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. They were used to determine *FLC*s of those groups of criteria as results shown in Figure 5.

From 150 samples, *FR*s were established based on frequency and shown in Table 4. According to the concept of Mamdani's *FIS*, in a rule one set of *FLC*s of *Kp*, *Ks*, *Kc*, and *Ma* can finally have only one class of *ADS*. Practically, some sets of *FLC*s of *Kp*, *Ks*, *Kc*, and *Ma* from the sample analysis could have more than one class of *ADS*. Therefore, in a rule, sets having *ADS* classes with lower frequency were declined to meet the requirement of the concept. Only the majority of *ADS* class for each certain set was selected to be in a rule. This finally reduced a number of valid samples to be 121.

3.4 Land Suitability Maps Based on 3 Scenarios of Ma

Established *FR* of Mamdani's FIS were applied to generating a set of raster-based *ADS* productivity maps of Buriram and Nakhon Ratchasima on the basis of 3 scenarios (low, medium, and high) of *Ma*. Cells in maps contain *ADS* productivity per year. To demonstrate the land suitability for rubber production, *ADS* productivity was divided into 3 classes. Areas of *ADS* yields between 250-300 Kg/rai/yr were high suitable (*S1*), 200-<250 Kg/rai/yr for medium suitable (*S2*), and 150-<200 Kg/rai/yr for low suitable (*S3*) and *N* for a nonsuitable, as results shown in Figure 6. *N* covers areas of saline soil, wetland/flood plain, urban, and governmental reservation including area with *ADS* less than 150 Kg/rai/yr (*S4*). *S4* exists only when low level of management was applied. With low management level, the study area totally falls into *S3*, *S4*, and *N* classes. When high and medium levels of management were applied, *S3* area was reduced, *S1* was increased while *S2* having less positive effect. It confirms that *Ma* is very important. When the higher management level is chosen, the area is able to immediately transform from *S3* to *S1*.



(a) (b) (c)

Suitability Levels (kg/rai/yr)	Management Levels		
	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:
- *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 6: *ADS* product based on (a) low management, (b) medium management, and (c) high management

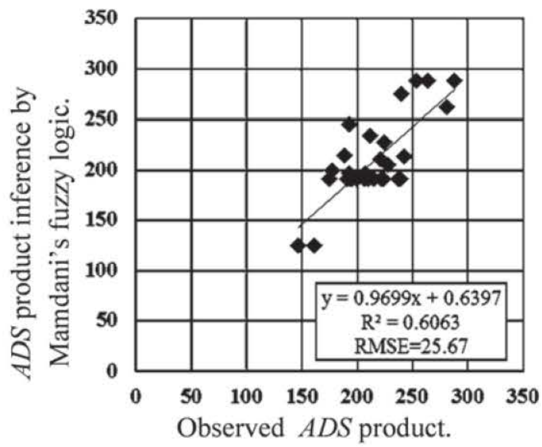


Figure 7: The comparison of 30 *ADS* samples from observation and Mamdani's *FIS*

3.5 Validated Result

To validate the results, comparison of modeled and observed *ADSs* from 30 samples at the same locations (Table 5) was performed. The *RMSE* of samples was 25.67 Kg/rai/yr. The graphic relationship of these 2 variables was a linear (Figure 7). The relationship was very close to 1:1. It means that over or under estimation correction is not necessary for the modeled result. It can directly incorporate with *RMSE* to provide the approximate range of *ADS*. For example, if the modeled *ADS* is 200 kg/rai/yr, the range of *ADS* will be 200±25.67 kg/rai/yr. The R^2 of this relationship was 0.6063 and indicates fairly acceptable relationship.

4. Conclusion

The study confirmed that Mamdani's *FIS* was well operative and acceptable for *LSA* of rubber plantation, particularly when dealing with uncertain spatial data. The results approve that the yield of rubber plantation is strongly related to the level of *Ma*. If the *Ma* recommended by the DOA is performed, the yield can be higher.

Table 5: Observed and modeled *ADS* productivity for validation

Sample no.	UTM zone 48 X	Y	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
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

$R^2 = 0.6063$
RMSE = 25.67

However, to obtain equal product, the plantation on area with higher suitability of soil physical and chemical properties spends lower cost of the management than the plantation on area with lower suitability. Therefore, in a future study, the cost of *Ma* 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 considering which suitability class of the land fit to the cost of which management level. In addition, to serve the policy which requires more plantation area, the area becomes more suitable when higher level or higher cost of management is applied. 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.

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