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Generalized Estimating Equations Models for Rubber Yields in Thailand

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Abstract

The objectives of this research are to estimate the monthly rubber yield in each province of Thailand, to investigate factors related to the rubber yields, and to draw the maps of rubber yields. A generalized estimating equation model (GEE) is used. The estimated rubber yields are used to draw the rubber yield maps. The rubber yields were extracted from the database of the Office of the Agricultural Economics Ministry of Agriculture and Cooperatives (OAE) and the climatic factors were extracted from the Thai Meteorological Department. The dependent variables are the monthly rubber yields. The factors considered are rainfall, averaged temperatures, seasons, and regions. The results reveal that the factors related to the rubber yields are, averaged temperature, regions, and seasons. The amounts of regional effects on the rubber yields, ranking from largest to smallest values, are southern region, eastern region, northeastern region, and central region, respectively, where western region and northern region have no regional effect. The amounts of seasonal effects on the rubber yields, ranking from largest to smallest values, are Aug-Oct, May-July, Nov-Jan, and Feb-Apr. The top ten provinces with high rubber yields, ranking from largest to smallest values, are Surat Thani in August ((16,597.34 ton), Yala in September (16,572.57 ton), Phatthalung in August (16,553.09 ton), Songkhla in August (16,537.12 to (, Chumphon in September (16,477.23 ton), Yala in August (16,458.35 ton), Phatthalung in September (16,418.09 ton), Pattani in August (16,400.21 ton) , Pattani in September (16,382.76 ton) , Nakhon Si Thammarat in August (16,364.22 ton) , respectively. The rubber yields maps are easy for readers to identify which areas have high or low yields. They are useful for rubber planning production.

Keywords: Generalized Estimating Equations (GEE), Rubber Yields, Rubber Yield Mapping.

INTRODUCTION

Rubber is an essential resource. It is required in the manufacturing of many industrial and consumer products, such as tires, gloves, elastics, and hoses. Thailand has become the world's foremost producer and exporter of high-quality rubber, accounting for 40% of global rubber production, exporting $13 billion (USD) worth each year. Its five key markets are China, neighboring Malaysia, Japan, the EU, and the US. And while plantations cover 3 million hectares of land, 95% of them belong to small landowners (TCEB, 2016). Monthly rubber yields in each province of Thailand are reported every year via the website of Office of the Agricultural Economics Ministry of Agriculture and Cooperatives (OAE, 2016). The reports are in the form of tables and graphs. Those data reports motivated us to do this research. They will be more informative if those reported data are deeply analyzed. We can see factors associated with those rubber yields or the distribution of the rubber yields in each area. Since the reported data can be treated as repeated data. One of the most powerful statistical model for repeated measures is a Generalized Estimating Equation (GEE), which was first introduced by Liang and Zeger (1986).

The generalized estimating equations (GEEs) methodology enables you to analyze correlated data that otherwise could be modeled as a generalized linear model. GEEs have become an important strategy in the analysis of correlated data. These data sets can arise from longitudinal studies, in which subjects are measured at different points in time, or from clustering, in which measurements are taken on subjects who share a common characteristic, such as belonging to the same litter (SAS, 2014). Umar et al. (2017) indicated that climatic factors which were rainfall, maximum and minimum temperature impacted on Latex yield of hevea brasiliensis. Golbon et al. (2015) used mixed models and multi-model inference techniques for rubber yield prediction by meteorological conditions. Li et al. (2014) found that temperature, precipitation and solar radiation were the three major climatic factors affecting latex yield. Zhang et al. (2014) presented that average temperature, rainfall, sunshine duration, relative humidity and ground temperature were factors on latex yield. Akpan et al. (2007) studied latex yield of rubber as influenced by clone planted and locations with varying fertility status. Li et al. (2014) reviewed influencing factors on latex yield of Hevea brasiliensis. Mesike and Esekhade (2014) studied rainfall variability and rubber production in Nigeria. Since the GEE has never been used before for an analysis of the rubber yields, it is adopted in this research. The monthly rubber yields from OAE (2014) are assumed to have a normal distribution. The associated factors considered include rainfall, average temperature from TMD (2016), region (central, north, north-east, east, south and west), season (Nov -

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Jan, May – July, Oct - Nov and Feb - May). The results of this study are useful for planning to increase the rubber production.

METHOD

The GEE model is the model used for the variables according to the observed values correlated. Let $Y_{ij}, j=1,...,n_i$, $i=1,...,M$, represent the observation value of unit i at time j and N denote the total number of observations, $N=\sum_{i=1}^{K} n_i$. Y_{ij} is related to the initial variable $\mathbf{X}_{ij}=(1,X_{ij.1},...,X_{ij.p})^T$ and the parameter $\boldsymbol{\beta}=(\beta_0,\beta_1,...,\beta_p)^T$ according to the following link functions, identity link: $g(a)=a$, natural log link: $g(a)=\log(a)$, logit link: $g(a)=\text{logit}(a)=\log(a/(1-a))$. The relationship between Y_{ij} and $\mathbf{X}_{ij}=(1,X_{ij.1},...,X_{ij.p})^T$ is expressed as $g(E(Y_{ij}\mid\mathbf{x}_{ij}))=g(\mu_{ij})=\mathbf{x}_{ij}{}^T\boldsymbol{\beta}$ which is the marginal regression model. The covariance Matrix of $\mathbf{Y}_i=(Y_{i1},...,Y_{ij})^T$ is $\mathbf{V}_i=\phi\mathbf{A}_i{}^{1/2}\mathbf{R}(\rho)\mathbf{A}_i{}^{1/2}$. When ϕ is dispersion parameter, $\mathbf{A}_i$ is Diagonal matrix of a variance function and $\mathbf{R}(\rho)$ is correlation matrix. The correlation matrix shows the pattern of data relations of $\mathbf{Y}_i=(Y_{i1},...,Y_{ij})^T$, which has the following forms.

Exchangeable structure:

$$\mathbf{R}(\rho)=\begin{bmatrix}1 & \rho & \cdots & \rho\\ \rho & 1 & \cdots & \rho\\ \vdots & \vdots & \ddots & \vdots\\ \rho & \rho & \cdots & 1\end{bmatrix},$$

First-order autoregressive (AR(1)) structure:

$$\mathbf{R}(\rho)=\begin{bmatrix}1 & \rho & \cdots & \rho^{j-1}\\ \rho & 1 & \cdots & \rho^{j-2}\\ \vdots & \vdots & \ddots & \vdots\\ \rho^{j-1} & \rho^{j-2} & \cdots & 1\end{bmatrix},$$

Unstructured structure:

$$\mathbf{R}(\rho)=\begin{bmatrix}1 & \rho_{12} & \cdots & \rho_{1j}\\ \rho_{21} & 1 & \cdots & \rho_{2j}\\ \vdots & \vdots & \ddots & \vdots\\ \rho_{j1} & \rho_{j2} & \cdots & 1\end{bmatrix}.$$

For the estimation of the parameter $\boldsymbol{\beta}$, the Quasi-likelihood is usually used. The estimates are from the Quasi-likelihood equations, which are called generalized estimating equations (GEE). For finding the solutions of that equation, the numerical iterators are applied. The function of $\boldsymbol{\beta}$ is represented as

$$U(\boldsymbol{\beta})=\sum\mathbf{D}_i{}^T\mathbf{V}_i^{-1}(\mathbf{Y}_i-\boldsymbol{\mu}_i)=\mathbf{0},$$

$$\mathbf{D}_i=\frac{\partial\mu_{ij}}{\partial\beta_k}, k=1,2,...,p.$$

For the model in this research, we let Y_{ij} be the number of rubber yields in province i at moth j where $i=1,...,62$ and $j=1,...,12$. In province i at moth j, $X_{ij.1}$ is rainfall (mm), $X_{ij.2}$ is temperature (degree Celsius), $X_{i.3}$ is the province in Northern region, $X_{i.4}$ is the province in Northeastern region. $X_{i.5}$ is the province in Southern region. $X_{i.6}$ is the province in eastern region. $X_{i.7}$ is the province in Western region. $X_{i.8}$ is the season from Nov to Jan. $X_{i.9}$ is the season from May to July. $X_{i.10}$ is the season from Oct to Nov. β_0 is Intercept and $\beta_1,...,\beta_{10}$ are regression coefficients of rainfall, temperature, North, Northern, South, East, West, season within No-Jan, May to July and Oct to No, respectively. Central is a reference region, and Feb to Apria is also a reference region. The correlation structure within the subject ($\mathbf{Y}_i$) resulted from repeated measures, the same as time series data, is assumed to have a first-order autoregressive form. The GEE model has the following form,

$$\begin{aligned}E(Y_i)=\mu_i=\beta_0+\beta_1X_{ij.1}+\beta_2X_{ij.2}+\beta_3X_{i.3}+\beta_4X_{i.4}+\\ \beta_5X_{i.5}+\beta_6X_{i.6}+\beta_7X_{i.7}+\beta_8X_{i.8}+\beta_9X_{i.9}\\ +\beta_{10}X_{i.10}\end{aligned}$$

The R, a statistical software, is used for parameter estimation. The significance of 0.5 is used as a criterion.

RESULTS AND DISCUSSION

The factors effecting to rubber yields are shown in Table 1. The estimated coefficients are presented in Table 2.

Table1: Factors effecting rubber yields

Source	Wald Chi-Square	Sig.
(Intercept)	13.61	<0.0001
region	53.373	<0.0001
season	20.416	<0.0001
rainfall	13.138	<0.0001
temperature	5.446	0.02

At the significance of 0.05, factors effected rubber yields are rainfall, temperature, Northeast region, Southern region, Western region, Eastern region where central region is a reference. Season in Nov to Jan, May to July, Oct to Oct where Feb to Apr is the reference.

If the rainfall increases 1 mm, the rubber yields will decrease 3.123 tons. If the temperature increases 1 Celsius, the rubber yields will decrease 169 .371 tons .Province in Northern region produces Rubber yields 913.944 tons more than provinces in central region. . Province in Southern region produces Rubber yields 15,421.437 tons more than provinces in central region. Province in Eastern region produces Rubber yields 4939.432 tons more than provinces in central region. Province in Western region produces Rubber yields 369.960 tons more than provinces in central region. The rubber yield in Nov to Jan is 859.859tons more than in Feb to Apr. The rubber yield in Aug to Oct is 2331.504 tons more than in Feb to Apr. The rubber yield in May to Jul is 2142.526tons more than in Feb to Apr. The estimated rubber yields in each month are used to produce maps as shown in Fig. 1 to Fig. 6. It is easy to see the distribution of rubber yields in each month. If the rainfall increases, the rubber yield will decrease. That is because during the rainy season, if it is rains continuously, the rubber trees cannot be tapped. Moreover, the outbreak of the disease which usually occurs with rubber trees during the rainy season is a problem. Although it is not too severe to make the rubber tree die, it makes the plant not grow well, then the rubber yield will decreasing. In rainy season, if there is flood, this may cause damage to the rubber trees as well. The appropriate temperature for rubber trees is about 25 - 28 degrees Celsius (Economic Office Agriculture, 2016). Thailand's average temperature is not less than 25 degrees Celsius. The higher temperature will lower the rubber yields. There is a regional effect because the weather in each region of Thailand varies. Seasonal factors occurs when the rainy season ends, it is considered to be a good time to tap rubber trees. In winter, the latex will flow longer and be obtained more than the other. A rubber yield map shows the average monthly rubber yield expressing in different colors. It emphasizes high productivity areas. It is easier to see which areas produce high yields. It is a benefit in agriculture in designing and planning for rubber production.

Table 2: The estimated coefficients

Parameter	Beta	Std. Error	95% Wald Confidence Interval		Hypothesis Test	
			Lower	Upper	Wald Chi-Square	Sig.
Intercept	3679.13	2008.92	-258.28	7616.54	3.35	0.07
North	-268.96	177.50	-616.85	78.94	2.30	0.13
Eastern	913.64	301.94	321.84	1505.44	9.16	0.00
South	15421.44	2816.04	9902.11	20940.77	29.99	<0.001
East	4939.43	1766.26	1477.63	8401.23	7.82	0.01
West	369.96	225.81	-72.62	812.54	2.68	0.10
Central	.	.	.	.	.	.
Nov-Jan	859.86	309.17	253.90	1465.82	7.74	0.01
May-July	2331.50	518.99	1314.31	3348.70	20.18	<0.001
Aug-Oct	2142.53	484.37	1193.18	3091.87	19.57	<0.001
Feb-Apr	.	.	.	.	.	.
Rainfall	-3.12	0.86	-4.81	-1.43	13.14	<0.001
Temp	-169.37	72.58	-311.62	-27.13	5.45	0.02

CONCLUSIONS

The objectives of this research are to estimate the rubber yield in each month of 63 provinces growing rubber trees in Thailand, to investigate factors influencing on the rubber yields, and to construct the maps of rubber yields. The generalized estimating equation model (GEE) is used. The estimated rubber yields are used to construct the rubber yield maps. The dependent variables are the rubber yield in each month of the provinces. The factors considered are rainfall, averaged temperatures, seasons, and regions. The results show that the factors influencing on the rubber yields are, averaged temperature, regions, and seasons. The rubber yields maps are easy for readers to identify which areas have high or low yields. They are a useful tool for planning rubber production.

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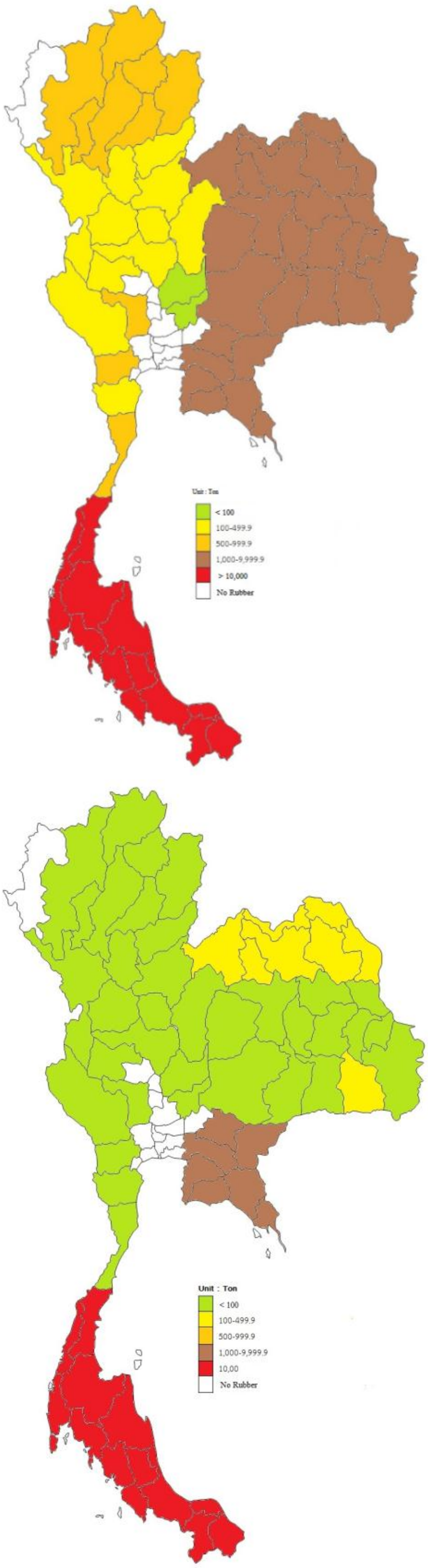

Figure 1: Rubber yields in January (top) and February (bottom)

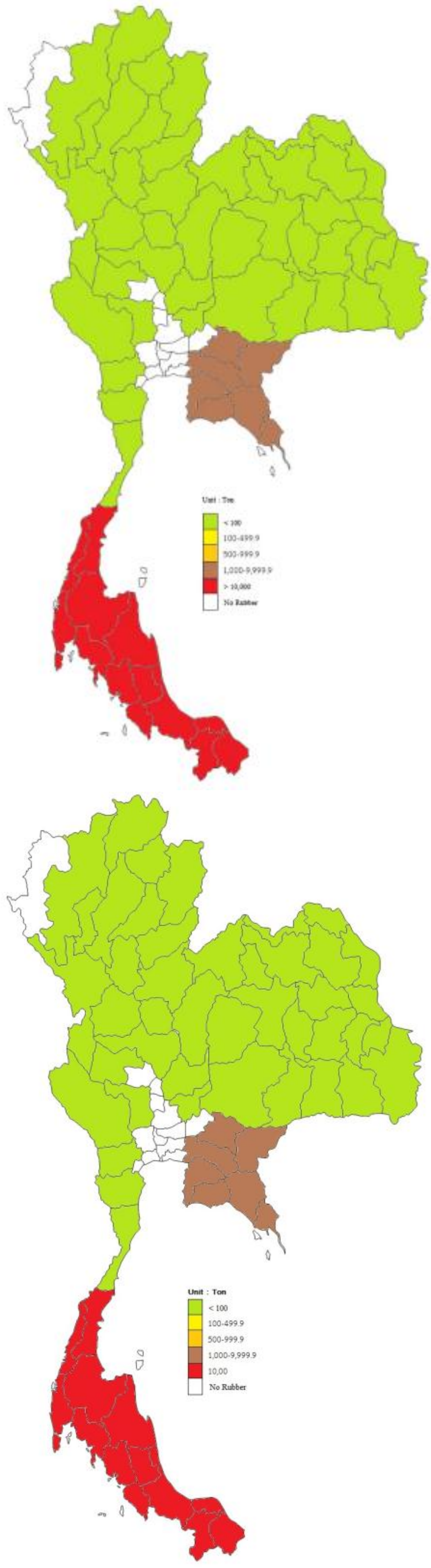

Figure 2: Rubber yields in March (top) and April (bottom)

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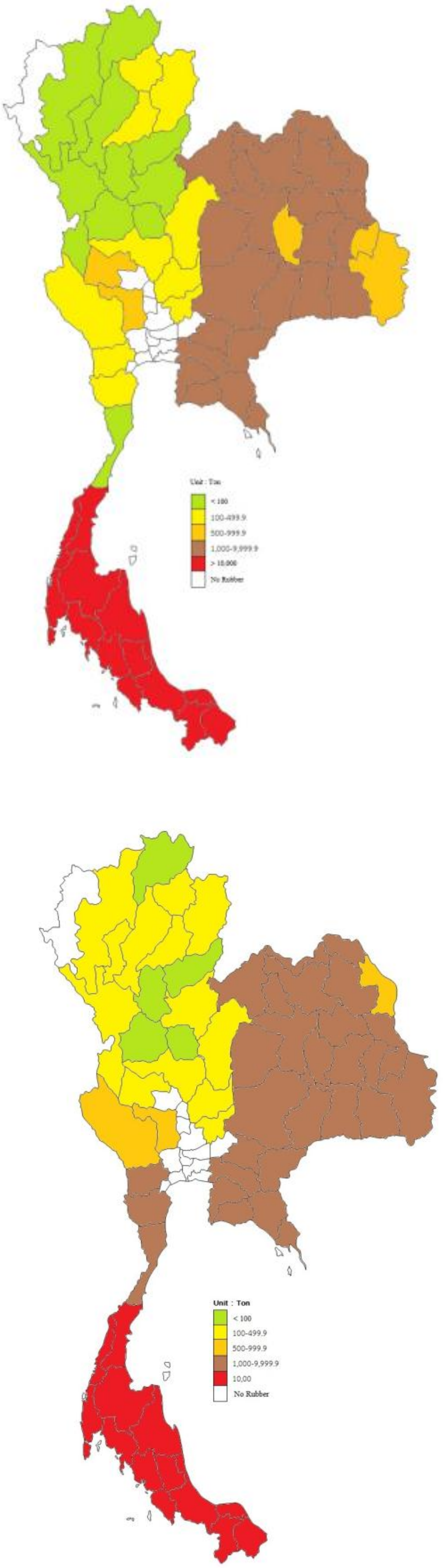

Figure 3: Rubber yields in May (top) and June (bottom)

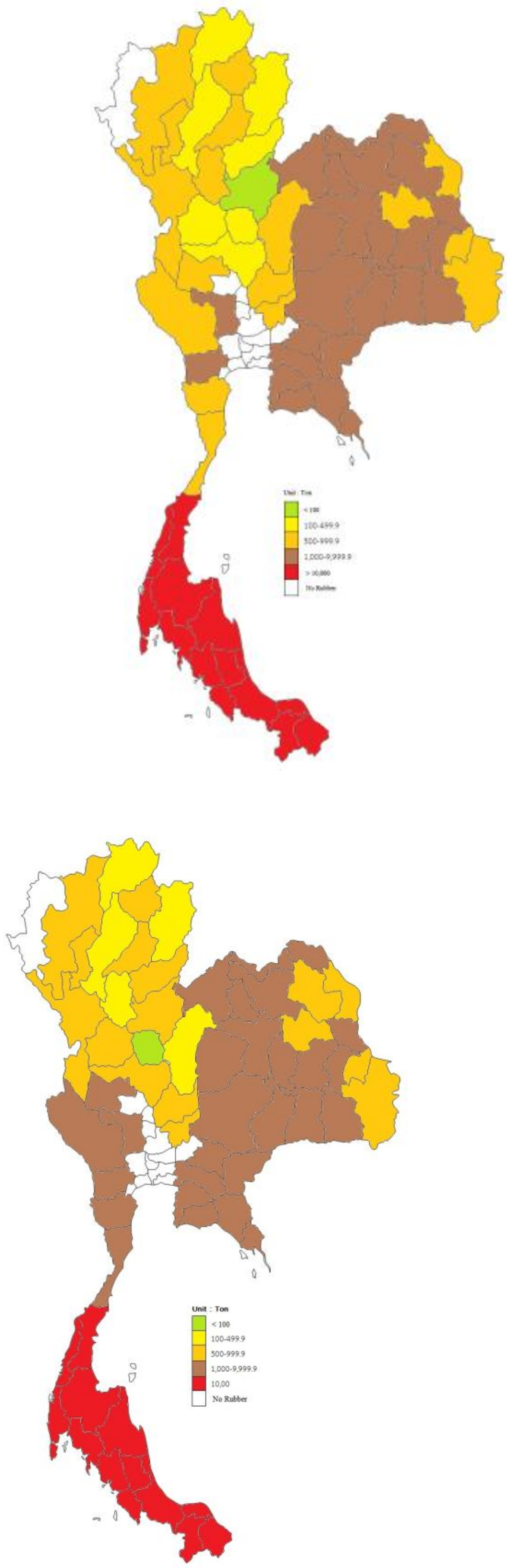

Figure 4: Rubber yields in July (top) and August (bottom)

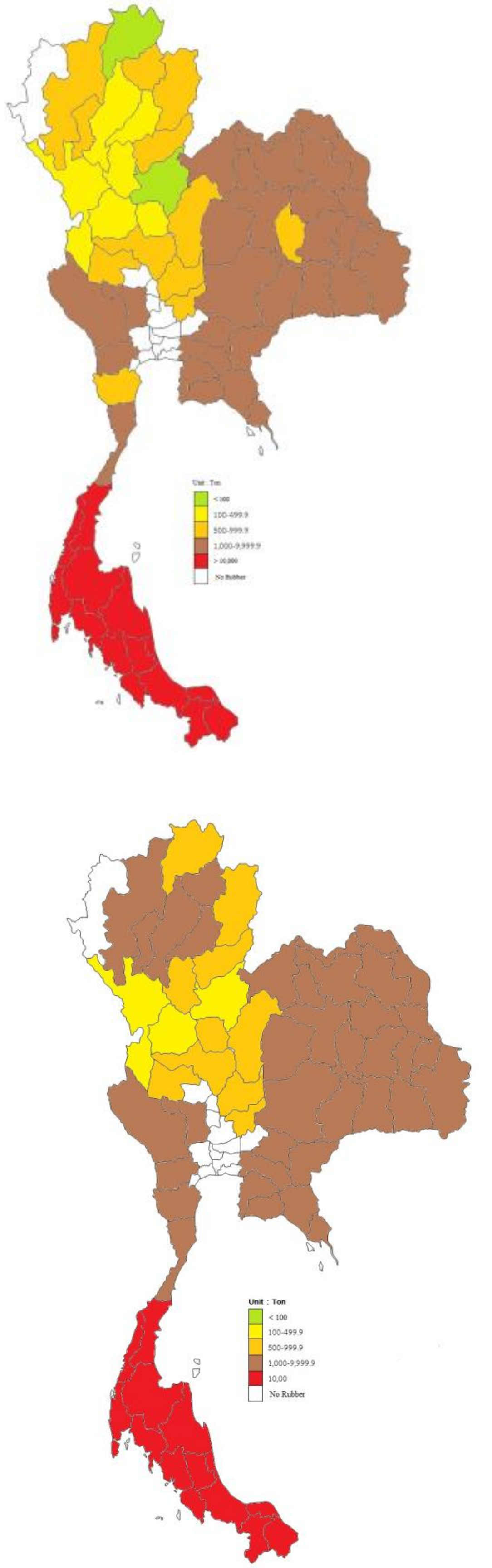

Figure 5: Rubber yields in September (top) and October (bottom)

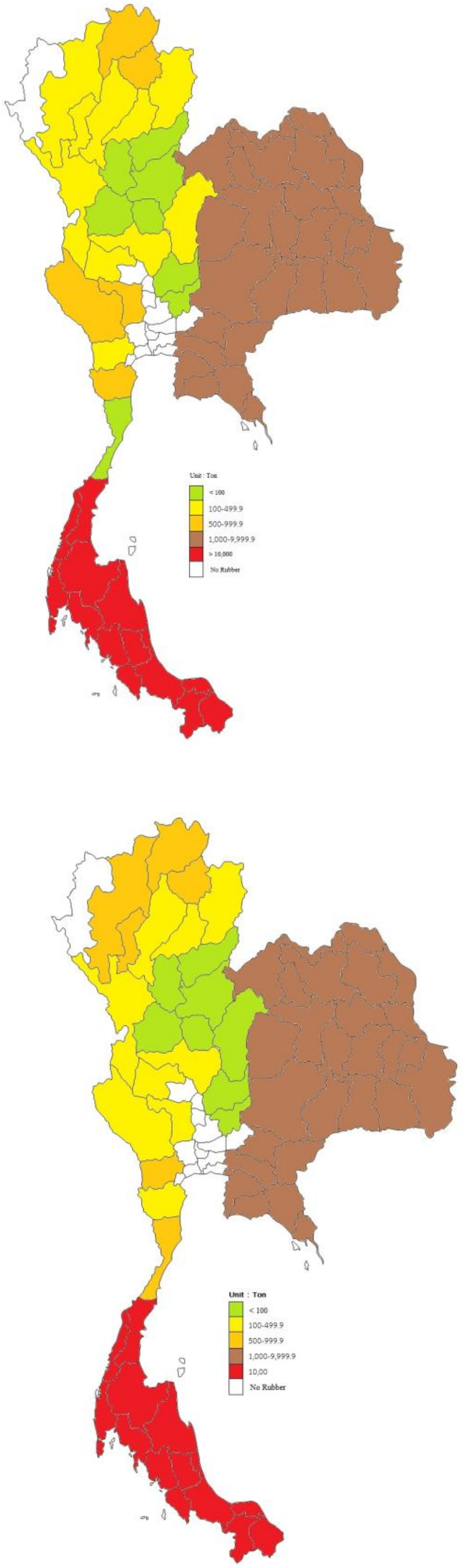

Figure 6: Rubber yields in November (top) and December (bottom)

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