Volume 21, Number 1, June 2015

Journal of ISSAAS

The International Society for Southeast Asian Agricultural Sciences

CONTENTS

J. ISSAAS Vol. 21, No. 1: 1-17 (2015)

PROFIT EFFICIENCY OF TEA PRODUCTION IN THE NORTHERN MOUNTAINOUS REGION OF VIETNAM

Nguyen Bich Hong and Mitsuyasu Yabe

Department of Agriculture and Resource Economics, Faculty of Agriculture, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University
6-10-1, Hakozaki, Higashi-ku, Fukuoka City, Japan
Corresponding author: nguyen.bich.hong85@gmail.com

(Received: June 5, 2014; Accepted: January 10, 2015)

ABSTRACT

Tea is known as one of the most economically efficient crop in Vietnam. However, tea profit efficiency in Vietnam as well as its relationship with market indicators and household characteristics has not been well understood. In order to have better understanding this relationship, this study was conducted using survey data in the Northern mountainous region of Vietnam from December, 2012 to December, 2013. A stochastic profit frontier model was applied to measure profit efficiency of Vietnamese tea production and analyze the impact of input prices and tea farmers` socio-economic characteristics on it. The study was designed as cross-sectional investigation which 193 tea farmers were randomly selected from various districts in the Northern mountainous region of Vietnam. The results show that there is high level of inefficiency in modern tea cultivation. The mean level of profit efficiency is 72.9 percent suggesting that an estimated 27.1 percent of the profit is lost due to a combination of both technical and allocative inefficiency in modern tea production. The profit efficiency difference is explained largely by farm size, household size, cooperative participation and irrigation.

Key words: Cobb-Douglass profit frontier function, stochastic frontier analysis, Vietnamese tea farmers

INTRODUCTION

Tea has a long history in Vietnam and has been cultivated and drunk there for thousands of years. Today, Vietnam is the fifth largest tea producer and exporter in the world. Tea is grown in 39 of 64 Vietnamese provinces. The best quality products are achieved in the North area. Tea production is an important source of income. In 2012, total exported tea reached 146,700 tons and grossed 224.6 million dollars (Vietnam Tea Association, 2012). Furthermore, tea production also plays an important role in generating employment. With 400,000 small households engaged in cultivation and process, tea industry created over 1.5 million jobs (Vietnam General Statistic Office, 2008).

The Northern mountainous region, with its mountainous topography and temperate climate, is one of the main tea cultivation areas in Vietnam. It has a total of 93,000 ha under tea, accounting for 71.6 percent of the total cultivation area in Vietnam, and 64.7 percent of the country's total tea output (Vietnam General Statistic Office, 2013). In addition, in this area, tea production is dominated by small scale farming systems with limited off-farm income sources. Therefore, boosting tea production in the Northern mountainous area is expected to motivate the region's economic growth and have a positive impact on livelihood of rural households.

However, Vietnam tea production is faced with many challenges. Vietnam remains a small player in the world tea market. In 2011, Vietnamese tea production accounted for 7 percent of global tea market, much lower than China (16 percent), India (16 percent), Sri Lanka (16 percent), and Kenya (15 percent) (Potts *et al.* 2014). As Vietnam continues its drive onward into twenty-first century tea production, it is increasingly forced to compete with those top producers, many of which are achieving comparatively higher yield and more efficient processing. Furthermore, in the international market, Vietnamese tea is considered of low quality and low price. In 2012, the average export price of Vietnamese tea only reached US$1,584 per ton, much lower than global average price (US$ 2,732 per ton) (Vietnam General Statistic Office, 2012). Therefore, Vietnam tea industry must strive to promote modern technology and increase production efficiency to improve its competitive edge in foreign tea markets.

Many researchers and policy makers have focused their attention on the impact that adoption of new technologies can have on increasing farm productivity and income (Hayami and Ruttan, 1985). In Vietnam, considerable work is being done to improve technology and yield in tea production. However, the implementation of these practices is lagging (Wenner, 2011). In fact, the majority of Vietnamese tea production is done by small households who often lack money or interest in the implementation of modern technology. Thus, in the short run, Vietnamese tea productivity should be increased by using the existing production technology. In this context, an understanding of the level profit efficiency and its determinants may contribute to the design of programs to increase the production efficiency of Vietnamese tea industry with given existing technology.

A number of studies have been undertaken to address the various aspects of profit efficiency. Most of these studies concentrated on estimating profit efficiency of rice production in some developing countries (Abdulail et al., 1998; Adesina et al., 1996; Ali and Flinn, 1989; Kolawole, 2006; Rahma, 2003). Profit efficiency has been measured various functional form (*i.e.* Cobb-Douglas, translog) using stochastic frontier method. However, currently, there has been no research done which analyses and provides information about the level of profit efficiency and its determinants in tea production. This study aims to fill the knowledge gap in that area.

The main objective of this study is to estimate the level of profit efficiency in the Northern mountainous region's tea production, recognizing how input prices and fixed factors affect tea farms' profit. The second concern is to identify the sources of these efficiencies in terms of famers' socio-economic characteristics, resource base, and other factors.

ANALYTICAL FRAMEWORK FOR MEASURING PROFIT EFFICIENCY

Economic profit is defined to be the difference between the revenue a firm receives and the cost that it incurs (Varian, 1992). A basic assumption of most economic analysis of a firm behavior is that producers seek to maximize profit.

Kumbhakar and Lovell (2000) came up with the variable profit frontier function as:

$$v\pi(p, w, z) = max_{y,x}\{p^T y - w^T x\} \quad (1)$$

The variable profit frontier $v\pi(p, w, z)$ shows the maximum excess of total revenue over variable cost when producers were assumed to use variable input vector *x*, variable input prices *w*, fixed input quantities *z* to produce scalar of output *y* (y>0) with available output prices *p*. In other word, $v\pi(p, w, z)$ is the maximum variable profit obtained from given output and input prices with fixed input quantities. If the firm produces only one output, the variable profit frontier function can be written as:

$$v\pi(p, w, z) = max\{pf(x, z) - wx\} \tag{2}$$

The first-order condition for single-output profit maximization problem is:

$$\frac{\partial y}{\partial x_i} = \frac{w_i}{p} \quad i = 1, \dots . n \tag{3}$$

This condition simply says that the value of the marginal product of each factor must be equal to its price. Particularly in the single-output case, it is frequently convenient to work with a normalized variable profit frontier. Since the variable profit frontier $v\pi(p, w, z)$ is homogeneous of degree (+1)[1] in (p,w), it is possible to divide maximum variable profit $v\pi(p, w, z)$ by p>0 to obtain a normalized profit frontier as:

$$v\pi(p, w, z)/p = max_{y,x}\left\{y - (\frac{w}{p})^T x\right\} \tag{4}$$

In determining its optimal policy, the firm faces market constraints which are those constraints that concern the effect of actions of other agents on the firm. The simplest kind of market behavior that firms will exhibit, namely that of price-taking behavior (Varian, H. R, 1992). Each firm will be assumed to take prices as given, exogenous variables to profit maximization problem. Thus, the firm will be concerned only with determining the profit-maximizing in the levels of output and input with given the input prices and the output prices they face.

Hotelling's lemma (1932) states that the vectors of profit-maximizing output supply and input demand equations can be obtained from the variable profit frontier as:

$$y(p, w, z) = \nabla_p v\pi(p, w, z) \tag{5}$$

$$x(p, w, z) = -\nabla_w v\pi(p, w, z) \tag{6}$$

Production efficiency, as defined by the pioneering work of Farell (1957), is the ability to produce a given level of output at lowest cost. Production efficiency has been estimated separately estimating technical and allocative efficiency from a production frontier using farm survey data. Technical efficiency measures the ability of a famer to achieve maximum output with given and obtainable technology, while allocative efficiency tries to capture a farmer's ability to apply the inputs in optimal proportion with respective prices (Farrell, 1957; Tim et al. 2005).

However, a frontier production function approach to measure efficiency may not be appropriate when farms face different prices and have different factor endowments (Ali and Flinn, 1989). This led to the application of stochastic profit frontier approach to estimate farm specific efficiency directly (Ali and Flinn, 1989; Ali et al. 1994; Rahman, 2003; Yotopoulos and Lau, 1973). Within profit-function context, profit efficiency is the ability of a farm to achieve highest possible profit given the prices and levels of fixed factors of that farm (Ali and Flinn,1989). A measure of profit efficiency is provided by the ratio of actual profit to maximum profit:

$$\pi E(y, x, p, w, z) = (p^T y - w^T x)/\, v\pi(p, w, z) \tag{7}$$

[1] A function is homogeneous of degree 1 if, when all its arguments are multiplied by any number t > 0, the value of the function is multiplied by the same number t.

Kumbhakar and Lovell (2000) summarized the estimation and decomposition of profit efficiency. Profit efficiency estimation begins by writing the stochastic production frontier function as:

$$y = f(x, z; \beta)\exp\{-u\} \tag{8}$$

Where: $y \geq 0$ is scalar output; $x = (x_1, \ldots . x_N) \geq 0$ is a vector of variable inputs; $z = (z_1, \ldots . z_Q) \geq 0$ is a vector of quasi-fixed inputs; β is unknown parameters and $u \geq 0$ represents output-oriented technical inefficiency.

If producers attempt to maximize variable profit, the first-order condition can be written as:

$$f_n(x, z; \beta)\exp\{-u\} = \frac{w_n}{p}\exp\{-\xi_n\}, n=1, \ldots, N \tag{9}$$

Where: $f_n(x, z; \beta) = \partial f(x, z; \beta)/\partial x_n$, the $\frac{w_n}{p}$ are normalized variable input price vectors, $w = (w_1, \ldots w_N) > 0$ is an input price vector, and $p>0$ is the scalar output price. The ξ_n are interpreted as allocative inefficiencies.

If the production frontier takes the Cobb-Douglas form, the production frontier function (8) and the first-order condition for variable profit maximization in equation (9) can be written in logarithmic form as:

$$\ln y = \beta_0 + \sum_n \beta_n \ln x_n + \sum_q \gamma_q \ln z_q + v - u \tag{10}$$

$$\ln x_n = \beta_0 + \ln\beta_n + \sum_k \beta_k \ln x_k + \sum_q \gamma_q \ln z_q - \ln\frac{w_n}{p} - u + \xi_n \tag{11}$$

Where: v is the stochastic noise error component associated with the production frontier.

Solving the $(N+1)$ equations (10) and (11) for the optimal values of $(N+1)$ endogenous variables gives the following output supply and variable input demand equations:

$$\ln y = \frac{1}{1-r}\beta_0 + \frac{1}{1-r}\sum_n \beta_n\left(\ln\beta_n - \ln\frac{w_n}{p}\right) + \frac{1}{1-r}\sum_q \gamma_q \ln z_n + \frac{1}{1-r}\sum_n \beta_n \xi_n - \frac{1}{1-r}u + v \tag{12}$$

$$\ln x_k = \frac{1}{1-r}\beta_0 + \frac{1}{1-r}\sum_n (\beta_n + (1-r)\delta_{nk})\left(\ln\beta_n - \ln\frac{w_n}{p}\right) + \frac{1}{1-r}\sum_q \gamma_q \ln z_n + \frac{1}{1-r}\sum_n (\beta_n + (1-r)\delta_{nk})\xi_n - \frac{1}{1-r} \tag{13}$$

Where: $r = \sum_n \beta_n < 1$ measures the degree of homogeneity of $f(x, z; \beta)$, $\delta_{nk}=1$ if $n=k$ and $\delta_{nk}=0$ if $n \neq k$.

It can be seen from equation (12) and (13) that variable profit-maximizing output production and variable input use depend on normalized variable input prices and quasi-fixed input quantities. They also depend on the magnitudes of both technical and allocative inefficiencies. Since both types of inefficiency reduce variable profit, it is important to quantify the effect of these inefficiencies on variable profit. This led to use the dual normalized variable profit frontier function (Kumbhakar and Lovell, 2000) such as:

$$\ln\frac{v\pi}{p} = \delta_0 + \sum_n \delta_n \ln\frac{w_n}{p} + \sum_q \delta_q \ln z_q + v_\pi + u_\pi \tag{14}$$

Where: $\frac{v\pi}{p}$ is dual normalized variable profit frontier, $\frac{w_n}{p}$ are normalized variable input prices, δ_0 is a constant, $\delta_n = -\frac{1}{1-r}\beta_n \, \forall n$, the $\delta_q = \frac{1}{1-r}\gamma_q \forall q$, $v_\pi = \left[\frac{1}{1-r}\right] v$ represents the impact of statistical noise on normalized variable profit, and $u_\pi \leq 0$ is the overall normalized variable profit inefficiency.

$$u_\pi = \ln\pi_u + \ln\pi_\xi \tag{15}$$

Where: $\ln\pi_u = -\left[\frac{1}{1-r}\right] u \leq 0$ represents the impact of technical inefficiency on normalized variable profit; $\ln\pi_\xi = [\frac{1}{1-r}\sum_n \beta_n \xi_n + \ln(1 - \sum_n \beta_n \exp\{\xi_n\}) - \ln r]$ represents the impact of allocative inefficiency on normalized variable profit.

The normalized variable profit frontier in equation (14) is structurally similar to the stochastic production frontier function (10).

The function is rewritten as:

$$\ln\frac{v\pi}{p} = \alpha_0 + \sum_n \alpha_n \ln\frac{w_n}{p} + \sum_q \alpha_q \ln z_q + V - U \tag{16}$$

where : $\frac{v\pi}{p}$ is normalized variable profit frontier, $\frac{w_n}{p}$ are normalized variable input prices, z_q are quasi-fixed input quantities, V represents the impact of statistical noise on normalized variable profit, U the overall normalized variable profit inefficiency and $\alpha_0; \alpha_n; \alpha_q$ are unknown parameters.

The two components V and U are assumed to be independent of each other. The V is independent and identically distributed as $N(0, \sigma_V^2)$. The U is independently distributed and obtained by truncation (at zero) of the half-normal distribution ($U \sim N(0, \sigma_U^2)$) with variance σ_U^2 (Battese and Coelli, 1995; Coelli et al. 2002).

The method of maximum likelihood is used to estimate the unknown parameters, with the stochastic frontier and the inefficiency effects functions estimated simultaneously. The likelihood function is expressed in term of the variance parameters, $\sigma^2 = \sigma_V^2 + \sigma_U^2$ and $\lambda = \sigma_U/\sigma_V$.

With $\varphi = V - U$, the profit efficiency of farm in the context of the stochastic profit frontier function is defined as:

$$PE = \exp(-\ddot{U}) = \exp\{-\mathrm{E}(U|\varphi)\} \tag{17}$$

Jondrow et al. (1982) have further shown the assumptions made on the statistical distributions of V and U, making it possible to calculate the conditional mean of U given φ as:

$$E(U|\varphi) = \sigma_* \left[\frac{\phi^*(\varphi\lambda/\sigma)}{1 - \Phi^*(\varphi\lambda/\sigma)} - \frac{\varphi\lambda}{\sigma}\right] \tag{18}$$

Where $\sigma_*^2 = \sigma_V^2\sigma_U^2/\sigma^2$, $\phi^*$is the standard normal density function, and $\Phi^*$is the distribution function, both functions being estimated at $\varphi\lambda/\sigma$.

With the assumption of half-normal model, a simple z-test will be used for examining the existence of profit inefficiency, the null and alternative hypotheses are H_0: $\lambda = 0$ and H_1: $\lambda > 0$ (Tim and Battese, 2005). The test statistic is:

$$z = \frac{\tilde{\lambda}}{se(\tilde{\lambda})} \sim N(0,1) \quad (19)$$

Where: $\tilde{\lambda}$ is the ML estimator of λ and $se(\tilde{\lambda})$ is the estimator for its standard error.

RESEARCH AREA, EMPIRICAL MODEL AND DATA

Research Area

Thai Nguyen is a province in the northeast region of Vietnam. With 18,000 ha of tea trees, Thai Nguyen is the second largest tea plantation area in Vietnam. However, it is the largest province in tea production with about 172,000 tons per year (Vietnamese General Statistic Office, 2011). The suitable natural conditions and temperate climate make Thai Nguyen tea have the finest quality throughout Vietnam. Therefore, this research was conducted in Thai Nguyen province. Four representative communes of two famous tea-producing districts (Dong Hy district and Thai Nguyen city) in Thai Nguyen province were chosen for the survey. The selected tea farms are representative of topographical conditions in tea production areas of Thai Nguyen province.

Tan Cuong and Phuc Xuan commune are administratively in the Thai Nguyen City. Tan Cuong is the most well-known for having the highest tea quality in Vietnam. Most of the tea farms are situated along the sides of the Cong river where fields are flatter (with 20% slope). Whereas, in the Phuc Xuan commune, tea is grown on hillsides and uplands. Two communes, Minh Lap and Song Cau, are in Dong Hy district. Minh Lap commune is located about 24 km east of Thai Nguyen town (the center of Thai Nguyen city) and borders the sides of the Cau river. Most of the tea farms in the Minh Lap commune are on uplands and hillsides with slopes ranging from 15% to 30%. The Song Cau commune, on the other hand, is located in the Northeast and about 20 km from the Thai Nguyen town. Tea farms in the Song Cau commune are similar to those in the Minh Lap.

The primary data for this study were collected in a field survey through direct interview with tea farmers during December 2012 by a group of enumerators. A pre-test was made to revise the questionnaire before the formal survey. A total of 200 tea growers were selected following a random sampling procedure. After computing, 7 tea farms got negative values of profit because of pest management problems in the production. Therefore, those tea farms were excluded from the analysis. Finally, the sample used for profit function estimation was 193 households.

The questionnaire in this study was structured to get responses from the selected tea farmers on their farming activities. An attempt was made to collect information on inputs and cost used for tea production as well as tea outputs and prices. Socio-economic data of the farmers and tea farms' characteristics such as age, gender, level of education, farming experience, participation in cooperative, household size, farm size and irrigation were also collected. This is expected to increase the explanatory power of the analysis significantly.

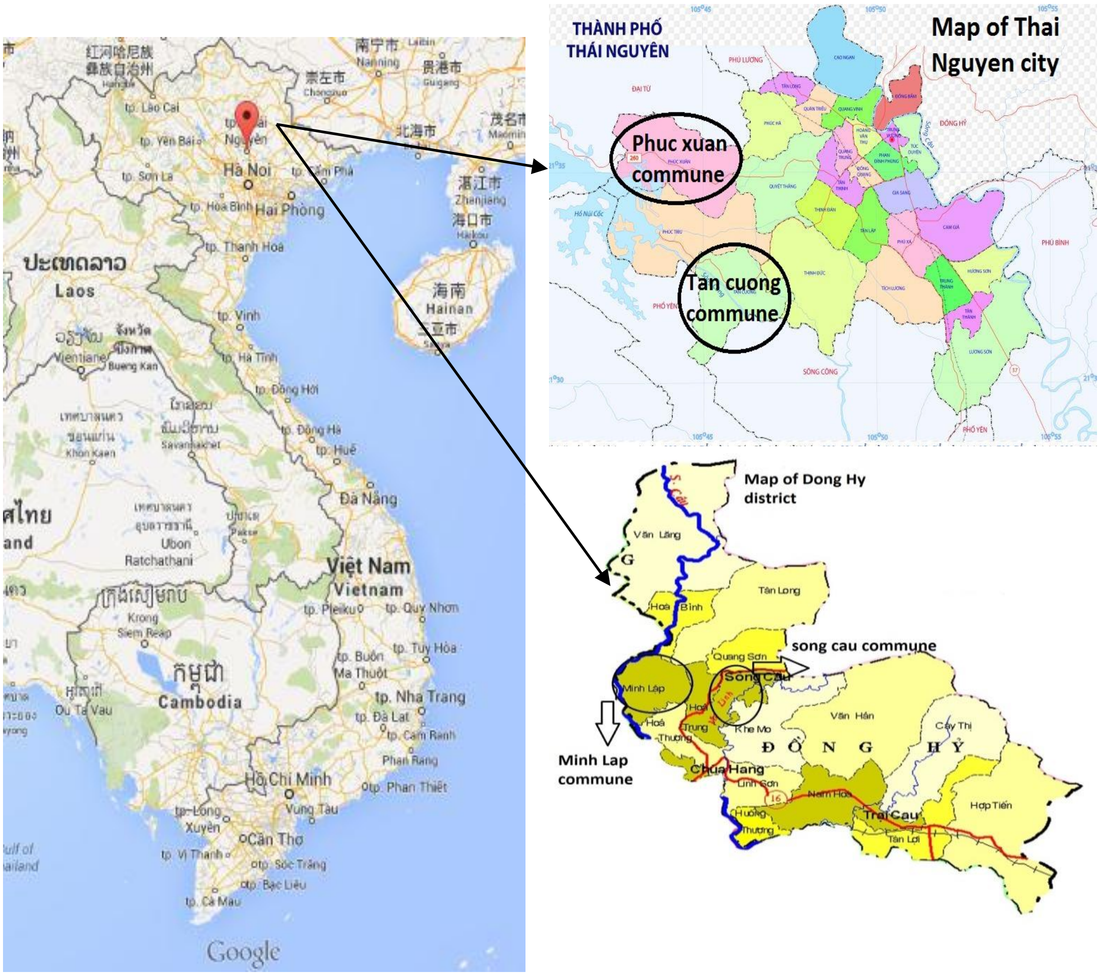


Fig. 1. Study locations in Thai Nguyen province

Empirical model

Tea profit efficiency as defined in this study is the profit gained from operating on the profit frontier taking into consideration variable input prices and quasi-fixed input quantities. A tea farm is assumed to operate by maximizing profit subject to perfectly competitive input and output market and a given output technology. The profit of a specific farm is measured in terms of gross margins that equal total revenue (TR) minus total variable cost (TVC) (Ali and Flinn, 1989; Kolawole, 2006; Rahman, 2003).

To estimate tea profit efficiency, the normalized dual variable profit frontier function in equation (16) was applied in this study. The empirical function is written as:

$$\ln \frac{\pi}{p} = \alpha_0 + \sum_{j=1}^{5} \alpha_j \ln \frac{w_j}{p} + \sum_{k=1}^{2} \beta_k \ln Z_k + V - U \qquad (20)$$

Where:

π = the variable profit of a specific tea farm, normalized by dividing tea price of each farm (p);

w_j= the price of the *j*th variable inputs used in a specific tea farm, normalized by dividing tea price of each farm (p) ;

j= 1, chemical fertilizer price
= 2, organic fertilizer price
= 3, pesticide price
= 4, herbicide price
= 5, labor wage

Z_k= the quantity of fixed inputs used in a specific tea farm;

k =1, tea cultivation area (ha)
= 2, capital of each farm (million VND)

V = the impact of statistical noise on normalized variable profit;

U = the impact of profit inefficiency on normalized variable profit;

α, β = vectors of unknown parameters.

The model specified in equation (20) was first estimated using OLS techniques. The estimates of the partial regression coefficients were used as the starting values for the maximum likelihood estimation of equation (20). The frontier program of STATA software version 11 was used to estimate the ML values of the equation, together with λ, σ.

In the second step,the presence or absence of profit inefficiency was tested in the study by using *z*-test. The null hypothesis is H_0: $\lambda = 0$, representing there is no profit inefficiency effects.

Finally, the regression function with profit efficiency level of tea farms as a dependent variable and socio-economic characteristic variables as independent variables was applied to determine factors that have effect on the profit efficiency of Vietnamese tea farmers in the North region.

The regression function is given by:

$$PE = \delta_0 + \sum_{d=1}^{n} \delta_d W_d + e \qquad (21)$$

Where: *PE* is the level of profit efficiency. A farm's profit-efficiency level is predicted by using the STATA software version 11;

W is the variable representing socio-economic characteristics of the farmers to explain profit efficiency: (1) Age of household head (years); (2) Gender of household head (dummy variable,1= male, 0=female); (3) Education (number of completed years of schooling); (4) Household size (number of household members); (5) Ethnicity (dummy variable,1=Kinh ethnicity, 0= Otherwise); (6) Experience (years); (7) Irrigation (dummy variable,1=Irrigation use, 0=Otherwise), (8) Cooperative (dummy variable, 1= Participation in cooperative, 0= Otherwise); (9) Credit (dummy variable, 1= Borrow loan for production, 0= Otherwise). *e* is an error term representing other factors outside model.

Data

The detailed statistic summary of the data is presented in Table 1. The results show that average total tea yield per farm was approximately 9.19 tons, with a range from 2.25 tons to 11.57 tons, suggesting the big variability of yield among tea farmers in Vietnam. The quantity of chemical fertilizer used ranged from 0 to 3.89 tons , and the organic ferilizer used ranged from 0 to 15 tons. There was a high variation in the amount of fertilizer application per farm. Some farmers did not apply any fertilizer at all on their tea production, while others used significantly. The average utilization of human labor per farm including hired and family labor was approximately 1,271 man-days with the minimum at 332 man-days and a maximum of 2,539 man-days, indicating that farming activities are highly labor intensive. The mean level use of pesticide is approximately 74 l/ha, with the range from 0 to 414.82 l/ha. The average use of herbicide is nearly 78 l/ha, with a miminimum of 0 and a maximum of 525.3 l/ha. There was a high variation in the amount of pesticide and herbicide application per farm. This variability may depend on farm size, farm attitude and preferences regarding these inputs' application.

The descriptive statistics of some important variables applied in profit frontier function and some tea farm specific characteristics are also presented in Table 1. The average farm size is around 0.32 ha with a range from 0.07 ha to 1.44 ha. The result also shows that tea growers have much experience in tea cultivation with the mean of nearly 27 years while their average education is more than 6 years. The result reveals that tea growers in the northern mountainous region of Vietnam have low education level and involved in small-scale production, but with much experience in tea production.

Table 1. Description of variables

Descriptions	Measure	Mean	Standard Deviation	Minimum	Maximum
Output and Input					
Dried tea yield	ton/ha	9.19	1.91	2.25	11.57
Chemical fertilizer	ton/ha	1.04	0.64	0	3.89
Organic fertilizer	ton/ha	1.72	2.21	0	15.00
Pesticide	l/ha	74.13	63.00	0	414.82
Labor	man- day/ha	1271.43	461.88	332.22	2538.90
Herbicide	l/ha	77.99	58.88	0	525.30
Variables for profit analysis					
Profit	million VND	11.51	0.65	4.58	49.09
Chemical fertilizer price	thousand VND /kg	5.60	1.81	2.45	12.00
Organic fertilizer price	thousand VND/ kg	8.90	2.60	1.67	27.75
Pesticide price	thousand VND/ L	9.30	9.31	3.00	75.00
Herbicide price	thousand VND/ L	6.40	7.70	1.00	70.00
Labor wage	thousand VND/ man- day	75.96	11.82	50.05	110.00
Farm size	ha	0.32	0.20	0.07	1.44
Capital	million VND	2.19	1.89	0	9.87
Tea price	thousand VND/kg	65.39	28.24	10	150.00
Managerial variables					
Age	years	46.90	9.81	27.00	70.00
Gender	1= male; 0 = female	0.38	0.49	0	1.00

Descriptions	**Measure**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Household size	number of HH members	4.73	1.63	2.00	10.00
Education	completed years of schooling	6.34	3.03	0	12.00
Experience	years of tea growing	26.56	12.70	10.00	52.00
Irrigation	1= irrigation use; 0 = other wise	0.94	0.24	0	1.00
Cooperative	1= coop member; 0 = otherwise	0.44	0.50	0	1.00
Credit	1= borrow loan for production, 0 = other wise	0.03	0.16	0	1.00

Source: Author's estimation

ESTIMATED RESULTS

Profit efficiency

To examine heteroskedasticity for the data of tea profit model, the Breusch-Pagan/Cook-Weisberg test was applied. The null hypothesis is H_0: Constant variance. The estimation results showed $R^2_{u^2} = 0.02$, *LM*=n×$R^2_{u^2} = 193 \times 0.02 = 3.86$ .At the significance of 0.05 level respectively, the critical value $\chi^2_{0.05}(7) = 12.59$. The caculated *LM* value is less than the critical $\chi^2_{0.05}(7)$ value. Therefore, we failed to reject the null hypothesis of homoskedasticity in the profit frontier model at the 5 percent level of significance, suggesting the absence of heteroskedasticity in data set of the model.

Table 2 provides the results of the OLS estimation for choosing the relevant variables and stochastic frontier estimation for tea profit efficiency. Some variables estimated in the OLS and MLE model are statistically significant at the 1 percent level of significance. The coefficient $R^2$is equal to 0.516, showing that 51.6 percent of the change of profit efficiency can be explained by the some input prices and fixed factors in the OLS model.

As this study used Cobb-Douglas profit frontier function, the coefficient value of the variables can be used as direct elasticity of the function. The elasticity of the stochastic profit frontier function represents how proportion changes in profit if the inputs price and fixed factors change in the production process. The results show that *Organic fertilizer price* had statistically negative and significant effect while chemical fertilizer price has no significant effect. Specifically, if the organic fertilizer price inreases 1 percent the profit will decrease 0.029 percent. *Pesticide price* showed statistically negative effect on profit. Increasing the pesticide price by 1 percent will decrease the tea profit by 0.119 percent. The *Farm size* variable had a positively effect to the normalized profit. The normalized profit will increase 0.597 percent if farm size increases 1 percent.

The estimation result from function (19) shows that $z_{statistic}=\frac{\hat{\lambda}}{se(\hat{\lambda})} = \frac{2.486}{0.949} = 2.62.$

At the significance of 0.01 level, the critical value $z_{\alpha/2} = 2.58$. The caculated z value is greater than the critical z value. Therefore, the null hypothesis was rejected, suggesting the presence of profit inefficiecy effects for tea growers in the Northern mountainous region of Vietnam.

Table 2. Model estimation for profit function

Variables		**OLS Estimation**		**MLE (Frontier Estimation)**	
	Parameters	**Coefficients**	***t- value***	**Coefficients**	***z -value***
Constant	α_0	6.030***	37.46	6.150***	37.23
Chemical fertilizer price	α_1	0.980	1.22	0.910	1.17
Organic fertilizer price	α_2	-0.028***	-3.18	-0.029***	-3.66
Pesticide price	α_3	-0.120***	-2.77	-0.119***	-3.19
Herbicide price	α_4	0.035	0.76	0.033	0.79
Labor wage	α_5	-0.001	-0.78	-0.001	-1.31
Farm size	β_1	0.573***	10.04	0.597***	11.45
Capital	β_2	-0.050	-1.61	-0.024	-0.68
R-squared		0.516			
F-statistic		28.140			
Prob > F		0			
Variance parameter					
σ_v		0.175			
σ_u		0.435			
$\tilde{\lambda}= \sigma_u / \sigma_v$		2.486			
$se(\tilde{\lambda})$		0.949			

Note: *** significant at 0.01 level
Source: Authors' estimation

Factors explaining profit efficiency

A regression function with PE (profit efficiency) as dependent variable and eight independent variables was used to analyze the impact of farmers' socio-economic characteristics on tea profit efficiency.

The sign of the variables in the efficiency model is very important in explaining the observed level of profit efficiency of the farmers. A positive sign on the coefficient implies that variables had an effect in increasing profit efficiency, while a negative coefficient significant the effect of reducing profit efficiency. The parameter estimates are shown in the Table 3. The results reveal that *Irrigation* has positive relationship with profit efficiency as expected. Tea farmers with good irrigation produce at higher profit efficiency than those without irrigation. One of the variables most worth mentioning in relation to profit efficiency is *Cooperative.* Its estimation coefficient shows a significant positive effect to profit efficiency, signaling that famers participating in cooperative could obtain higher profit than others.*Household size* has a negative relation to profit efficiency. This means that families with small household size produced higher profit efficiency compared to the ones with large household size. However, estimation results reveal that the variables such as *Age, Education, Gender, Experience, Credit* have no signficant effect on profit efficiency of tea production.

Table 3. Factors associated with tea profit efficiency

Variables	Explanation	Coefficient	t-value
Constant		8.036^{***}	3.52
Age	Age of household owner in years	0.002	0.82
Gender	1=Male HH head, 0=Female HH head	0.033	1.59
Education	Completed years of schooling	0.001	0.41
HH size	Number of household members	-0.015^{***}	-2.40
Experience	Years of tea growing	-0.002	-1.23
Irrigation	1=Irrigation, 0=Non-irrigation	0.120^{***}	2.72
Cooperative	1=Participation in cooperative, 0=Non- participation	0.048^{**}	2.34
Credit	1=Borrow loan for tea production, 0=Not borrow	0.105	1.65

Note: ** and *** indicated statistical significance at the 0.05 and 0.01 level, respectively
Source: Author's estimation

DISCUSSION

Based on the estimation of the profit frontier function, the frequency distribution of the profit efficiency of tea farming is presented in Table 4. The profit efficieny (PE) of Vietnamese tea farmers ranges from 27.6 percent to 93.9 percent, with an average of 72.9 percent. It is clear that there are opportunities for tea growers to increase the profit efficiency by an average of 27.1 percent through improving their tecnical, allocative and scale efficiencies. The highest frequency range of PE from 80 percent to 90 percent comprises 58 farms, which is 30.1 percent of the total. The lowest PE score lower than 50 percent includes 18 farms, or 9.3 percent, indicating that most tea farms in the North region achieve rather high profit efficiency in production. In addition, the best practice farmers operated at 93.9 percent efficiency, while the least practice farmer operated at 27.6 percent. This shows that, there is a chance of improvement for low profit efficient farmers to achieve maximum efficiency like their most efficient counterparts if determinants of efficiency are improved.

In crop production, input price variability is one of popular risks that farmers often face. Variability in fertilizer price and pesticide price appear to be the main components of input price variability in agricultural production because fertilizer and pesticide contribute to most of the input costs in conventional agriculture. Furthermore, as comodity themselves, fertililizer and pesticde are subject to price fluctuations like all other comodities. Farmers often use chemical fertilizer and organic fertilizer in agricutural production. These fertilizers may have different impact on production efficiency.

Table 4. Frequency distribution of profit efficiency for tea farming

Efficiency level (%)	Frequency	Relative frequency (%)
≤50	18	9.3
>50≤60	18	9.3
>60≤70	40	20.7
>70≤80	45	23.3
>80≤90	58	30.1
>90≤ 100	14	7.3
Total	**193**	**100**
Minimum (%)	27.6	
Maximum (%)	93.9	
Mean (%)	72.9	

Source: Author's estimation

The interesting finding of this study is the impact of chemical fertilizer price and organic fertilizer price on tea production's profit analyzed independently. The study reveals that *Organic fertilizer price* had statistically negative and significant effect on profit while chemical fertilizer price has no significant effect. This result is consistent with the studies of Kolawole (2006), Rahman (2003), Abdulaiand Huffman (1998), and Ali and Flinn (1989) which indicated that fertilizer price has negative and significant effect to profit. Similarly, *Pesticide price* showed statistically negative effect on profit. This result is consistent with Ali and Flinn (1989), Kolawole (2006), and Rahman (2003). The negative effect of organic fertilizer price and pesticide price on tea production's profit conform with the theoretical hypothesis that there is a negative relationship between profit and input prices. It means that in a consistently situation of rising fertilizer price and pesticide price, the declining effect of profitability in tea farming is more clear. Therefore, a policy response aimed at stabilising price fluctuations organic fertilizer and pesticide would make tea farmers' profit increase.

Besides, the significant effect of organic fertilizer price instead of chemical fertilizer price on profit may be due to thefact that tea farms in the Northern mountainous region of Vietnam haveadopted more ecological farming practices in their farms by reducing the use of chemical fertilizer and increasing the use of organic fertilizer. The mean level of chemical fertilizer used in tea farms is 1.04 tons per hectare while this level of organic fertilizer is 1.72 tons (Table 1). In recent years, to develope tea production sustainably, Vietnamese governent supported tea farmers a lot of training courses on ecological farming practices. In these course, farmers were learnt about negative economic, health and environmental impacts related to the excessive use of chemical fertilizer as well as safe and appropriate use of chemical fertilizer. These courses also often contain components on ecological farming practices such as increasing use of organic fertilizer as well as how to compost organic fertililizer in farms.150 of 193 tea respondents in this study have applied ecological farming approaches. Advocation for tea farmers to adopt more ecological farming practices is a good measure that Vietnamese gorvernment should continue implementing in order to sustain tea production.

Farm size variable had positively effect to the normalized profit. This result is similar with the finding of Rahman (2003) for Bangladeshi rice farmers. Namely, larger farms enable farmers to take advantage of economies of scale to improve profit.

For policy purposes, it is very useful to determine which factors of farmers' socio-economic and farm characteristics have impact on the tea profit efficiecy. Water is one of the most important inputs for agricultural production. It is evident in many studies that modern farming benefits significantly from better irrigation (Ali and Flinn, 1989; Rahman 2003; Sharma, 2001). This sudy reveals that tea farmers with good irrigation obtain higher profit efficiency (Table 4) and incur less profit-loss (Table 5). This finding makes a strong case in favoring construction of proper irrigation system to all tea farms in Vietnam. This study also shows that tea farmers who join cooperatives operate at significantly higher level of profit efficiency. In recent years, Vietnamese tea cooperatives played an important role in increasing farmers' income through their improvement of production techniques and machines, knowledge about financial management, and market access's capacity. Infact, farmers who joined or formed cooperatives in Vietnam are given priority to attend training courses about production technique and financial management which are funded by the government and other supporting organizations. In these courses, farmers were taught expenditure management, modern tea planting techinques, use of pesticide, integrated pest control and so on. These tea cooperatives also help members establish contracts with other chain actors i.e. supplier of farm inputs and other materials for tea farming; processors; wholesalers; distributors and retailers, develope policies and procedures for procurement; storing and packing as well as support members in equiping sieving machine; vacuum packaging machine and scenting machine. In addition, when participating in cooperatives, Vietnamese tea farmers have more opportunities to exchange information with other members on input markets and services. This enable farmers to adjust their production more effectively.

Table 5. Profit loss by the key constraints

Farm-specific Characteristics	N	Estimated profit-loss (thousand VND/ha)	Profit efficiency
Profit-loss by household size			
Small household size	142	349	0.76
Large household size	51	546	0.75
t-value		-5.19***	4.12***
Profit-loss by Irrigation			
Farm without irrigation	12	536	0.62
Farm with irrigation	181	392	0.74
t-value		1.96**	-2.86***
Profit-loss by Cooperative			
Non participation	85	404	0.71
Participation	108	398	0.75
t-value		0.18	-2.07**

Note: Profit loss is computed from the maximum profit for given prices and fixed factor endowments. Maximum profit per hectare is computed by dividing the actual profit per hectare of individual farms by its efficiency score;
Small households are families that have size smaller than average size (4.73);
Large households are families that have size larger than average size (4.73);
** and *** indicate statistical significance at the 0.05 and 0.01 level, respectively.
Source: Author's estimation

Rahman (2003) also indicated that exchange information on input markets among cooperative members such as timely availability of fertilizers, pesticides and seed at competitive prices may positively affect to their profitability. This finding is sufficient enough to encourage Vietnamese tea farmers join or form cooperatives. Besides, it was observed that families with small household size got higher profit and incured significantly lower profit-loss (Table 5). This is due to difference in proportion of working-age adults (from 16 to 64 year olds) among households. The mean proportion of working-age adults in small-size households interviewed is 0.7 while this proportion in large-size households is only 0.5. A small-size household with high proportion of working-age adults implies more labor for income-generating activities.

CONCLUSIONS AND POLICY IMPLICATIONS

There is a considerable agreement with the notion that an effective economic development strategy depends critically on promoting productivity and ouput growth in agricultural sector, particularly among small-scale producers (Johnston and Mellor, 1961). Although tea is a very promising crop not only for farmers' income but also for the national economy, until now there has been no obvious research concerned with the profit efficiency and its determinants of tea production in Vietnam. The findings of this study will propose useful policy recommendations to increase profit efficiency of Vietnamese tea industry under the current condition of inputs and technology and improve tea farmers'income.

The study used stochastic Cobb-Douglas profit frontier function to analyze profit efficiency of tea production in the Northern mountainous region of Vietnam. Using filed survey data obtained from 193 tea farms spread over 4 communes during December 2012, we revealed that average profit efficiency level of tea production in this region is 72.9 percent, with wide variation among farmers ranging from 27.6 percent to 93.9 percent. These results suggests that there are considerable opportunities for tea farmers to increase their profit by an average of 27.1 percent through technical, allocative and scale efficiency.

Results of this study clearly shows that profitability of tea farming in the Northern mountainous region of Vietnam is vunerable to changes in prices of major inputs such as organic fertilizer and pesticide.In order to increase the profit of tea production, Vietnamese government should have suitable measures to stabilize organic fertilize and pesticide prices. We suggest that the government should focus on following issues: intensifying quality control of organic fertilizers and pesticides circulated on the market, controlling the organic fertilizer and pesticide production activities; regulating and balancing the supply and demand of organic fertilizers and pesticides through organic fertilizer and pesticide reserves, regulating the organic fertilizer and pesticide import resources through tax policies and having support policies to improve the capacity of the distribution system to ensure that organic fertilizer and pesticide are circulated from production and import to the farmers as well as avoid overlapping and reduce unnecessary intermediate cost. In addition, the government needs to organize routine inspection and control of the market to prevent the violation of trade fraud, speculation of organic fertilizer and pesticide and raising the prices unreasonably.

Furthermore, this study indicated that tea profitability will increase sustantially with increase in tea farms' size. This is expected result in the Northern mountainous region of Vietnam where most of tea farms are small size, averagely 0.32 hectares. Therefore, land reform measures aimed at promoting tea farmers to extent their farm size will have a positive impact on increasing tea profit efficiency.

The tea farmers' social-ecomic characteristics and other farm-specific variables used to explain profit efficiency shows that farmers in the irrigated land produce tea more efficiently than those in the non-irrigated area. It is interesting to reveal that the smallerhousehold size is, the higher profit efficiency is. This study also shows that farmers who join in cooperatives are more efficient than farmers who do not. From aboved results, improving infrastructure like irrigation plays a significant role in increasing the profit efficiency of tea production. Also, the government should encourage non-participant farmers to join in cooperatives.

ACKNOWLEDGEMENT

This research was funded by Monbukagakusho scholarship, Ministry of Education, Culture, Sports, Science, and Technology – Japan. The authors thank the Environmental Economics Laboratory, Faculty of Agriculture and Kyushu University for providing the opportunity and facilities to conduct the research. The authors are grateful to the unknown reviewers for their valuable suggestions and comments on this manuscript.

REFERENCES

Abdulai, A., and W. E. Huffman. 1998. An examination of profit inefficiency of rice farmers in Northern Ghana.Iowa State University, Department of Economics. Staff paper, No. 296

Adesina, A. A. and K. K.Djato. 1996 . Farm size, relative efficiency and agrarian policy in Côte d'Ivoire: profit function analysis of rice farms. Agricultural Economics. 14(2): 93-102.

Aigner, D.J, C.A.K.Lovell and P.Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. Journal of econometrics. 6(1): 21-37.

Ali, M. and J. C. Flinn.1989. Profit efficiency among Basmati rice producers in Pakistan Punjab. American Journal of Agricultural Economics. 71(2): 303-310.

Ali, F., A. Parikh and M. K. Shah. 1994. Measurement of profit efficiency: Using behavioral and stochastic frontier approaches. Applied Economics. 26: 181-188.

Battese, G. E. and T. J. Coelli. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical economics. 20(2): 325-332.

Bravo-Ureta, B. E. and A. E. Pinheiro. 1997. Technical, economic, and allocative efficiency in peasant farming: evidence from the Dominican Republic.The Developing Economies. 35(1): 48-67.

Bravo-Ureta, B. E. and A. E. Pinheiro.1993. Efficiency analysis of developing country agriculture: A review of the frontier function literature. Agricultural and Resource Economics Review. 22(1): 88-101.

Coelli, T. J., D. S. P. Rao, C. J. O'Donnell, and G. E. Battese. 2005. An introduction to efficiency and productivity analysis. Springer Science & Business Media. 345 p.

Farrell, M. J. 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society. Series A (General), 120(3): 253-290.

Hayami, Y. and V. W. Ruttan. 1971. Agricultural development: An international perspective. Baltimore, Md/London: The Johns Hopkins Press. 397 p.

Hotelling, H. 1932. Edgeworth's Taxation Paradox and the Nature of Demand and Supply Function. Journal of Poliical Economy. 40: 577-616.

Johnston, B. F. and J. W. Mellor. 1961. The role of agriculture in economic development. The American Economic Review. 51(4): 566-593.

Jondrow, J., C. A. K. Lovell, I. S. Materov and P. Schmidt.. 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. Journal of Econometrics. 19:2/3 (August): 233-38.

Kolawole, O. 2006. Determinants of profit efficiency among small scale rice farmers in Nigeria: A profit function approach. Research Journal of Applied Sciences. 1(1): 116-122.

Kumbhakar, S. and C.A. K. Lovell. 2000. Stochastic Frontier Analysis. New York: Cambrige University Press. 344 p.

Meeusen, W. and J. V. D. Broeck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review. 18(2): 435-444.

Potts, J., L. Mathews, W.Ann, H.Gabriel, C.Maxine, and V.Vivek. 2014. The state of sustainability iniatialtives review 2014. International Institute for Sustainable Development. 363 p. http://www.iisd.org/pdf/2014/ssi_2014.pdf

Rahman, S. 2003. Profit efficiency among Bangladeshi rice farmers. Food Policy. 28(5-6): 487-503.

Sharma, K. R., N. C. Pradhan and P. Leung. 2001. Stochastic frontier approach to measuring irrigation performance: An application to rice production under the two systems in the Tarai of Nepal.Water Resources Research. 37(7):2009-2018.

Varian, H. R. 1992. Microeconomic analysis. New York: Norton, Vol.2. 563 p.

Vietnam General Statistic Office. 2008, 2011, 2012. General Report on Agricultural Product Import and Export. 24 p, 30p, 33p.

Vietnam Tea Association. 2012. General Report on Tea sector. 17 p.

Wenner, R. 2011. The Deep Roots of Vietnamese Tea: Culture, Production and Prospects for Development. Independent study project (ISP) collection. Paper 1159. http://digitalcollections.sit.edu/isp_collection/1159

Yotopoulos, P. A. and L. J. Lau. 1973. A test for relative economic efficiency: some further results. The American Economic Review. 63(1): 214-223.

J. ISSAAS Vol. 21, No. 1: 18-30 (2015)

DETERMINANTS OF SUSTAINABLE RUBBER PLANTATION IN JAMBI PROVINCE, INDONESIA

Saad Murdy and Suandi

Department of Agribusiness, Faculty of Agriculture
University of Jambi, Jambi, Indonesia
Corresponding author: saad_murdy@yahoo.com

(Received: May 5, 2014; Accepted: March 29, 2015)

ABSTRACT

Rubber production is still important in the development of the Jambi province economy. This study sought to: determine the business management system of smallholder rubber plantations; (2) determine the development of various social capital types and their relationship with the sustainable development of smallholder rubber plantations and (3) analyze the causality between the level of sustainable development of smallholder rubber plantations and business management system. The study was conducted in Jambi province by selecting two districts, namely: Sarolangun and Batang Hari district . This study employed cross-section primary data. The data collection was conducted form March until September 2013 by interviewing 600 respondents who were selected by cluster and purposive sampling. The data analysis was conducted using both structural equation model and binary logistic regression. The results show that the sustainable development of rubber plantation has not been yet fully achieved. The social capital has a positive relationship with sustainable rubber plantations. The determinants of sustainable rubber plantations in all dimensions are benefit form association and working spirit.

Key words: capital, welfare of farmers, mutual cooperation, regional economy

INTRODUCTION

The rubber plantation is the main livelihood for farmers in Jambi province, however, the level of management is still very simple and even rarely consider the environment sustainability therefore the production obtained is relatively unfavorable while the land owned by farmers is quite vast, reaching an average of 2 hectares per farmers (Dinas Perkebunan Jambi, 2013). The limited development system of smallholder rubber plantation in Jambi province impact that the productivity level which is much lower (0.44 tons per hectare per year) compared with the level of Indonesian rubber plantation productivity (0.8 tons per hectare per year) let alone compared to the rubber productivity of neighboring countries, such as Thailand which reached 1.875 tons per hectare per year (Chantuma et al, 2012). However, along with the optimization of rubber plantations, in the next 5 years, the domestic rubber productivity could be increased to 1.5 tons per hectare, Indonesia even can produce 6 million tons of rubber in 2020, or the world’s largest rubber producer in 2020, and without the need to increase the plantation area, except for the acceleration of the rubber tree rejuvenation.

To achieve these targets, various efforts in enhancing both production and productivity either in the technology development or the development of farmers’ and institutional resources in the community is needed. Considering these three subsystems are inter-related to each other, especially public institutions. According to some researchers, farmer institutions (social capital) plays an important role towards the progress and acceleration of rural society development, which includes technology and human resource of rubber farmers' development, such as Haddad and Maluccio's findings (2000). The existence of strong individual households social capital (social networks) can contribute to obtain various forms of access in society. For every family member which participates in the activities of local associations, especially productivity associations will increase family income by 6.2 percent per year (Suandi, 2010).

Based on the above backgorund, the research sought to determine the business management system of sustainable smallholder rubber plantations; determine the development of various social capital types and their relationship with the sustainable development of smallholder rubber plantations; and analyze the causality between the level of sustainable development of smallholder rubber plantations and business management system.

METHODOLOGY

The study design was cross-sectional. The study was conducted in the province of Jambi by selecting two districts, namely: Sarolangun, and Batang Hari. Among nine districts in Jambi province, during last ten years the new plantation of rubber has been done by farmers in those two districts. The farmers in other districts mostly did not make new plantation and some converted from rubber to palm oil crop. The duration of this research was eight months. Research data was collected by means of observation, direct interview in-depth interview and focus group discussion (FGD) with a sample of 600 families or10 percent of the population (6,120 rubber farmers) are taken successively by the cluster, purposive, and simple random sampling. The data was collected from March until September 2013. Research variables in this study are: (1) development of sustainable smallholder rubber, (2) rubber farmer welfare, and (3) Social capital (socio-cultural and peasant characters). The research data were collected by observation, interviews, in-depth interview and Focus Group Discussion (FGD) with the sample as many as 5 percent of the population (rubber farmers) were taken consecutively with the method of cluster, purposive and simple random sampling.

To answer the objectives of research on the relationship between social capital on sustainable smallholder rubber development and economic well-being of rubber farmers' family in the study area, Structural Equation Modeling (SEM) was applied. In this study, the SEM model is used as there are some proposed latent endogenous variables: local association, society character, sustainable rubber plantation development and welfare (Cortina, 2011). They are hypothesized to have relationship with some manifest variables as indicators such as trust, solidarity, working spirit, components of sustainable development indicators and welfare variables. Every variable is measured using the scale from 1 to 4. To account the sustanaibility of rubber plantations, some indicators are used to capture the level of each sustainble development componet. The list of variables measured are attached at the appendix. The score of 1 for very low and 4 for very high then are used to present the level of sustainability achieved by farmers.

The logistic regression is used to satisfy the objective of finding the causality between the level of the sustainability of smallholder rubber plantations. In this model, the level of sustainability is classified only into two categories: Low and High. From the interview with respondents, such level is actually categorized into four levels: very low, low, high and very high. Two first categories are grouped into Low and the rests are grouped into High. Each component of sustainable development is regressed to some explanatory variables from manifest varaibles at SEM model: X1 up to X6. The empirical model for logistic regression is as follows:

$$Y_i = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \mu_i \quad \text{................................} \quad (1)$$

where:

Y_i = 1 if the level of sustainability is High and 0 if the level is Low
X_1 = number of association followed
X_2 = level of participation
X_3 = benefit of assocation
X_4 = trust
X_5 = solidarity
X_6 = working spirit

There are four equations (similar with equation 1) which are estimated in this study, each is for Y1 up to Y4. Each of components of sustanaibility development (ecology system, agronomy system, economic system and socio-demographic system) is hypothesized to be influenced by six explanatrory variables which represent business management system.

The procedure to evaluate the goodness of fit of the logistic regression is referred to some previous studies, such as form Ibok (2014) and Park (2013). The model is expected to produce determinants of the level of the sustainability of smallholder rubber plantations.

RESULTS AND DISCUSSION

Characteristics of Sustainable Development of People's Rubber Plantation

Sustainable development is development that embodies the present needs without compromising the ability of future generations to achieve their needs. In other words, the concept of sustainable development is oriented in three dimensions of sustainability, namely: sustainable economic enterprises (profit), the sustainability of human social life (people), natural ecological sustainability (planet), or Triple-P pillar.

Ecological system or ecosystem is something formed by a reciprocal relationship between the living and the environment. Ecological system consists of various components, such as: the carrying capacity of land, land suitability, and land use. The data showed that more than 60 percent of the rubber farmers implemented ecological system that is in compatible with a sustainable farming system. Another sustainability is the economic system, field data indicate that the distribution of rubber farmers in the study are belong to the group of high economic system. The results showed more than 50 percent of the rubber farmers have been able to run a good economic system. Then, the socio-demographic dimension also shows good results that the average system of socio-demographic of rubber farmer sin the study area is high. The results showed there are as many as 70 percent of the rubber farmers belong to the high socio–demographic system (Table 1). This indicates that the average welfare level of rubber farmers is high, but not in line with the level of household welfare expenditure proxy.

Table 1. Distribution of respondents based on sustainability level of community rubber development

No	Sustainability level	Distribution of respondents (%)			
		Ecology system	**Agronomy system**	**Economic system**	**Socio-demographic system**
1	Very low	29.60	15.41	14.89	5.43
2	Low	33.63	38.53	32.40	24.17
3	High	33.63	35.73	38.35	53.06
4	Very high	3.15	10.33	14.36	17.34
	T o t a l	**100,00**	**100,00**	**100,00**	**100,00**

Community Social Capital

The number of local associations which followed by sample family in the study area are grouped into four categories, namely: very few (one association), few (two associations), many (three associations), and very much (more than three associations). Field observations found that the number of local associations which sample family followed in the study area is relatively many because more than 65 percent sample family follows three or more local associations. With the increasing number of local associations followed by sample family members, it is to support or influence the level of unity and solidarity among members of the community, which in turn will have an impact on the welfare and progress of the village. Later, during the era of globalization, reformation and regional autonomy, local associations which thrive in the area and followed by members of the public will play a big role in holding and sustaining a variety of information in the form of new innovations that come from the outside, especially with regard to the life of the community and regional development.

The associations that developed in the study area amounted to 12 associations, both formal and informal associations/groups. The type of association followed by the respondents include: indigenous groups, *yasinan* groups, social gatherings, and groups of working women, youth group, farms' credit (KUT),various ethnic or tribal associations, and other associations.

When grouped, distribution of respondents turned out to be relatively balanced among a few or low association group with a high association group, respectively 48.4 and 51.6 percent. By district, most of the respondents involved in the associations found in the district of Batang Hari, reaching 58.2 per cent, whereas in Sarolangun respondent's involvement in the activities of the association is only as much as 47 percent. The amount of local associations attended by members of the household respondents in the study area is affected by the development of the association itself and the relationship between a tribe with other tribes which have a high level of kinship and high dependency with one another. These findings are in line with results reported by Suandi (2010), that Jambi people come from several tribes or ethnicity, namely: Malay (Jambi and Palembang), added with Javanese, Sundanese, and Minang ethnic. Particularly Javanese and Sundanese ethnic are people who follow the transmigration program sponsored by the government, while the Minang tribe are spontaneous migrants.

Rubber Farmers Welfare

According to field observations, there are significant differences between small expenditure (poor) with a relatively large expenditure (wealthy family). Spending in the needy group is nearly 69 percent, and is much greater than the welfare of rice farmers in Kerinci district (58%) (Suandi et al, 2011). When divided by area, most of this group is at Sarolangun and Batang Hari regency which represents 73% and 65%, respectively. Based on total family expenditure per year in the study area is Rp. 11,670,000, - and the amount of expenditure is slightly below the average of the welfare benchmarks approached by the Central Statistics Agency (BPS, 2010).

The percentage of total expenditure was allocated to food (60%), followed by spending on non-food (clothing, energy, communication, social and other) (31%), and the smallest spending is for investment (education and health) which only amounted to 9%. This indicates that the consumption patterns of families on food is still relatively high, and this matched the results of research done by Suhardjo, Hardinsyah and Retnaningsih (Mangkuprawira, 2002) which ranges between 60-70 percent. In this connection, referring to the level of expenditure, the welfare level of families in the study area are relatively poor.

Social capital relationship with sustainable rubber plantation development and farmers welfare

The social capital linkages with sustainable rubber plantation development and the welfare of farmers were analyzed using SEM models. Through this model the effect or causal relationship between the construct can be seen. In accordance with the hypothesis, so the variable construct consists of three main latent variables, namely: social capital, sustainable people's rubber plantation development, and welfare of farmers. In the analysis, social capital is broken down into two parts: (1) Local Associations (Aslok) and (2) Society character (Kmas) with loading variables: X1 up to X6 in equation 1; (3) development of sustainable smallholder rubber plantations (PPKRB) with loading variables: (Y1) ecological systems, (Y2) agronomic systems, (Y3) economic system, and (Y4) socio-demographic system; (4) rubber farmers welfare (Kesra) with loading variables: (Y5) the need for food, (Y6) non-food needs, and(Y7) the need for human resource investment for household.

According to analysis using SEM model with LISREL program, results indicate that the level of construct validity study of social capital influence the sustainable development of smallholder rubber plantations and the welfare of farmers in the study area is quite valid. That is, the models developed in the study design suitable or fit to the data collected. Suitability or reliability research design and data captured characterized by the values of the test equipment used. The value of the model test results of the approach and exceed the cut-off value desired for each test equipment (Table 2).

Table 2. Goodness of fit index effects of social capital on sustainable rubber plantation development and farmers welfare, 2012

No.	Goodness of Fit Index	Cut-off value	Field Result
1	X^2 (Chi – Square) = *no sign* or smaller	0.00	0.00
2	RMSEA (*Root Mean Square Error of Approximation*)	$\leq$ 0.08	0.09
3	GFI (*Goodness of Fit Index*)	$\geq$ 0.90	0.94
4	CFI (*Comparative Fit Index*)	$\geq$ 0.94	0.96

According Freund (2004), there are 31 test equipment used to test the model. However, the test is often used to measure the relevant values and Chi-Square (X2), Root Mean Square Error of Approximation (RMSEA), Goodness of Fit Index (GFI) and the Comparative Fit Index (CFI) (Baker, et al., 2005). Through the results of testing the model turned out item loadings for latent variables in the model also shows the internal consistency (reliability) is very significant.

As shown in Figure 1, the local association latent variables (Aslok) for example, which consists of three dimensions, namely: the number of associations, the level of participation, and the benefits of the association has a significant loading value. Through the model it is known item loadings (X1) number followed associations (λ =0.72), (X2) participation rate (λ =0.77), and (X3) associations benefit (λ =0.71). The same is indicated by the item loading son latent variable character of the community, sustainable rubber plantation development and farmers' welfare are all showing the value (λ) is significant. The results show that social capital variables (local associations and community character), either directly or indirectly has a real positive effect and significant to the Sustainable rubber plantation development and farmers' welfare with gamma values respectively are 3.84 and 3.31.

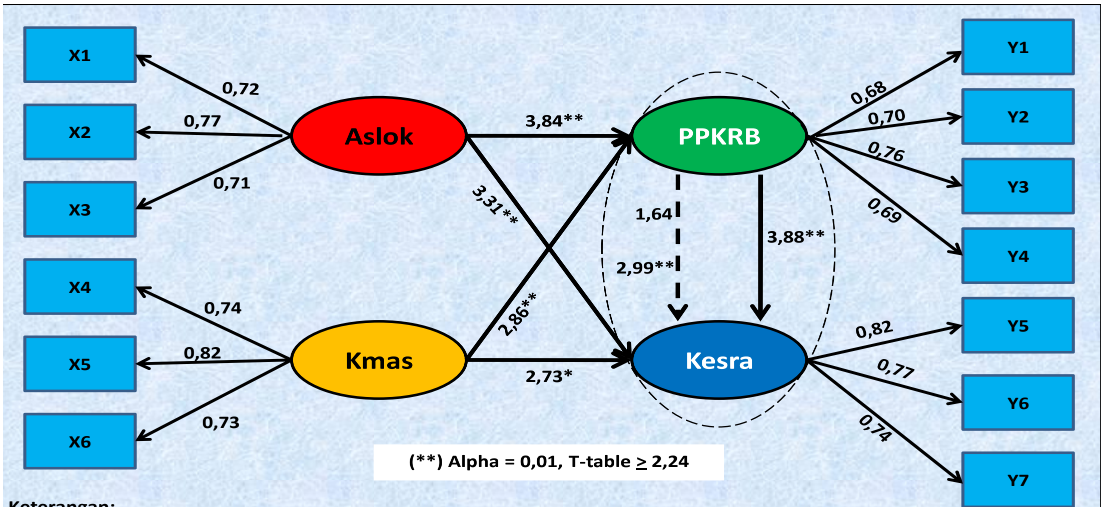


Fig. 1. Structural relationship between social capital factors with sustainable rubber plantation development and farmer's welfare

This proves the hypothesis built earlier that social capital in this case the local associations and the public character causality may affect sustainable rubber plantation development and farmers. That is, the higher the level of social capital owned by the family the better the management of sustainable rubber plantation development and farmer's welfare, which in turn can accelerate the regional economic development in the study area.

With regard to the role of social capital to sustainable rubber plantation development and farmer's welfare in the study area through SEM model and supported by the results of a descriptive analysis of the benefits of social capital to the family needs suggests that social capital in the form of number of associations, the level of participation as well as the use fullness or benefits of associations for rubber farmers are very influential to their reduction of capital constraints and other capital for rubber farming purposes. The most beneficial social capital according to the community is an association engaged in the production, reaching 48percent. The results showed that the association engaged in the production is composed of three types of associations that developed in the community, namely: Farming Credit associations (KUT), Financial Credit, society of social groups and associations of indigenous institutional. KUT association for instance is a government-sponsored associations engaged in agriculture with activity: seed aid (crop, livestock and fish) and other assistance, financial credit assistance engaged in venture capital and other capital, while *pagayuban* and indigenous groups engaged in social field either for everyday needs(basic needs), and social activity in the development of rubber farming. Intimacy and togetherness among farmers is very beneficial in the use of shared facilities because it has a high emotional level for the common good. These findings is similar with previous ones from Kahkoren and Grootaert (Suandi 2010) in Bangladesh, for the case of management of irrigation. They find that the spirit of cooperation for the group that came from the same ethnic and needs very beneficial in the management of irrigation dams, especially the spirit of cooperation.

Another social capital which is quite important in improving farmer family needs is a group of productive work. Through this group, family income could rise further as the result of the value of family members working in the joint working group (collective action). Average family members engage in productive work groups is two people with a frequency of work twice a month and ten months effective work in a year with value of 50.000,- per person per each productive work group activities- and through the analysis it is obtained that the productive work group activities contribute to the family income Rp.1.000.000, - per year or about 8.6 percent of total family income, and this figure is much higher than the results of Suandi's study (2010) which is only 6.4%. These findings are supported by the results of research conducted by Grootaert (Suandi, 2010) that every one member of the family actively participates in the activities of local associations, especially production associations can increase family income by 6.2 percent per year.

The same study also found in Latin America, that there is a very real and positive difference in the level of activity significant family member son the activities of local associations in improving the economic welfare of the family (Durkin, 2000). On the other hand, social capital plays a role in getting access to a variety of public facilities in the community, such as: water supply and irrigation, credit, and agricultural / technology inputs. The amount of access to social capital is due to the network being built in various groups (production and social) in society. The results are not much different from the findings of Haddad (2000) in South Africa that the existence of strong individual household social capital (social networks) can contribute to obtain various forms of access in society. Results of recent research that has been proven by Granoveter (Bandiera, 2006) through research in Mozambique about the adoption of new technologies by farmers through social networks that develops in the society especially those networks built through neighborhood groups and families (bonding and bridging). His research concluded that social relationships with in the community has a very real positive impact and significant to farmers in adopting new technologies in rural areas.

Causality between the level of sustainable development of smallholder rubber plantations and business management system

Based on regression logistic analysis, some variables in business management system are found statistically to influence the sustainability with ecological system dimension at the level of 90% (see Appendix 2). Estimation of the model has satisfied the goodness of fit tests, as shown by the Pearson, Deviance and Hosmer-Lemeshow statistics. Those statistics indicate estimation could not reject the null-hypothesis as all p-values are found to be more than 0.1. This means the model is fit (the alternative hypothesis states the model is not fit). In this model the significant variables are benefit of association and working spirit. This indicates the sustainability level from ecology system dimension are influenced by the benefit generated from the association followed by farmers and their working spirit. The farmers wh0 receive the benefit and which have a higher working spirit tend to have higher level of sustainability. In this case, working spirit has a larger impact. This is indicated by the odd-ratio value from regression which is more than 5. From the regression results, this study finds the same variables (benefit of association and working spirit) influence the economic system dimension. For socio-demographic system, number of association followed is found also to affect the level of sustainability. This means two factors: benefit of association and working spirit are very important to be modified if the sustainability of rubber plantation management needs to be increased.

By using the same assesment with above results, this study finds some factors which influence other dimensions significantly. All models show that G-tests indicate the null hypothesis is rejected which means the model is overall fit. For the second dimension, four variables: number of association followed, benefit of association, trust and working spirit are found to influence the level of sustainability statistically significant. Those variables may be interpreted as important factors which help improve the sustaibility level from agronomic criteria. Those factors are important becase from the agronomic side, farmers need to increase the skills to manage the rubber plantation. In this case, the working spirit also mostly diferrentiates between low and high sustainable rubber plantation management, as indicated by it odds-ratio value.

CONCLUSION AND RECOMMENDATION

Based on the results, this study derives some conclusions as follows. Management systems of smallholders' rubber plantation in the study area still do not follow the good system of sustainable agriculture, such as the carrying capacity of the land, soil and water conservation, plant cultivation systems, garden maintenance system, and utilization of a technology package in the management of rubber plantations. Social capital (local associations and community character), either directly or indirectly, has a positive relationship with the sustainable rubber plantation development and farmer's welfare. Benefit of association received by farmers and their working spirit are statistically significant to influence the level of sustainability of rubber plantation.

Some recommendations may be proposed to policy makers. Acceleration of regional economic development policy particularly in rubber plantation and the welfare of farmers in rural areas need to consider "social capital" indicator as a determinant variable of such development. Social capital has a value of local knowledge interwoven from generation to generation into a habit and force in people's daily lives.

Social capital strengthening is very precise in empowering rural communities to accelerate the region's economic development and the welfare of farmers because social capital has the power to create a relationship between community groups and relationship among them. Acceleration of regional economic development programs in order to improve the welfare of the people in the research areas is prioritized to some efforts to increase the benefit form association followed by farmers and working spirit. They are: (a) the development of community character through various training and non-formal education including religious education, especially for the adult and elderly dropouts (head of family), (b) building teamwork system and mutual networking between community groups and other stakeholders, and (c) establishing joint work efforts through partnership and investment for rubber agricultural laborers.

ACKNOWLEDGEMENT

This research was financed by DP2M Higher Education in 2012 DIPA Dit.Litabmas DGHE accordance with Letter Agreement on Implementation of the National Master Plan for the Acceleration and priorities Expansion of Indonesian Economic Development (MP3EI), Contract Number: 226 / SP2H / PL / DIT.LITABMAS / V / 2012, dated May 23, 2012

REFERENCES

Baker, K R, O M Beth, Z Zachary, T Zhe and C Yi-Li. 2005. Reciprocal effects of health and economic well-being among older adults in Taiwan and Beijing. Working Paper No. 197. New York: Policy Research Division. Population Council: 1-24.

Bandiera, O. and I Rasul. 2006. Social networks and technology adoption in Northern Mozambique. The Economic Journal 116: 869-902.

Chantuma, A, A, Kunarasiri and P. Chantuma. 2012. Rubber new planting in Thailand: Towards the world affected on climate change, Rubber Thai Journal 1:40-47.

Cortina, J M. and G. Chen. 2001. Testing interaction effects in LISREL: Examination and illustration of available procedures. Organizational Research Methods 4 (4): 324-360.

Dinas Perkebunan Jambi, 2013. Annual Report of Dinas Perkebunan Jambi: 1-120.

Durkin, J. 2000. Measuring social capital and its economic impact. Chicago: Horis Graduate School of Public Policy Studies University of Chicago: 1-40.

Freund, A. and A Carneli. 2004. The relationship between work commitment and organizational citizenship behavior among lawyers in the private sector. The Journal of Behavioral and Applied Management. 5 (2): 93 -113.

Haddad, L. and J. Maluccio. 2000. Social capital and household well-being in South Africa: Pathways of influence. Prepared for presentation at the Study of African Economies. Washington: International Food Policy Research Institute: 1-15.

Ibok, O W, I C Idiong, N E Bassey and E S Udoh. 2014. Food security and productivity of urban food crop farming households in Southern Nigeria. Agricultural Science. 2 (3): 01-12.

Park, H A. 2013. An introduction to logistic regression: From basic concepts to interpretation with particular attention to nursing domain. Journal Korean Acad Nurs. 43(2): 154-164.

Suandi and Y Damayanti, 2010. Research Report: *Kajian Modal Sosial Masyarakat dan Ketahanan Pangan Rumahtangga di Daerah Perdesaan Provinsi Jambi Sebagai Model Pengentasan Kemiskinan. Jambi*: 1-30.

Suandi, Y Damayanti, Jamaluddin, Yulismi and Y Alia, 2011. Research Report: *Kajian Pengembangan Usaha Agrobisnis Pedesaan di Provinsi Jambi*: 1-20.

Appendix 1. Indicators of Sustainable Development Components Ecology System

Indicator	Scoring
Land capability	Very low to very high
Land cultivation system	Not precised to Precised
Soil micro elements content	Very low to very high
Pesticide use	Organic to >50% chemical
Fertilizer use	Organic to >50% chemical
Land and water conservation	Never to every year
Technology access	Very low to very high
Land suitabilty	Very not suitable to very suitable

Agronomy System

Indicator	Scoring
Rubber cultivation system	Very simple to very modern
Rubber seed use	Not certified to certified
Rubber tree management system	Very limited to high managed
Technology use	Very low to very high
Harvest system	Very simple to very modern
Level of production	25% to > 75%

Economic System

Indicator	Scoring
Income from rubber cultivation	Very low to very high
Access to Financial institution	Very low to very high
Access to local market	Very low to very high
Farm gate price	Very low to very high
Land ownershiop	25% to > 75%

Socio-Demographic System

Indicator	Scoring
Nutrients of food consumption	Very low to very high
Eating frequency	Once to more than 3 times
Food diversification	Not very diversified to very diversified
Nutrient status of family member	Very bad to very good
Family size	3 to more than 7
Education level	Under elementary to high school
Health condition	Very bad to very good

Appendix 2. Results of Logistic Regression Analysis
Logistic Regression Table for Y1

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-7,95557	0,787656	-10,10	0,000			
x1	0,587130	0,517796	1,13	0,257	1,80	0,65	4,96
x2	-0,171761	0,586656	-0,29	0,770	0,84	0,27	2,66
x3	0,475125	0,172468	2,75	0,006	1,61	1,15	2,26
x4	0,289662	0,597360	0,48	0,628	1,34	0,41	4,31
x5	0,511428	0,525549	0,97	0,330	1,67	0,60	4,67
x6	1,61503	0,188013	8,59	0,000	5,03	3,48	7,27

Log-Likelihood = -211,395
Test that all slopes are zero: G = 286,857, DF = 6, P-Value = 0,000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	109,866	139	0,968
Deviance	109,207	139	0,971
Hosmer-Lemeshow	8,945	7	0,257

Logistic Regression Table for Y2

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-7,11111	0,728466	-9,76	0,000			
x1	1,22566	0,498258	2,46	0,014	3,41	1,28	9,05
x2	-0,799361	0,517906	-1,54	0,123	0,45	0,16	1,24
x3	0,280917	0,162377	1,73	0,084	1,32	0,96	1,82
x4	1,00989	0,530538	1,90	0,057	2,75	0,97	7,77
x5	-0,569013	0,514340	-1,11	0,269	0,57	0,21	1,55
x6	1,76202	0,195457	9,01	0,000	5,82	3,97	8,54

Log-Likelihood = -231,995
Test that all slopes are zero: G = 270,733, DF = 6, P-Value = 0,000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	318,447	139	0,000
Deviance	140,362	139	0,452
Hosmer-Lemeshow	1,936	7	0,963

Logistic Regression Table for Y3

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-4,04046	0,512939	-7,88	0,000			
x1	-0,0520398	0,388748	-0,13	0,894	0,95	0,44	2,03
x2	-0,314589	0,446192	-0,71	0,481	0,73	0,30	1,75
x3	0,359114	0,132646	2,71	0,007	1,43	1,10	1,86
x4	0,487296	0,454361	1,07	0,284	1,63	0,67	3,97
x5	0,350351	0,391942	0,89	0,371	1,42	0,66	3,06
x6	0,881721	0,142273	6,20	0,000	2,42	1,83	3,19

Log-Likelihood = -316,799
Test that all slopes are zero: G = 127,415, DF = 6, P-Value = 0,000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	152,947	139	0,198
Deviance	167,875	139	0,048
Hosmer-Lemeshow	1,928	7	0,964

Logistic Regression Table for Y4

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-5,01805	0,571479	-8,78	0,000			
x1	0,967298	0,433821	2,23	0,026	2,63	1,12	6,16
x2	-0,323885	0,463169	-0,70	0,484	0,72	0,29	1,79
x3	0,330502	0,138113	2,39	0,017	1,39	1,06	1,82
x4	0,501249	0,471876	1,06	0,288	1,65	0,65	4,16
x5	-0,430835	0,446241	-0,97	0,334	0,65	0,27	1,56
x6	0,996808	0,148483	6,71	0,000	2,71	2,03	3,62

Log-Likelihood = -300,553
Test that all slopes are zero: G = 170,760, DF = 6, P-Value = 0,000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	208,276	139	0,000
Deviance	170,046	139	0,038
Hosmer-Lemeshow	8,194	7	0,316

J. ISSAAS Vol. 21, No. 1: 31-45 (2015)

COMPARISON OF INTEGRATED CROP-LIVESTOCK AND NON-INTEGRATED FARMING SYSTEMS FOR FINANCIAL FEASIBILITY, TECHNICAL EFFICIENCY AND ADOPTION
(Case of Farmers in Gunung Kidul Regency, Yogyakarta, Indonesia)

Fanny Widadie and Agustono

Department of Socio-Economic of Agriculture and Agribusiness,
Faculty of Agriculture, University of Sebelas Maret
Jalan Ir. Sutami 36 A Kentingan, Surakarta, Jawa Tengah, Indonesia 57126
Corresponding author: fannywidadie@staff.uns.ac.id

(Received: July 12, 2014; Accepted: March 31, 2015)

ABSTRACT

One of the cultivation technologies that incorporate the concept of sustainable agricultural development is mixed farming or an integrated crop-livestock farming system. In a dry field area, which is scarce in agricultural resources, the implementation of an integrated crop-livestock farming system is highly appropriate and recommended. This study aimed to compare financial feasibility and technical efficiency between farmers who have adopted an integrated crop-livestock farming system and those who employ non-integrated crop-livestock systems and to describe factors determining the adoption of an integrated crop-livestock system among farmers in Gunung Kidul Regency. Primary data were collected from 112 farmers, divided into 65 farmers who applied integrated crop-livestock farming and 47 farmers who applied non-integrated crop-livestock farming. The study was conducted on October – December 2013. Financial feasibility methods used were analysis of cost-return and B/C ratio and, for measuring technical efficiency, a stochastic frontier approach. A logit model was used to determine factors affecting adoption. The study revealed that a farming method that uses integrated crop-livestock on dry land is more profitable and efficient than non-integrated farming methods. An intercropping method combined with an integrated crop-livestock farming system on dry land can reduce production costs, increase yield and enhance farming income. The results further show that family member, education level, number of cows, farmer's income and training and frequency of contact with extension agents were the main determinants of integrated crop-livestock technology adoption among farmers.

Key words: mixed farming, intercropping, logit, stochastic frontier and dry field.

INTRODUCTION

Nowadays, the issue of sustainable agricultural production has received worldwide attention because of major problems such as uncontrolled population growth and lack of agricultural resources (arable land and water) (Herrero et al., 2010; Slangen, 2001). The negative impact of the green revolution has been a threat to crop production because of a proliferation of pests and diseases, decreased soil fertility, and overdependence on chemical fertilizers (Conway and Barbier, 2013). The main challenge for agricultural production in the near future will be how to increase crop production in the face of climate change and scarce agricultural resources (Franzluebbers et al., 2014). Therefore, practicing sustainable agriculture plays a key role in tackling these problems, particularly in maintaining crop productivity in the near future.

Sustainable agriculture is defined as both a philosophy and a system of farming rooted in values reflecting an awareness of local ecological, economic and social realities and that seek to balance environmental conservation, agricultural production, farm profit and family and community well-being (Francis and Yongberg, 1990). Among criteria for sustainable agriculture, SEARCA (1995) lists economic viability and an ecologically sound, friendly, socially just, culturally appropriate, systematic and holistic approach. Based on these criteria, the concept of agricultural sustainability is directed not only on ecological view but also is expanded broader to include economic and social-politic elements. Ecological focuses on environmental protection to increase ecosystem resources and preservation of biodiversity; economic aspects intend to assign value and management resources and increase income and rural growth; and social-political elements concern on socially acceptable improvement, wide adoption by farmers and promotion of local institutions, cooperative farmer and culture.

One of agricultural systems that having sustainability criteria are mixed farming. The mixed farming or integrated crop-livestock system (ICLS) includes several resource-saving practices and an efficient farming system that aim to achieve acceptable profits and sustained production levels while minimizing the negative effects of intensive farming and preserving the environment (IFAD, 2010). Many studies have found that utilizing CLS could increase soil fertility, soil biological activity and nutrient recycling due to the accumulation of organic matter (Salton et al., 2010; Carvalho et al. 2010), increase crop yields and increase efficiency of resource usage, particularly of fertilizers (Devendra, 1993), reduce soil erosion and environmental risk (Tichit et al., 2011) and improve farmers' livelihoods through increased pasture productivity and livestock performance indexes and creating employment in rural areas (Herrero et al., 2010; Carvalho et al., 2010). Based on these benefits, it is clearly that in the mixed farming system is correlated with agricultural sustainability criteria consisted of ecological view (use local and renewable resource, improve soil fertility); economic aspects (diversity of source income, optimization of inputs, reduce risk); and social-political elements (empower communities, create job opportunities in the rural and meet farmers need).

The sustainability of an integrated crop–livestock system (ICLS) depends greatly on the coordinated framework and complementarities between crops and livestock, and the synergies of livestock to the land (Van Keulen and Schiere, 2004). Crop residues can be used for animal feed, while livestock faeces can be recycled into manure that can enhance crop production and farm profits by maintaining soil fertility and reducing the use of chemical fertilizers (FAO, 2001; Bonaudo et al., 2014). In an ICLS, there are product exchanges between crops and livestock from two farms that are merged as one under the same ownership. Two main elements, animals and crops, are interconnected as one form of mixed-farming sustainability. The interactions between animals and crops are divided into two, direct and indirect interaction. Direct interactions occur simultaneously between grassland and or hay grazed by livestock, and indirect interactions occur in energy and manure processing as compost for the land, in the context of an integrated crop–livestock (ruminant) system. The important factor about the interaction between animals and crops in mixed farming is that it is not only aimed at a bio-technical exchange (manure and grassland) but also combined with social innovations in regard to agricultural sustainability development.

According to Devendra (1993), the kinds of crop–animal systems are identified as two types: (i) systems combining animals and annual cropping, and (ii) systems combining animals and perennial cropping. Furthermore, these animals are distinguishable as two types: (1) systems involving non-ruminants (ponds, chickens, pigs and fish), and (2) systems involving ruminants (water buffalo, cattle, goats and sheep). In developing countries, particularly in Southeast Asia, the ICLS is a well-known farming system that has long been implemented and adopted by small-scale farmers, with different types relying on local resources, agro-climate and culture. In the Philippines, there are various types of crop–animal systems that have successfully developed the integration of ruminants/non-ruminants and annual/perennial cropping. Two examples are combining rice, pigs, and fish and rice, fish, azolla and ducks. These mixed-farming systems have increased the productivity of the land, especially animal proteins, and rice yields have increased income for farmers in ways that are ecological and environmentally sustainable (Devendra, 2000). In the Mekong River Delta of Vietnam, a successful example is the combined agriculture–aquaculture rice, pigs, fish, ducks and vegetable system (Thien et al., 1996). In Indonesia, the integration system of arable cropping and ruminant production is also familiar, especially in dry-land areas of East Indonesia. The system combines crops (maize, groundnut and cassava) with shrubs and trees to produce and conserve food for cattle and goats throughout the year. As a result, the weight gain of cattle has increased 19%, and farmers' incomes increased 31% (Pamungkas,and Hartati, 2004). The integration of rice and ruminants (especially cows) is familiar in Java, where farmers also maintain small ruminants with the main purpose of providing manure for their fruit trees and paddy (Budisatria et al, 2007). In Thailand, the integration of maize baby and cattle for beef production is a good example of mixed farming that has increased the economic gain of fattening cattle (Prucsasri and Thanonwongwathana, 1995). In addition, in Malaysia much mixed farming is found in the integration of perennial cropping, especially oil palm with cattle (ruminants) and chickens (non-ruminants) (Nasir et al. 2007). Another successful example of combining perennial crops and animals has been used in the Philippines. The integration of ruminants (goats and sheep) and coconut trees over three years increased farmers' incomes (PCAARRD, 1994).

Based on these examples, it is clear that integrated crop–livestock or mixed-farming systems have been popular and traditional among farmers in Southeast Asia, with the integration of rice, vegetables, perennial crops, fish and livestock. However, the problem is that the system is still managed traditionally by small-scale farmers. As a result, the economic benefit of ICLS cannot achieve a maximum level, and product exchange is still not efficient. Although farmers practice mixed-farming systems, they still rely in part on external inputs because of the limitation of available local resources and the lack of capability in manure processing. Generally, these farmers are not commercial producers of livestock, and they usually own one or two ruminants and a few chickens and ducks maintained under a scavenging system (Devendra, 2000). For some farmers, this is not sufficient to produce manure for their lands; that is the internal challenge facing mixed farming in developing countries. Therefore, the integration of crop–livestock systems requires additional advanced technology and management in order to increase self-sufficiency and resource-use efficiency for small-scale farmers. The technologies are aimed to accelerate livestock production through, for example, crossbreeding, group housing for small ruminants, and supplementary feeding, and also to process manure. In addition, small-scale farmers should be able to shift from subsistence farming to commercial farming through the creation of a community that facilitates their ability to get input easily from its members and to improve their bargaining power in the marketplace.

The Green Revolution in the 1980s caused the existence of mixed farming to disappear among farmers; they became highly dependent on agro-chemicals and used non-renewable input resources. Since 2002, the government of Indonesia has been committed to developing ICLS through the program known as 'Sistem Integrasi Padi Ternak Sapi (SIPT)'. SIPT is one kind of mixed farming that combines ruminants (cattle and goats) and crops (rice and maize) with the major aim of increasing rice productivity. The program has been introduced and launched in 11 provinces in Indonesia, included in Yogyakarta. One of the regions in Yogyakarta that has an ICLS project for dry-field farming and has received substantial support from the local government is the Gunung Kidul Regency. Mixed farming of crops and livestock in Gunung Kidul is aimed to develop crop and livestock sustainability in dry-field farming. The SIPT program is designed to disseminate cultivation technologies for cattle, small-ruminant management, upland rice, manufacturing feed concentrate, and processing of organic fertilizer or compost.

A few recent studies have evaluated the economic impact of mixed farming in the SIPT program compared to non-mixed farming. Therefore, the major aim of the study was to evaluate the impact of the integrated crop–livestock system on financial feasibility and efficiency by comparing farmers who have adopted it with those who have not. It is very important to clarify and justify the beneficial impact of an integrated crop–livestock system in economic and financial dimensions. Although ICLS has been introduced through the SIPT program, not all farmers in the region have applied it. Furthermore, this study examines the socioeconomic characteristics that influence a farmer's willingness to adopt integrated crop-livestock farming. Therefore, policy makers might use the results of this investigation to effectively persuade more farmers to adopt the technology.

DATA AND METHODOLOGY

Data Collection

The study was undertaken in the Tepus District, Gunung Kidul Regency, in the province of Yogyakarta, Indonesia, because the region has received SIPT or ICLS programming from the government through the local agriculture ministry. A multistage sampling technique was utilised to choose the sample. Among five villages in the Tepus District, in the first stage two villages, Tepus and Sumberwungu, were purposely selected because the villages have become target areas for crop–livestock integration in the Tepus District. For the second stage, 112 farmers were randomly selected and divided into two categories: 65 farmers who had implemented an integrated crop–livestock farming system or adopters of mixed farming (38 farmers in Tepus; 27 farmers in Sumberwungu) and 47 farmers non-adopters (18 farmers in Tepus; 29 farmers in Sumberwungu)

The criteria for the inclusion of adopters in this study were farmers who had implemented SIPT and met the principles of integrated crop (intercropping) and livestock (ruminant) systems. These criteria meant that there were product exchanges between crop residues and animal faeces in their farming and that the need for organic fertilizer was met by manure from their farms' livestock. By contrast, the non-adopters were farmers who had not implemented SIPT and had not met the criteria for integrated crop–livestock systems. They maintained their crops and livestock separately or there was no interaction between crops and livestock. Furthermore, they depended heavily on external input in their farming, particularly for organic fertilizer and animal feed. The lack interaction between crops and livestock, which was indicated in using 50 percent more external inputs of organic fertilizer and/or animal feed, was not included in the criteria for adopters, because they did not meet the main aims of SIPT and ICLS, that is, minimizing external input and maximizing internal input using the concept of LEISA (Low External Input and Sustainable Agriculture) and zero waste.

The primary data was collected through questionnaires and focus group discussions. Face-to-face interviews were conducted with structured questionnaires. The household survey consisted of information about socioeconomic characteristics, input and output of their farming, and the respondents' farming and livestock management.

Cost-Return and Benefit-Cost Ratio Analysis

A financial feasibility study on farming employed analysis of cost-return and benefit-cost ratio. the formula for net income is as follows:

$$\Pi = TR - TC \qquad (1),$$

where Π is the net farming income (IDR/ha), TR is the gross return (IDR/ha) and TC is the total cost (IDR/ha). TR is derived from the price of crops (paddy, maize, cassava and peanut) per kg (IDR/kg) that is multiplied with the total crops production (Soekartawi, 2002; Spoor, 2010). Total Cost (TC) consists of fix and variable cost. Furthermore, the analysis of benefit and cost ratio is calculated by using the formula:

$$B/C\ ratio = Gross\ Return\ /\ Total\ Cost \qquad (2),$$

B/C ratio analysis is used to evaluate the financial feasibility of a business or project. If the incremental B/C ratio is more than 1 (>1), the farm business will be accepted; however, if the incremental B/C ratio is less than 1 (<1), the farm business will be rejected (Obst et al., 2007). Lastly, in order to compare the results of the two means between adopters and non-adopters, a t-test statistical analysis was employed.

Technical efficiency analysis

Technical efficiency is a component of productive efficiency reflecting the ability of the farmer to maximize output for a given set of resource inputs (Chirwa, 2003). This study used parametric frontiers with stochastic frontier approach to measure technical efficiency. The stochastic frontier approach assume the part of the deviations from the frontier are due to reflecting measurement errors and statistical noise and other parts due to specific inefficiency (Coelli et al, 1998; Battese, 1992)

According to Battese and Coelli (1995), the stochastic frontier production function is defined as follows:

$$TE_i = \exp(X_i\beta + V_i - U_i) / \exp(X_i\beta + V_i) \quad (3),$$

$$TE_i = \exp(-U_i) \quad (4),$$

where exp $(X_i\beta + V_i - U_i)$ is the actual output, and exp $(X_i\beta + V_i)$ represents the maximum of the feasible output or frontier output (Y_1^*). The difference between the observed output (Y) and the frontier output (Y^*) is embedded in U_i. If U = 0, the farm is on the frontier input, therefore, 100 per cent efficient. But if U>0, the farm is inefficient (Idiong, 2007).

The maximum likelihood estimates (MLEs) of the parameters in the stochastic frontier production model above were obtained using the software of FRONTIER 4.1, which was developed by Coelli (1994). In addition, the parameter variances, β_u^2 and β_v^2, is expressed as $\delta^2 = \delta_v^2 + \beta_u^2$ and $\Upsilon = \delta_u^2/\delta_v^2$, where Υ ranges from 0 to 1, and, if $\Upsilon = 1$, this indicates that all deviations are due to technical inefficiency, and, if $\Upsilon = 0$, inefficiency effects are absent (Coelli, 1994; Idiong, 2007).

Furthermore, the study also uses a term of the Cobb-Douglas function to estimate factors affecting the production functions in the stochastic frontier model. The specific production function is,

$$\text{Ln } Y = \beta_0 + \beta_1 \text{Ln}X_1 + \beta_2\text{Ln}X_2 + \beta_3\text{Ln}X_3 + \beta_4\text{Ln}X_4 + \beta_5\text{Ln}X_5 + \beta_6\text{Ln}X_6 + \varepsilon_i \quad (5),$$

where Y is the total output of the harvested crops (paddy, maize, cassava and peanut) in kg/ha, X_1 is farm size (m^2), X_2 is non-land farm assets (IDR), X_3 is quantity of seed (kg), X_3 is the fertilizer applied (kg), X_5 is the quantity of pesticide (ml), X_6 is labour in man-hours per week, β_0-β_6 are parameters to be estimated and ε_i is the composite error term, defined as V_i-U_i in equation (4). The models of technical efficiency and Cobb-Douglas are used separately in the two types of farming methods, integrated crop-livestock and non-integrated crop-livestock farming.

Logit model

A logit model is employed to evaluate a farmer's decision to adopt an integrated crops-livestock farming system. The most used model, which better explains the diffusion process, is the logistic function form of the regression model (Maddala, 1983). The farmer's decisions or willingness are categorical dependent variables but the factors influencing them as independent variable are multilateral. Multiple regression of logit model accommodates this kind of problem.

The general form of the logit model is as follows:

$$p_i = G(a + \sum_{j=1}^{m} \beta_i X_{ij}) = \frac{1}{1+\exp[-(a+\sum_{j=1}^{m} \beta_i X_{ij})]} \quad (6),$$

where α is a constant, β_1 is a parameter of each independent variable and m is defined as factors ranging from 1 to m. In order to explain the probability model for adopting integrated farming technology, equation (6) can be rewritten as follows:

$$Ln \frac{\rho_j}{1-\rho_j} = \alpha + \sum_{j=1}^{m} \beta_j X_j \quad (7),$$

where ρ_j is the probability of each farmer adopting the integrated farming technology and X_j is the explanatory variables illustrating the factors influencing a farmer's willingness to adopt an integrated crops-livestock farming system. The definitions, measurements, and expected directions of all explanatory variables and dependent variable can be seen in Table 1.

RESULTS AND DISCUSSION

Characteristics of farm households

In Tepus District, Gunung Kidul Regency, most farmers practice intercropping with a type of strip intercropping – growing three crops (paddy, maize and cassava) together in strips wide enough to allow independent cultivation and it is combined with crop rotation method, where after paddy and maize are harvested, peanut is planted. Over one year, the crops planted using the intercropping and crop rotation method were paddy, maize, cassava and peanut. Table 1 illustrates the demographic profile of respondents-farm households using integrated and non-integrated crop-livestock system. In the variables of family member, education level of household head and his wife, and number of cows, integrated crop-livestock system (ICLS) has a higher mean than non-integrated farming. Even though farm size and length of experience in integrated crop-livestock farming have a higher mean than non-integrated crop-livestock, statistically, there is no significant difference.

Cost-return analysis

A comparison of the cost-return analysis of intercropping cultivation technology between farmers who implemented an integrated crop-livestock system and those who did not was made (Table 2). It can be seen clearly that net income in the farming system of integrated crop-livestock farms was higher than that of non-integrated farms. The gap of net income, IDR 2,984,988.26, between adopters and non-adopters had a significant difference at the 10 per cent level. This means that the use of an integrated farming system on dry land is more profitable than the use of non-integrated methods. Adopting an integrated farming system increased net-income by 41 per cent. The total gross return of farmers adopting an integrated farming system was much higher than that of farmers who did not apply an integrated farming system. This indicates that an integrated crop and livestock farming system can increase the productivity and yield of crops. The main difference between an integrated farming system and other cultivation systems is in the use of livestock manure. According to Hoffman (2002), the benefits of using livestock manure for crops are improvements to soil fertility and the provision of N, P, K and other mineral nutrients. The largest contribution of gross return was paddy yield. Farmer-adopters produced a paddy yield at 1.3 tons ha^{-1}, but non-adopters only reached 1 ton ha^{-1}. Livestock manure in the integrated farming system can improve the physical properties of soil; as a result, crop yields are higher, particularly increased paddy harvest till 30 percent in this study.

Table1. Definitions, measurements, and expected direction of selected variables and profile of respondents

Variables	**Variable Range**	**Definition**	**Integrated crop-livestock (Adopters) (n = 65)**		**Non-integrated (Non-adopters) (n = 47)**		**Expected sign**
			Mean	**SD**	**Mean**	**SD**	
Dependent Variable:							
Technology of integrated farming system on rice-cattle	0 ~ 1 (Dummy variable)	Adopters (Farmers who applied a technology of an integrated farming system between rice and cattle) = 1; Non-adopters = 0	1	0	0	0	
Explanatory Variables:							
Experience in rice farming	Continuous variable	Head of household farmers' experience in farming *(year)*	42.04	11.46	41.04	12.19	+
Family member	Continuous variable	Number of family members in a household *(number)*	3.38***	1.2	2.78	0.85	+
Household head education level	Continuous variable	Household head spent time on formal education *(year)*	6.4***	3.04	5.25	2.95	+
Household wife education level	Continuous variable	Wife of household head spent time on formal education *(year)*	5.92**	2.6	4.57	2.98	+
Farming income	Continuous variable	Net income of farming *(IDR [1](million) /year)*	10.344*	4.085	7.359	3.138	+
Farming size	Continuous variable	Farming size (m^2)	5,231.61	3,102.8	5,091.9	2,939.7	+
Number of cows	Continuous variable	Cows (number)	1.84***	1.2	0.97	0.98	+
Employing household labour for cattle farming	Continuous variable	Time allocation of household labour for cattle farming (hours of work per week[2])	61.45**	72.08	31.52	44.84	+
Membership of organizational institution	Continuous variable	Membership and involvement in formal and informal institutional societies	1.38	1.2	1.1	1.08	+
Frequency of contact with agricultural extension services	0 ~ 1 (Dummy variable)	Often =1; Seldom = 0	0.56* (1 = 37)	0.49	0.36 (1 = 17)	0.48	+
Training of integrated crop-livestock farming system	0 ¬ 1 (Dummy variable)	Follow a training integrated crop-livestock farming system = 1; No training = 0	0.63 (1 = 41)	0.48	0.31 (1 = 15)	0.47	+

[1] IDR = "Rupiah" is Indonesian currency (note; 1USD = IDR 11,600 (approximately) as of October, 2013 currency exchange rate)

[2] Representing the average household labour time spent on farming activities, such as rice farming and cattle rearing, in hours per week.

* Mean values are significantly different from non-integrated farming at the 10% level

** Mean values are significantly different from non-integrated farming at the 5% level

*** Mean values are significantly different from non-integrated farming at the 1% level

Based on the total production cost, the total cost for farmers who applied an integrated farming system had a similar mean to that of non-integrated farming statistically. However, for variable costs such as fertilizer and pesticide/weedicide, the non-adopters had to pay more than did the adopters. It was certainly true that farmers using an integrated farming system obtained manure from their livestock waste, which is both more economical and efficient. For non-integrated farming, farmers had to pay more to get fertilizer, because mostly they do not have livestock waste resources. Farmer adopters have more cows than farmer non-adopters (Table 1). The implementation of an integrated farming system among farmers decreased fertilizer expenditure by 54 per cent. The use of pesticide/weedicide in the non-integrated method was much higher than in the integrated farming system. This was caused by a need to avoid pests, such as the leafhopper and rat, and diseases.

Table 2. Comparison of cost-return analysis of adopters and non-adopters of the integrated crop-livestock farming system

Items	Integrated crop-livestock (Adopters)	Non-Integrated crop-livestock (Non-Adopters)
Farming yield:		
- Paddy yield (quintal)	13.88**	10.08
- Maize yield (quintal)	7.37	7.64
- Peanut yield (quintal)	2.80*	2.20
- Cassava yield (quintal)	7.68**	5.58
Gross Return: (IDR)		
- Paddy	5,414,940**	3,931,863
- Cassava	1,305,809**	949,721
- Maize	3,317,953	3,439,819
- Peanut	4,208,076*	2,966,170
Total Gross Return	14,346,780*	11,287,574
Cost:		
Average of fixed cost: (IDR)		
- Field tax	56,127.69	50,019,54
- Rent (field and equipment)	1,561,176.92	1,400,548.08
- Depreciation of equipment	84,535.38	88,894.25
Sub Total	1,701,840.00	1,539,461.91
Average of variable cost: (IDR)		
- Seed	894,868.73	768,800
- Fertilizer	611,266.15**	1,334,468
- Pesticide / Herbicide	86,827.69*	531,978
- Hired and family labour	607,481.30	628,555.78
Sub Total	2,200,443.892	2,388,604.70
Total Cost	3,902,283.89	3,928,066.61
Net Income	10,344,496.11*	7,359,507.85
B/C ratio	3.39	3.35

Note: * Mean values are significantly different than non-integrated crop livestock farming at the 10% level
** Mean values are significantly different than non-integrated crop livestock farming at the 5% level
*** Mean values are significantly different than non-integrated crop livestock farming at the 1% level

Benefit-cost ratio

The mean of the B/C ratio score in each farming system is shown to be more than 1, i.e. 3.39 for the integrated method and 3.35 for the non-integrated method. This means that it was feasible to apply both integrated and non-integrated farming systems on dry land and that there was no farmer in a position of loss in terms of his farming (B/C ratio < 1). In addition, there is no significant difference in the B/C ratio mean value between integrated and non-integrated farming systems. This means that the B/C ratio among all farmers had a similar mean. The B/C ratio was 3.39 for the integrated farming system; this reveals that, for every unit of cost, the farmers gained a 3.39 unit of benefit. This can be interpreted in the same way for non-integrated farming methods with a ratio of 3.35, which means that, for every unit of cost in non-integrated farming, farmers gained a 3.35 unit of benefit.

Technical efficiency

Technical efficiency levels among farmers adopting integrated farming and non-integrated farming are presented in Table 3. The average technical efficiency level for integrated farming (0.791) was much higher than for non-integrated farming (0.677), and it was significantly different statistically. This indicates that integrated farming is more efficient than non-integrated farming. Using the efficiency index criterion of 0.70, only 26.16 per cent of all integrated farms were inefficient, and, for non-integrated farming, the figure was 53.19 per cent for the inefficiency criterion (< 0.70). The low efficiency, particularly for non-integrated farmers was caused by a combination of production factors which were not at the optimum level, though they still had the opportunity to increase crop yields by 32.3 per cent. The non-integrated farmers operated their farms lower levels of frontier production function. The high level of efficiency for farmers who used integrated farming was an indication that the usage of input production factors was optimum, and only a small fraction of the output can be attributed to wastage (Idiong, 2007).

Table 3. Technical efficiency distribution of adopters and non-adopters of the integrated crop-livestock farming system

Efficiencies	**Integrated crop-livestock**		**Non-Integrated crop-livestock**	
	Frequency	**Percentage (%)**	**Frequency**	**Percentage (%)**
< 0.5	1	1.54	5	10.64
0.5–0.59	7	10.77	9	19.15
0.6–0.69	9	13.85	11	23.40
0.7–0.79	19	29.23	12	25.53
0.8–0.89	17	26.15	9	19.15
0.9–99	12	18.46	1	2.13
Total	65	100	47	100
Average	0.791***		0.677	
Min	0.412		0.293	
Max	0.981		0.919	
Std Dev.	0.117		0.149	

Note: *** Mean value is significantly different than non-integrated farming at the 1% level

The estimation result for integrated farming in Table 4 reveals that variables of farm size, fertilizer and labour were significant parameters influencing crop production positively. If farm size, fertilizer and labour usage increase, the crop yields will increase. Meanwhile, in non-integrated farming, factors influencing crop production positively and statistically significant were farm size, non-land capital and fertilizer. This implies that, in order to increase farm yields, the use of input productions such as farm size, non-land capital and fertilizer has to increase in the case of non-integrated farming as well. The estimated gamma (ϒ) parameter in integrated farming was low (0.006) and not significantly different from zero; it can be interpreted that all deviations from the model are ascribed to random error and that inefficiency effects are absent. In contrast, the estimated value of ϒ in non-integrated farming was 0.985 and strongly statistically significant at 1 per cent, meaning a 98 per cent variation in the output of crop yields was attributed to technical inefficiency.

Table 4. Maximum likelihood estimates of the stochastic production frontier for farmers of integrated and non-integrated farming

Variables	Parameters	Integrated crop-livestock		Non-Integrated crop-livestock	
		Coefficients	**t-ratio**	**Coefficients**	**t-ratio**
Constant	β_0	-165.63***	172.03	-57.89***	12.31
Farm size	β_1	3.44***	167.94	12.96***	7.893
Non-land capital	β_2	0.087	0.4185	0.187***	4.968
Seed	β_3	0.036	0.6501	0.020	0.040
Fertilizer	β_4	0.382***	4.8330	1.867**	2.484
Pesticide	β_5	-3.404***	14.829	-14.50***	8.939
Labour	β_6	0.149*	1.6652	-0.179***	4.964
Sigma-squared		0.310***	5.520	0.652*	1.686
Gamma (Υ)		0.006	0.244	0.985***	5.474
LR		20.31		-0.28.2	

Note: Significance at *10, **5 and ***1 per cent levels of error probability

Surprisingly, the pesticide coefficient in both integrated and non-integrated farms had negative signs and was strongly significant at the 1 per cent level. This means that an increase in pesticide use will decrease farm yields. This implies that pesticide is an important variable and that the use of pesticide in sampled farms exceeded the dosage expected. The averages of pesticide use were 2.3 ml and 3.3 ml for integrated and non-integrated farming respectively. The kinds of pests most often attacking the crops in the sampled farms were rats and leafhoppers, and the most common disease was tungro disease. Therefore, the implementation of integrated pest management is needed by the farmers to minimize the usage of pesticide, which is not environmental friendly or sustainable. In addition, interestingly, the labour coefficient between integrated and non-integrated farmers has a contrast sign. This implies that, in the integrated farming, an increase in labour use will increase farm yields, and in contrast, for non-integrated farming, an increase in labour use will decrease crop yields. This indicates that the total utility of labour in integrated farming is still low, but, for farmers of non-integrated farming, labour use is too high and is not effective. Therefore, a decrease of labour use for non-adopters will effectively increase farm yields and will increase gross returns as well.

Econometric Result on Factors Determining Adoption

A logit regression model was used to estimate the direction and sizes of marginal effects of each explanatory variable. Using the statistical software Statistical Product and Service Solutions (SPSS) version 13.0, the result of the logit model is presented in Table 5. Based on the result in Table 5, the model prediction of farmers adopting an integrated farming system is 87.70 per cent while that of non-adopters or those using a non-integrated method is 70.2 per cent, and the total prediction accuracy is 80.04 per cent. This indicates that the model employed in this research is quite high for estimating the probability of farmers' decisions. The statistic LR is 98.87, which illustrates that the model's fit effect is preferable; the value of the χ^2 test is 54.48 (p-value=0.00 <0.05), which indicates that at least one variable coefficient is non-zero in the model and that it is of statistical significance. Based on the Hosmer-Lemeshow test, this shows that there are no significant differences between the observation data and prediction data. The value is 0.926 (and > 0.05). This reveals that the model's fit effect is preferable for use as estimation in explaining farmer behaviour.

The result of the logit model indicates that number family members, education level, farming income, number of cows and frequency of farmers contacting agricultural extension services and doing training are positively significant factors explaining integrated farming adoption. The number of family members in the household characteristic variable affects a farmer's decision to adopt an integrated crop-livestock farming system. As the number of family members changes per unit, the odds ratio of farmers adopting an integrated farming system will increase by 2.187. A possible explanation is that family members have a role in providing of free and timely farming labour. This could help the farm production including livestock management and also contribute to obtaining knowledge of and insight into appropriate cultivation technologies. The higher composition of family labour in the household is the higher also tendency of practicing integrated crop-livestock system. Another household characteristic affecting farmer adoption strongly is educational level. The odds ratio is 1.287, which means that, for more educated household head, the probability of selecting an integrated farming system is higher at 1.287 times that for household-head who have a low educational level. It is also in line with the wife education level that has significant influence of decision-making in selecting farming way. These results are consistent with the hypothesis. Education plays an important role in increasing knowledge and the ability to receive new methods. Educational for women has positive influence of in integrated crops-livestock adoption. Meanwhile, length of experience in farming has the expected positive sign but it is not statistically significant in influencing farmers' decisions. It means that even though the years of farming enable a farmer to understand and have better knowledge in crop and livestock management practices, it is not guarantee that the farmers will adopt ICLS technology. The new farmers in the study area had viewed ICLS as an alternative technology to increase their farm yields and they had practiced it sustainability. The young farmers seem more attractive and responsive when the new technologies were introduced.

Among farming characteristic variables, only farming income and number of cows have significant influence on farmer adoption of an integrated farming system as expected. With an increase in farming income, the desire of farmers to select integrated farming will increase. A possible reason is that a higher farming income level will increase a farmer's ability to invest in integrated crop-livestock technology, especially the purchase of cattle and compost processing tools. Farming income strongly determines whether farmers will invest in and adopt an integrated crop-livestock system. With regard to the number of cows, the odds ratio is 2.183, which indicates that the more cows' farmers have; the higher is the probability of farmers adopting an integrated farming system. Without cows, farmers will find it hard to adopt this technology. Contrary to expectations, farming characteristics like farm size and the availability of household labour for cattle do not significantly influence farmer adoption. Although farm size has significant role in influencing farm production, in the case of adoption farm size do not significant influence. Farmers who operate large farm size are sometimes less productive to optimize their yields. They do not too aware on new technology that could enhance their farm yields including ICLS technology. It is in line with household labour for cattle, even though a farmer household provides a greater family labour for operating livestock practices of manure and compost, it is not indicates the probability of farmer to adopt ICLS will increase. With the possession of small number of cows, the availability of family labour to work for cattle practices in the study area had enough.

Lastly, institutional variables that have a significant impact on farmers' willingness to adopt integrated farming are frequency of contact with agricultural extension agents and attending integrated farming system training. Farmers who make contact with extension agents and institutions are more likely to adopt an integrated farming system than are those who seldom make contact with extension agents. Contact with extension agents allows farmers greater access to the newest information in agricultural practices and, hence, increases the probability of the adoption of any agricultural technology. As hypothesized, attending integrated crop-livestock farming training has a positive effect on the adoption of integrated farming technology. Agricultural extension trains farmers in integrated crop-livestock methods through the implementation of programs of farmer schools from the agricultural ministry. They learned how to make compost, keep livestock and engage in organic cultivation and about the role of integrated crop-livestock methods. This is expected to have a positive effect on the adoption of integrated farming technology. However, contrary to the hypothesis, membership in an institution or association does not significantly influence farmer adoption of an integrated farming technology. This indicates that membership without active participation in an association does not have a significant effect on farmer adoption.

Table 5. Logit model for adoption of the integrated crops-livestock farming system

Variables	Coefficient(B)	WD	P-Value	Exp (B)
Intercept	-6.765 ***	15.438	0.000	0.001
Experience in rice farming	0.012 ns	0.295	0.587	1.012
Family member	0.782 **	7.175	0.007	2.187
Household head education level	0.252 **	6.539	0.011	1.287
Household wife education level	0.178 *	3.016	0.082	1.195
Farming income	0.000 *	3.280	0.074	1.150
Farm size	0.000 ns	0.941	0.332	1.000
Number of cows	0.781**	6.850	0.009	2.183
Household labour for cattle	0.001 ns	0.016	0.899	1.004
Membership of institutions	0.196 ns	0.842	0.359	1.217
Frequency of contact with agricultural extension service	1.271 **	4.866	0.027	3.565
Training	1.289 **	5.967	0.015	3.629
Prediction of the probability of selecting an integrated farming system	87.70%	Chi-square χ^2		54.48***)
Prediction of the probability of selecting non-integrated farming	70.2%	Negelkerke R^2		0.518
Overall probability of prediction accuracy	80.04%	Hosmer and Lemeshow test		0.926
LR	98.87			

Note: *, ** and *** represent significance at 10, 5 and 1 per cent levels of error probability, respectively and ns is non-significant

Even though integrated crop-livestock systems are much more profitable and efficient than non-integrated farming, the small-scale farmers did not adopt it at all. The main obstacle to farmers adopting it because they lack mixed farming input, particularly the livestock, and they lack the capabilities of manure processing effectively. In the main, small-scale farmers maintained small ruminants in their yard as a saving priority to provide security and capital. Another reason is providing manure for their crops and fruit; however, they do not have the ability to produce compost effectively that could meet the need of crops. They do not know the technology of compost processing well. Based on the result of the logit model and these problems, the aids of mixed farming inputs such as cows and training which aim to produce compost are very useful to accelerate integrated crop-livestock adoption. In addition, to support the development of small-ruminants management, the training and programmes which aim to increase rural livestock production should be considered by government.

CONCLUSION

A financial feasibility analysis through net income and B/C ratio values indicates that both farming systems, the integrated crop–livestock system and the non-integrated system, are feasible to apply to dry fields in the Tepus District. However, an integrated farming system is more profitable than non-integrated farming systems, as shown by the higher net-income value. The implementation of integrated farming systems could increase farmers' net income by 41% and their paddy yields by 30%. There was no significant difference between integrated and non-integrated farming based on the B/C ratio score. The study further revealed that the integrated-farming system was more efficient than non-integrated farming, based on the average score of the technical efficiency level (0.791 and 0.677, respectively). Therefore, it can be concluded that the implementation of integrated crop–livestock farming on dry land is more economical and more efficient than non-integrated farming.

With regard to the logit model analysis, factors such as number of family members, educational level, farming income, number of cows, and frequency of contact with extension agents as well as attending integrated-farming training are positively correlated to farmers' adoption of integrated farming systems. In order to disseminate this technology to farmers effectively, the government should provide training for farmers through role-plays with extension agents. Technology extension and demonstrations of integrated crop–livestock farming systems will increase farmers' willingness to adopt integrated-farming technology. Most farmers still lack the latest information regarding agricultural practices and lack capabilities in producing manure effectively, so appropriate training in integrated crop-livestock farming is very useful for increasing its adoption. At the same time, to facilitate this technology and make its adoption more likely, the government should also provide productive aids and inputs that support integrated farming such as cows, crossbreeding technology and small-ruminants development. The availability of these inputs is very useful for farmers to increase the manure production. In addition, programmes that increase farmers' incomes and provide free education for poor people should be continued and/or considered by the government; such programmes have a great impact not only on rural development but also for supporting the adoption of agricultural innovation and integrated farming among small-scale farmers. With higher incomes, farmers will be able to invest in mixed farming technology, and with more education, farmers will be able to practice mixed farming more easily and effectively.

ACKNOWLEDGEMENT

Special thanks are directed to the Directorate General of Higher Education, Indonesia Ministry of Education and Culture, and BOPTN, SebelasMaret University for funding this research through the competitive research grant " Hibah Pemula 2013" and "Hibah Peneliti Utama 2014".

REFERENCES

Battese, G.E. 1992. Frontier production functions and technical efficiency: a survey of empirical applications in agricultural economics. Agricultural Economics 7, 185-208.

Battese, G. E. and T. J. Coelli. (1995). A model for technical efficiency effects in a stochastic frontier production function for panel data. Empirical Economics, 20, 325–332.

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F. and M. Tichit. 2014. Agroecological principles for the redesign of integrated crop–livestock systems. European Journal of Agronomy, 57, 43–51.

Budisatria, I.G.S., Udo, H.M.J., Eilers, C.H.A.M. and A.J. van der Zijpp. 2007. Dynamics of small ruminant production: a case study of Central Java, Indonesia. Outlook Agric. 36, 145-152

Carvalho, D.F., P. C., Anghinoni, I., de Moraes, A., de Souza, E. D., Sulc, R. M., Lang, C. R., and C. Bayer. 2010. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. Nutrient Cycling in Agroecosystems, 88(2), 259–273.

Chirwa, Ephraim W. 2003. Sources of technifal efficiency among smallholder maize farmers in Southern Malawi. Wadonda Consult Working Paper WC/01/03. University of Malawi, Chancellor College, Department of Economics. pp. 1-22 .

Coelli, T. J. 1994. A Guide to Frontier 4.1: A Computer Programme for Stochastic Frontier Production and Cost Function Estimation, CEPA Working Paper. Armidale, NSW Australia: Department of Econometrics, University of New England. pp. 3-8.

Coelli, T.J., Prasada, R. and G.E. Battese. 1998. An Introduction to Efficiency and Productivity Analysis. Boston: Kluwer Academic Press. p. 242

Conway, G. R., and E. B. Barbier. 2013. After the Green Revolution: Sustainable Agriculture for Development. Routledge, UK. pp. 105-107

Devendra, C. 1993. Sustainable Animal Production from Small Farm Systems in South East Asia. FAO Animal Production and Health Paper. FAO Rome. pp. 52-54

Devendra C. 2000. Crop-animal systems in tropical regions: Review. Asian- Australasian Journal of Animal Sciences: 13(2): 265-276

Food and Agriculture Organization [FAO] of the United Nations. 2001. Mixed crop – livestock farming: a review of traditional technologies based on literature and field experience. Animal Production and Health Papers, pp 152.

Francis, C., and G. Youngberg. 1990. Sustainable agriculture: an overview. In C. A. Francis, C. B. Flora, and L. D. King (Eds.), Sustainable Agriculture in Temperate Zones. New York, NY: Wiley. p. 1-12

Franzluebbers, A. J., Lemaire, G., de Faccio Carvalho, P. C., Sulc, R. M. and B. Dedieu. 2014. Toward agricultural sustainability through integrated crop-livestock systems: environmental outcomes. Agriculture, Ecosystems and Environment, 190, 1–3.

Herrero, M., Thornton, P. K., Notenbaert, a M., Wood, S., Msangi, S., Freeman, H., and M. Rosegrant. 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science (New York, N.Y.), 327(5967), 822–5.

Hoffman, I. 2002. Crop-livestock interaction and soil fertility management in northwest Nigeria. In First Virtual Global Conference on Organic Beef Cattle Production, September, 02 to October, 15, 2002. p.2.

Idiong, I. C. 2007. Estimation of farm level technical efficiency in small scale swamp rice production in cross river state of Nigeria: a stochastic frontier approach. World Journal of Agricultural Sciences, *3*(5), 653–658.

International Fund for Agricultural Development [IFAD]. 2010. *Integrated crop-livestock farming system*. Rome, Italy. Retrieved from: http://www.ifad.org/lrkm/factsheet/integratedcrop.pdf (Accessed March 22, 2014). pp. 1-2.

Maddala, G. S. 1983. Limited Dependent Variables and Qualitative Variables in Econometrics. Cambridge, England: Cambridge University Press. p. 13

Nasir, B., H. Ragu and A. Fadila. 2007. Integrated tree crops-livestock farming: experience in FELCRA Bhd. Proc. Integrate tree crops-ruminant systems, (ITCRS): assessment of status and opportunities in Malaysia (Ed. C. Devendra, S. Shanmugavelu and H.K. Wong). Academy of Sciences, Kuala Lumpur, Malaysia, pp. 102-111.

Obst W.J., Rob, G. and C. Graham. 2007. Financial Management for Agribusiness. Coalingwood, Australia: Landlinks Press. pp. 220-225.

PCAARRD. 1994. Philippines recommends for sustainable integrated small ruminants-coconut systems. PCAARRD Philippines Series No. 77, PCAARRD, Los Banos, Philippines, p. 57

Pamungkas, D and Hartati. 2004. The role of animal in farming system sustainability). Proceeding National seminar integrated crops-livestock system. Balai Pengkajian Teknologi Pertanian Bali dan Crop-Animal Systems Research Network (CASREN) (In Indonesian). pp. 304-312

Prucsasri, P. and S. Thanomwongwathana. 1995. Integration of beef cattle and baby maize production. In Crop-Animal Interactions (Eds. C. Devendra, and C. Sevilla). IRRI, Los Banos, Philippines, p. 241-247.

Salton, J. C., CostaB, A. R. and C. J. A Zanata. 2010. Aggregation of an oxisol under management systems for 14 years in the midwest of Brazil. In Proceedings of the 19th World Congress of Soil Science: Soil solutions for a Changing World, *Brisbane, Australia, 1-6 August 2010*. International Union of Soil Sciences (IUSS), c/o Institut für Bodenforschung, Universität für Bodenkultur. pp. 13-16.

Southeast Asian Regional Center for Graduate studies and Research in Agriculture [SEARCA]. 1995. Working Paper on Sustainable Agriculture Indicators. Laguna, Philippines: SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA) College. p. 101.

Slangen, Louis H.G. 2001. Sustainable agriculture: getting the institutions right (No.1). CEESA (Central and Eastern European Countries) discussion paper/Humboldt-Universitat Berlin, Department of Agricultural Econonomics and Social Sciences. p. 6.

Soekartawi. 2002. Farming Analysis. Jakarta, Indonesia UI-Press. (In Indonesian). p. 110.

Spoor, M. 2010. Dragon with Clay Feet: Transition, Sustainable Land Use, and Rural Environment in China and Vietnam. United Kingdom: Lexington Books. pp. 218-219.

Thein, N., N. Cong Quoc, D. Xuan Tuyen and M. Sasaki. 1996. Rice-fish-duck-pig production in Vietnam. Proc. Symp.. on Integrated systems of animal production, in the Asian region, Tokyo, Japan (Ed. H. Hayakawa, M. Sasaki and K. Kimura). FAO, Rome, Italy, pp. 53-57

Tichit, M., Puillet, L., Sabatier, R., and F. Teillard,. 2011. Multicriteria performance and sustainability in livestock farming systems: functional diversity matters. Livestock Science, 139(1), 161-171.

Van Keulen, H. and H. Schiere. 2004. Crop-livestock systems: old wine in new bottles. In new directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, 26 September – 01 October, Brisbane, Australia. p. 9.

CULTURE FILTRATE OF PLEUROTUS OSTREATUS ISOLATE Poa3 EFFECT ON EGG MASS HATCHING AND JUVENILE 2 OF *Meloidogyne incognita* AND ITS POTENTIAL FOR BIOLOGICAL CONTROL

Amornsri Khun-in [1], Somchai Sukhakul[1], Chiradej Chamswarng[1], Prapaporn Tangkijchote[2] and Anongnuch Sasnarukkit[3]

[1]Department of Plant Pathology, Faculty of Agriculture at Kampheang Sean, Kasetsart University, Kampheang Sean Campus, Nakhon Pathom, 73140, Thailand.
[2]Department of Horticulture, Faculty of Agriculture at Kampheang Sean, Kasetsart University, Kampheang Sean Campus, Nakhon Pathom, 73140,Thailand.
[3]Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Bangkok, 10900, Thailand.
Corresponding author: agrscsk@ku.ac.th

(Received: July 17, 2014; Accepted: April 6, 2015)

ABSTRACT

A possible alternative to chemical nematicides is the use of biological control agents for the management of root - knot nematode. This research was conducted from 2006 to 2008. One *Pleurotus ostreatus* isolated from Nakhon Pathom locations in Thailand, was evaluated for their *in vitro* antagonistic effects against egg masses and the juveniles 2 (J2) stage of root knot nematode, *Meloidogyne incognita.* Toxic droplets water agar tests demonstrated that *P. ostreatus* isolate Poa3 gave significantly higher colonized egg masses and parasitized hatching J2. Filtrates of the tested Poa3 grown in 1% malt extract broth were toxic to the infected egg masses and J2. The results showed that the culture filtrate of Poa3 reduced egg hatching and paralyzed juveniles of *M. incognita* after inoculation. The egg masses on tomato roots, the density of J2 and the number of galls were reduced in screen house bioassays of tomato plants parasitized by *M. incognita*.

Key words: nematode management, egg hatching and paralysis.

INTRODUCTION

In Thailand, the most destructive group of plant parasitic nematodes (PPN) is root-knot nematodes (RKN) or *Meloidogyne* spp., which exist in soils fromthe temperate and tropical regions. The most prevalent root-knot nematode in the northern part of Thailand is *Meloidogyne hapla* (*Mh*), whereas *M. incognita* (*Mi*) and *M. javanica* (*Mj*) are found in the central part of the country. The *Mi* is the most widespread, attacking more than 2,000 plant species including the families of Solanaceae, Cucurbitaceae and many others. They cause severe yield losses, approximately 78 billion US dollars worldwide annually (Sun et al., 2006; Caillaud et al., 2008). Nematicides are widely used for pest control, nevertheless current effective nematicides, such as carbofuran and others will be prohibited in the future because of their negative environmental impact. In addition, the safer newly introduced chemical pesticides are not 100 percent effective. Moreover, various problems were found in plants grown in greenhouses after continue application of the pesticides. This effect may consequently cause environment pollution, resulting in reduced biodiversity and impacts on food safety.

Currently, biological control of plant parasitic nematodes is one of the alternative measures receiving much attention around the world. The existing management procedures for nematode control can be enhanced by biological control strategies (Siddiqui and Shahid, 2003). Mushrooms have been reported for the ability of controlling root-knot nematodes. The fungi can directly infect some nematodes using their mycelia and produce nematotoxin (Khun-in et al., 2005). The mushroom *Pleurotus ostreatus* is considered to be a successful biological control agent against nematode. It immobilizes the second stage juveniles of *M. incognita* by parasitized oyster mushroom mycelia (Khun-in et al., 2005 and Heydari et al, 2006). Barron and Thorn (1987) reported that nematode which touched such droplets, showed an instant response in the form of the head region shrinking, hyphae infected the body orifices and homed.

Previously, the *P. ostreatus* isolates Poa3 could directly parasitize the infective juvenile 2 of *M. incognita* (Khun-in et al., 2005**)** (Fig 1). However, another stage of the nematode is the egg mass which is the critical stage for producing abundant infective juvenile 2. It has been reported that the nematode produce the secondary metabolite (Sun et al., 2006 and Ruanpanun et al., 2010), resulting in a deformed egg (Khun-in et al. 2005**).** *P. ostreatus* isolate Poa3 had the ability of antibiosis mechanism against the egg mass and juvenile 2 of *M. incognita*. Therefore, the objectives of this study were to investigate the effects of culture filtrate of *P. ostreatus* isolate Poa3 on egg hatching and juvenile 2 of *M. incognita* and to examine its potential for controlling *M. incognita*.

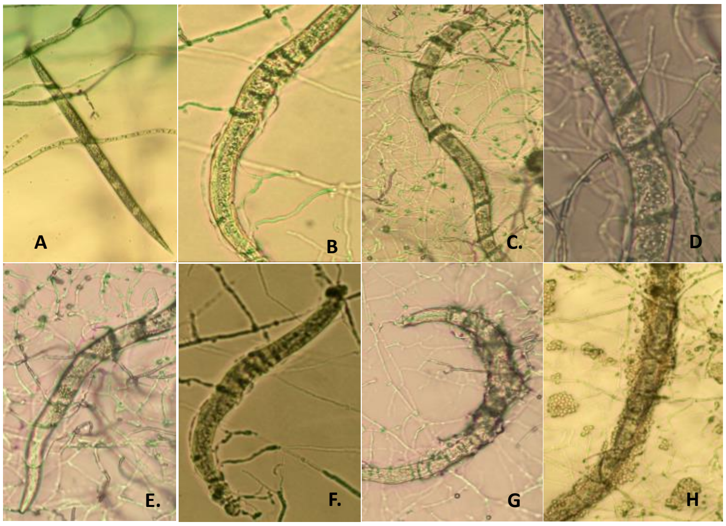


Fig. 1. Nematode trapping structures of *P. ostreatus* isolate Poa3 on water agar culture (A-G). Hysis of *M. incognita* J2 after infection and colonization by hyphae of *P. ostreatus* isolate Poa3.

MATERIALS AND METHODS

Nematode collection

Infective juvenile 2 (J2) of *M. incognita* were collected from Petchaburi Province (12º41'49.5"N99º54'15.1"E). The nematode was identified using the perennial pattern as described by Taylor and Netscher (1974). *M. incognita* was inoculated on tomato seedlings in a greenhouse from a single egg mass for 45 days. Just one egg mass was collected from infested roots and surfacedisinfected with 0.1% sodium hypochlorite (NaOCl) solution. For the J2 preparation, eggs in water were incubated at room temperature (RT) for 48 hr or more until eggs hatched, the J2 were carefully removed and immediately used for experiments (McClure et al., 1973).

P. ostreatus isolate Poa3 cultures

The fungal isolation of Poa3 was provided by Associate Professor Dr. Prapaporn Tangkijchote. Sampling sites were in Nakhon Pathom Province (lat.14º01'54.5"N and long 99º58'11.6"E) in 2003. Fruit body morphogenesis and amplified fragment length polymorphism (AFLP) technique (Anna et al., 2012) was used to identify genus and specie of the fungus. The fungus were cultured onto potato dextrose agar (PDA) and incubated at 25°C for 7 days. The hyphae were transferred to PDA for testing *in vitro* for antagonistic activity against *M. incognita*.

Parasitism and antibiosis effects of *P. ostreatus* isolate Poa3 on nematode egg mass

The active hyphae of isolate Poa3 grown on PDA were used to test for its parasitism effect on nematode egg mass and its antibiosis effect on nematode egg hatching. One plug of the fungal isolate Poa3 was placed at the center of water agar (WA) plates and cultured for 7 days at room temperature. The fungi approximately radiated 3-3.5 cm from the agar plug. Four egg masses of *M. incognita* were placed far from the edge of the fungal colony about 1 cm. The plate was incubated at room temperature and periodically observed for number of infected nematode egg mass and number of eggs hatched by using a compound microscope at 6, 12, 24, 48, 72 and 96 h after application. The eggs, juveniles and dead juveniles were then counted and egg hatching rate and juvenile mortality were calculated according to the following formulas: egg hatching rate = 100 x juveniles/(eggs + juveniles) and juvenile mortality = 100 x dead juvenile/total juvenile (Sun et al., 2006). All experiments were conducted in 7 replications.

P. ostreatus isolate Poa3 culture filtrates

The fungal isolate Poa3 was cultured in Erlenmeyer flasks (500 mL) containing 250 ml of potato dextrose broth (PDB) + 1% of yeast extract. Each flask was inoculated with a 1 cm agar block derived from 5-day-old fungal colonies grown on PDA. The fungi were cultured for one week on a rotary shaker, at a low speed of forward and backward motion at room temperature (25-28ºC). The filtrate was first passed through a layer of filter paper (Whatman Cat. No: 1001110) and then filtered through a 0.45 µm membrane filter. The filtrate was used at concentrations of the original preparation and diluted to 25/100, 50/100 (Heydari et al., 2006).

Effect of *P. ostreatus* isolate Poa3 culture filtrate on *M. incognita* juvenile mortality

Two hundred J2 of nematode were added into each well of a 24-well plate containing 1 ml of each concentration of isolate Poa3 filtrates mentioned above. The same amount of avermectin and a sterile water was used as positive and negative control, respectively. Five replicates were tested per treatment. Each well was used as a replicate. Viability of the J2 was determined after 12, 24, 48, 72, and 96 h of incubation. The infective juveniles and dead juveniles were then counted and juvenile mortality rates were calculated according to the following formula: Juvenile mortality = 100 x dead juveniles/total juvenile (Sun et al., 2006).

Juveniles that did not move even after touching the tail were considered to be dead. After the incubation period, the fungal culture filtrate was replaced with tap water and mortality of the egg mass and infective juveniles were checked after 12-120 h. All experiment were conducted in 7 replications.

Effect of *P. ostreatus* isolate Poa3 culture filtrate on *M. incognita* egg mass

One sterilized egg mass of *M. incognita* was mixed with 1 ml Poa3 filtrate of each different dilutions, 25/100, 50/100 and 100 and dropped in 24 wells tissue culture plate. Egg mass in a sterile distilled water and 10µg ml^{-1} abamectin were served as negative and positive control, respectively. Each treatment contained five replication. The plate was incubated at room temperature (25-30°c) and the number of egg hatching was checked at 6, 12, 24, 48, 72 and 96 h post inoculation, respectively. The percentage of hatched eggs were calculated according to the procedures described by Heydari et al., 2006. Eggs that did not hatch and juveniles that did not move were considered to be dead. The culture filtrate was replaced with a tap water after incubating for 12-96 h and the mortality of the egg mass and juveniles were checked. All experiments were conducted in 7 replications.

Relationship between inoculum density and plant growth after applying the *P.* ostreatus isolate Poa3 culture filtrates

The experimental design was a completely randomized design with 12 treatments, 7 replications (tomato seedlings). The number of galls and total egg masses were recorded, and recoded to galling index which based on a scale of 0 = no galls; 1 = 1 to 5 galls; 2 = 6 to 20 small galls; 3 = more than 20 galls homogeneously distributed in the root system; 4 = reduce and deform root system with some large galls; and 5 = completely deformed root system with few but large galls (Di et al., 1979).

The treatment were the treated hatched eggs and J2 from each plate after 6, 12, 24, 48, 72, 96 and 120 h post inoculated and untreated hatched and J2 for the control. All treatments were inoculated on 10-day-old tomato seedlings in a pot for 45 days under screen house conditions.

Statistical analysis

All data were subjected to analysis of variance (ANOVA) using Tukey's range test (p<0.05) T-test was used to rank the pathogenicity level of Poa3 with *M. incognita* egg and juveniles. All experimental data were analyzed by SPSS program version 18.0 (2007 SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Parasitism and antibiosis effects of *P. ostreatus* isolate Poa3 on nematode egg mass

Results showed that egg mass of *M. incognita* was aggressively attacked by isolate Poa3 as time went by. The fungus infected the eggs using its hyphal tips to penetrate and colonize the eggs, and then digested the embryos within eggs during the early stages of infection (Fig. 2). This also revealed the ability of the fungus to destroy J2 of nematode inside egg masses, as well as after hatching (Table 1). Our results were similar to that of other fungal egg-parasites report by Gortari and Hours (2008) who demonstrated that the parasite caused death of the nematode by halting the embryo development, resulting in the reduction of host population growth.

Table 1. Percentage of mycelial infectivity and egg mass hatching after *M. incognita* were infected by hyphae of *P. ostreatus* isolate Poa3.

Treatment	Period (h)	Percent infection	
		Mycelia infectivity	Egg mass hatching
Control	12	0 ±0.0[d]	3.1±1.6[h]
	24	0±0.0[d]	27.7±2.9[e]
	48	0±0.0[d]	60.0±6.2[d]
	72	0±0.0[d]	80.1±5.6[c]
	96	0±0.0[d]	95.8±4.1[b]
	120	0±0.0[d]	135.1±5.2[a]
P. ostreatus	12	14.2±13.4[d]	1.14±1.1[h]
	24	42.8±12.2[c]	14.7±2.6[g]
	48	75.0±14.4[b]	21.5±2.4[ef]
	72	100.0±0[a]	16.0±2.4[fg]
	96	100.0±0[a]	14.7±1.8[g]
	120	100.0±0[a]	12.5±2.4[g]

Note: Means followed by different superscript letter in each column are significantly ($p < 0.05$) different from each other.

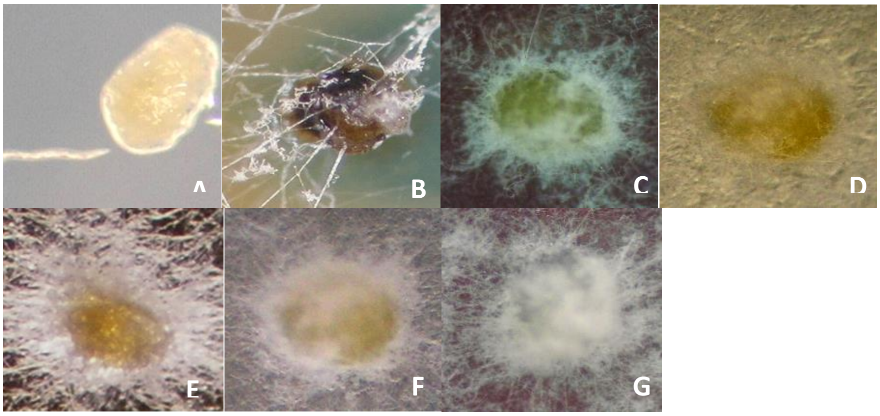


Fig 2. Egg mass of *Meloidogyne incognita* parasitized by *Pleurotus ostreatus* isolate Poa3 after egg mass inoculation with the fungus 12, 24, 48, 72 and 96 hours (panel B-G, respectively). Panel A represents only egg mass as a control treatment without fungal inoculation.

Effect of *P. ostreatus* isolate Poa3 culture filtrate on *M. incognita* juvenile 2

The effect of culture filtrates of the Poa3 in potato dextrose broth; paralyzed J2 after an exposure period of 48 h and all J2 after 72h. The dilute 10^{-2} of culture filtrates isolate Poa3 at 100% was tested for effect on J2 of *M. incognita*. The mortality showed significance compared with the control except for 50/100 and 75/100 dilutions. At 72 and 96 h after filtrates exposure, the effect of avermectin on percentage mortality significantly higher than the effects of the culture filtrates, except at 10 mg/ml, (Table 2). The isolate Poa3 was capable of producing tiny appendages on the vegetative hyphae which secreted droplets of a potent toxin as described by Thorn and Barron (1984), Barron and Thorn (1987) and Peterson (1993). When nematodes came into contact with this culture filtrate, they suddenly and dramatically became immobilized in a few minutes (Tadaaki Satou et al. 2008).

Table 2. Effect of Poa3 culture filtrates on Juvenile 2 mortality at various exposure time.

Treatment	Dilution	Juvenile mortality (%)					
		6 h	**12 h**	**24 h**	**48 h**	**72 h**	**96 h**
Control (water)	0	$0±0.0^{a}$	$0±0.0^{a}$	$0±0.0^{a}$	$0±0.0^{a}$	$0±0.0^{a}$	$0±0.0^{a}$
Avermectin	10 ppm	$1.4±1.1^{e}$	$4.8±1.1^{e}$	$25.8±1.6^{d}$	$35.8±2.5^{c}$	$43.8±2.3^{b}$	$56.6±2.5^{a}$
	50 ppm	$6.8±1.9^{d}$	$10.2±1.1^{d}$	$35.2±1.9^{c}$	$37.2±2.9^{c}$	$50.4±1.9^{b}$	$65.4±2.1^{a}$
	100ppm	$10.6±1.9^{e}$	$15.0±1.8^{d}$	$42.0±2.2^{c}$	$42.6±2.1^{c}$	$58.0±1.6^{b}$	$70.2±2.8^{a}$
Poa3	25/100	$0±0.0^{d}$	$0.6±0.5^{d}$	$4.0±1.0^{c}$	$6.8±1.3^{c}$	$17.0±2.0^{b}$	$25.2±2.9^{a}$
	50/100	$0±0.0^{d}$	$1.4±0.5^{d}$	$12.8±1.9^{d}$	$14.8±1.8^{c}$	$25.8±1.9^{b}$	$33.4±2.7^{a}$
	75/100	$0.6±0.5^{e}$	$3.0±1.0^{e}$	$17.8±2.2^{d}$	$24.6±2.3^{c}$	$37.2±2.9^{b}$	$44.8±2.8^{a}$
	100%	$1.0±0.0^{f}$	$5.4±1.9^{e}$	$24.0±1.6^{d}$	$36.0±2.7^{c}$	$46.4±2.4^{b}$	$55.2±2.6^{a}$

Note: Means followed by different superscript letter in the same row are significantly ($p < 0.05$) different.

Effect of *P. ostreatus* isolate Poa3 culture filtrate on *M. incognita* egg mass

The hatchability test (Table 3) demonstrated that culture filtrates of Poa3 strongly suppressed hatching of *M. incognita* egg masses. The percentage reduction ranged from 0.4 to 43.5%. The different concentrations of the culture filtrate exhibited significant differences compared to the control; only the 25/100 dilution had no significant difference when compared to the avermectin.

Table 3. Effect of *P. ostreatus* isolate Poa3 cultures filtrate on *M. incognita* egg hatching at various exposure times.

Treatment	**Dilution**	**Egg hatched (%)**					
		6 h	**12 h**	**24 h**	**48 h**	**72 h**	**96 h**
Control	0	$0±0.0^{f}$	$10.7±1.8^{e}$	$20.1±3.2^{d}$	$40.5±2.6^{c}$	$71.0±2.4^{b}$	$107.0±5.8^{a}$
Avermectin	10 ppm	$0±0.0^{f}$	$4.1±1.3^{e}$	$12.8±2.5^{d}$	$29.1±2.0^{c}$	$42.7±3.6^{b}$	$52.1±3.0^{a}$
Poa3	25	$0±0.0^{f}$	$5.0±1.9^{e}$	$16.8±2.4^{d}$	$34.2±3.7^{c}$	$56.4±2.9^{b}$	$70.0±2.6^{a}$
	50	$0±0.0^{e}$	$2.1±0.7^{e}$	$9.4±1.7^{d}$	$25.7±3.7^{c}$	$34.5±2.7^{b}$	$43.5±3.7^{a}$
	75	$0±0.0^{e}$	$1.0±0.8^{de}$	$4.2±1.5^{d}$	$12.5±1.1^{c}$	$22.1±3.6^{b}$	$32.1±2.7^{a}$
	100	$0±0.0^{d}$	$0.4±0.5^{d}$	$1.1±0.4^{d}$	$5.2±1.8^{c}$	$11.0±2.6^{b}$	$23.4±2.1^{a}$

Note: Means followed by different superscript letter in row are significantly ($p < 0.05$) different from each other.

The variables evaluated included egg parasitism, egg hatch rate variations could be related to other mechanisms like antibiosis, competition and predation besides parasitism (Cayrol 1983; Kwork et al., 1992; Zaki 1994). Previous findings showed that culture filtrate from the same Poa3 isolated induced juvenile mortality and inhibited *M. incognita* egg hatching. A compound microscopy study of treated egg masses showed severe alterations caused by the filtrate of isolate Poa3 on *M. incognita* egg masses suggesting that enzyme and toxin-based strategies were part of the Poa3 nematocidal behavior (Regaieg et al.2010).

Relationship between inoculum density and plant growth after applying the *Pleurotus* culture filtrates

The efficacy of the root-knot nematode control agents were tested under greenhouse conditions to evaluate the most antagonistic activity of Poa3. The culture filtrates of Poa3 reduced the numbers of root galls index after exposure for periods of 72 to 120 h when compared with other periods and the control (inoculated) at 45 days after inoculation with *M. incognita*, (Table 4).

The number of *M. incognita* egg masses on roots were significantly (P\0.05) affected by Poa3 (Table 3). The application of Poa3 reduced the J2 density as well as the number of galls by 0.1gall/plant/ period of 120 h, when compared to the control. Finally, the galling inside roots clearly demonstrated that Poa3 filtrate inhibited the hatching of nematode egg masses. Comparison of Poa3 to others which are good candidates for practical exploitation in bio-control, such as *Paecilomyces lilacinus* (Kiewnick and Sikora, 2006) and *Trichoderma* spp. (Thienhirun et al. 1997), Poa3 shows similar or higher levels of nematode control.

Table 4. Average numbers of galls and egg masses of *M. incognita* in tomato seedlings roots after were infected by hyphae of *P. ostreatus* isolate Poa3

Treatment	Period (h)	Index of investigation	
		Number of galls	Egg mass in roots
Control	12	98.1±6.6^{a}	21.0±2.2^{a}
	24	97.8±9.9^{a}	21.8±3.9^{a}
	48	103.8±5.2^{a}	20.4±2.3^{a}
	72	97.4±5.9^{a}	19.5±1.4^{a}
	96	98.8±9.0^{a}	18.2±2.8^{a}
	120	99.8±4.9^{a}	20.0±3.0^{a}
P. ostreatus	12	48.4±3.5^{b}	3.7±0.8^{b}
	24	51.4±3.3^{b}	3.7±0.8^{b}
	48	28.2±3.9^{c}	1.5±1.0^{b}
	72	0.7±0.8^{d}	0±0.0^{b}
	96	0.2±0.5^{d}	0±0.0^{b}
	120	0.1±0.4^{d}	0±0.0^{b}
Control (healthy)	-	0±0.0^{d}	0±0.0^{b}

Note: Means followed by different superscript letter in each column are significantly ($p < 0.05$) different from each other.

CONCLUSIONS

The culture filtrate from *P. ostreatus* isolate Poa3 shows antagonistic effect on both egg hatching and juvenile 2 of *M. incognita*. Results from greenhouse experiments demonstrate its potential for biological control of root-knot nematode. Field experiments should be investigated in the future to test the efficacy of the fungal filtrate for controlling the disease caused by *M. incognita*. In addition, the biologically active substance(s) in fungal filtrate of isolate Poa3 affecting both nematode egg hatching and juvenile 2 should be further investigated.

ACKNOWLEDGEMENT

The authors would like to thank Associate. Prof. Dr. Prapaporn Tangkijchote who provided the *P. ostreatus* and Assistant.Prof. Udom Farongsang, who obtained the compound micrographs.

REFERENCES

Anna, P, Grzegorz, J, Joanna, K, Wanda, M and R. Jerzy. 2012. Genetic diversity of the edible mushroom *Pleurotus* sp. by amplified fragment length polymorphism. Curr. Microbiol., 65:438-445.

Barron, G.L and R.G. Thorn. 1987. Destruction of nematodes by species of *Pleurotus*. Can. J. Bot., 65:774-778.

Caillaud, MC, Dubreuil, G, Quentin, M, Perfus-Barbeoch, L, Lecomte, P, Engler, JDA, Abad, P, Rosso, MN and B. Favery. 2008. Root-knot nematode manipulate plant cell functions during a compatible interaction. J Plant Physiol. 165:104-113.

Cayrol, J.C. 1983. Lutte Biologique contre les *Meloidogyne* au moyen d′ *Arthrobotrys irregularis*, Revue de Nematologie. 6:265-273.

Di, Vito, Lamberti, F and A. Carella. 1979. La resistenza del pomodoro nei confronti dei nematodi galligeni: prospettive e possibilit. Rivista di Agronomia. 13:313-322.

Gortari, MC and RA. Hours. 2008. Fungal chitinases and their biological role in the antagonism onto nematode eggs. A Rev Mycol Progress. 7:221-238.

Heydari, R, Pourjam, E and E. Mohammadi Goltapeh. 2006. Antagonistic effect of some species of *Pleurotus* on the root-knot nematode, *Meloidogyne javanica in vitro*. J Plant Pathol. 5(2): 173-177.

Kiewnick, S and R.A. Sikora. 2006. Biological control of the root-knot nematode, *Meloidogyne incognita* by *Paecilomyces lilacinus* strain 251. Biol Control. 38:179-187.

Khun-in, A, Sukhakul, S, Chamswarng, C and P. Tangkijchote. 2005. The influence of some mushrooms on root-knot nematode, *Meloidogyne incognita*. MS. Thesis, Graduate School of Kasetsart University of Agriculture. Nakhon Pathom. Thailand.

Kwork, O.C.H, Plattner, R, Weisleder, D and D.T. Wicklow. 1992. A nematicidal toxin from *Pleurotus ostreatus* NRRL 3526. J Chem Ecol. 18:127-136.

McClure, M.A, Kruk, T.H and I. Misaghi. 1973. A method for obtaining quantities of clean *Meloidogyne* eggs. J Nematol. 5:230.

Peterson, R.H. 1993. Cultural characters and asexual reproduction as aids in separating genera of *Pleurotoid basidiomycetes*. Inoculum. 44:53.

Regaieg, H, Ciancio, A, Horrigue Raouani, N, Grasso, G and L. Rosso. 2010. Effect of culture filtrates from the nematophagus fungi *Verticillium lebtobactrumon* viability of root-knot nematode *Meloidogyne incognita*. World J Microbiol Biotechnol. 26:2285-2289.

Ruanpanum, P.N, Tangchitsomkid, K.D, Hyde and S. Lumyong. 2010. Actinomycetes and fungi isolated from plant-parasitic nematode infested soils: screening of effective biocontrol potential, indole-3-acetic acid and siderophore production. World J. Microbiol. Biotechnol. 26:1569-1578.

Siddiqui, I.A. and S. Shahid Shaukat. 2003. Suppression of root-knot disease by *Pseudomonas fluorescens* CHAO in tomato: Importance of bacterial secondary metabolite, 2, 4-diacetylphologlucinol. Soil Biol Biochem. 35:1615-1623.

Sun, MH, Gao, L, Shi, YX, Li, BJ and XZ. Liu. 2006. Fungi and actinomycetes associated with *Meloidogyne* spp. eggs and females in China and their biocontrol potential. Invertebr Pathol J. 93:22-28.

Tadaaki, Satou, Katsutoshi Kaneko, Wei Li and Kazuo Koike. 2008. The toxin produced by *Pleurotus ostreatus* reduces the head size of nematodes. Biol. Pharm. Bull. 31(4) 574-576.

Taylor, D.P. and C. Netscher. 1974. An improved technique for preparing perennial pattern of *Meloidogyne* spp. Nematol J. 20:268.

Thienhirun, P, Sontirat, S, Rakvidhyasastra, V, Chamswarng, C and S. Ketsa. 1997. Efficacy of *Trichoderma* spp. in controlling root-knot nematode (*Meloidogyne incognita*). Ph.D. Thesis, Graduate School of Kasetsart University of Agriculture. Bangkok. Thailand.

Thorn, R.G. and GL. Barron. 1984. Carnivorous mushrooms. Science (Washington D.C.) 224:67-78.

Zaki, F. 1994. Effect of culture filtrates of *Paecilomyces lilacinus* on *Meloidogyne javanica*. Nematol. Mediterr. 22:41-43.

J. ISSAAS Vol. 21, No. 1: 55-67 (2015)

FARMERS SUSTAINABILITY INDEX: THE CASE OF PADDY FARMERS IN STATE OF KELANTAN, MALAYSIA

Rika Terano*, Zainalabidin Mohamed,
Mad Nasir Shamsudin and Ismail Abd Latif

Department of Agribusiness and Information Systems,
Faculty of Agriculture, Universiti Putra Malaysia,
43400 UPM Selangor Darul Ehsan
Corresponding author: rika_t@upm.edu.my.

(Received: October 28, 2014; Accepted: March 30, 2015)

ABSTRACT

Sustainable agriculture is closely related to farming practices. In order to develop sustainable agriculture, there are important farming practices to be focused such as land preparation, use of fertilizers and weedicides among other indicators of farming practices. In particular, weed and pest control are focus points for certain crops such as cotton, rice, vegetables, and fruit with heavily applied chemical inputs. Among food crops, paddy requires heavy doses of fertilizers, weedicides and pesticides to keep it healthy and productive. This study, conducted in 2013, observes paddy farming practices, and estimate the Paddy Farmer Sustainability Index (PFSI) as a measurement to estimate whether or not farmers are practicing sustainable agriculture. The objective of this study is to examine the degree of sustainability at field level under the current paddy farming systems through Paddy Farmer Sustainability Index (PFSI) based on the current 30 practices at field level. A field survey was conducted by personal interviews targeting 61 paddy farmers in PPKs (Farmer Organization Association) areas of KADA, Kelantan. The PFSI was measured on a scale of 0 to 100. The results indicate that the average sustainability level in the paddy farming is relatively unsustainable implying that it requires further extension of proper farm practices among paddy farmers. Chi-square analysis shows that the level of farmers' awareness toward sustainable agriculture and positive attitude are significantly different with the level of PFSI.

Key words: farm practices, sustainable agriculture, extension

INTRODUCTION

In general, sustainable agriculture addresses the ecological, economic and social aspects of agriculture (Leopold Center for Sustainable Agriculture, 2014). The development of sustainable agriculture occurs within a dynamic and calving set of interlocking ecological, economic, and social systems. It involves the use of chemical inputs as well as agronomic practices that could cause the degradation of the environment and it must be viewed from a holistic perspective (Shi, 2010). However in some particular cases, the phrase "sustainable agriculture" has been used in a limited sense to describe agricultural practices that lower input requirements and preserve soil quality while maintaining the economic yield (Singh, 2013). Sustainable agriculture is not a call for going back to farming practices that forced farmers to practice subsistence farming systems. However it is to guide them toward the right ways of practicing farming and adopting new agricultural innovations for maximum benefits while saving the environment for the future generations.

The usage of pesticides, herbicides and weedicides as synthetic chemical inputs has reduced production loss thus increasing productivity in agriculture. However it has had its negative effects on the exterior environment. Wilson and Tisdell (2001) have pointed out that these externalities include damage to agricultural land, fisheries, fauna and flora, which additionally have caused unintentional destruction of beneficial predators of pests thereby increasing the virulence of many species of agricultural pests. IRRI (2009) has also reported that in addition to many hidden costs associated with the indiscriminate use of pesticides what is alarming is that excessive pesticide use has damaged the health of both farmers and consumers. For instance, in the U.S.A the total estimate for the negative impact of the use of pesticides on the environment, the society and public health, resistance in pests, crop and bird losses and ground water contamination is about USD12 billion per year (Pimentel, 2009).

In reality, in developing countries farmers are lacking in knowledge about sustainable systems (Sampson and Hair, 1990). For example, in Ghana (Northern Presbyterian Agricultural Services and Partners, 2012), a report indicates that there are three key aspects of the unsafe use of pesticides by farmers. These is the use of pesticide including all chemical inputs which might have violated sustainable farming, the misuse of pesticides by spraying too close to harvest and contaminating the crop before consumption, over-applying the dosage, applying pesticides intended for cash crops to grow food crops, and using obsolete pesticides. Most farmers fail to use any protective equipment while virtually no farmers use all that is recommended. Storing pesticide containers near to or even in food stores is widespread and has contributed to several recent deaths and an untold number of illnesses. Despite the potential benefits of farming practices and systems that improve sustainability, their adoption are far less widespread than the society might want (Kornegay, 2010 and NPAS, 2012). Furthermore there has been no tangible aggressive extension of work or teaching about the adoption of sustainable practices (Nwankwo, 2010). There is poor training and/or a lack of money for buying proper pesticide application equipment, making farmers directly exposed to chemicals that injure their eyes, skin, respiratory tract and nervous system. Also farmers sometimes apply pesticides very close to harvest, which can endanger the health of consumers (IRRI, 2009).

Excessive use of synthetic chemical inputs exposes farmers to serious health risks and has negative consequences on the environment as such crop yields contaminate the air, soil and water, thus making consumers increasingly concerned about the chemical input residues in their food. The serious consequences of pesticide-related occupational exposure have been amply documented among farming communities, heightening social sensitivity towards agricultural workers' rights and welfare (Rai, 2011). Surprisingly little effort has gone into detailed "knowledge, attitudes, and practices" studies to develop the country's agriculture in general and for rice in particular considering the importance of farmers' perceptions in making decisions about pest control (Rola, 1993). Precision agriculture requires the use of new technologies, such as global positioning system (GPS), geographic information systemGIS, optical sensors, and satellites or aerial images to understand and evaluate te variations. Colllected information may be used to more precisely evaluate optimum sowing density, estimate fertilizer and other input needs, and accurately predict crop yiled (Sui, 2008). Thus the adoption of the Precise Agricultural Practice (PAP) technology reduces adverse impact on the environment. The timely application of agrochemicals at an accurate rate would avoid excessive residue in soil and water, and thus, reduce environmental pollution (Rola, 1993).

In case of Malaysia, there had been extensive use of chemicals as plant nutrients to combat pests and diseases. However, in recent years, the results of studies conducted on the sustainable agriculture among farmers have shown an increasing awareness of health and environmental issues (Faridah, 2001). The establishment of sustainable practices among farmers is the main cause of development of sustainable agriculture in Malaysia.

Since the introduction of the 7th Malaysian Plan (1996-2000), long-term management of natural resources to ensure their sustainable use and development relating to land resources with environmental consideration has been emphasized. In order to persuade paddy farmers to consider more sustainable practices there is the necessity to examine their level of current sustainable farming practices for further improvements. There is the Paddy Checklist which was published and distributed by MADA (Muda Agricultural Development Authority) to all paddy farmers and has been in use as a basis of paddy farming practices. It consists of 10 checklist items to fulfil for higher production as well as sustainable practices. The following are the 10 points of the checklist suggested by MADA for paddy farmers (Rice Check, 2014):

1. Soil acidity status: to make sure the soil has no acidic fields,
2. Plot condition: it must be flat and well maintained,
3. Weed control: it can reduce paddy yields by up to 90%,
4. Irrigation schedule: follow the scheduled irrigation timetable to save water,
5. Land preparation: to rotate the soil in 10 cm–15 cm (4 inch – 6 inch) depth and puddle soil and size less than 2.5 cm (1 inch), sustaining flat field within 5 cm (2 inch) differences.
6. Seedling: required to use seed from legal source, percentage of seed germination must not less than 80%, and need 140 kg/ha to get at least 400 seeds need to be germinated in a square meter.,
7. Fertilizer application: high yields obtained through adequate supply of nutrients and timely required information,
8. Water management: efficient water management and adequate time is essential to achieve higher productivity,
9. Pest control: weed and pest can reduce paddy yield, and
10. Harvesting: harvest the crop when 85% the paddy ripe to ensure that the loss percentage (rice spill) is at the minimum level.

While sustainable agriculture has been publicly acknowledged as both a societal and an economic issues, actual farming practices which farmers apply have just started to get public attention for the important role they play in attaining sustianability in agriculture. Many research has been conducted at farm level to understandthe ways of driving this sector from a conventional to a sustainable one at farm level. For measuring sustainable agriculture of various crops and farming practices, the variety and range of research has been varied and broad. There are certain approaches in the sustainable agriculture research; one being the measurement of the actual farming practices; while the other being the observation of farmers' perspectives and attitudinal characteristics towards sustainable agriculture by having the intention to adopt sustainable practices. Adebayo and Oladele (2012) carried out a research in South Western Nigeria on organic farming in sustainable agriculture. Cluster sampling technique was adopted for selecting the required sample of urban vegetable producers. Fifty producers each were randomly selected from the nine clusters to give a total sample size of 450 respondents. The results revealed an overwhelming general positive attitude by vegetable farmers towards organic agriculture. The most prominent attitudinal statements as ranked by the farmers were that organic agriculture improves soil fertility and soil structure, organic agriculture encourages the use of indigenous knowledge. The results of the probit model revealed that farming experience, farm size, household size, organization membership and frequency of extension contact showed a significantly positive relationship with attitude to organic farming practices. Therefore, Adebayo and Oladele suggested that training of extension agents should include more messages on organic agriculture techniques to the farmers. In the United Kingdom, a study on the farm-level indicators of agricultural sustainability based on patterns of input use was constructed for a sample of 237 organic and conventional farmers (Rigby et al., 2001). Each farm related to five aspects of horticultural production on the holdings: seed source, pest and disease control, weed control, maintenance of soil fertility and crop management with different farming practices within each of these categories being identified. The impact of these farming practices on farm sustainability was assessed by allocated simple scores to each farming practice. By comparing organic and conventional farming practices, it was concluded that the greatest gap was in the pest control category. Organic farms were typically scoring nearly six times as many sustainable points as their conventional counterparts. In India, Bonny and Vijayaragavan (2001) studied the adaptation of sustainable production practices in paddy fields. Farmer Sustainability Index (FSI) was developed to measure the adoption of sustainable practices by traditional paddy growers in agro-ecosystem. It proved that the conventional and sustainable groups acted differently on all production practices in accordance with their technological allegiance.

A variety of evaluation methods were proposed to address the questions of sustainability and environmental impact of agronomic practices in agriculture. Taylor et al. (1993) have conducted a study in Cameron Highlands on English cabbage farming. This study fell into the category of research related to measurement of actual farming practices. It especially identified the factors associated with the adoption of sustainable farming practices through the development of Farmer Sustainability Index (FSI) as a Malaysian case. It visualized the degree of sustainability in farming practices. The indices to compute the FSI scores were the practices to control pests and weeds, maintain/enhance soil fertility, and control soil erosion.

There are a number of studies concerning farmer's attitudinal characteristics such as perception and attitude towards sustainable agriculture. Two such studies focused on farmer's attitudinal characteristics and demographic profile together with observation of farming practices among onion and sweet corn growers in Utah, in the United States of America by using a random sample of 964 farmers (Drost, 1996) in one study and 170 farmers (Drost, 1998) in the other. Some of the indicators used were onion growers' management of the farm, Integrated Pest Management (IPM), years of farming experience, age, and education level. The results of the study have shown that there is no direct association between demographic variables and the sustainable agricultural practices. However most respondents have a positive perception regarding sustainability of production systems such as IPM and the use of organic fertilizer.

Thus the objective of this study is to examine the degree of sustainability at field level under the current paddy farming systems. In this study, the degree of sustainability is measured by creating a Paddy Farmer Sustainability Index (PFSI) based on current practices. A field survey is conducted by personal interviews targeting 61 paddy farmers in the area of KADA, Kelantan. This study will provide an insight into the sustainability of the agronomic practices of paddy farmers in the mentioned area and holds potentials to promote sustainable agricultural practices among paddy farmers in the area.

MATERIALS AND METHODS

This study was conducted through a field survey of personal interviews with paddy farmers in KADA granaries area, Kelantan. The survey area was selected among those farms which were under the supervision of Area Farmers Organization (Pertubuhan Peladang Kawasan: PPK). Kelantan is the third largest granary in the peninsular Malaysia involving 73,104 ha after Kedah and Perak states. However paddy yield is 3.74 tons per ha which is rather lower than 3.82 tons per ha Malaysian average yield. Since paddy sector in Kelantan still holds potential to provide more rice production, the granary in Kelantan is very strategic and key granary in the Peninsular. Systematic random sampling method was applied to collect data from the respondents under the same farming and irrigation systems in PPKs areas. A list 150 paddy farmers was obtained from PPK and a total of 61 paddy farmers were selected randomly for the interviews. The survey was conducted in the main season 2013. With reference to the FIS measured Zainal et al. (1994) which measured Farmer Sustainability Index for English cabbage, this study aims to estimate an FSI to measure the level of farmer's sustainability for paddy farming.

In order to have a more tangible data, the interpretation of PFSI values were adjusted within a range of 0 to 100 as an index to compare the numerical scale with one another. In this study, PFSI measurements were applied to estimate PFSI value and range as suggested by Taylor et al. and Zainal et al. (Taylor et al., 1993 and Zainal et al., 1994). The agronomic practices such as land preparation, seedling selection, fertilizer application, weed control, pest control, water management and others that related to farming practces were collected to compute the PFSI scores. Each practice will be given a score value for sustainable and non-sustainable practice respectively (see Table 1 for detail explaination on the scoring methodology). The total PFSI value for each farmer represented the sum of the indexed sustainability scores for the paddy check list numbers 1 to 9 broken up into 30 production practices starting from the faming practice of land preparation to that of pest control.

Scoring specific production practices

In order to score the selected farming practices, every approachable farming practice is weighed independently upon how strongly each practice is believed to influence sustainability. Farming practices cover the whole process of paddy farming which include 30 farming practices. There are 30 farming practices taken into consideration in calculating the PFSI. We assigned positive values when farmers conduct and follow the dosage and frequencies such as for the use of organic pesticide, herbicide and fertilizer and proper timing and frequency of chemical inputs and their dosage. A value of 0 was assigned to neutral practices when pesticide application was conducted as recommended in Paddy check. On the other hand, negative values were given to the practices that had a negative effect on sustainability. Some of these instances include: a farmer not following a certain dosage of inputs and frequencies, overuse of chemical inputs, chemical inputs being used too often or too extensively to control weed and pest, no proper timing for application as stipulated by the manufacturer in the instruction manual and as recommended by Paddy check. The main part of production practices for FSI in paddy farming practices are basically referred by the paddy check list numbers 1 to 9. Table 1 shows the detail of production practices and the unadjusted Paddy Farmer Sustainability Index.

Paddy farmer sustainability index values

Throughout the entire process of farming practices in growing paddy, there six main processes are selected to be abstaining PFSI in this study. The minimum and maximum unadjusted scores and score range for each group practice are as follows;

1. Land preparation : 0 to 3; range 3 points,
2. Seedling : -1 to 1; range 2 points,
3. Fertilizer application : -1 to 5 ; range 6 points,
4. Water management : 0 to 2 ; range 2 points,
5. Weed control : -4 to 15 ; range 19 points, and
6. Pest control: -4 to 7 ; range 11 points.

In this study, we referred to Taylor et al. (1993) and Zainal et al. (1994) FSI measurements and applied them to paddy farming practices to estimate PFSI value and range as suggested by them. In order to facilitate the interpretation of the PFSI scores, the indexes were adjusted to fall within a range of 0 to 100 as quotient. The continuous PFSI values were assigned to six discrete sustainability categories, with the following range of index values:

- Sustainable: > 70.0;
- Somewhat sustainable : 60.1 - 70.0;
- Intermediate : 50.1 - 60.0;
- Possibly unsustainable : 40.1 - 50.0;
- Possibly quite unsustainable : 40.0 - 20.0; and
- Possibly very unsustainable: <= 20.0.

Table 1. Production practices included in the unadjusted Farmer Sustainability Index (FSI) based on Rice Check 2014.

Farming practice	Amount/frequency	Max score	Min score
1. Land preparation			
1.1 Soil acidity	Yes = 1, No = 0	1	0
1.2 Flat land	Yes = 1, No = 0	1	0
1.3 Soil to a depth of 10cm to 15cm	Yes = 1, No = 0	1	0
2.Seedling (Rice check 6)			
2.1 Amount of seeds, 140kg/hectare	below130kg/ha = 0 130-150kg/ha = 1 150 and above/ha = -1	1	-1
3. Fertilizer application			
3.1 timing 1st application (15-20 days after direct-seeding)	Not following = 0, Within 15-20 days = +1	1	0
2nd application (35-40 days after direct-seeding)	Not following = 0 Within 35-40 days = +1	1	0
3rd application (50-55 days after direct-seeding)	Not following = 0 Within 50-5 days = +1	1	0
4th application (70-75 days after direct-seeding)	Not following/No application = 0 Within 70-75 days = +1	1	0
3.2. Amount of fertilizer, 979 kg/ha	(range 900 to 1000kg/ha) = +1, Less than 900kg/ha = 0 Exceeding amount (above 101%) = -1,	1	-1
4. Water management			
4.1 Following irrigation schedule	Yes = 1, No = 0	1	0
4.2 Observing depth of water	Yes = 1, No = 0	1	0
5. Weed control			
5.1. Frequency	0 or 1 time = 1, 2 times = 0, above 3 times = -1	2	-1
5.2.Timing ・1st application (3-5 days after direct-seeding)	Not following schedule = 0, within 3-5 days = +1	1	0
・2nd application	Not following schedule = 0	2	0
Ex.: less than 15 days after direct-seeding -very good	Less than 15 days = +2		
15-30 days after direct-seeding -good	within 15-30 days = +1		
exceed 30 days after seedling-not effective	exceeding 30 days = 0		
5.3. Amount of herbicide	Within limit = 1, Exceeding additional 50% = 0 Exceeding additional 100% = -1	1	-3

Farming practice	Amount/frequency	Max score	Min score
	Exceeding additional 200% = -2 Exceeding additional 300 above = -3		
5.4. Burning dried straw	Yes = 1, No = 0	1	0
5.5. Soil rotavation at 7-14 days after burning the dried straw	Yes = 1, No = 0	1	0
5.6.Usage of herbicide (Glyphosate)	Yes = 1, No = 0	1	0
5.7. Second rotation in a wet way (stagnant water)	Yes = 1, No = 0	1	0
5.8. Pretilachlor at the rate of 1.76 L/ha	Yes = 1, No = 0	1	0
5.9. Third rotation at distances 10 feet between the lanes.	Yes = 1, No = 0	1	0
5.10. Use of seeds from legal source	Yes = 1, No = 0	1	0
5.11. Pulling of weeds by hand	Yes = 1, No = 0	1	0
5.12. Type of pesticide			
▪2,4-D butyl ester	Used = +1, not used = 0	1	0
Pest control			
6.1. Frequency	0 or 1 time = 1, 2 times = 0, above 3 times = -1	1	-1
6.2. Record of farming activities	Yes = 1, No = 0	1	0
6.3. Proper protective clothing for applying chemical inputs	Yes = 1, No = 0	1	0
6.4. Storing chemical input safely	Yes = 1, No = 0	1	0
6.5.Proper disposal of pesticide container	chemical disposal = 1, others = 0	1	0
6.6. Amount of pesticide applied (whether exceeding limit or not)	Within limit = 1 Exceeding additional 50% = 0 Exceeding additional 51-100% = -1 Exceeding additional 200% = -2 Exceeding additional 300% above = -3	1	-3
6.7. Use of organic pesticide	Organic pesticide used = 1, no = 0	1	0
Total score		**33**	**-10**

Source: Own calculation based on surveyed data and the formula is adopted from Taylor et al.(1993), 2013

After estimating the PFSI value to look at the level of sustainability among paddy farming practices, chi-square analysis was carried out to find the statistical association between the socio-demographic variables such as age, education level and farm size; awareness and attitude on practicing sustainable farming with PFSI values. The following hypotheses are formulated to identify the significant difference between the farmers' characteristics in different PFSI categories.

Research hypothesis are as follows;

1. H_0: There is no statistically significant association between PFSI value and the age of the farmers. It is hypothesize that the older farmers are less sustainable than the younger farmers due to their habit and way of doing thing for the past 30 to 40 years. This factor might cause resistance to change and to be sustainable.

2. H_0: There is no statistically significant association between PFSI value and the education level of the farmers. It is hypothesized that the more educated farmers are more sustainable in their farming practices than the lower educated farmers due to their understanding and exposure to go green campaign while they were in school or college.

3. H_0: There is no statistically significant association between PFSI value and the farm size. It is hypothesized that that larger the farm size the less sustainable the practices are. This is due to maintaining larger farm size is expensive and more tedious.

4. H_0: There is no statistically significant association between PFSI value and types of job between full-time and part-time farmers. It is hypothesize that the full-time farmer can take care of their plant more properly based on paddy check required in the way of more sustainable agriculture than part time farmers because care and attention are more given to each farming practice.

5. H_0: There is no statistically significant association between PFSI values and farmers' awareness towards sustainable agriculture and farming practices. It is hypothesize that the farmer positive awareness towards sustainable agriculture will translate into more sustainable practices.

6. H_0: There is no statistically significant association between PFSI values and farmers' atttitude towards sustainable agriculture and farming practices. It is hypothesize that the farmers' positive attitude towards sustainable agriculture will encourage them into more sustainable practices.

If chi-square test shows no statistical difference between farmers' characteristics, awareness and attitude, and PFSI values, each variables have no statistical association, then the tested failed to reject null hypothesis.

EMPIRICAL FINDINGS

Table 2 shows the demographic profile of interviewed farmers in five PPKs in KADA, Kelantan. The average age of a farmer was 51 years, with only four female farmers among them. The majority of farmers have completed elementary school as their educational background. Half of the farmers were also employed as part-time workers in the off-farm sector, while the other half were working as full time farmers. The average farm size was 7.1 hectares.

Based on the range of FIS values defined by Taylor et al. (1993) and Zainal et al. (1994), paddy adjusted sustainable indices are shown in Table 3 by the six discrete sustainability categories. There were 19 farmers (31.1 %) whose farming practices were possibly unsustainable. There were 17 farmers (28.0 %) whose farming practices were possibly quite unsustainable. This is while 19 farmers (31.1 %) fell within the category of intermediate sustainability. Among 61 farmers, only six (9.8 %) were at the level of somewhat sustainable. Hence none of the 61 paddy farmers practiced sustainable agriculture (> 70.0) and none of them are possibly very unsustainable nor they are sustainable. The range of sustainability falls between possibly very sustainable and somewhat sustainable.

Table 2. Demographic profile of paddy farmers in KADA areas, Kelantan.

	No.
Gender	
Male	57
Female	4
Age	
Young adults (below 34 years old)	15
35-49 years old	21
Above 50 years old	25
Education	
No education/primary school	18
More than secondary school	43
Farm size	
Above average (6.2 ha)	17
Below average (6.2 ha)	44
Full/part-time farmer	
Full time farmer	31
Part time farmer	30

Source: Survey, 2013

Table 3. Paddy adjusted sustainable index in KADA area, Kelantan.

FSI measure	**FSI value**
Mean	45.7
Median	45.7
Mode	50.0
Range	21.7-67.4
Frequency distribution (%)	
Possibly very unsustainable: <20.0	0
Possibly unsustainable: 20.0 - 40.0	31.1
Possibly quite unsustainable: 40.1 - 50.0	28.0
Intermediate sustainable: 50.1 - 60.0	31.1
Somewhat sustainable: 60.1 - 70.0	9.8
Sustainable: > 70.0	0

Source: Author's calculation based on survey data, 2013.

Chi-square analysis between PFSI value categories and farmers' characteristics

Table 4 shows the statistical association of farmers' characteristics (age, education level, farm size and types of job), farmer's awareness and attitude towards sustainable agriculture with PFSI values. The chi-square test indicates that there are no significant differences among the age, education level, and farm size in the level of sustainability in practicing farming practices. Thus regardless of their age, education, farm size and types of job, their level of sustainability is well distributed. Which means to say that even though the farmer are educated, younger and small farm size, none of them really practices sustainable farming. On the other hand, farmers' awareness (X^2 =5.973, p<0.050) and attitude (X^2 =7.769, P<0.050) towards sustainable agriculture have statistical association with PFSI values. Looking at more details, Table 5 shows cross-tabulation tables to see if differences are present in response to the result of chi-square analysis across multiple categories. Cross-tabulation of PFSI values shows that there is 44 (72.1%) of the farmers who have been aware of sustainable agriculture out of 61 farmers in the survey area. Frequency distribution that farmers being aware of sustainable agriculture are tend to be categorized into upper PFSI values. Also 25 (41.0%) of paddy farmers who think sustainable agriculture is important in rice farming are categorized into higher PFSI value while negative attitude towards sustainable agriculture tends causing lower value of PFSI. Overall, chi-square analysis revealed the statistical association between PFSI and farmers' awareness, and also PFSI and farmers' attitude towards suitable agriculture. Regardless of farmers' characteristics such as age, education level, and farm size, and types of job, PFSI value have statistical association with farmers mindset such as awareness of sustainable agriculture and attitude that sustainable agriculture is important practices for rice farming.

Table 4. Chi-square analysis of PFSI value to different categories in KADA, Kelantan.

Chi-square	**Value**	**Df**	**Asymptotic Significance**	
Age of respondents	4.031	4	0.402	
Education level of respondents	0.067	2	0.967	
Farm size	0.336	2	0.845	
Types of job (Full-time/part-time job besides paddy farming)	2.811	2	0.245	
Awareness: have you heard of sustainable agriculture from agricultural officer?	5.973	2	0.050	**
Attitude: is sustainable agriculture important practices for rice farming?	7.769	2	0.021	**

Source: Author's calculation based on survey data, 2013.

Table 5. Cross-tabulation of farmers' characteristics among PFSI value categories.

Chi-square	**PFSI (Paddy Farmer Sustainable Index)**		
	<40.0	40.0-49.9	>50.0
Age of respondents			
Young adults (below 34 years old)	6.6%	3.3%	14.8%
35-49 years old	9.8%	13.1%	11.5%
Above 50 years old	14.8%	11.5%	14.8%
Education level of respondents			
Until elementary school	9.8%	8.2%	11.5%
After secondary	21.3%	19.7%	29.5%
Farm size			
Below average	9.8%	8.2%	27.9%
Above average	21.3%	19.7%	31.1%
Types of job: Full-time and part-time job			
Full-time farmer	11.5%	18.0%	21.3%
Part-time farmer	19.7%	9.8%	19.7%
Awareness: have you heard of sustainable agriculture from agricultural officer?			
Yes	16.4%	24.6%	31.1%
No	14.8%	3.3%	9.8%
Attitude: is sustainable agriculture important practices for rice farming?			
Yes	6.6%	16.4%	24.6%
No	24.6%	11.5%	16.4%

Source: Author's calculation based on survey data, 2013.

CONCLUSIONS

In order to estimate the Paddy Farmer Sustainability Index (PFSI) 30 farming practices based on Paddy Rice Checklist suggested by KADA was used. The feedback for the 30 farming practices covered Paddy checklist 1 to 9 and was estimated from farmers through face to face interviews.

In this paper, we have explained how a Farmer Sustainability Index was estimated that combined 30 different practices by 61 paddy farmers among PPKs covered by KADA, Kelantan, Malaysia. The PFSI was measured on a scale of 0 to 100. The result showed that more than half of the farmers fell in the categories of those whose paddy farming practices were possibly unsustainable or possibly quite unsustainable. The average of the actual sustainability level in the paddy farming was still possibly unsustainable implying that it required further extension of the proper production practices. Although MADA (Muda Agricultural Development Authority) has come out with Paddy Check List and have distributed it among farmers, nevertheless the farmers are not following the instructions as prescribed. The distribution of PFSI has shown that farmers in each frequency distribution category hold different farming practices individually. It is critically important to disseminate the recommended sustainable farming practices among the 61 paddy farmers surveyed. Currently some paddy farmers are still not aware of or do not understand the importance of the environmental conservation and the concept of sustainability in agriculture. Although there are no significant difference between paddy farmers age, education level, job type and farm size in their sustainable practices, there are the above said various variables in terms of their awareness and attitude toward conservation of environment and sustainable agriculture. Those farmers that are aware and have positive attitudes toward sustainable agriculture should be given more attention to transform them into sustainable farmers. This will be a great challenge for the extension officers to boost the sustainability level among paddy farmers. The results of the study are quite alarming and immediate steps need to be taken to educate paddy farmers through extension programs and trainings.

ACKNOWLEDGEMENT

This research was funded by Universiti Putra Malaysia (UPM) under the Research University Grant Scheme Initiative 2 (RUGS-2). The authors would like to thank UPM for sponsoring this research from September 2012–August 2014.

REFERENCES

Adebayo, S. and O. Oladele. 2012. A review of selected theories and their application to information seeking behavior and adoption of organic agricultural practices by farmers. Life Science Journal,9(3), 63-66.

Bonny, B. P. and K. Vijayaragavan. 2001. Adoption of sustainable agricultural practices by traditional rice growers. Journal of Tropical Agriculture, 39(2) 151-156.

Drost, D., Long, G., Wilson, D., Miller, B. and W. Campbell. 1996. Barriers to adopting sustainable agricultural practices. Journal of Extension [on line serial], 34(6). Available at http://www.joe.org joe december 1996 feature 1.

Drost, D. and G. Long. 1998. Targeting Extension Efforts for the Adoption of Sustainable Farming. Journal of extension. Available at 36(5), http://www.joe.org/joe/1998october/rb1.php.

Faridah, A. 2001. Sustainable agriculture system in Malaysia, paper presented at Regional Workshop on Integrated Plant Nutrition System (IPNS), Development in Rural Poverty Alleviation, 18-20 September 2001, United Nations Conference Complex, Bangkok, Thailand.

International Rice Research Institution (IRRI). 2009. *The costs of pesticide use Rice knowledge bank*. Retrieved January 9, 2014, from http://www.knowledgebank.irri.org/ipm/the-costs-of-pesticide-use.html

Kornegay, J. 2010. *Report in brief: Foward Sustainable Agricultural Systems in the21st Century*. Washington, D.C: National Academy of Sciences. 598p.

Leopold Center for Sustainable Agriculture (n.d.). *What is Sustainable Agriculture?* Retrieved April 19, 2014, http://www.leopold.iastate.edu/about/sustainable_agriculture.

Northern Presbyterian Agricultural Services and Partners [NPAS]. 2012. *Ghana's pesticide crisis; the need for further government action.* 50p.

Nwankwo, U. M. 2010. *Sustainable biotechnology adoption in Nigeria to reduce food insecurity: involving cooperatives in the process*. Frankfurt am Main: Peter Lang. 259p.

Pimentel, D. 2009. Environmental and Economic Costs of the Application of Pesticides Primarily in the United States. *Integrated pest management innovation-development process.* (pp. 89-111). Dordrecht: Springer.

Rai, M. (2011). *Save and grow: A policymaker's guide to sustainable intensification of smallholder crop production*. Rome: Food and Agriculture Organization of the United Nations.

Rice Check. (n.d.). Laman Web Rasmi Lembaga Kemajuan Pertanian Muda. Retrieved June 27, 2014, from http://www.mada.gov.my/semakan-tanaman-padi

Rigby, D., Woodhouse, P., Young, T. and M. Burton. 2001. Constructing a farm level indicator of sustainable agricultural practice. Ecological Economics, 39(3), 463-478.

Rola, A. C. 1993. *Pesticides, rice productivity, and farmers' health an economic assessment.* Manila: IRRI; Washington: World Resources Institute. 100p.

Sampson, R.N. and D. Hair. (Eds). 1990. *Natural resources for the 21st century*. Washington, DC: American Forestry Association and Island Press. 350p.

Seventh Malaysian Plan. 2000. Chapter 19 Environment and Sustainable Resource Management. Putra Jaya: Economic Planning Unit. 40p.

Shi, T. 2010. *Sustainable ecological agriculture in China bridging the gap between theory and practice*. Amherst, NY: Cambria Press. 342p.

Singh, B. P. 2013. *Biofuel crop sustainability*. Ames, Iowa: Wiley-Blackwell. 480p.

Sui, D. 2008. *Geospatial technologies and homeland security research frontiers and future challenges*. Dordrecht, Netherlands. Springer. 360.

Taylor, D. C., Mohamed, Z. A., Shamsudin, M. N., Mohayidin, M. G. and E. F Chiew. 1993. Creating a farmer sustainability index: A Malaysian case s tudy. American Journal of Alternative Agriculture. 8(04) 175.

Wilson, C. and C. Tisdell. 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecological Economics, *39*, 449-462.

Zainal, A. M., Nasir, S. M., Chiew Eddie, F. C. and M. M. Ghazali. 1994. Farmers' production practices and sustainable development: the case of English cabbage production in Cameron Highlands. Malaysian Journal of Agricultural Economics. 11, 1-22.

J. ISSAAS Vol. 21, No. 1: 68-77 (2015)

FIRST REPORT OF *MELOIDOGYNE INCOGNITA* CAUSED ROOT KNOT DISEASE OF UPLAND RICE IN THAILAND

Pornthip Ruanpanun* and Amornsri Khun-In

Department of Plant Pathology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University,
Kamphaeng Saen Campus, Nakhon Pathom, 73140, Thailand
*Corresponding author: fagrptr@ku.ac.th

(Received: October 3, 2014; Accepted: March 10, 2015)

ABSTRACT

Thailand is a major exporter in the world rice market and it is expected to increase rice production. The major economic constrain for upland and lowlang rice production is the infection of rice-parasitic nematodes. A survey of the plant-parasitic nematode infestation of upland rice fields was conducted from October 2012 to April 2013, in Pathio District, Chumphon Province, Thailand. The field survey revealed that root-knot nematode, *Meloidogyne incognita* was mainly distributed in four upland rice (*Oryza sativa* L.) varieties *viz* Dok Kham, Dok Payom, Lebnok and Nangdam grown in Pathio district. The infestation of this nematode resulted in 100% yield losses. In this paper, we first report about infestation of *M. incognita* in upland rice field in Thailand. Under greenhouse conditions, these upland rice and other commonly cultivated upland rice varieties including T1, T2, T3, T4, Pukaotong, Kaoneaw-med-yai, were susceptible to *M. incognita*. This pest may cause poor upland rice yield. Thus, monitoring and control methods for *M. incognita* should be well manipulated for rice cultivation improvement in Thailand.

Key words: *Oryza sativa* L., root-knot nematode, surveillance

INTRODUCTION

Rice (*Oryza sativa* L.) is the world's most important food crop of Asian origin. In Thailand, rice is a traditional staple and important export crop. In 2013, its production was 24.2 million tons and its export quantity was the world's third highest at 7.0 million tons (FAO, 2013). Most rice is grown under wetland conditions. Nowadays, decreasing of the quality and yield crops caused by water shortage are serious problems for rice cultivation. Additionally, droughts, as a result of global warming and climate change, have occurred commonly in the recent years (Lan et al. 2011). In this situation, upland rice, with its high drought tolerance, has become one of potential crops and planted as alternative crops for household consumption or for local market sale. Recently, most upland rice is grown in northern and southern of Thailand, where it represents about 10% of total rice area (Nokkoul and Wichitparp 2013) and will be increasing in the future. Nevertheless, damaging from pests leads to lose amount of their yields which result in rice availability and security. Root-knot nematodes (RKNs) (*Meloidogyne* spp.) are serious problem in rice cultivation system throughout the world especially *M. graminicola* (MacGowan and Langdon 1989; Dutta et al. 2011; Jain et al. 2011; Win et al. 2013). Fortuner and Merny (1979) reported that *Meloidogyne* is associated with upland rice in most countries where this crop is cultivated. Win et al. (2013) studied the host response of lowland and upland rice varies to rice root-knot nematode in Myanmar suggested that *M. graminicola* has the highest potential of causing economic damage. Moreover, several previous studies reported only the association of rice root-knot nematode *M. graminicola* in rice cultivation system in Thailand (Arayarungsarit 1987; Dongre and Simon 2013; Upadhyay et al. 2014). However, in the course of our survey for plant-parasitic nematode infestation in upland rice field, we found *M. incognita* in these areas. Although this nematode has been generally found in wide plant range in Thailand (Cliff and Hirschmann 1984; Handoo et al. 2005; Ruanpanun et al. 2010), *M. incognita* species had not been found in upland rice before.

This study, describes the results of a survey on *M. incognita* infestation in upland rice field in Chumphon Province. Furthermore, we describe about the investigation of host response of *M. incognita* on selected commonly upland rice varieties cultured in southern region of Thailand. This is the first report of the infestation of *M. incognita* on upland rice in Thailand. The obtained result might be used as basis information for surveillance of nematode infestation on upland rice and plan for this pest management in the future.

MATERIALS AND METHODS

Survey of plant-parasitic nematodes in upland rice

A survey was conducted during October 2012-April 2013 in Pathio district (lat. 73ºS-00ºN and long. 22ºW-50ºN), Chumphon Province to find out the infestation of root- knot nematode in upland rice field. The sampling sites were randomly selected. Rice which presented above-ground symptoms including stunting, slow growth, yellowing, early senescence and abnormal wilting were collected. A total of 40 soil samples were taken in this survey (10 samples/rice variety). The rice and their rhizosphere soils were placed in plastic bags, sealed, and transferred to the Nematology laboratory, Department of Plant Pathology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University Kamphaeng Saen campus.

The rice samples were determined for galling root and stained the roots by using sodium-hypochlorite-acid-fuschin method (Byrd et al. 1983) in order to observe juvenile in root under stereo microscope. While, the 500 g soil of each samples were separated for juveniles by using Christie and Perry technique (Bravo, 1977). The root-knot nematodes were counted and identified. Five replicates were performed.

Meloidogyne species identification

Root-knot nematodes were identified to species base on characteristic of morphology and perineal pattern according to Hunt and Handoo (2009).The Perineal pattern with oval to rounded, typically with high, squared, dorsal arch, striae usually wavy, lateral field absent or weakly demarcated by forked stria characteristics presents on adult female nematode indicated that the nematode is *Meloidogyne incognita* (Hunt and Handoo, 2009).

Preparation for second stage juveniles of *M. incognita*

Eggs and infective-second stage juveniles (J2) of *M. incognita* obtained from nematode-infested soils at Chumphon Province were cultured on *Oryza sativa* L. variety Lebnok in a greenhouse condition (30ºC ± 5) for 40-45 days. Root pieces with galls were collected and washed in running tap water to rid of soils. The only egg masses were separated from the root. The egg masses were put in water and incubated for 48 hr or more until the eggs were hatched. The J2 were carefully removed and used for experiment.

Test for upland rice response to *M. incognita*

The response of various upland rice varieties were tested in a greenhouse for their response to *M. incognita*. The susceptible upland rice from infested field varieties *viz* Dok Kham, Dok Payom, Lebnok, Nangdam and selected commonly upland rice varieties including T1, T2, T3, T4, Pukaotong, Kaoneaw-med-yai, and Nangkruan were sown in trays with sterile soil. A single 2-week-old rice seedling were transferred to each 15-cm-diam pot (7 kg soil), regular watered for a week and then stopped watering 2 days before J2 inoculation. J2 of *M. incognita* was inoculated beside the root tip of rice seedling by 25 J2/g soil. The 11 varieties without nematode inoculation used as control group. Five replicates were performed for each rice variety. A total of 110 pots were arranged in a randomized block design. The experiments were conducted under greenhouse conditions at an average temperature of 30°C over 45-day period. The resulting plants were separated carefully from the soil and the roots were examined to determine the number of galls caused by *M. incognita*. J2 population density in rice roots were observed by extracting and staining the root with sodium-hypochlorite-acid-fuschin method (Byrd et al. 1983) and the population of J2 was determined under stereo microscope. Moreover, the egg mass numbers, of *M. incognita* inside the roots and in the 20 g soil were extracted and then enumerated. Finally the shoot length and fresh shoot weight were measured.

Statistical analysis

All data were analyzed by SPSS program version 17.0 (2008 SPSS Inc., Chicago, IL). The data *M. incognita* population density in root and soil were subjected to the analysis of variance (ANOVA) and treatment means were separated using Tukey’s Studentized range test at 5% level. *T*-test at 5% level was used to determine the difference of dry shoot weight and shoot length between un-infested/un-inoculated and infested/inoculated groups.

RESULTS AND DISCUSSION

Occurrences of *M. incognita*

The major objectives of our study were to monitor root- knot nematode infestation on upland rice in Pathio district, Chumphon Province and evaluate the host response to *M. incognita* infection of commonly cultivated upland rice varieties which are being grown in southern part of Thailand. The monitoring was determined the species of root-knot nematode infestation in upland rice field, the juvenile population density in the rice rhizosphere and root. Moreover, damages of rice and yield loss caused by root-knot nematode were included.

Four upland rice varieties, Dok Kham, Dok Payom, Lebnok and Nangdam which showed above-ground symptoms including stunting, slow growth, yellowing, early senescence, and abnormal wilting were collected from fields and determined for plant- parasitic nematode infestation. Field survey revealed that only *Meloidogyne incognita* was widely distributed in all of four local upland rice varieties. The severity of infestation of root knot-nematode in 12-week rice was determined based on dry weight of shoot, shoot length and percentage of yield losses. Population density of *M. incognita* in the soil and root and root galling severity were also presented.

Dry weight of shoot and shoot length of all nematode-infested rice varieties were significantly ($p < 0.05$) lower than that of un-infested rice varieties. No yield was obtained from rice infested with nematode (Table 1). The population density of *M. incognita* in the soil and root of rice variety Lebnok was the highest while in the rice variety Nang Dham was the lowest among four rice varieties. (Fig.1, Table 2). On the other hand, the lowest *M. incognita* density in rhizosphere and root was detected from Nang Dham varietys. All four varieties showed a lot of gall caused by root-knot nematode in their roots (Fig. 2) with root-galling index respectively 90, 70, 60, and 55 for rice varieties Lebnok, Dok Kham, Nangdam, and Dok Payom.

The results of survey showed that only *M. incognita* occurred in the upland rice fields in Pathio district. Several *Meloidogyne* species such as *M. graminicola*, *M. tritocoryzae*, *M. oryzae*, *M. incognita*, *M. javanica* and *M. arenaria* were reported to attack rice (Pokharel et al. 2007; Dutta et al. 2011,). However, only *M. graminicola* was reported its attack on rice in Thailand and considered as the most important constraints in rice Production (Arayarungsarit, 1987; Dongre and Simon 2013; Upadhyay et al. 2014) but this rice root-knot nematode was not found in upland rice in Pathio district.

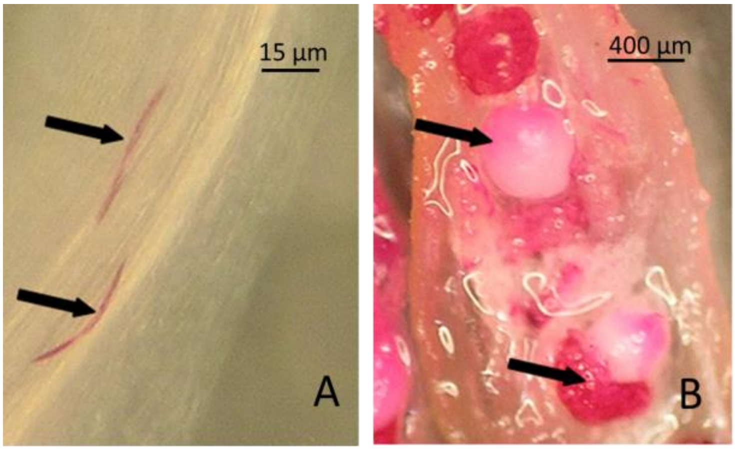


Fig. **1.** *M. incognita* in rice root collected from field: second-stage juvenile (A) and adult female (B).

Table 1. Dry weight and length of shoot of four upland rice varieties that infested and un-infested by *M. incognita* from rice field in Pathio District, Chumphon Province, Thailand

	Dry weight of shoot (g)[a]			**Shoot length (cm)[a]**			**Yield (kg/Ha)**	
Rice varieties	**Uninfested**	**Infested**	***T*-test**	**Uninfested**	**Infested**	***T*-test**	**Uninfested**	**Infested**
Dok Kham	2.6 ± 0.5	0.9 ± 0.4	*	121.6 ± 8.6	65.2 ± 7.5	*	237.4	0
Dok Payom	2.1 ± 0.3	1.0 ± 0.3	*	105.2 ± 5.0	58.4 ± 9.4	*	236.2	0
Lebnok	3.2 ± 0.6	0.7 ± 0.2	*	107.2 ± 2.6	64.2 ± 9.0	*	181.1	0
Nangdam	2.7 ± 0.4	1.0 ± 0.2	*	105.4 ± 9.1	63.6 ± 8.5	*	199.9	0
Average	2.6 ± 0.6	0.9 ± 0.4		105.4 ± 9.1	62.8 ± 8.3		-	-

[a] Average ± standard error from five replicates
*Significantly different (p≤ 0.05) according to the *T*-test

Table 2. Population densities of *M. incognia* in soil and root and root gall index of four upland rice varieties cultivated in Pathio District, Chumphon Province

Rice varieties	Gall Index[1]	No. of J2/20g soil[a]	No. of J2/plant[a]
Dok Kham	70	439.8 ± 172b*	7312.2 ± 3114a
Dok Payom	55	518.2 ± 200ab	6773.6 ± 2387a
Lebnok	90	757.0 ± 191a	10826.4 ± 2479a
Nangdam	60	302.2 ± 230b	1694.0 ± 406b
Average	-	504.4 ± 230	6653.0 ± 3968

[a] Average ± standard error from five replicates

* Values with the same letter in the same column are not significantly different (p < 0.05) according to Tukey's Studentized range test

[1] Roots were scored for degree of galling: 1= less than 25%, 2= 25-50, 3= 51-75% and 4= >75% of total root system galled. Galling index = [(number of plants in class 1 × 1) + (number of plants in class 2 × 2) + (number of plants in class 3× 3) + (number of plants in class 4 × 4)] × 100/(number of plants × 4) (Barker, 1985).

Fig. 2. Root galls caused by root-knot nematode of 4 upland rice varieties collected from field: Dok Kham (A), Dok Payom (B), Lebnok (C) and Nangdam (D)

Characterization of perineal pattern

Perineal patterns of root-knot nematode obtained from upland rice varieties Dok Kham, Dok Payom, Lebnok and Nangdam were shown in Fig. 3. They presented oval to rounded, typically with high, squared, dorsal arch, striae usually wavy, lateral field weakly demarcated by forked striae. These perineal patterns were similar to the pattern which described for *M. incognita* (Hunt and Handoo 2009). The results accorded to the standard characteristic for identification of the most common *Meloidogyne* species since 1949 (Chitwood 1949). The perineal patterns of all root-knot nematodes in this study were similar to recent published perineal patterns for *M. incognita* (Hunt and Handoo 2009). Dutta et al. (2011) reported that although *M. incognita* is a serious pest of dicotyledonous crops, it can infect and reproduce on some cereals. According to this study, it was possible to find *M. incognita* in upland rice fields due to different geographic weather and rice varieties. This is the first report demonstrating that *M. incognita* caused rice root-knot disease has emerged as a major pest which caused potential yield loss in the upland rice crop.

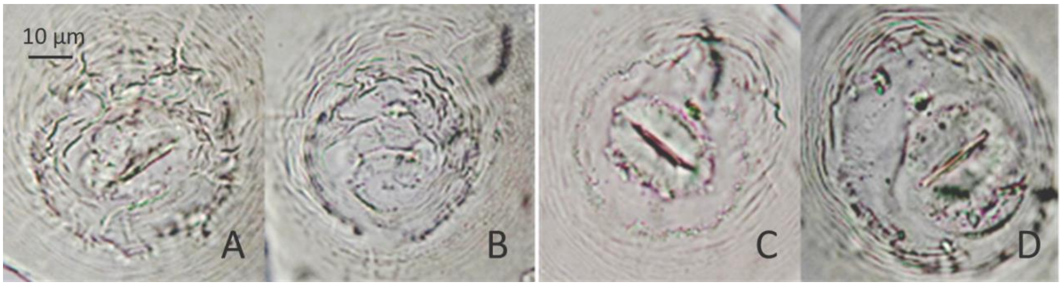


Fig. 3 Perineal patterns of *M. incognita* collected from 4 infested upland rice: Dok Kham (A), Dok Payom (B), Lebnok (C) and Nangdam (D)

Infection, symptom and host range of *M. incognita*

Four upland rice varieties *viz*. Dok Kham, Dok Payom, Lebnok and Nangdam from infested field and seven local upland rice varieties *viz*. T1, T2, T3, T4, Pukaotong, Kaoneaw-med-yai and Nangkruan were susceptible to the *M. incognita* with swelling symptom and gall through the root system.

An interaction between the upland rice varieties and nematode infection was observed for dry weight of shoot and shoot length. The dry weight of shoot and shoot length of nematode-infested rice varieties were significantly ($p < 0.05$) lower than that of un-infested rice varieties after 12-week incubation period. The highest reduction dry weight of shoot and shoot length was observed in T2 (79.2) and Lebnok (41.8), respectively. While the lowest reduction in dry weight of shoot and shoot length was observed in Nangkruan (56.2) and T2 (26.6), respectively (Table 3).

Soil and root population density of *M. incognita* in the soil and root and root galling severity of 11 upland rice varieties are presented in Table 4. The lowest J2 population density per pot was observed in the rhizosphere of the variety Pukaotong (194.6) but, this density was not significantly different ($p > 0.05$) from most of other varieties except for the varieties Lebnok (933.6), Nangdam (410.2) T1 (826.4) and T2 (646.0). The lowest J2 population density per gram of roots was recovered from the variety T4 (1859.6) which was not significantly ($p > 0.05$) lower than most of upland rice varieties except Dok Kham (5536.2), Lebnok (8533.0), T2 (4837.6), Pukaotong (4737.0) and Kaoneaw-med-yai (6496.6).

The severity of root galling (root- galling index) observed on the roots of all rice varieties were measured as 45-85 by scoring root gall index. Varieties Lebnok (85), T1 (75) and, Dok Kham and T2 (65) were the three varieties with the highest root-galling index. In contrast, T4 and Kaoneaw-med-yai (45) were the varieties with the lowest root-galling index.

Based on severity of root galling, J2 population density in rhizosphere and root, dry weight of shoot and shoot length indicated that variety Lebnok was the most susceptible variety to *M. incognita*. However, although Lebnok was the most susceptible variety among others, all of the test varieties (Dok Kham, Dok Payom, Lebnok and Nangdam) exhibited yield losses by 100%. It is possible that the initial population density of J2 might be high. Poudyal et al. (2005) reported that rice root-knot nematode adversely affected the yield and yield components of rice cv. Masuli at initial population density of 0.1-10 J2/g soil reduced yield ranged from 31-97%. Meanwhile, Soomro and Hauge (1993), Main and Khan (1995), Amarasinghe et al. (2007) and Waele et al. (2013) indicated that rice roots were heavily infested by nematode in seedling stage caused an insufficient in root system uptake. This may affect the flowering stage afterwards.

Table 3. Comparison of weight and length of shoot of each 11 upland rice varieties between inoculated and uninoculated with 25 *M. incognita* J2/g soil in greenhouse condition at 12-week after inoculation

Rice varieties	**Dry weight of shoot(g)[a]**			**Shoot length (cm)[a]**		
	Uninoculated	**Inoculated**	**% Increased change* (increased)**	**Uninoculated**	**Inoculated**	**% Increased change***
Dok Kham	2.5 ± 0.4	0.8 ± 0.2	66.0 ± 9.7*	105.2 ±7.9	66.4 ± 5.9	36.3 ± 10.0*
Dok Payom	2.4 ± 0.5	0.9 ± 0.2	63.0 ± 9.4*	112.8 ± 5.2	67.8 ± 8.6	39.8 ± 8.2*
Lebnok	2.7 ± 0.4	0.8 ± 0.3	70.3 ± 8.0*	108.0 ± 6.0	62.6 ± 6.6	41.8 ± 7.4*
Nangdam	2.8 ± 0.2	0.8 ± 0.3	69.6 ± 12.7*	122.0 ± 2.2	60.2 ± 2.8	50.6 ± 2.4*
T1	1.9 ± 0.3	0.6 ± 0.2	70.6 ± 11.3*	97.8 ± 1.9	57.2 ± 2.8	41.5 ± 2.0*
T2	2.9 ± 0.2	0.6 ± 0.2	79.2 ± 4.5*	111.0 ± 4.3	81.2 ± 6.4	26.6 ± 8.4*
T3	2.4 ± 0.2	0.8 ± 0.2	68.5 ± 9.7*	119.2 ± 3.0	81.8 ± 5.5	31.3 ± 5.1*
T4	2.5 ± 0.4	0.9 ± 0.4	63.0 ± 17.1*	116.0 ± 3.4	74.2 ± 4.1	36.0 ± 4.7*
Pukaotong	2.4 ± 0.4	0.8 ± 0.2	66.3 ± 15.0*	120.6 ± 4.0	85.8 ± 6.0	28.8 ± 5.5*
Kaoneaw-med-yai	2.9 ± 0.3	0.7 ± 0.2	75.2 ± 6.9*	116.2 ± 5.4	74.0 ± 4.4	36.2 ± 4.8*
Nangkruan	1.8 ± 0.2	0.8 ± 0.3	56.2 ± 14.8*	98.0 ± 2.5	63.2 ± 4.4	35.5 ± 4.8*
Average	2.5 ± 0.5	0.8 ± 0.2	68.0 ± 11.9	111.5 ± 5.3	70.4 ± 10.5	36.8 ± 8.6

[a] Average ± standard error from five replicates
*significant different ($p \leq 0.05$) according to *T*-test

To confirm these studies, four susceptible upland rice (Dok Kham, Dok Payom, Lebnok and Nangdam) and seven local upland rice varieties (T1, T2, T3, T4, Pukaotong, Kaoneaw-med-yai and Nangkruan) were inoculated by 25 J2/g soil of *M. incognita* (average J2 density from infested field data) in seedling stage in greenhouse. Based on the data of dry weight of shoot and shoot length, there were significantly decreased between inoculated and uninoculated of each varieties and all of rice varieties did not produce any yield. That means none of 11 upland rice varieties was resistant to *M. incognita* after inoculation in seedling stage by initial J2 population density at 25 J2/g soil. *M. incognita* may reduce the yield in other rice cultivars and be causing poor rice yield in infested field. The study of damage of rice caused by *M. incognita* should be continued in Thailand. The management of nematode control should be prepared to overcome this disease in upland rice cultivation in the future.

Table 4. Population densities of *M. incognita* in the soil and root and root gall index of 11 upland rice varieties cultivated in greenhouse condition 12-week after inoculation

Rice varieties	Gall Index[1]	No. of J2/20g soil[a]	No. of J2/plant[a]
Dok Kham	65	311.4 ± 220c*	5536.2 ± 1952abc
Dok Payom	55	341.2 ± 135bc	4447.0 ± 2511bc
Lebnok	85	933.6 ± 116a	8533.0 ± 2088a
Nangdam	60	410.2 ± 170bc	4099.6 ± 2212bc
T1	75	826.4 ± 182a	3392.2 ± 1785bc
T2	65	646.0 ± 172ab	4837.6 ± 2158abc
T3	50	211.4 ± 85c	3235.0 ± 1332bc
T4	45	356.8 ± 161bc	1859.6 ± 934c
Pukaotong	50	194.6 ± 132c	4737.0 ± 2269abc
Kaoneaw-med-yai	45	321.0 ± 56c	6496.6 ± 1944ab
Nangkruan	60	203.6 ± 103c	3897.4 ± 1021bc
Average	-	396.4 ± 293	4255.9 ± 2656

a Average ± standard error from five replicates

* Values with the same letter in the same column are not significantly different ($p > 0.05$) according to Tukey's Studentized range test.

[1] Roots were scored for degree of galling: 1= less than 25%, 2= 25-50, 3= 51-75% and 4= more than 75% of total root system galled. Galling index = [(number of plants in class 1 × 1) + (number of plants in class 2 × 2) + (number of plants in class 3× 3) + (number of plants in class 4 × 4)] × 100/(number of plants × 4) (Barker, 1985).

CONCLUSION

This is the first report that presents occurrence of root-knot nematode, *Meloidogyne incognita* in upland rice in Thailand. It caused root knot disease on various upland rice varieties. The infested rice which had 25 root-knot nematode juveniles per 1 g in their rhizosphere soils lost yield by 100%. This report indicates that monitoring and surveillance of root-knot nematode, *M. incognita* in upland rice field in Thailand should be earnestly pursued. Moreover, control measures for this pest in upland rice must be studied for better management in the future.

ACKNOWLEDGEMENT

The financial support of the Department of Plant Pathology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University is thankfully acknowledged. We thank Assoc. Prof. Dr. Raumjit Nokkoul for her assistance in the field surveys.

REFERENCES

Arayarungsarit, L. 1987. Yield ability of rice varieties infields infested with root-knot nematode. International Rice Research Notes 12:14.

Amarasinghe, LD, Kariyapperuma, KADPS and Pathirana, HNI. 2007. Study on approaches to integrated control of *Meloidogyne graminicola* in rice. J Sci Univ Kelaniya. 3:29–46.

Barke, KR. 1985. Nemaode extraction and bioassays. In: Barker KR, Carter CC and Sasser JN (eds), An Advanced Treatise on Meloidogyne, Vol. II. North Carolina State University Graphics, Raleigh, NC, pp 29–30.

Bravo, MAC. 1977. Comparison of the Christie and Perry and the centrifugal flotation methods for extracting *Xiphinema mediterraneum* from soil. Agron. Lusit 38: 203-212.

Byrd, DW, Jr, Kirkpatrick, T and KR Barker. 1983. An improved technique for clearing and staining plant tissue for detection of nematodes. J Nematol 14:142–143.

Chitwood, BG. 1949. Root-knot nematode. Part I. A review of the genus *Meloidogyne* Golden, 1887. Proceedings of the Helminthological Society of Washington 16:90–104.

Cliff, GM and H. Hirschmann. 1984. *Meloidogyne microcephala* n. sp. (Meloidogynidae) a root-knot nematode from Thailand. J Nematol 16:183–193.

Dongre, M and S. Simon. 2013. Infestation and host studies of *Meloidogyne graminicola* in rice nurseries of Allahabad. Int J Bot and Res 3:27–34.

Dutta, TK, Powers, SJ, Kerry, BR, Gaur, HS and RHC Curtis. 2011. Comparison of host recognition, invasion, development and reproduction of *Meloidogyne graminicola* and *M. incognita* on rice and tomato. Nematology 13:509–520.

Food and Agriculture Organization [FAO]. 2013. Rice market monitor http://www.fao.org/economic/est/publications/rice-publications/rice-market-monitorrmm/en/

Fortuner, R and G. Merny. 1979. Les nématodes parasites des racines du riz. Mise au point bibliographique. Rev Nematol 2:79–102.

Handoo, ZA, Skantar, AM, Carta, LA and EF Erbe. 2005. Morphological and molecular characterization of a new root- knot nematode, *Meloidogyne thailandica* n. sp. (Nematoda: Meloidogynidae), parasitizing ginger (Zingiber sp.). J Nematol 37:343–353.

Hunt, DJ and ZA Handoo. 2009. Taxonomy identification and principal species. In: Perry RN, Moens M, Starr JL (eds) Root-knot Nematodes. CABI publishing, Wallingford pp 55–97.

Jain, RK, Khan, MR and V. Kumar. 2011. Rice root-knot nematode (*Meloidogyne graminicola*) infestation in rice. Arch Phytopathol. Plant Prot. 45:635–645.

Lan, CH, Anh, NT and CH Mau. 2011. The diversity of some local upland rice cultivars in Northern of Vietnam. International Conference on Life Science and Technology IPCBEE IACSIT Press, Singapore 3:188–192.

Main, IH and MMA Khan. 1995. Effects of inoculum level on the post penetration development of *Meloidogyne graminicola* in rice root. Bangladesh J Sci Ind Res. 30:55–64.

MacGowan, JB and KR Langdon. 1989. Hosts of the rice root-knot nematode, *Meloidogyne graminicola*. Nematol Cir. 172.

Nokkoul, R and T. Wichitparp. 2013. Quality of upland rice seed produced during the rain season in southern Thailand. Int J Pl An and Env Sci. 3:181–184.

Pokharel, RR, Abawi, GS, Zhang, N, Duxbury, JM and CD Smart. 2007. Characterization of isolates of *Meloidogyne* from rice-wheat production fields in Nepal. J Nematol 39:221–230.

Poudyal, DS, Pokharel, RR, Shrestha, SM and GB Khatri-Chetri. 2005. Effect of ioculum density of rice root knot nematode on growth of rice cv. Masuli and nematode development. Australasian Plant Pathol 34:181–185.

Ruanpanun, P, Tangchitsomkid, N, Hyde, KD and S. Lumyong. 2010. Actinomycetes and fungi isolated from plant-parasitic nematode infested soils: screening of the effective biocontrol potential, indole-3-acetic acid and siderophore production. World J Microbiol Biotechnol. 26:1569–1578.

Soomro, MH and NGM Hauge. 1993. Relationship between inoculum density of *Meloidogyne graminicola*, growth of rice seeding and development of the nematode. Pakistan. J Nematol. 11:103–114.

Upadhyay, V, Bhardwaj, NR, Neelam and PK Sajeesh. 2014. *Meloidogyne graminicola* (Golden and Birchfield): Threat to rice production. Res J Agric For Sci 2:31–36.

Waele, DD, Das, K, Zhao, D, Tiwari, RKS, Shrivastava, DK, Vera-Cruz, C and A. Kumar. 2013. Host response of rice genotypes to the rice root-knot nematode (*Meloidogyne graminicola*) under aerobic soil conditions. Arch Phytopathol Plant Prot. 46:670–681.

Win, PP, Kyi, PP, Maung, ZTZ and DD Waele. 2013. Evaluation of the host response of lowland and upland rice varieties from Myanmar to the rice root-knot nematode *Meloidogyne graminicola*. Arch Phytopathol Plant Prot. 47: 869–891.

J. ISSAAS Vol. 21, No. 1: 78-95 (2015)

ENVIRONMENTAL SUSTAINABILITY AND CLIMATE BENEFITS OF GREEN TECHNOLOGY FOR BIOETHANOL PRODUCTION IN THAILAND

Jintana Kawasaki[1], Thapat Silalertruksa[2], Henry Scheyvens[1] and Makino Yamanoshita[1]

[1]Institute for Global Environmental Strategies, Natural Resources and Ecosystem Service Area
2108-11, Kamiyamaguchi, Hayama, Kanagawa 240-0115, Japan
[2] The Joint Graduate School of Energy and Environment,
King Mongkut's University of Technology Thonburi,
126 Prachauthit Road, Bangkok 10140, Thailand
Corresponding author: jkawasaki@iges.or.jp

(Received: August 20, 2014; Accepted: April 26, 2015)

ABSTRACT

Biofuels are often presented as an environmentally friendly alternative to fossil fuels; however, empirical analysis that is widely reported in the literature shows that biofuel production can have negative environmental and social impacts. The potential for these negative impacts can be avoided through careful planning of biofuel feedstock production and processing. This report focuses on how green technologies and practices can be introduced into ethanol production to reduce its environmental footprint. The research site of this study is located in Khon Kaen province in north-eastern Thailand. Emissions from ethanol production were estimated using life cycle greenhouse gas emission analysis. The analysis covered land use change, cultivation of cassava and sugarcane, ethanol processing, and transportation. Farming data from the study sites in 2013 was used to estimate emissions from crop cultivation and the transportation of cassava and sugarcane to the ethanol plants. Emissions from ethanol production processing were estimated from production data from a combined sugar milling and molasses ethanol factory and a cassava flour and ethanol factory. The estimated emissions from sugarcane farming (32 g CO_2eq/MJ ethanol) were much higher than for cassava farming (5 g CO_2eq/MJ ethanol) due to greater application of chemical fertilizer and burning during harvesting. The research estimated that the application of green agricultural technologies for sugarcane farming –non-burning, drainage management in irrigated areas, reduced use of chemical fertilizer, and increased use of green compost – would reduce emissions per year by 17 g CO_2eq/MJ ethanol. The ethanol production from cassava generated high emissions from the burning of coal in the internal boilers of the ethanol production processing plant (56 g CO_2eq/MJ ethanol). Utilisation of the waste to generate electricity and biogas would reduce emissions by 14 -26 g CO_2eq/MJ ethanol per year by reducing dependence on coal and conventional sources of electricity. The research concluded that the green technologies and practices studied could contribute to both lower GHG emissions and better environmental outcomes from biofuel production.

Key words: GHG emissions, climate change mitigation

INTRODUCTION

Biofuel production is widely promoted to enhance energy security and reduce greenhouse gas (GHG) emissions in Thailand. However, biofuel production can have negative local environment and socio-economic impacts. Some studies found that the cultivation of biofuel crops such as cassava and sugarcane required heavy application of fertilizer and pesticide, with negative environmental impacts (Suksiri et al., 2008). Another problem is that the burning of sugarcane leaves before harvesting, which is a common practice, increases carbon dioxide (CO_2) emissions and air pollution (Chomyong and Higano, 2008).

Past and on-going ethanol production in Thailand is associated with land use change. Agricultural areas under rice and other food crop cultivation have been converted to sugarcane and cassava for biofuel production due to the higher returns from the latter, and because the fertility of the soils in some areas is too low to sustain rice cultivation (Pannangpetch et al., 2009; Kawasaki and Herath, 2011). The Government of Thailand has encouraged the use of gasohol, with a 10% blend of bioethanol and 90% gasoline to achieve its target of reducing reliance on crude oil imports. Under Thailand's 15 year Renewable Development Plan (2008-2022), the Government set a target of increasing bioethanol production from 6.2 M litre/day in 2016 to 9.0 M litre/day in 2022), for both reducing fossil fuel dependency and reducing GHG emissions (Department of Alternative Energy Development and Efficiency, 2008). As a follow on from these policies, the following targets were set for the cultivation of energy crops: Sugarcane, 690,000 hectares, with 88,000 hectares (13% of total area target) for biofuel production and the remainder for food; Cassava, 1,184,000 hectares (7% (86,400 hectares) biofuels); Oil palm, 880,000 hectares (up from 480,000 hectares) (30% (264,000 hectares) biofuels) (Ministry of Agriculture and Cooperatives, 2014). These policies led to a rapid increase in bioethanol production, from 0.3 million litres/day in 2006 to 1.3 million litres/day in 2011 (Department of Alternative Energy Development and Efficiency, 2012).

The main areas with the most potential for cassava and sugarcane production are in the northeast of Thailand. These are located in the upland plateaus, where temperature ranges from 19 to 30 °C, with an average annual rainfall of about 1,300 millimetres (Office of Agricultural Economics, 2011). Over 65% of these areas is covered by clayey and poorly drained paleaquults (soils) that are suitable for cassava and sugarcane cultivation (Ekasingh et al., 2007).

Biofuel production in northeast Thailand has involved land use change and is associated with environmental harm because of heavy fertilizer and pesticide use in cultivation. Agricultural areas under rice cultivation have been converted to biofuel feedstocks, specifically sugarcane and cassava. This is associated with the policies mentioned above and the suitability of the soils for these crops.

In Thailand, biofuel crop cultivation has negative externalities, but there are ways to reduce these. For example, making better use of the waste from ethanol plants by employing green technologies would reduce environmental impacts and contribute to the sustainable development of the bioethanol industry (Food and Agriculture Organization, 2012). Total agricultural residues in Thailand in 1997 amounted to about 61 million tons; hence this could be a huge source of materials for producing biogas and green manure (Chaiprasert, 2011). Twenty million tons of bagasse, as residues from sugar mills, or nearly 29% of the total weight of sugarcane, were used to produce steam and electricity for the mills in 2004 (Papong et al., 2004).

One study on biomass utilization found that electricity generation from cane trash could reduce GHG emissions at 288 kg CO_2eq/1000 litres (Silalertruksa and Gheewala, 2009). Another study found that using bagasse in sugar mills to generate electricity could reduce emissions at 500,000 ton CO_2eq per year by substituting for electricity from conventional sources (Siemers, 2010). Another study found that avoiding the burning of cane trash could reduce emissions by over 5,000 ktons CO_2eq (Jenjariyakosoln et al., 2013). Yet another study concluded that the biogas produced from waste water treatment associated with ethanol production could reduce emissions from coal at 734 g CO_2 per FU (Papong and Malakul, 2010).

While the literature suggests that there is potential to introduce green technologies and practices into biofuels production in Thailand, there are also a number of challenges that need to be faced. First, ways need to be found to effectively use all the bagasse from the mills. Second, most farmers still burn sugarcane during harvesting and persuading them to adopt other practices need to be found (Luanmanee and Lertna, 2014). Third, technology options for waste utilization remain quite limited and expensive (Wood, 2006; Bara and Delivand, 2011).

One way forward is through a better understanding of the benefits of introducing green technologies and practices into biofuels production for GHG emissions and environmental impacts. While studies have been conducted on reducing GHG emissions through management of the waste generated in the ethanol production process and avoiding the burning of cane trash during harvesting, these studies did not assess the potential for other green agricultural practices to contribute to GHG emission reductions, because of their limited data. Important questions that need to be addressed regarding the sustainability of biofuels production in Thailand include: How can green technologies and practices contribute to GHG emissions reductions? How effective are green technologies in reducing emissions? What are the challenges of introducing green technologies into bioethanol production?

This study aims to (1) examine the potential of green technologies and practices to reduce GHG emissions by using data from biofuel feedstock growers and ethanol producers in Khon Kaen province, and (2) estimate the amount of emissions reduction associated with green technologies.

METHODOLOGY

Study Sites

Khon Kaen province is located in the central part of northeast Thailand and has an elevation of 100-200 metres above sea level. It comprises 26 districts, with a total area of 10,886 square kilometres, and has approximately 1.76 million inhabitants, 24% of whom are engaged in farming.

Three districts in Khon Kaen were selected for this study: Nam Phong (E16°42′10″ N102°51′17″), Kranuan (E16° 42′ 22″ N103° 4′ 44″) and Mueang Khon Kaen (E16°26′18″ N102°50′20) (Figure 1). Nam Phong and Kranuan are the main fuel crop planting areas, while Mueang Khon Kaen was chosen as an area where conversion from paddy to fuel crops has taken place. There are currently two sugar mills and two ethanol plants using molasses and cassava in Khon Kaen.

The total rainfed area in Khon Kaen was nearly 82% or 539,913 hectares of the total farmland in 2010 (Khon Kaen Meteorological Station, 2012). The fertility of 65% of the total farming area is naturally low. Rice and vegetables are usually planted in lowland areas, while cassava and sugarcane occupy the upland areas. Changes in market prices have played an important role in determining the kind of upland crops. Rice is grown for household consumption, but cash crops (e.g. cassava and sugarcane) seem to be preferred by farmers for generating quick financial returns.

Because water supply has become increasingly scarce and because a constraint in labor supply is being experienced during the peak season, some farmers have shown interest in converting rice lands for sugarcane and cassava cultivation (Khon Kaen Provincial Statistical Office, 2012). The area under rice cultivation decreased from 413,000 hectares to 393,000 hectares within a 15 year period – 1993-2009.

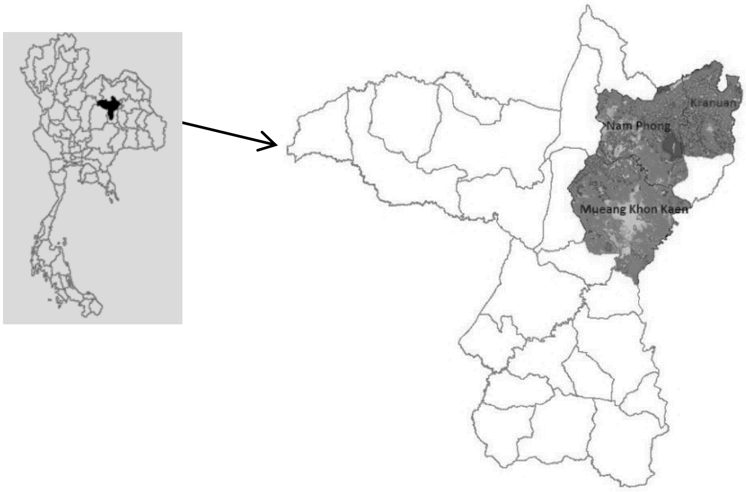


Fig. 1. Location of study sites in Khon Kaen province, Thailand

Life Cycle Greenhouse Gas Emissions Calculation

The GHG emissions of ethanol production were calculated applying the life cycle assessment (LCA) methodology that is widely used by the International Sustainability and Carbon Certification (International Sustainability Carbon Certification, 2010). GHG removals and emissions during cultivation and harvesting of feedstocks, transportation of raw materials to the mills, ethanol processing and transportation of the ethanol to the point of sale are incorporated in the calculations. The emissions sources are: emissions from the extraction or cultivation of input materials (E_{ec}), emissions from carbon stock changes caused by land-use change and management (E_l), emissions from the process for producing the biofuel (E_p), emissions from transport and distribution (E_{td}), and emissions from the use of biofuel (E_u). The emissions credits are: emissions saving from soil carbon accumulation via improvement of agricultural practices by adopting green agricultural technologies and management of field drainage, e.g. through the building of levees and drains (E_{sca}), and emission savings from the biofuel production system, such as savings associated with organic fertilizers from waste utilization, biogas recovery and excess electricity from co-generation (E_{crd}). The net GHG emissions formula (mega joule-MJ) is thus:

$$E = E_{ec} + E_l + E_p + E_{td} + E_u - E_{sca} - E_{crd} \quad (1)$$

Various materials and inputs including diesel, fertilizers, pesticides and electricity were used in the feedstock cultivation. There were no differences in types of input used for cassava farming and sugarcane farming at the study sites. The emissions from input materials (E_{ec}) were estimated from the amount of materials and inputs used in farming and their emission factors. Nitrous oxide (N_2O) emissions from the application of nitrogen fertilizer to the soil and soil disturbance are assessed. The emissions from crop residues and biomass waste were estimated from the volume of biomass burnt multiplied by the combustion and emission factors. The amount of crop residues available for burning was estimated from average yield multiplied by residue to product ratios (RPR) (Department of Energy Development and Promotion, 2012).

The equation used in the estimation of emissions from extraction of input materials (E_{ec}) is:

$$E_{ec} = \sum_i (M_i \times EF_i) \quad (2)$$

Where: M_i is amount of materials and inputs used (kg/ha or litre/ha); EF_i is emission factors of inputs used (kg CO_2-eq/ha); and i is materials and inputs type.

Land-use change in terms of replacing one crop type with another, specifically rice to cassava and rice to sugarcane, was found in the study areas. The increase in biomass stocks of the annual crops in a single year was assumed equal to biomass losses from harvest and mortality in the same year, and thus there was no net accumulation of biomass carbon stocks. With this assumption, the emissions from carbon stock changes caused by land-use change and management (E_l) was estimated from soil organic carbon stock (SOC) of farming practices and soil conditions on site before and after biofuel crop production. To make this comparison, total emissions were divided by the IPCC's default value for 20 years. Emissions from carbon stock changes caused by land-use change and management (E_l) were estimated as follows:

$$E_l = \frac{CS_R - CS_A}{\text{Crop yield x 20}} \text{x} 3.664 \text{x} BCF \qquad (3)$$

$$= \frac{C_{B,R} + SOC_R - C_{B,A} - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$$

$$= \frac{SOC_R - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$$

$$SOC = SOC_{Ref} \text{ x } F_{LU} \text{ x } F_{MG} \text{ x } F_l$$

Where: CS_R means total carbon stocks before conversion of other crops to biofuel crop (ton C/ha); $C_{B,R}$ is biomass and SOC_R is soil organic carbon before conversion of other crops to biofuel crop; CS_A is total carbon stocks after conversion of other crops to biofuel crop (ton C/ha); $C_{B,A}$ is biomass and SOC_A is soil organic carbon after conversion of other crops to biofuel crop; SOC_{Ref} is the reference value of SOC based on the IPCC's default values; F_{LU} is stock change factor for the land use system; F_{MG} is stock change factor for the land management; F_l is stock change factor for input of organic matter; constant "3.664" is the conversion factor for mass carbon to mass carbon dioxide (CO_2), and "BCF" means the amount of feedstocks required to produce bioethanol.

The emissions from bioethanol production processing (E_p) were measured from all inputs used in the processing stages of ethanol production, and the processing of waste to generate electricity, steam and biogas, etc. Emissions from molasses-based ethanol production were calculated from the emissions of the sugar mills and ethanol plants.

The processing of molasses-based ethanol began with the sugarcane being loaded into the crushing process in the sugar mills to extract sugarcane juice. The sugarcane juices were clarified to remove impurities and concentrated into syrup, seed with raw sugar crystals in a vacuum pan, and boiled until sugar crystals had formed and grown. The crystals were separated from the syrup by a centrifugal process to extract the raw sugar products and molasses. The molasses was used in the ethanol production. The main processes of the ethanol production processing were fermentation, distillation and dehydration. The ethanol product from molasses was 99.5% pure ethanol.

The main processes of the cassava-based ethanol processing were milling, mixing and liquefaction, fermentation and distillation and molecular sieve dehydration. The emissions of cassava ethanol production were estimated from the combustion of fuels in the industrial boilers for steam production, and the electric power used for drying cassava chips and ethanol. The cassava ethanol was purified to 99.5%.

The emissions from bioethanol production processing (E_p) were calculated from:

$$E_p = \sum_j (M_j \times EF_j) \quad (4)$$

Where: M_j is amount of materials used in the bioethanol production processing (litre or kg or kWh per year); EF_j is emission factors of materials used (kg CO_2-eq /MJ biofuel); and j is material type.

The emissions from the transportation of feedstock (E_{td}) were estimated from the amount of feedstock required for producing bioethanol, emission factors for transportation with full load and empty load, and transportation distance with/without load. The formula used to estimate emissions from the transportation of feedstock is:

$$E_{td} = (M_{full\ load} \times Distance_{full\ load} \times EF_{full\ load}) + (M_{empty\ load} \times Distance_{empty\ load} \times EF_{empty\ load}) \quad (5)$$

Where: $M_{full\ load}$ is amount of feedstock with full load (ton feedstock/MJ bioethanol); $Distance_{full\ load}$ is distance with full load (km); $EF_{full\ load}$ is emission factor for transportation with full load (kg CO_2-eq/ton-km); $M_{empty\ load}$ is amount of feedstock with empty load (ton feedstock/MJ bioethanol); $Distance_{empty\ load}$ is transportation distance with empty load (km); and $EF_{empty\ load}$ is emission factor for transportation with empty load (kg CO_2-eq/ton-km).

The emissions from the use of biofuel (E_u) was estimated from the amount of biofuel used, non-CO_2 GHG emission factor from the use of biofuel, and global warming potential factors for non-CO_2 GHGs. It is assumed that CO_2 emissions from the use of bioethanol was balanced by the CO_2 fixation during crop growth and set to zero. The formula is:

$$E_u = (M_{biofuel} \times EF_{Non\text{-}CO2} \times GWP) \quad (6)$$

Where: $M_{biofuel}$is amount of biofuel used (unit per MJ of biofuel); $EF_{Non\text{-}CO2}$ is Non-CO_2 GHG emission factor from biofuel used (kg CH_4/MJ biofuel and kg N_2O/MJ biofuel); and GWP is global warming potential factors for the non-CO_2 GHG (kg CO_2-eq/kg)

The emissions reduction from the use of green technology can be considered to be the results of adopting green agricultural technology and waste utilization, as presented in Table 1. Emission reduction from adopting green agricultural technology (E_{sca}) was estimated from reduction in the amount of synthetic chemical inputs used, an increase in the use of green compost and manure, drainage management of irrigated land, and avoided burning during harvest:

$$E_{sca} = \frac{(M_{substituted\ fuel} \times EF_{substituted\ fuel}) \times BCF}{Crop\ yield} \quad (7)$$

Where: $M_{substituted\ fuel}$ is the amount of fossil fuel derived material inputs (e.g. urea) that would be substituted by green manure or compost during the biofuel crop production (kg or MJ/ha); $EF_{substituted\ fuel}$ is emission factor of the fuels or materials that would be replaced by the by-product generated from bioethanol production system (kg CO_2-eq/kg); crop yield means annual yield of biofuel crops (ton/ha); and BCF is amount of feedstocks required to produce bioethanol (kg feedstock/MJ bioethanol).

The emission reduction from bioethanol production processing (E_{crd}) was assessed from waste utilization including producing green compost from crop residues, producing steam and electricity from bagasse as waste of ethanol plants, and producing biogas from the upflow anaerobic sludge blanket (UASB) wastewater treatment system. The green compost was distributed from the sugar mill to member sugarcane growers as organic fertilizer. The formula for emission reduction from bioethanol production processing is:

$$E_{crd} = \frac{(M_{Exc-elec} x EF_{substituted\ elec}) + (M_{substituted\ fuel/materials} x EF_{substituted\ fuel/materials})}{Yield} \quad (8)$$

Where: $M_{Exc-elec}$ is amount of the excess electricity from the bioethanol production system. It will be sold to the grid-electricity system in Thailand (kWh/year); $M_{substituted\ fuel/materials}$ is amount of fuels or materials that can be substituted by the by-products generated from the bioethanol production processes (kg or MJ/year); $EF_{substituted\ elec}$ is emission factor of the grid-electricity that can be substituted by the excess electricity of bioethanol production system (kg CO_2-eq/kWh); $EF_{substituted\ fuel/materials}$ is emission factor of the fuels or materials that can be replaced by the by-product generated from bioethanol production system (kg CO_2-eq/MJ bioethanol); and yield is annual yield of biofuel crops (MJ bioethanol).

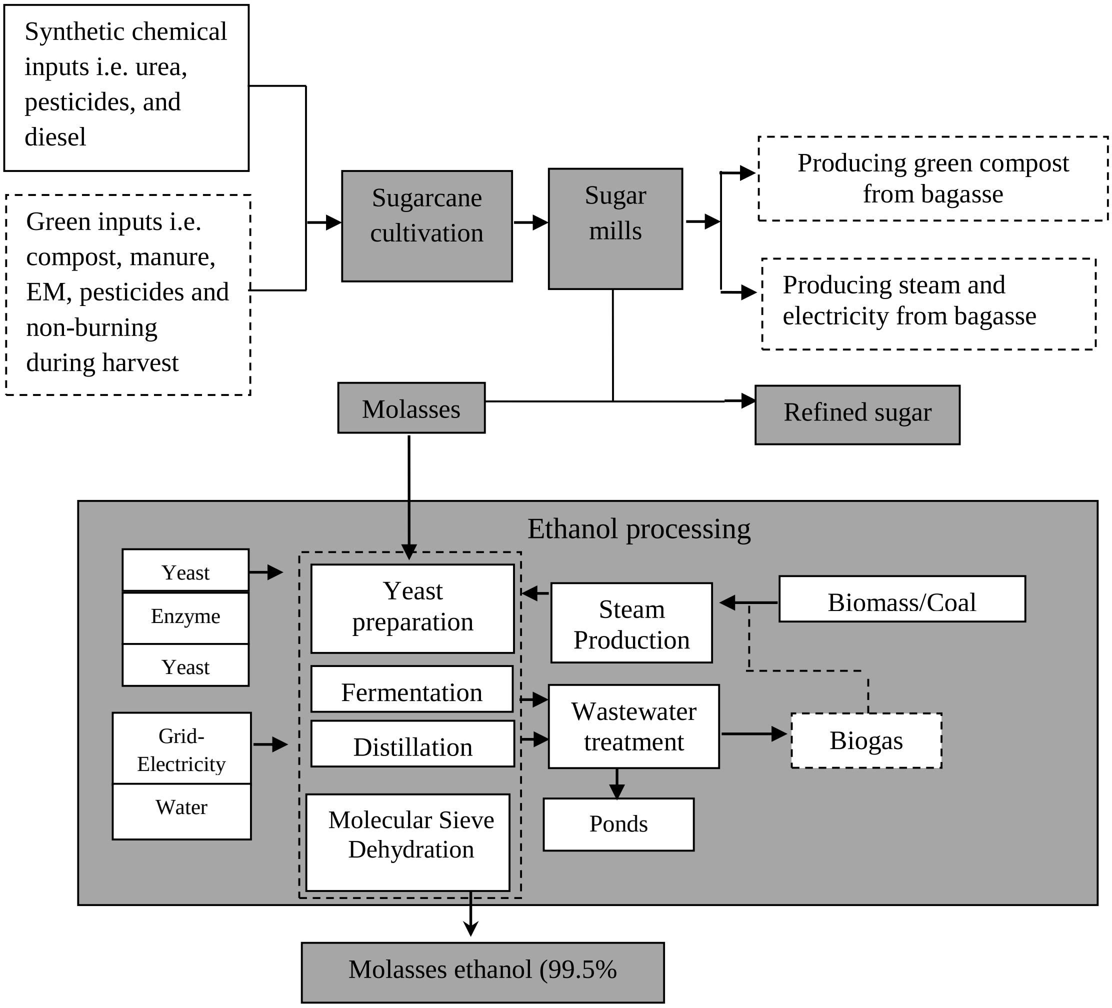
Table 1. Green technology for the ethanol production assessed in this study

Green Technology	
1) Green agricultural technology	
1.1 Using green compost from crop residues and manure from raising cows and chickens	/
1.2 Simple practices to reduce use of chemical pesticides	/
1.3 Reduction of open field burning	/
1.4 Management of field drainage to reduce N_2O emissions	/
2) Waste utilization	
2.1 Producing green compost from field crop residues and waste from biofuel production processing such as bagasse	/
2.2 Producing steam and electricity from bagasse	/
2.3 Producing biogas from treatment of wastewater by the upflow anaerobic sludge blanket (UASB) system of the ethanol production processing from cassava	/

The green technologies for ethanol production from molasses and cassava are shown in Figures 2 and 3.

Data Sources

The data for biofuel crop cultivation and transportation were obtained from interviews with 91 biofuel crop growers in the study sites in Khon Kaen province in 2013. The data for the ethanol processing are production data from the sugar mills and bioethanol plants in Khon Kaen province. The formulas and emission factors used are from the published literature and statistical records (Intergovernmental Panel on Climate Change, 2006; Ecoinvent Centre, 2010; International Sustainability Carbon Certification, 2010; Office of Agricultural Economics, 2012; Thailand Greenhouse Gas Management Organization, 2013).



Note: [ ] are the elements of green technology

EM is the effective microorganisms

Fig. 2. Green technology in molasses-based ethanol production

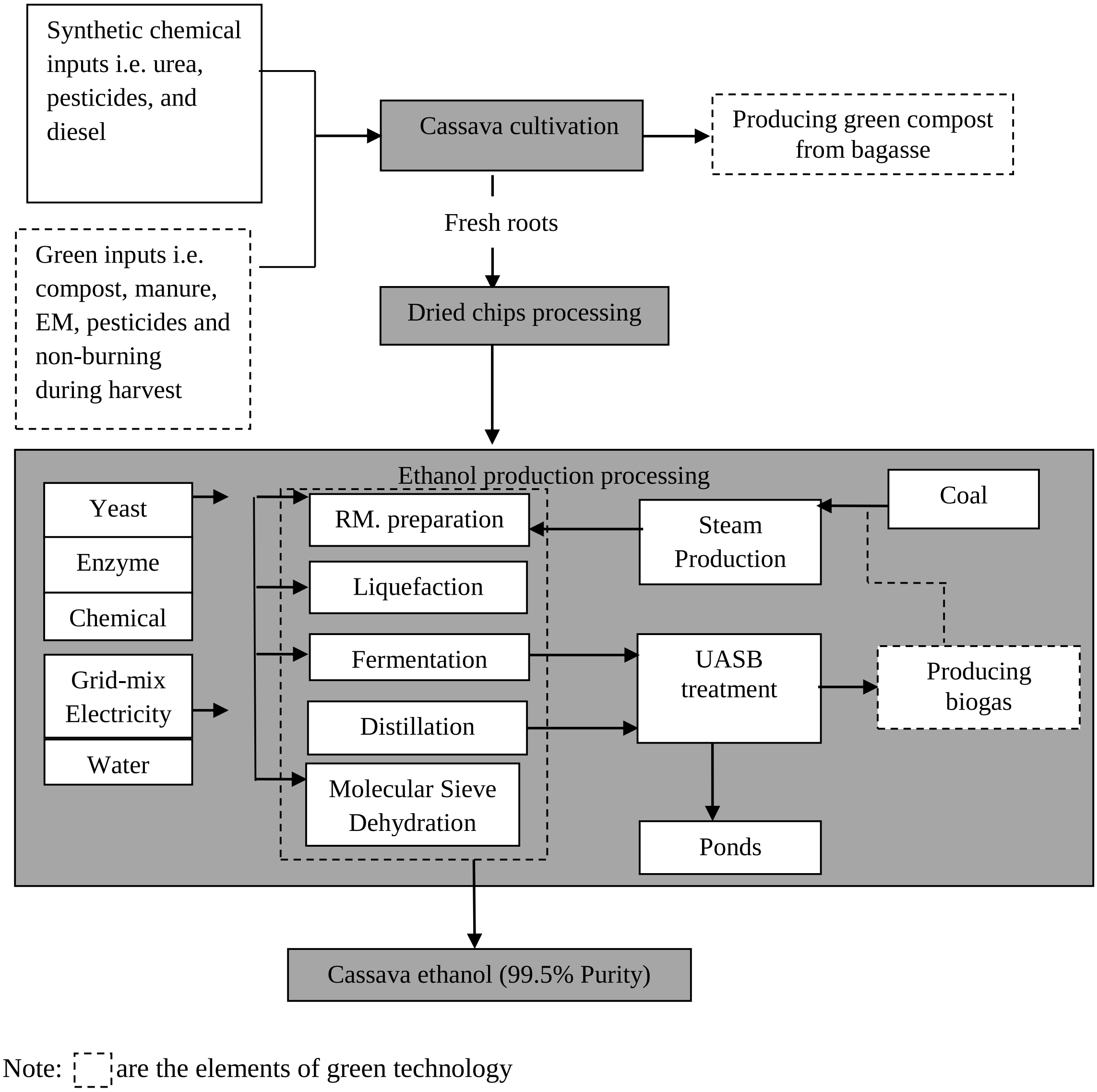


Fig. 3. Green technology in cassava-based ethanol production

RESULTS AND DISCUSSION

Life Cycle Greenhouse Gas Emissions Assessment of Ethanol Production

The emissions from sugarcane ethanol production are estimated from land use change, sugarcane cultivation and harvesting, sugar milling, molasses ethanol processing, and transportation of fresh sugarcane, molasses and ethanol. Table 2 shows the average yield of sugarcane and input values of molasses ethanol production. The average yield of sugarcane was 79 ton per hectare. Chemical fertilizers and herbicides were the major inputs for sugarcane cultivation.

At the study sites most farmers were small-scale sugarcane and cassava growers, meaning they likely used small tractors for land preparation and planting. For harvesting cassava, the farmers preferred to dig by hand, as the use of machines caused roots to break. For sugarcane harvesting, the farmers applied two approaches. First, some farmers cut the cane manually and burnt the leaves and trash before harvesting. Half of the sugarcane supplied to sugar mills in Khon Kaen province (Office of Cane and Sugar Board, 2007) was burnt before harvesting. Second, for large-scale sugarcane cultivation, farmers used harvest tractors to cut the cane. This approach separated out the sugarcane leaves. One harvest tractor could harvest 1 ton of sugarcane in 1.5-2.5 hours. The use of harvest tractors reduced emissions from the burning of the sugarcane leaves, but produced emissions from diesel combustion. Generally, at the research sites sugarcane was delivered to the sugar mills by 16 ton trucks. The distance from the study sites to sugar mills was nearly 30 km.

Land use changes associated with the production of biofuel feedstocks were observed in the research area and from historical land use data (Land Development Department, 2012). A comparison of land use and land cover of the years 2000 and 2012 in the three study districts shows that the rice cultivation areas in Mueang Khon Kaen district increased from 9,396 hectares in 2000 to 29,334 hectares in 2012, and that 5,190 hectares of rice areas were converted to sugarcane and cassava in Nam Phong district and 3,742 hectares in Kranuan district over the same period. Average soil carbon stock of land before conversion to biofuel crops was 43 ton C per hectare, and after conversion was 22 ton C per hectare.

According to data from a sugar mill in Khon Kaen province, 1 ton of sugarcane produced 109 kg of sugar and 45 kg of molasses. The sugar milling required two main inputs – lime and NaOH. The processing of molasses ethanol required four main inputs – molasses, sulfuric acid, urea and electricity. The molasses ethanol plants were attached to the sugar milling plants and the molasses were transferred from sugar mills to ethanol plants by pipelines.

Table 2. Average inputs used for the ethanol production from sugarcane in Khon Kaen, 2013

Life cycle stage	Inputs	Unit	Range	Mean
1. Cultivation and harvesting				
	Main inputs:			
	• Diesel use	litre/ha	12.1-213.5	53
	• N-fertilizer	kg/ha	26-203.4	89
	• P-fertilizer	kg/ha	26-204	90
	• K-fertilizer	kg/ha	23.4-582	229
	• Urea	kg/ha	0-412.2	71
	• Herbicides (Paraquat)	kg/ha	0-525.4	84
	Average yield of sugarcane	ton/ha	78.7-79.4	79
2.Transportation				
	• 10 wheel truck, 16 ton load	ton sugarcane/L ethanol		0.023
	• Distance from farms to sugar mills and ethanol plants	km	4-69	30
3. Sugar milling				
	Main inputs:			
	• Lime	kg/L ethanol		0.038
	• NaOH	kg/L ethanol		0.01
	Main outputs:	kg sugar/ton cane		109
	• Sugar products	kg molasses/ton cane		45

Life cycle stage	Inputs	Unit	Range	Mean
	• Molasses • Excess electricity	kWh/ton cane		37
4. Ethanol production processing				
	Main inputs:			
	• Sugarcane	kg/L ethanol		23.3
	• Sugarcane molasses	kg/L ethanol		4.6
	• Sulfuric acid	kg/L ethanol		0.024
	• Grid-electricity	kWh/L ethanol		0.223
	• Urea	kg/L ethanol		0.003
	• Steam (internal supply by sugar mill)	kg/L ethanol		3
	Main output: 1 litre of bioethanol			

Note: The energy density of bioethanol is about 21.2 mega joules (MJ) per litre
Source: Field data, 2013.

Fresh cassava was the main raw material for the cassava ethanol production. Dry cassava chips were used when there was a shortage of fresh cassava. The average yield of cassava was about 30 ton per hectare (Table 3). The production of 1 litre of cassava ethanol required 6.1 kg of fresh cassava. The use of chemical fertilizers and chemical pesticides were greatly lower in cassava farms than inputs values in sugarcane farms. The main inputs for the cassava ethanol processing were fossil fuel, electricity and steam. The steam used in the ethanol processing was produced in the internal boilers by burning coal. The electricity bought from the national grid system used about 0.31 kWh for 1 litre of ethanol.

Table 3. Average inputs used for the ethanol production from cassava in Khon Kaen, 2013

Life cycle stage	Inputs/outputs	Unit	Range	Mean
1. Cultivation and harvesting				
	Main inputs:			
	Diesel use	litre/ha	0.4-10.6	3.1
	N-fertilizer	kg/ha	23.4-188.5	50
	P-fertilizer	kg/ha	23.4-188.5	50
	K-fertilizer	kg/ha	23.4-266.1	87.5
	Urea	kg/ha	0-208.3	28.8
	Herbicides (paraquat)	kg/ha	0-5	0.6
Average yields of cassava		ton/ha	15.6-45.8	30
2.Transportation				
	• 4 wheel truck, 7 ton load	ton cassava/ L ethanol	10-52	0.0061 25
	• Distance from farm to ethanol plant	km		
3. Ethanol production processing				
	Main inputs:			
	• Cassava	kg/L ethanol		6.1
	• Coal	kg/L ethanol		0.33
	• Grid-electricity	kWh/L ethanol		0.31
	• Water	L/L ethanol		16.02
	Main output: 1 litre of bioethanol			

Source: Field data, 2013

Emissions Reductions from Green Technology

Based on data obtained from interviews with farmers and the ethanol factory in Khon Kaen province, the emissions of ethanol production consisted of five factors: conventional fuel crop production, carbon stock changes caused by conversion of rice land to fuel crops, feedstock processing and biofuel production, transportation of feedstock, and use of bioethanol. It is assumed that there was limited technology for waste utilization.

An example of how the life cycle GHG emissions of molasses ethanol production were calculated is:

$E = E_{ec} + E_l + E_p + E_{td} + E_u$

(1) $E_{ec} = EM_{fertilizers} + EM_{diesel} + EM_{paraquat} + EM_{field\ burning} + EM_{N2O\ of\ land\ management} + EM_{CO2\ of\ urea\ application}$

$EM_{fertilizers} = (M_{N\ fert} \times EF_{N\ fert}) + (M_{P\ fert} \times EF_{P\ fert}) + (M_{K\ fert} \times EF_{K\ fert}) + (M_{urea} \times EF_{urea})$
$= (88.75x2.6) + (90x0.252) + (228.75x0.16) + (70.63x5.53)$
$= 681$ kg CO_2eq/ha
$= 681/79 = 8.57$ kg CO_2eq/ ton sugarcane
$= (8.57 \times 23.3)/1{,}000 = 0.2$ kg CO_2eq/L ethanol

$EM_{diesel} = (M_{diesel} \times EF_{diesel})$
$= (53.13x0.33)/79 = 0.22$kg CO_2eq/ton sugarcane
$= (0.22 \times 23.3)/1{,}000 = 0.0051$ kg CO_2eq/L ethanol

$EM_{paraquat} = (M_{paraquat} \times EF_{paraquat})$
$= (84.38x3.23)/79 = 3.43$kg CO_2eq/ton sugarcane
$= (3.43 \times 23.3)/1{,}000 = 0.08$ kg CO_2eq/L ethanol

$EM_{field\ burning} = M_{field\ burning} \times$ confusion factor $\times (EF_{N2O} \times GWP_{N2O} + EF_{CH4} \times GWP_{CH4})$
$= 19.84 \times 0.5 \times (0.00007x298+0.0027x25) \times 1{,}000 = 876.70$ kg CO_2eq/ha
$= 876.70/79 = 11.05$ kg CO_2eq/ton sugarcane
$= (11.05 \times 23.3)/1{,}000 = 0.26$ kg CO_2eq/L ethanol

$EM_{N2O\ of\ land\ management} = (F_{ON} + F_{SN}) \times GWP_{N2O} \times EF_{N2O\text{-}N}$
$= (0+88.75) \times 298x0.0157 = 416$ kg CO_2eq/ha
$= 416/79 = 5.24$ kg CO_2eq/ton sugarcane
$= (5.24 \times 23.3)/1{,}000 = 0.12$ kg CO_2eq/L ethanol

$EM_{CO2\ of\ urea\ application} = (M_{urea} \times EF_{CO2urea})$
$= 70.625 \times 0.2 = 14.13$ kg CO_2eq/ha
$= 14.13/79 = 0.18$ kg CO_2eq/ton sugarcane
$= (0.18 \times 23.3)/1{,}000 = 0.004$ kg CO_2eq/L ethanol

Therefore,

$E_{ec} = 0.2 + 0.0051 + 0.08 + 0.26 + 0.12 + 0.004 = 0.67$ kg CO_2eq/L ethanol
$= 668.42$ g CO_2eq/L ethanol
$= 668.42 /21.2 = 31.53$ g CO_2eq/MJ ethanol

(2) $E_l = \frac{CS_R - CS_A}{\text{Crop yield x 20}} x3.664xBCF = \frac{C_{B,R} + SOC_R - C_{B,A} - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF = \frac{SOC_R - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$

SOC rice field = $SOC_{Reference} \times F_{LU} \times F_{MG} \times F_I$
= 39 x 1.1 x 1.0 x 1.0
= 42.90

SOC sugarcane = $SOC_{Current} \times F_{LU} \times F_{MG} \times F_I$
= 39 x 0.48 x 1.15 x 1.0
= 21.528

$E_l = \frac{42.90-21.53}{79\times20}\times3.664\times1{,}000$

= 49.36 kg CO_2eq/ ton sugarcane
= (49.36 x 23.3)/1,000 = 1.15 kg CO_2eq/L ethanol
= 1,150 g CO_2eq/L ethanol
= 1,150 / 21.2 = 54.25 g CO_2eq/MJ ethanol

(3) $E_p = \sum_j (M_j \text{ x } EF_j)$

EM $_{\text{sugar milling}}$ = $(M_{lime} \text{x} EF_{lime}) + (M_{NaOH} \text{x} EF_{NaOH})$
= (0.038 x 1.0154) + (0.01 x 1.1148)
= 0.0497 kg CO_2eq/L ethanol

EM $_{\text{ethanol processing}}$ = $(M_{sulfuric} \text{x} EF_{sulfuric}) + (M_{urea} \text{x} EF_{urea}) + (M_{electricity} \text{x} EF_{electricity})$
= (0.024 x 0.1219) + (0.003 x 3.2826) + (0.223 x 0.61)
= 0.1488 kg CO_2eq/L ethanol

E_p = EM $_{\text{sugar milling}}$ +EM $_{\text{ethanol processing}}$
= (0.0497 + 0.1488) x 1,000 = 198.54 g CO_2eq/L ethanol
= 198.54 / 21.2 = 9.36 g CO_2eq/MJ ethanol

(4) $E_{td} = E_{\text{full load}} + E_{\text{empty load}}$
= $(M_{\text{full load}} \text{ x Distance}_{\text{full load}} \text{ x } EF_{\text{full load}}) + (M_{\text{empty load}} \text{ x Distance}_{\text{empty load}} \text{ x } EF_{\text{empty load}})$
= (0.0233 x 30 x 0.0451) + (0.0233 x 30 x 0.0357)
= 0.05647 kg CO_2eq/L ethanol
= 56.47 g CO_2eq/L ethanol
= 56.47 / 21.2 = 2.66 g CO_2eq/MJ ethanol

(5) $E_u = (M_{biofuel} \times EF_{Non-CO2} \times GWP)$
= $(M_{biofuel} \text{ x } EF_{CH4} \text{ x } GWP_{CH4})$
= (1 x 0.000018 x 25) = 0.00045 kg CO_2eq/L ethanol
= 0.00045x21.2x1,000 = 9.54 g CO_2eq/L ethanol
= 0.00045x1,000 = 0.45 g CO_2eq/MJ ethanol

The net GHG emissions of molasses ethanol production (as shown in Table 4) was calculated from (1) +(2)+(3)+(4)+(5) = 31.53 +54.25 +9.36+ 2.66+0.45 = 98.26 g CO_2eq/MJ ethanol.

The life cycle GHG emissions of ethanol production from molasses and cassava are shown in Table 4. The emissions of molasses ethanol production (98 g CO_2eq/MJ ethanol) was not so different to that of cassava ethanol production (100 g CO_2eq/MJ ethanol). The large amount of chemical inputs and burning during harvesting caused high emissions from sugarcane cultivation (32 g CO_2eq/MJ ethanol). In the cassava ethanol production, the highest source of emissions was the cassava ethanol processing (56 g CO_2eq/MJ ethanol) due to coal combustion in the internal boilers. These findings indicate that the GHG emissions of ethanol production from sugarcane and cassava could be reduced by introducing green agricultural technology and waste utilization.

Table 4. Net GHG emissions per year of ethanol production from molasses and cassava in 2013

Type of emissions	**Mean (g CO_2 eq/MJ ethanol)**	
	Molasses	**Cassava**
E_{ec}: Extraction or cultivation of raw materials	31.53	5.36
E_l: Carbon stock changes caused by conversion of rice land to feedstock crops	54.25	37.58
E_p: Feedstock processing and biofuel production	9.36	55.53
E_{td}: Transportation of feedstocks	2.66	1.33
E_u: Use of bioethanol	0.45	0.45
Net GHG emissions	98.26	100.25

The emissions reductions from green agricultural technology were evaluated from the amount of chemical inputs reduced by increasing the amount of organic fertilizers used in the study sites in Khon Kaen province. There were five farmers in the study sites producing green compost from crop residues in their farms. After harvest, crop residues were stored, chopped, and ploughed in farms. Before planting cassava or sugarcane, cowpea was planted and ploughed after 50 days to increase nitrogen fixation and improve soil structure. Some farmers in irrigated areas applied drainage management in their farms during the rainy season. Drainage practices reduced N_2O emissions by nearly 0.33 kg N_2O/ha.

The amounts of farm residues in the study sites were nearly 23 tons per ha of top and leaves on the sugarcane farms, and 3 tons per ha of stalk on the cassava farms. Open field burning emits greenhouse gas emissions as CO_2, N_2O and methane (CH_4). In this study, emissions from field burning were estimated using the amount of farm residues available for combustion (M_{FB}), the combustion factor (C_f), N_2O and CH_4 emissions factors for field burning (EF), and global warming potential (GWP). The N_2O and CH_4 equivalence factors for 100 years were used for this assessment. The burning of weeds and crop residues in cassava fields in the study sites was rare, so in this case the emissions reduction from non-burning was assumed to be zero. Most farmers burned sugarcane before harvest due to labor constraints with the high wage rate. Recently, some farmers had avoided burning because the price of sugarcane from non-burning farming was 50-70 THB per ton higher than from burning farming due to the Government and Thai Sugar Cooperation promotion of non-burning.

The sugar mills were encouraged by the Government of Thailand to produce electricity from bagasse. However, the number of sugar mills that generated electricity was small due to the high costs of electricity generation. One small sugar mill in the study sites produced about 30 megawatts of electricity and 450,000 tons of steam per year. The biomass residues of the ethanol processing were used to produce about 6,000 tons of organic fertilizer per year. Biogas was produced from the treatment of wastewater. The sugar mill distributed organic fertilizers with lower prices to member sugarcane growers. The emissions reductions from excess electricity, steam, organic fertilizer and biogas as by-product of the ethanol production were included in net emission calculation.

The average amount of emissions reduced by applying green technology in ethanol production in Khon Kaen province in 2013 was 43 g CO_2eq/MJ ethanol for molasses ethanol production and 16 g CO_2eq/MJ ethanol for cassava ethanol production (Table 5). If there was non-burning of sugarcane in the fields, the emission would be reduced by another 12 g CO_2eq/MJ ethanol. Waste utilization was found to have high potential to reduce emissions for molasses ethanol (26 g CO_2eq/MJ ethanol) and cassava ethanol (14 g CO_2eq/MJ ethanol).

The results demonstrate that green technologies and waste utilization can make an important contribution to GHG emissions reductions. Figures 4 and 5 present the estimated GHG emissions of ethanol production with and without green technology. In these figures, minus (-) means positive impacts of surplus electricity.

Table 5. Net GHG emissions reduction per year of ethanol production applying green technology in 2013

Type of emissions	**Mean (g CO_2eq/MJ ethanol)**	
	Molasses	**Cassava**
E_{sca}: Good agricultural practice		
• Increasing use of green compost and manure	3.35	0.93
• Non-burning during harvest	12.14	none
• Drainage manage in the irrigated areas	1.36	0.94
E_{crd}: Waste utilization		
• Producing organic fertilizers, steam, and electricity from biomass waste and bagasse, and producing biogas from waste water treatment system	26.47	13.92
Total GHG emissions reduction	43.32	15.79

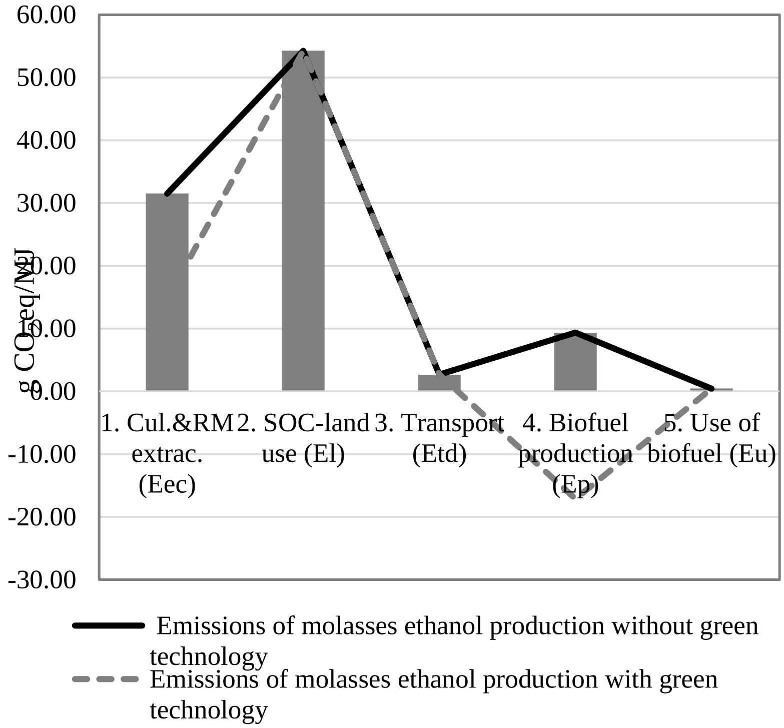


Fig. 4. Life cycle emissions reduction per year of molasses ethanol production applying green technology

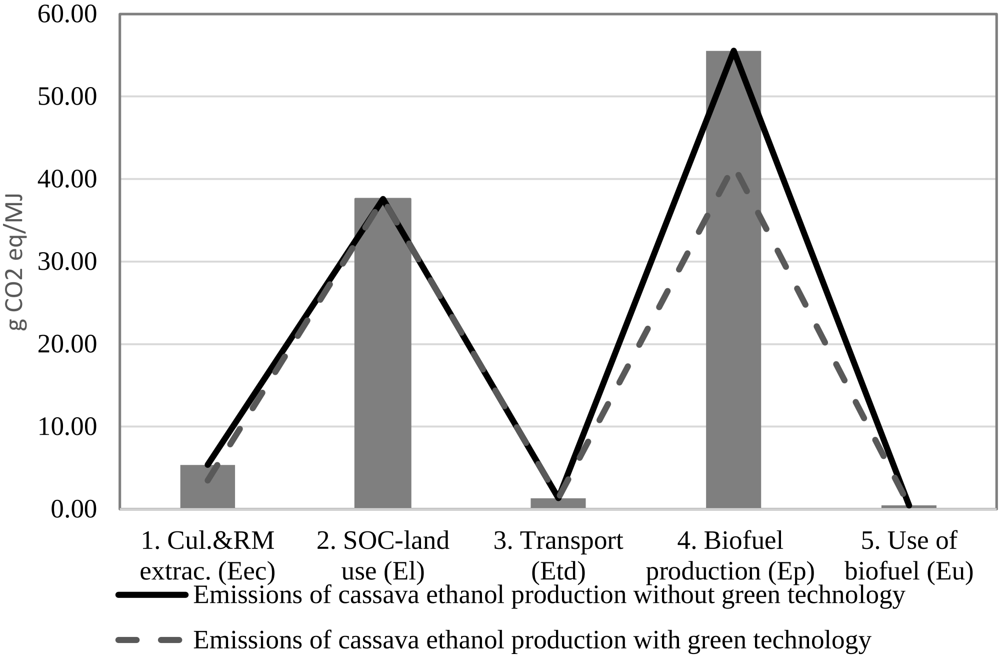


Fig. 5. Life cycle emissions reduction per year of cassava ethanol production applying green technology

CONCLUSIONS AND RECOMMENDATIONS

This study quantified the potential of selected green technologies in the form of green agricultural practices and waste utilization to reduce GHG emissions from ethanol production. The results demonstrate that green technologies and waste utilization can make an important contribution to GHG emissions reductions. Of the various technologies found at the study sites in Khon Kaen province, Thailand, the generation of excess electricity from molasses ethanol processing was found to have the highest emissions mitigation potential. Although sugarcane farming still depended on chemical fertilizers, some sugarcane farmers reduced emissions by increasing the amount of organic fertilizers used (3.35 g CO_2eq/MJ ethanol).

The study uncovered a number of challenges to applying green agricultural technologies in biofuel feedstock cultivation, namely insufficient supplies of organic fertilizers to replace synthetic fertilizers, as well as a shortage of labor and high wage rates during sugarcane harvesting, which makes the burning of agricultural residues attractive from a purely financial perspective. High costs are also a problem for waste utilization in the ethanol processing plants, and this applies to both electricity generated from bagasse and biogas produced from wastewater.

These results suggest a number of policy recommendations that would facilitate the uptake of green technology in ethanol production in Thailand. First, the Government should examine ways to encourage the production of organic fertilizer and biogas from biomass residues. Second, investments in the development of more efficient sugarcane harvest machinery that can harvest large volumes of sugarcane in short periods at lower costs than existing machinery is desirable. Third, the Government / Thai Sugar Cooperation should consider providing guaranteed farm prices for sugarcane produced without the field burning of residues.

ACKNOWLEDGEMENT

The outputs of the research were produced as part of a project on climate change funded by the Ministry of Environment of Japan in FY2013.

REFERENCES

Bara, M. and M. K. Delivand. 2011. Agricultural residues as promising biofuels for biomass power generation in Thailand. Journal of Sustainable Energy & Environment Special Issue. 21-27.

Chaiprasert, P. 2011. Biogas production from agricultural wastes in Thailand. Journal of Sustainable Energy and Environment Special Issue. 63-65.

Chomyong, C. and Y. Higano. 2008. Sustainable development and utilization of crop residues in Udonthani Province, Northeast Thailand. Japan Section of the Regional Science Association International. 6p.

Department of Alternative Energy Development and Efficiency. 2008. 15 Years alternative energy development plan. Ministry of Energy, Thailand: Government Printer (in Thai). 163p.

Department of Alternative Energy Development and Efficiency. 2012. Monthly ethanol production: 2007–2012. Ministry of Energy, Thailand: Government Printer (in Thai). 6p.

Department of Energy Development and Promotion. 2012. Biomass renewable energy. Ministry of Energy, Thailand: Government Printer (in Thai). 8p.

Ecoinvent Centre. 2010. Ecoinvent data v2.0. Swiss Center for Life Cycle Inventories. 40p.

Ekasingh, B., C. Sungkapitux, J. Kitchaicharoen, and P. Suebpongsong. 2007. Competitive commercial agriculture in the Northeast of Thailand. Chiang Mai University, Thailand. 181p.

Food and Agriculture Organization. 2012. Green jobs for a revitalized food and agriculture sector. Rome. 51p.

Intergovernmental Panel on Climate Change. 2006. Chapter 2: Generic methodologies applicable to multiple land-use categories. IPCC Guidelines for National Greenhouse Gas Inventories**.** 10p.

International Sustainability Carbon Certification. 2010. ISCC 205 GHG emissions calculation methodology and GHG Audit. 28 p.

Jenjariyakosoln, S., B. Sajjakulnukit, and S. Garivait. 2013. Energy and greenhouse gas emissions reduction potential of sugarcane field residues power generation in Thailand. International Journal of Environmental Science and Development. 4(2): 182-186.

Kawasaki, J. and S. Herath. 2011. Impact assessment of climate change on rice production in Khon Kean Province, Thailand. Journal of ISSAAS. 17(2): 14-28.

Khon Kaen Meteorological Station. 2012. Average annual temperature and rainfall in Khon Kaen Province 2012. Statistics of weather in Thailand. Thai Meteorological Department, Thailand: Government Printer (in Thai). 92 p.

Khon Kaen Provincial Statistical Office. 2012. Provincial statistical report. National Statistical Office, Ministry of Information and Communication Technology, Thailand: Government Printer (in Thai). 247 p.

Land Development Department. 2012. Land use and land cover. Ministry of Agriculture and Co-Operative, Thailand: Government Printer (in Thai).

Luanmanee, S. and S. Lertna. 2014. Developing farming systems for climate change mitigation in Thailand. Asian Development Bank Institute (ADBI). 6p.

Ministry of Agriculture and Cooperatives. 2014. Thailand agricultural development plan from 2007 – 2011. Ministry of Agricultural and Cooperatives, Thailand: Government Printer (in Thai). 90 p.

Office of Agricultural Economics. 2012. Agricultural statistics of Thailand 2012. Ministry of Agriculture and Co-Operative, Thailand: Government Printer (in Thai). 199p.

Office of Agricultural Economics. 2013. Agicultural statistics of Thailand 2013. Ministry of Agriculture and Co-Operative, Thailand: Government Printer (in Thai). 237p.

Office of Cane and Sugar Board. 2007. Production report on sugar and sugarcane. Ministry of Industry, Thailand: Government Printer (in Thai).

Pannangpetch, K., V. Sarawat, S. Boonpradub, S. Ratanasriwong, C. Buddhaboon, K. Kunket, P. Kapetch, V. Damrhikhemtrakul, and K. Ek Un. 2009. Impacts of global warming on rice, sugarcane, cassava, and maize production in Thailand. Thailand Research Fund. Ser. No. RDG5130007. 168p.

Papong, S., C. Yuvaniyama, P. Lohsomboon, and P. Malakul. 2004. Overview of biomass utilization in Thailand. Presented at meeting for LCA in ASEAN biomass project, 28 October 2004, Japan. 10 p.

Papong, S. and P. Malakul. 2010. Life-cycle energy and environmental analysis of bioethanol production from cassava in Thailand. Bioresource Technology. 101: 112-118.

Siemers, W. 2010. Greenhouse gas balance for electricity production from biomass resources in Thailand. Journal of Sustainable Energy and Environment Special Issue. 1: 65-70.

Silalertruksa, T. and S. H. Gheewala. 2009. Environmental sustainability assesment of bio-ethanol production in Thailand. Journal of Energy. 34(11): 1933-1946.

Suksiri, P., Y. Moriizumi, H. Honda, and Y. Wake. 2008. Sustainable agriculture in Thailand – An evaluation on the sustainability in ethanol production. Digital Asia Regional Strategy Research Center. Ser. No. 08-004. 21 p.

Thailand Greenhouse Gas Management Organization. 2013. Emission factor: Carbon footprint of products. Thailand Greenhouse Gas Management Organization (TGO), Thailand.

Wood, D. 2006. The future of biofuels in Thailand. The 2nd Joint International Conference on "Sustainable Energy and Environment (SEE 2006)". King Mongkut's University of Technology Thonburi, The Joint Graduate School of Energy and Environment. Bangkok, Thailand. 5p.

J. ISSAAS Vol. 21, No. 1: 96-106 (2015)

A SIMPLE AND RAPID METHOD FOR RNA EXTRACTION FROM YOUNG AND MATURE LEAVES OF OIL PALM (*ELAEIS GUINEENSIS* JACQ.)

Chanakan Laksana[1] and Sontichai Chanprame[1,2,3,4]

[1] Center for Advanced Studies for Agriculture and Food, Kasetsart University Institute for Advanced Studies, Kasetsart University, Bangkok 10900, Thailand (CASAF, NRU-KU, Thailand)
[2]Center for Agricultural Biotechnology, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand
[3]Center of Excellence on Agricultural Biotechnology (AG-BIO/PERDO-CHE), Thailand
[4]Department of Agronomy, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Nakhon Pathom 73140, Thailand
*Corresponding author: agrstc@ku.ac.th

(Received: January 15, 2015; Accepted: April 17, 2015)

ABSTRACT

Oil palm leaves are rich in phenolic compounds, polysaccharides and secondary metabolites. These compounds cause difficulty when high quality RNA isolation for gene expression analysis is required. In an attempt to rapidly isolate high-quality RNA from young and mature oil palm leaf, we compared various protocols: the standard protocol, modified protocols, and RNA extraction kits. Our modified protocol has proven to be far better than said protocols for isolating RNA from both types of leaf. This modified method can reduce time, the whole process can be completed within 1.5 h. RNA analyzed spectrophotometrically showed high purity (A260/280=1.9) and high concentration (2,877 ng/ul). Electrophoresis analysis on denaturing formaldehyde agarose gels confirmed the presence of high integrity RNA containing multiple ribosomal bands. Using the extracted RNA, as a template, a fragment of the *Actin* and *BOR* genes were successfully amplified by RT-PCR. A cDNA library was also successfully constructed, using extracted RNA as a template. The extracted RNA, using our modified protocol, could be kept at -80ºC for at least 24 months without degradation. This indicates that the modified protocol is suitable for RNA isolation from young and mature oil palm leaf and also for further applications.

Key words: phenolic compound, reverse transcription-polymerase chain reaction (RT-PCR), dot blot hybridization

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important oil crops in the world and is the highest oil yielding crop (Jamek *et al.*, 2010). Palm oil can be used for bio-fuel, thus the demand for palm oil is expected to increase in the future. In order to meet the expected demand for palm oil, an improvement in both yield and quality of palm oil will be required shortly. However, genetic improvement of oil palm via conventional breeding is very slow as each selection cycle lasts for approximately 10 years (Mayes et al. 1997).

Biotechnology is an important tool, which can be used to assist in the improvement of oil palm yield, by reducing the time of oil palm breeding through the use of the transcriptome (RNAs)

(Jaligot, 2010). Transcriptome studies involving Northern blot analysis, RT-PCR, cDNA-AFLP and cDNA libraries are critical approaches for the identification of the genes involved response to various environmental conditions (Thanh et al., 2009). Extraction of RNA is a very important basic step in the studies of the transcriptome. The availability of high quality RNA is the primary requirement for molecular gene expression studies, however, the isolation of high quality RNA from oil palm is difficult due to the oil palm's high concentration of polysaccharides, phenolics and RNase (Sasidharan et al., 2010; Rosalina et al., 2011). Phenolic compounds are readily oxidized to quinone, which binds to RNA, hindering isolation of good quality RNA. Secondary metabolites often co-precipitate with RNA and affect yield and quality (Loomis, 1974; Li et al., 2006; Kansal et al., 2008).

Many researchers use commercial RNA extraction kits or conventional protocols, that were designed for other plants (Le Provost et al., 2007; Jamek et al., 2010; Thuc et al., 2011) to extract RNA from oil palm. The time consuming cetyltrimethylammonium bromide (CTAB) protocol modified from Le Provost et al. (2007), has been inefficient for the isolation of abundant high quality RNA from leaves of oil palm. To date, no literature has been found describing total RNA extraction from young and mature oil palm leaf. The objective of this paper is to describe a rapid and efficient RNA isolation protocol that was developed through the combination and modification of two separate protocols, from Le Provost et al. (2007) and Saidi et al (2009). This new protocol can produce high quality RNA and solve the time problem and the multiple steps of the standard protocol. The isolated RNA by this new protocol can be kept for a long time with adequate high quality for further application.

MATERIALS AND METHODS

Plant materials

Young (the upper most leaf) and mature (fully expanded leaf) leaves of *tenera* oil palm were collected from 3 year-old plants.

RNA extraction protocols

Total RNA was extracted from young and mature oil palm leaves (0.1 g) using seven protocols: the standard protocol, four modified protocols [(modified from Le Provost et al. (2007) and Saidi et al. (2009)] as well as, two RNA extraction kits (Geneaid and Qiagen). The two types of leaves were ground separately in liquid nitrogen to a fine powder and used for total RNA extraction in all protocols tested. RNA extraction buffers used for each protocol are reported in Table 1. Each of the protocol had two replications.

Table 1. The composition of total RNA extraction buffers

Chemical	Protocol						
	1	**2**	**3**	**4**	**5**	**6**	**7**
1. 2% CTAB	□	□	□	□	□		
2. 2% PVP	□	□	□	□	□		
3. 2 M NaCl	□	□	□	□	□	Company 1	Company 2
4. 25 mM EDTA	□	□	□	□	□		
5. 100 mM Tris-HCl pH 8	□	□	□	□	□		
6. 1% Triton X100			□		□		
7. 2% ß -mercaptoethanol	□	□	□	□	□		

- ß-mercaptoethanol should only be added to the extraction buffer immediately preceding use

Protocol 1 (Standard Protocol): Six hundred µl of RNA extraction buffer were added to 0.1 g of the leaf powder in 1.5 ml RNase free microcentrifuge tube and vortexed vigorously. The mixture was incubated at room temperature (27ºC) for 10 min. Then 600 µl of phenol:chloroform:isoamyl alcohol (25:24:1) was added and mixed by inverting the tubes. The mixture was centrifuged at 15,000 x g for 20 min at 4ºC. The supernatant was transferred to a clean microcentrifuge tube. One volume of chloroform:isoamyl alcohol (24:1) was added and mixed by inverting the tubes. The mixture was centrifuged at 15,000 x g for 10 min at 4ºC and the supernatant was transferred to a clean microcentrifuge tube. Finally, ¼ volumes of 8 M LiCl was added to the supernatant and mixed by inverting the tubes and incubating overnight at 4ºC.

The solution was centrifuged at 15,000 x g for 20 min at 4ºC. The supernatant was removed and the pellet was suspended in 300 µl of SSTE buffer (1M NaCl, 0.5% SDS, 100 mM Tris-HCl and 25mMEDTA). The solution was purified by phenol:chloroform:isoamyl alcohol (25:24:1) and chloroform:isoamyl alcohol as described earlier. For final precipitation, 100 µl of 5 M NaCl and two volumes of cold absolute ethanol (-20ºC) were added, mixed well, and incubated for 3 h at -20ºC. The mixture was centrifuged at 15,000 x g for 20 min at 4ºC. The supernatant was discarded and the pellet was washed with 400 µl of cold 70% ethanol. The pellet was air dried, then suspended in 20 µl of DEPC-treated water.

Protocol 2: Extraction buffer and cell lysis procedure were the same as Protocol 1 except that 8 M LiCl was replaced with 100 µl of 5 M NaCl and 400 µl of cold isopropanol. The mixture was mixed well by inverting the tubes, incubated on ice for 10 min and centrifuged at 15,000 x g for 20 min at 4ºC. The supernatant was discarded and the pellet was washed with 400 µl of ice cold 70% ethanol. The pellet was air dried and suspended in 50 µl of DEPC-treated water.

Protocol 3: The extraction buffer was the same as Protocol 1- except 1% tritonX100 was added to the buffer. The total RNA extraction procedure was as the same as Protocol 2.

Protocol 4: The procedure was as the same as Protocol 1, except 400 µl of ice cold isopropanol was replaced with ice cold absolute ethanol in the precipitation step of day 2. The incubation time in this step was only 10 min on ice.

Protocol 5: The extraction buffer and total RNA extraction procedure were the same as Protocol 4 except that 1% Triton X100 was added to the buffer.

Contamination of genomic DNA derived from Protocols 1 to 5 was removed by treating the RNA samples with 1U of DNase I (Fermantas) per 1 µg of RNA at 37ºC for 30 min and stored at -80ºC until use.

Protocols 6 and 7: Total RNA extraction procedures were performed according to the manufacturers' instructions of Plant Total RNA Mini Kit (Company 1) and RNeasy Plant Mini Kit (Company 2), respectively.

Determination of quantity and quality of total RNA

The concentration of RNA derived from each protocol was determined spectrophotometrically using NanoDrop® (ND1000, Thermo Scientific, Delaware, USA). The A260/A280 ratio is expected to be approximately 2.0. The purity of RNA was visualized on a 1.5% denaturing formaldehyde agarose gel.

First strand cDNA synthesis and PCR amplification

First-strand cDNA synthesis was performed with 1 µg total RNA and 100 µM oligo $dT_{(21)}$ primer using SuperScript® III First-Strand Synthesis kit (Invitrogen, USA) following the manufacturer's instructions. PCR amplification was performed using first strand cDNAs as the template and specific primers for *Actin* and Boron transporter gene of oil palm (*BOR*). The primers were as follows: *Actin* forward: 5'-CATGCCATCCTTCGATTGG-3'; *Actin* reverse: 5'-CACATCTGCTGGAAGGTGC-3'; *BOR*2 forward: 5'-CATACTCTGCTGCAT CCA-3' and *BOR*2 reverse 5'-GTCCTCTGGGGTTACTTT-3'. The PCR was performed in a volume of 20 ul, which consisted of 200 ng of first-strand cDNA, 0.1 mM dNTPs, 1 U of *Taq* polymerase (5 u/µl), 5 mM $MgCl_2$, 1x buffer, and 0.125 µM of each forward and reverse primer. The amplification was performed under the following conditions: preliminary denaturation at 95°C for 3 min; 30 cycles of denaturing at 94°C for 1 min, annealing temperature of both sets of primers was the same at 58°C for 1 min, and extension at 72°C for 1 min; and final extension at 72°C for 5 min. The amplification products were resolved on a 0.7% agarose gel electrophoresis.

DNA Sequencing and analysis

PCR fragments were eluted from the 0.7% agarose gel using PCR cleanup and gel extraction kit (NucleoSpin® Extract II) following the manufacturer's protocol and were sequenced by 1st BASE Company (Selangor Darul Ehsan, Malaysia). The sequences were identified by BLAST similarity search using GenBank databases (www.ncbi.nlm.nih.gov/BLAST/).

Second-strand cDNA synthesis

First-strand cDNAs were further used as a template for second-strand synthesis. The second-strand reaction mix consisted of 14 µl of 10x *E. coli* DNA Polymerase I buffer, 1 µl of 10 mM dNTP, 1 µl of 10 U *E. coli* DNA ligase, 3 µl of 30 U *E. coli* DNA polymerase I, and nuclease-free water to a final volume of 100 µl. The mixture was then transferred into a centrifuge tube and mixed gently. The reaction was incubated at 15ºC for 2 min and cooled at 4ºC for at least 2 min. Two µl of 5 U T_4 DNA polymerase was added and the mixture was incubated at 15ºC for 5 min. The mixture was cooled at 4ºC for 2 min. After incubation, 5 µl of 0.5 M EDTA were added to inhibit the activity of T_4 DNA polymerase enzyme. The product of the reaction was purified using PCR clean-up and gel extraction kit (NucleoSpin® Extract II) following the manufacturer's protocol.

Dot blot hybridization

Dot blots were prepared from cDNAs that were transcribed from 1 µg of total RNA, spotted onto a positively charged nylon membrane (Hybond N Amersham Biosciences, Sweden) and fixed with UV using gel documentation system (GeneGenius, SynGene, USA.) for 5 min. The membranes were pre-hybridized in 12 ml of pre-hybridization buffer (0.75 M NaCl, 75 mM sodium citrate, 0.1% N-lauroylsarcosine, 0.02% SDS, 1% blocking solution (Roche, Germany) at 65ºC for 1 h. Probes were denatured by heating to 100°C for 10 mins and then added to the solution and hybridization was carried out overnight at 60°C. The partial cDNA sequence of *Actin* and *BOR* were used as probes and labeled using a PCR DIG Probe Synthesis Kit (Roche Applied Science, USA). After hybridization, the membranes were washed at room temperature (27ºC) in 40 ml of 20 X SSC and 2 ml of 20% SDS for15 min each. Finally, the membranes were washed with a washing buffer [0.1 M maleic acid, 0.15 M NaCl, pH 7.5, 0.3% (v/v) Tween 20] for 15 min. For chemiluminescent detection, the membranes were blocked with 1% blocking solution in maleic acid buffer for 30 min at room temperature (27ºC) and incubated with antidigoxigenin antibody conjugated with alkaline phosphatase (1:10,000 dilution in blocking solution) for 30 min. The membranes were washed twice with washing buffer for 15 min, incubated with detection buffer for 3 min and incubated with chemiluminescent substrate (CDP Star^{TM}, Roche, Germany) for 1 min in the dark. The blots were exposed to X-ray film (Amersham Biosciences, Sweden) for detection.

cDNA library construction

Total RNA extracted from young and mature oil palm leaves using the best protocol was used for cDNA library construction. This cDNA was ligated into the pJET1.2 cloning vector (Thermo Scientific, Lithaunia) and transformed into *E. coli* DH5α. To evaluate the cDNA library and size of fragment inserted into each colony, PCR was conducted for 22 representative colonies using vector-specific primers.

Duration of storage of the extracted RNA at -80ºC was also determined. The 12- and 24-months old total RNA derived from the best protocol were used as template for RT-PCR with *Actin* primer. The amplification products were resolved on a 0.7% agarose gel electrophoresis.

RESULTS AND DISCUSSION

Quality and quantity of extracted RNA

The quality and yield of total RNA isolated using standard protocol, modified protocols and commercial RNA extraction kits were compared by the intensity of 28S and 18S rRNA in agarose gel (Fig. 1) and spectrophotometric measurement (Table 2), respectively. All tested protocols yielded various quality and quantity of the extracted RNA from both types of oil palm leaf. The commercial kits (Protocols 6 and 7) gave the lowest while Protocol 2 delivered the highest quality and quantity of extracted RNA from both types of leaf.

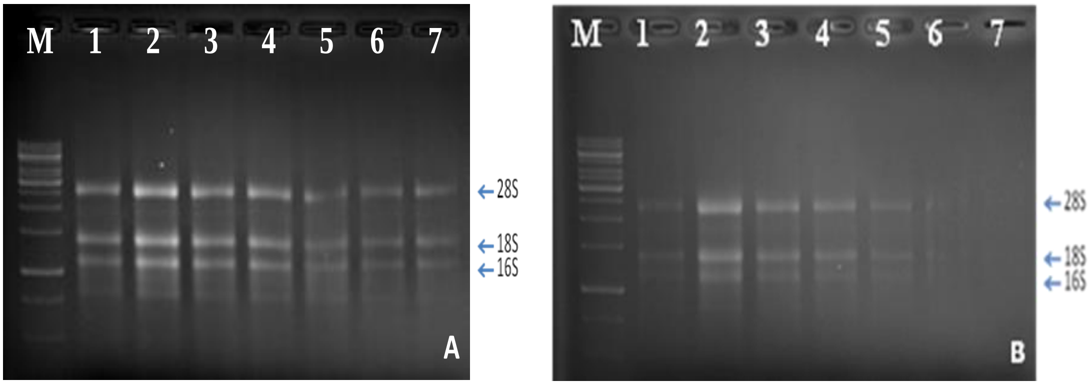


Fig.1 Ethidium bromide stain of 1.5% agarose formaldehyde gel of total RNA (1µg) from young leaf (A) and mature leaf (B). M: 1 kb DNA ladder (Fermentas), 1-5: total RNA derived from protocol 1 to 5, 6-7: total RNA derived from RNA extraction kit, Company 1 and Company 2, respectively.

Table 2. Quantity and quality of RNA extracted from young and mature oil palm leaf using seven different protocols.

Protocol	RNA yield of young leaf			RNA yield of mature leaf		
	Conc. (ng/µl)	A 260/280	A 260/230	Conc. (ng/µl)	A 260/280	A 260/230
1	1,267.5	2.1	2.0	741.2	1.9	1.2
2	2,877.2	1.9	1.9	1,448.5	1.9	2.0
3	1,619.0	1.9	1.8	1,273.5	1.9	1.7
4	1,189.4	2.1	2.0	693.6	2.1	1.4
5	1,170.6	2.2	1.6	700.3	1.9	1.6
6	489.8	2.2	1.9	60.6	1.8	0.5
7	778.1	2.2	1.9	54.1	1.9	1.0

RNA integrity was of high quality with clear ribosomal bands for 28S, 18S and 16S rRNA from every protocol in mature leaves except commercial kits (Fig.1). The sharpness and intensity of the bands indicated minimal degradation of isolated RNA. The 28s rRNA band was more abundant than 18s rRNA, indicating that little or no RNA degradation occurred during the extraction. The A260/280 ratio of total RNA from young and mature leaves derived from the different protocols was between 1.8-2.2 indicating minimal contamination with polysaccharides and proteins. The A260/280 ratio should be 2.0 ±0.1. (Farrell, 2005). The A260/230 ratio of all RNA samples from young leaf were 1.6-2.0 indicating that no or low contamination with phenolic compounds and polysaccharides. However, in samples from mature leaf, the A260/230 ratio ranged between 0.5-2.0 (Table 2). A260/230 ratio for mature leaf less than 1.8 was derived from all protocols except Protocol 2, indicating the presence of contamination with phenolic compounds and polysaccharides. The A260/230 ratio should be greater than 2 and less than 2.4 (Farrell, 2005). Only the total RNA yielded from Protocol 2 showed A260/230 ratio at 2.0. These results i ndicate that Protocol 2 was the best protocol for extracting RNA from young and mature oil palm leaf. Total RNA extracted by Protocol 2 was of high purity, free of proteins, polysaccharides and phenolic compounds. CTAB, polysaccharide and other remaining contaminants were removed from this phase by chloroform extraction (Chang *et al*., 1993). This protocol also yielded the highest concentration of total RNA at 2,877 ng/µl in young leaf and 1,448 ng/µl in mature leaf. This protocol is a single step protocol, performs in a relatively short time (about 1.5 h) compared to the standard protocol which took 2 days with two steps but only yielded a low concentration of total RNA. Triton X100 was added into the extraction buffers used in Protocols 3 and 5 but did not improve the quality or yield of the extracted total RNA from both types of leaf. In Protocol 2, 5 M NaCl replaced 8 M LiCl for RNA precipitation. It was shown that 5 M NaCl was adequate for this purpose but caused DNA contamination in the RNA sample. LiCl is used to selectively precipitate RNA but the resulting RNA pellet will still contain small amounts of DNA and other residues (Wang et al., 2011). DNase I can be used for removing the genomic DNA contamination. A high concentration of Na^+ ion increases the solubility of polysaccharides, thereby reducing their co-precipitation with RNA in subsequent steps (Fang et al., 1992). NaCl can dissolve the CTAB-RNA complex, allowing the RNA to be partitioned back into the aqueous phase (Chang et al., 1993).

All the modified protocols (2, 3, 4 and 5) used isopropanol for RNA precipitation because isopropanol is more efficient than absolute ethanol. The RNA isolation from oil palm requires purification with phenol:chloroform:isopropanol because small amounts of proteins and salts in the

RNA pellet can inhibit or influence downstream molecular procedures such as reverse transcription-polymerase chain reaction (RT-PCR), real time PCR and cDNA library construction. In addition, phenol plays an important role in inhibiting RNase activity during the stages of RNA isolation. Chloroform and isopropanol are used to remove phenol residues (Wang et al., 2011). The purity and yield of RNA extracted using commercial kits (protocols 6 and 7) were low for both types of leaf (Table 2). Furthermore, there was no rRNA band present on agarose gels for the RNA extracted from mature leaves (Fig.1B). These kits have proven effective for isolating RNA from young leaves of oil palm but not for the mature leaves, as mature leaves contain higher amounts of phenolic compounds than those of younger leaves. It could be inferred that RNA extraction kits may not be designed specifically for extracting RNA from plant tissues rich in phenolic compounds and secondary metabolites.

cDNA synthesis, dot blot hybridization and cDNA library construction

To confirm the intactness and suitability of the extracted RNA to be used for various applications, PCR with specific primers, sequencing analysis, dot blot hybridization and creation of a cDNA library were carried out. Total RNA (1 µg) obtained from each protocol was used as a template for first-strand cDNA synthesis and used for PCR amplification of house-keeping gene, *Actin* and boron transporter gene, *BOR*. The results revealed that the amplified fragments of *Actin* were about 500 bp and *BOR* were about 270 bp (Fig. 2 and 3). This indicated that RNA obtained from both types of oil palm leaves, using 7 different RNA extraction protocols, was pure enough for successful amplification using specific primers.

However, Protocol 2 yielded the highest concentration and best quality of RNA. So, the RNA derived from Protocol 2 was used for subsequent experiments.

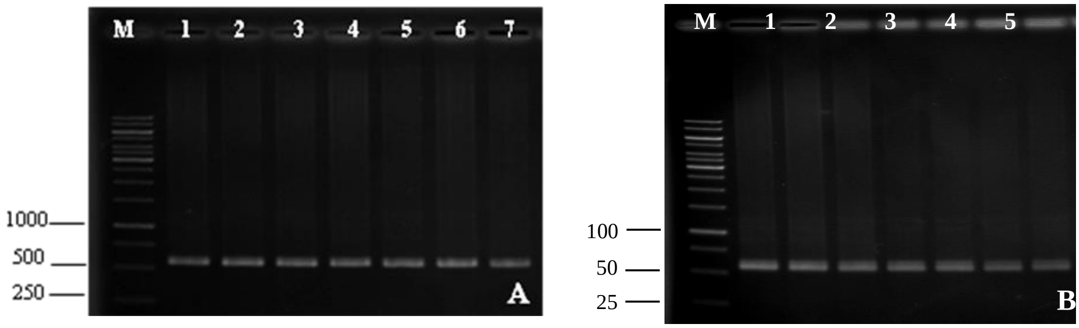


Fig. 2 *Actin* fragment derived from PCR using first-strand cDNA derived from the total RNA of young leaves (A) and mature leaves (B) of oil palm extracted by different protocols. Lane 1: Marker, 1 kb DNA ladder (Fermentas), Lane 2: standard protocol, Lane 3-5 modified protocols (2-5), Lane 6-7: RNA extraction kits, Company 1 and Company 2, respectively.

The 270 bp of PCR products derived from Protocol 2 using RNA from both types of leaf was sequenced and compared to NCBI database. The results showed the homology of the amplicons with the *BOR* gene of many plant species (Tables 3).

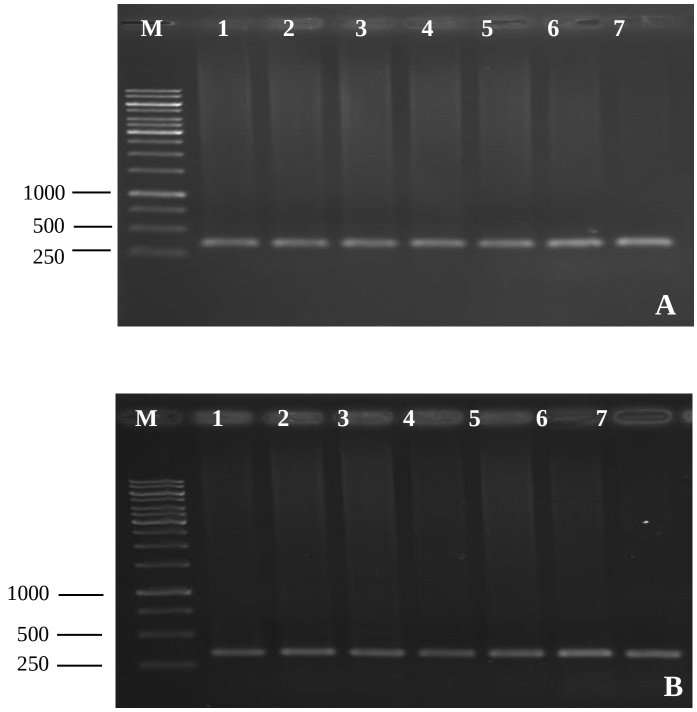


Fig. 3. *BOR* fragment derived from PCR using first-strand cDNA derived from the total RNA of young leaves (A) and mature leaves (B) of oil palm extracted by different protocols. Lane 1: Marker, 1 kb DNA ladder (Fermentas), Lane 2: standard protocol, Lane 3-5 modified protocols (2-5), Lane 6-7: RNA extraction kits, Company 1 and Company 2, respectively.

Table 3. BLASTn analysis showing significant matches of *BOR* fragment derived from amplification of total RNA of young oil palm leaves.

Plant	Best match in database	Identity (%)	E-value
Ricinus communis	Boron transporter	87%	7e-66
Vinifera vinifera	Boron transporter	82%	1e-57
Brassica napus	Boron transporter	78%	7e-21
Solanum lycopersicum	Boron transporter-like mRNA	77%	3e-34

To confirm the quality and efficiency of total RNA from young and mature leaves derived from Protocol 2, cDNA was synthesized from total RNA using oligo (dT_{21}) primer. The cDNA were blotted onto nylon membrane and hybridized with *Actin* and *BOR* probes. Distinct and sharp signals, as well as clear background, were obtained (Fig. 4). These results demonstrated that the obtained total RNA was of high integrity and the mRNA could be reverse-transcribed into cDNA.

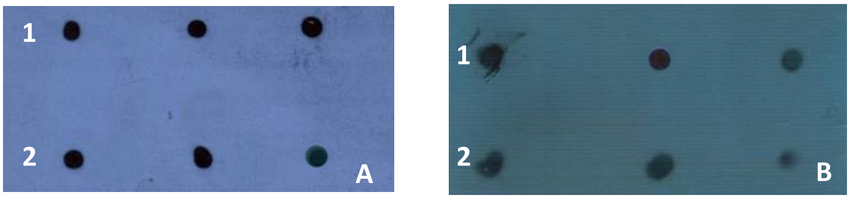


Fig. 4. Dot blot hybridization analysis of cDNA derived from the total RNA extracted using Protocol 2 (A) *Actin* and (B) *BOR*, 1: young leave 2: mature leave.

cDNA was ligated into the pJET1.2 cloning vectors and transformed into *E. coli* DH5α to construct a cDNA library. Twenty-two colonies were randomly selected from the library and were amplified by PCR using the pJET primer. The PCR products indicated that each clone contained a different size of inserted cDNA that ranged from 250-1,000 bp (Fig. 5). Again, this confirmed the high quality of total RNA extracted by Protocol 2.

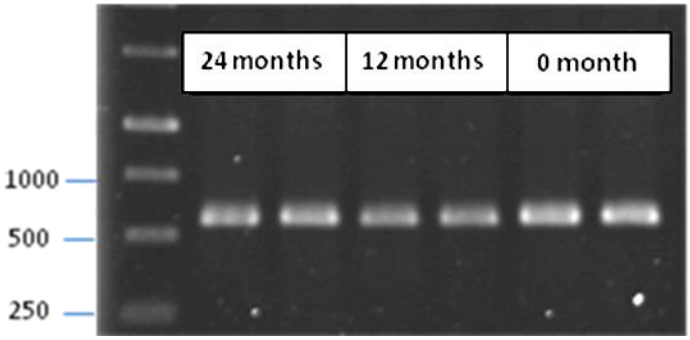


Fig. 5 Gel analysis of amplicons obtained from 22 randomly selected colonies of cDNA library using vector primers to identify colonies with inserts.

Total RNA derived from Protocol 2 kept in -80ºC for 12 and 24 months was used as template for RT-PCR by amplifying *Actin* gene. The result showed 550 bp of actin fragments. This indicated that the quality of the extracted RNA could be maintained in such condition for at least 24 months (Fig. 6).

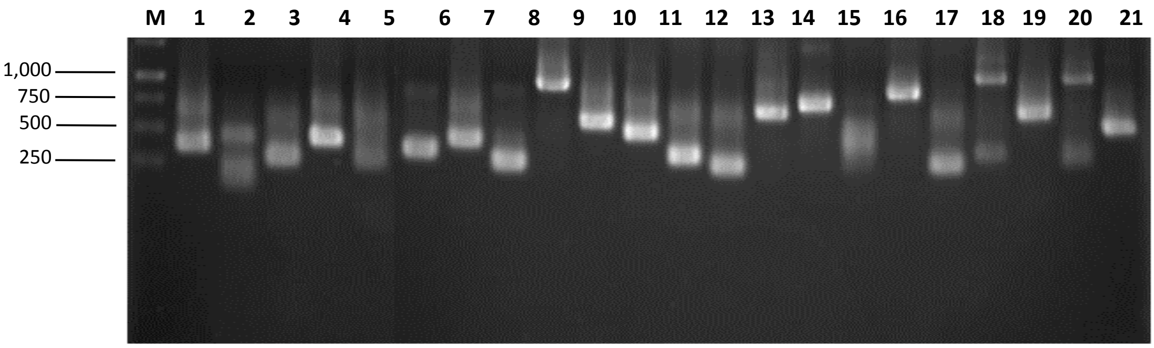


Fig. 6 RT-PCR of total RNA derived from Protocol 2 and kept in -80ºC for 12 and 24 months showing the amplified actin fragments.

CONCLUSION

The extraction of high quality RNA is essential for all molecular analysis. The best extraction protocol described here is efficient, simple, and cost effective. The total RNA extracted by Protocol 2 is completely suitable for RT-PCR, dot-blot hybridization, nucleotide sequencing, and cDNA construction. Also using Protocol 2, the extracted total RNA could be kept for 24 months without losing integrity and adequate high quality for further application. This new protocol can produce high quality RNA and solve the problem of time consuming, multiple steps of the standard protocol. Moreover, the protocol could be applicable to other tissues of oil palm or other plants containing high levels of phenolic compounds and secondary metabolites without or with little modifications.

ACKNOWLEDGEMENTS

This work was partially supported by the Center for Advanced Studies for Agriculture and Food, Institute for Advanced Studies, Kasetsart University under the Higher Education Research Promotion and National Research University Project of Thailand, and the Center for Agricultural Biotechnology, Post Education and Research Development Office, Commission on Higher Education, Ministry of Education, Thailand.

REFERENCES

Chang, S., J. Puryear and J. Cairney. 1993. A simple and efficient method for isolating RNA from pine trees. Plant Mol. Biol. Rep. 11: 113-116

Fang, G., S. Hammar and R. Grumet. 1992. A quick and inexpensive method for removing polysaccharides from plant genomic DNA. Biotechniques 3: 52-56.

Farrell, R.E. 2005. RNA Methodologies a Laboratory Guide for Isolation and Characterization. Elsevier Academic Press. USA.

Jaligot, R.A. 2010. Oil palm biotechnologies are definitely out of infancy. Oléagineux Corps Gras Lipides. 17: 368-374.

Jamek, S.B., N.G. Cheng and C.T. Guan. 2010. The isolation and amplification of full length cDNA of oleosins from oil palm (*Elaeis guineensis* Jacq.). Afri. J. Biotechnol. 9: 1859-1863.

Kansal, R., K. Kuhar, I. Verma , R.N. Gupta , V.K. Gupta and K.R. Koundal. 2008. Improved and convenient method of RNA isolation from polyphenols and polysaccharide rich plant tissues. Indian. J. Exp. Biol. 46:842-845.

Le Provost, G., R. Herrera, J.A. Paiva, P. Chaumeil, F. Salin and C. Plomion. 2007. A micromethod for high throughput RNA extraction in forest trees. Biol. Res. 40: 291-297.

Li, B., B. Wang, K. Tang, Y. Liang, J. Wang and J. Wei. 2006. A simple and convenient approach for isolating RNA from highly viscous plant tissue rich in polysaccharides. Coll. Surf. B: Biointerf. 49: 101–105.

Loomis, M.D. 1974. Overcoming problems of phenolics and quinones in the isolation of plant enzymes and organelles. Methods Enzymol. 31:528-44.

Mayes, S., P.L. Jack, R.H.V. Corley and D.F. Marshall. 1997. Construction of a RFLP genetic linkage map for oil palm (*Elaeis guineensis* Jacq.). Genome 40: 116–122.

Rosalina, T.R.T., S. Mohamed, G.F. Samaneh, M.M. Noordin, Y.M. Goh and M.Y.A. Manap. 2011. Polyphenol rich oil palm leaves extract reduce hyperglycaemia and lipid oxidation in STZ-rats. Int. Food Res. J. 18: 179-188.

Saidi, M.N., R. Gargouri-Bouzid, M. Rayanni and N. Drira. 2009. Optimization of RNA isolation from brittle leaf disease affected date palm leaves and construction of a subtractive cDNA library. Mol. Biotechnol. 41: 63-68.

Sasidharan, S., R. Nilawatyi, R. Xavier, L.Y. Latha and R. Amala. 2010. Wound healing potential of *Elaeis guineensis* Jacq. leave in an infected albino rat model. Molecules 15: 3186-3199.

Thanh, T., H. Omar, M.P. Abdullah, V.T. Chi, M. Noroozi, H. Ky and S. Napis. 2009. Rapid and effective method of RNA isolation from green microalga *Ankistrodesmus convolutus*. Mol. Biotechnol. 43:148-53.

Thuc, V.L., N. Sarpan, K. Huynh, S.E. Ooi, S. Napis, C.L. Ho, M. Ong-Abdullah, C.F. Chin and P. Namasivayam. 2011. A novel transcript of oil palm (*Elaeis guineensis* Jacq.), Eg707, is specifically upregulated in tissues related to totipotency. Mol. Biotechnol. 48: 156-64.

Wang, X., H. Xiao, G. Chen, X. Zhao, C. Huang, C. Chen and F. Wang. 2011. Isolation of high-quality RNA from *Reaumuria soongorica*, a desert plant rich in secondary metabolites. Mol. Biotechnol. 48:165-72.

J. ISSAAS Vol. 21, No. 1: 107-122 (2015)

FARMER-TRADER RELATIONSHIPS IN THE MODERN FOOD SUPPLY CHAIN IN INDONESIA

Sahara[1] and Arief Daryanto[2]

[1&2]Department of Economics, Bogor Agriculture University.
[1]International Center for Applied Finance and Economics
[2] Graduate Program of Management and Business
Jl. Kamper-Kampus IPB Darmaga Bogor Lantai II
Bogor Agricultural University, Indonesia 16680
Corresponding author: sahara_ipb@yahoo.com

(Received: April 26, 2014; Accepted: April 25, 2015)

ABSTRACT

Supermarkets have penetrated rapidly in developing countries including Indonesia and provided new market opportunities for small farmers. Participating in supermarkets is not easy for small farmers since they face capital constraints, time constraints and knowledge constraints in order to meet product requirements posed by supermarkets. In order to ensure the specific requirements of the products, supermarkets prefer to look for suppliers who can work with them in vertical partnerships. While supermarkets are developing, the traditional retails still exist with increasing competition between them. Unlike supermarkets, the transaction in traditional markets is mainly on the basis of price; therefore it often involves one-off transaction. In such situation, it seems that the mutual relationship between actors along the supermarket chains is closer and stronger than those in traditional markets. However, no research has compared the level of relationship quality between these two types of markets. In fact, improving relationship quality among trading partners is very essential in order to enhance efficiency and reduce transaction costs along the supply chain. This paper attempts to examine farmer-trader relationships in the modern food supply chain in Indonesia. We use the data from a farm survey between March and April 2010 of 602 chili farmers selling to the traditional and supermarket channels in West Java Province. Factor analysis and Partial Least Square methods are conducted to estimate farmer-trader relationships. Results indicate the levels of relationship quality between farmers and traders are influenced by non-economic satisfaction and price satisfaction. While actual price received by farmers is not significant in influencing the levels of their relationships. Further analysis shows that price satisfaction is influenced significantly by price equity and price correctness. Supermarket farmers have higher perceptions of non-economic satisfaction compared to farmers selling to traditional channels. To improve farmer-trader relationship quality, traders should not only focus on giving higher prices to farmers but also consider the psychological aspects of price and non-economic satisfaction issues.

Key words: supermarket, price satisfaction, non-economic satisfaction

INTRODUCTION

For a variety of reasons including rapid growth of income per capita, liberalization of foreign direct investment in retail sector and urbanization, modern retail markets have penetrated rapidly into developing countries (Reardon and Berdegué, 2002; Reardon et al., 2004). Similar situations occur in

Indonesia where the number of supermarkets[1] increased from only 1 in 1970 to about 11,868 in 2008 (Pandin, 2009). Between 2004-2008, the number of supermarkets increased significantly by about 80.23 percent.

The dramatic increase in modern retail markets has important consequences for agrifood supply chain (Reardon and Timmer, 2007; Reardon et al., 2009; Weatherspoon and Reardon, 2003) in terms of improving food quality and safety standards, prices and consistency in supply of agricultural products (Weatherspoon and Reardon, 2003; Reardon et al., 2004). Supermarkets provides market opportunity for small farmers with relatively higher price in comparison to traditional markets. However, farmers also face capital constraints, time constraints and knowledge constraints in order to meet product specifications and requirements posed by the supermarkets (Boselie et al., 2003; Dries et al., 2009; Kaganzi et al., 2009; Weatherspoon and Reardon 2003).

In order to control the specific requirements of the products, supermarkets prefer to look for suppliers who can work with them in vertical partnerships (Hingley et al., 2006). Agreement either oral or written applies between supermarkets and suppliers including price, quantity, quality and supply consistency as well as technical assistance, credits, inputs and training (Reardon et al., 2009). In such, trade relationships between supermarkets and their suppliers shift from spot market relations towards closer coordination (Ecscobal and Cavero, 2011; Rao and Qaim, 2011; Reardon et al., 2009). While supermarkets are developing, the traditional retails still exist with increasing competition between supermarkets and traditional markets (Suryadarma et al., 2010). In contrast to supermarkets, the transaction in traditional markets is mainly on the basis of price; therefore it often involves one-off transaction without promise for repeated transaction or any agreement between traders and their suppliers (Rao and Qaim, 2011). Under such situation, it seems that the mutual relationship between actors along the supermarket chains (including farmers and traders) is closer and stronger than those in traditional markets. However, research has not been done to compare the level of relationship quality between these two types of markets (traditional market and supermarket).

That the relationship quality determines the probability of continued transaction between trading partners has been recognized by many authors. Improving relationship quality among trading partners is very essential in order to enhance efficiency and reduce transaction costs along the supply chain (Coronado et al., 2010; Ellram and Hendrick, 1995; Kalwani and Narayandas, 1995). In case of agricultural products, improving relationship quality enables farmers and traders to coordinate the fluctuation of supply and demand; therefore increase opportunity for farmers to compete in both supermarkets and traditional markets. In order to achieve stable relationships, it is very essentials to determine which variables are most important for farmers to establish long-term relationships with their traders.

Price is an important variable in shaping the transactions between supermarkets and traditional markets. Transactions in traditional markets tend to follow price mechanism as outlined in neo classical economics. Actual prices are determined by daily situation of supply and demand with subject to large price fluctuation (Rao and Qaim, 2011). Commodities are marketed based on the best prices that can be obtained by the suppliers. In contrast, supermarkets set prices before delivery with relatively fixed for certain period. Most studies show that farmers selling to supermarkets have greater price per kg relative to those who supply to traditional markets in order to "lock in" farmers to consistency supply to supermarkets with high quality standard products (Reardon et al., 2009). While in relationship marketing literature the primary motivation of actors along a certain supply chain establishing long-term relationships is more influenced by relational variables such as trust, satisfaction and price perception (price satisfaction). Instead of including actual price in the model,

[1] The term supermarket refers to modern food retailers, including hypermarkets, supermarkets and convenience stores.

the marketing literature measure prices based on the price perception in term of fairness, reliability, confidence and transparency (Gyau and Spiller, 2007; Matzler et al., 2006b; Matzler et al., 2007). However, whether actual prices or price perceptions have stronger influence on the level of farmer-trader relationship is still questionable. Gyau and Spiller (2007) has compared the impact of actual price and price satisfaction in the German dairy industry and found significance relationship between price satisfaction and relationship quality but no significance relationship between actual price and relationship quality. This paper attempts to test whether this is also true in the context of chili commodity in Indonesia.

Chili was chosen as it is an important ingredient in the Indonesian daily diet. It is mainly produced by small farmers and included as an important source cash flow income. Although only a small volume of chilies end up in supermarkets, this commodity is a main item in fresh produce sections in supermarkets and it is estimated that its share will increase along with the rapid rise of supermarket in Indonesia. To participate in supermarket chains, chili farmers collaborate with specialized wholesalers, who supply a range of supermarket chains by organizing hundreds of small farmers and providing all the necessary product-specific guidelines. In Indonesia, these specialized wholesalers communicate intensively with farmers via traders or farmer groups, conveying supermarket requirements as well as assisting with access to quality seeds, technical assistance and related support. Meanwhile farmers participate in traditional markets through traders, brokers and other buyers who purchase chilies directly from farmers. These traders then sell the chilies in the local wholesale markets or directly to traditional retail markets.

Focusing on the first segment of the chili supply chain (farmers to traders), this paper examines the impact of actual price and price satisfaction on their relationship quality variables. This paper also compares the level of the relationships from the perspective of farmers selling the chilies to supermarkets and those selling to traditional markets

CONCEPTUAL MODEL AND HYPOTHESES

To answer the objectives, we place relationship quality variables that consist of trust and commitment as the main dependent variables. Independent variables include relational variables (non-economic satisfaction and price satisfaction) and economic variable (actual chili price). To compare the level of relationship quality between farmers selling to supermarkets and traditional markets, a dummy variable of supermarket participation is included as independent variable. Following Gyau *et al*. (2011) we also include size of farm as control variable in the model. The relationship between dependent and independent variables will be discussed below.

Relationship Quality: Trust and Commitment

According to Holmlund (2008) relationship quality refers to joint cognitive evaluation of business interaction by significant individuals in both firms in the dyad. The evaluation including a comparison of experienced with desired, potential, usual or previous interactions which constitute comparison standards. A review of relationship marketing literature indicates that there is a lack of consensus related to relationship variables. Some authors propose that relationship quality as a composite measure of three relational variables: satisfaction, trust and commitment (e.g., Caceres and Paparoidamis, 2007; Smith, 1998). Others utilize two relational variables such as commitment and trust (e.g., Kwon and Suh, 2004; Sargeant and Lee 2004; Wong and Sohal, 2002) as well as trust and satisfaction (Ashnai et al., 2009; Bejou et al., 1996; Parsons, 2002).

A majority of literature in agricultural economics and business have identified trust as a proxy variable to measure the level of relationship quality between farmers and traders. Trust is influenced by other relational variables including satisfaction. In case of relationship between farmers and potato seed suppliers in the Philippines, Batt (2001) found that improving farmers' satisfaction will increase farmers' trust that will in turn improve their loyalty to those seed suppliers. Likewise, the positive relationship between satisfaction and trust in farmer-trader relationships are found by Batt and Rexha (1999); Batt (2003); Gyau and Spiller (2007). Besides trust, Österberg and Nilsson (2009) utilized the variable of commitment in studying the degree of success in Swedish agricultural cooperatives from the perspective of farmers as members of the cooperative. Other authors employed the three relational variables - satisfaction, trust and commitment - to measure relationship quality between farmers and traders in Germany in the context of dairy products (Gyau et al., 2011) and pork and dairy products (Schulze et al., 2006).

Given that a majority studies have identified the variable of trust as a central element in the trader-farmer relationship, we placed trust as one variable of the relationship quality. Similar to trust, previous studies show the importance of variable commitment in determining the level of buyer-seller relationship. Sabel (1993) defines trust as the 'mutual confidence that no party to an exchange will exploit the other's vulnerabilities'. Commitment, on the other hand, is 'an exchange partner believing that an ongoing relationship with another is so important as to warrant maximum efforts at maintaining it; that is, the committed party believes the relationship is worth working on to ensure that it endures indefinitely' (Morgan and Hunt, 1994).

Hypothesis

1) Satisfaction: Non-Economic Satisfaction and Economic Satisfaction

A growing number of studies have recognized the presence of two different types of satisfaction: non-economic and economic satisfaction (e.g., Geyskens et al., 1999; Geyskens and Steenkamp, 2000). According to Geyskens et al. (1999), non-economic satisfaction can defined as 'a channel member's positive affective response to the non-economic, psychosocial aspects of its relationship, in that interactions with the exchange partner are fulfilling, gratifying, and easy'. If an exchange partner feels satisfied with the non-economic aspect of his relationship, he gives positive value and stays to work with his partner since he believes that the partner is concerned, respectful and willing to share ideas.

Following Geyskens et al. (1999) we hypothesize that:

H_1: Non-economic satisfaction will have positive influence on relationship quality

Economic satisfaction refers to 'a channel member's positive affective response to the economic rewards that flow from the relationship with its partner, such as sales volume and margins' (Geyskens et al., 1999). The success of relationship in economic satisfaction is considered based on economic expectation of exchange partners that can be related to price, product quality and service (Fischer and Reynolds, 2010). Hence, economic satisfaction requires a specific level of knowledge about prices and products to assess whether economic outcome meet the expectation of an exchange partner or not. As discussed previously, price has important role in chili commodity; therefore, in this paper we focus on economic satisfaction from the perspective of price satisfaction.

Price satisfaction can be defined as the result of a comparison of the price expectation with price perception (Matzler et al., 2006a; Matzler et al., 2006b; Matzler et al., 2007). Current literature has identified the dimensions of price satisfaction, as well as analyzing which dimension has stronger impact on overall price satisfaction (Boniface et al., 2010; Gyau et al., 2011; Matzler et al., 2006b; Matzler et al., 2007). Several dimensions of price satisfaction exist in the literature including 'relative price', 'price quality ratio', 'price fairness', and 'price transparency' (e.g., Matzler et al., 2006b; Matzler et al., 2007). Relative price refers to the price which farmers receive from their buyers when compared to the price offered by other buyers and paid to other farmers. Price transparency was defined as a clear, comprehensive, current and effortless overview of buyers quoted prices, which was offered by other buyers. Price-quality ratio refers to a ratio between chili qualities and price paid by the buyers. Price fairness was defined as the farmer's perception of whether the difference between the socially accepted prices is reasonable, acceptable or justifiable. Price reliability was defined as an awareness of price changes in which any price changes will be communicated to the farmers by the buyers. Gyau et al. (2011) and Boniface et al. (2010) find positive relationship between price satisfaction and relationship quality.

In the context of chili commodity, we placed the dimensions into two categories: 'price correctness' and 'price equity'. The first dimension contains three items (statements) representing 'relative price', 'price quality ratio' and 'price fairness' while 'price equity' refers to two items in line with 'price transparency'.

In line with previous literature, we hypothesize that:
H_2: Overall price satisfaction will have a positive influence on relationship quality
H_3: Price correctness will have a positive effect on overall price satisfaction
H_4: Price equity will influence overall price satisfaction positively

2. Real Price

While studies in marketing literature mostly focus on the customers' perception of price and its relationship with relational variables (*e.g.,* trust, satisfaction and commitment), in neoclassical theory it is market price that direct the allocation of resources and commodities in the markets. Market price is determined by interaction by supply and demand in the market. In case of chili commodity in Indonesia, chili prices are determined by daily situation of demand and supply in the major wholesale markets. The price information from these markets is utilized as a baseline for other traders involved in the chili supply chains including supermarket chains. Based on economic theory, farmers make a decision to sell their products to whoever offers the best price. Price can be included as an important factor for farmers since it influences their economic performance: revenues and ultimately their profits. Although price has an important role in determining the economic performance of farmers, only a few studies has associated this variable to relationship quality (Gyau et al., 2011).

Following Gyau et al. (2011), we hypothesize that:

H_5: Real price will have a positive effect on overall price satisfaction
H_6: Real price will influence relationship quality positively

3. Supermarket Participation

Farmers market their chilies to supermarkets through agents, including preferred traders or specialized wholesalers. Due to high transaction cost exchange with a lot of small farmers, the supermarket agents often build agreement with other traders instead of buying chilies directly from farmers. Therefore, it is the traders that have direct relationship with farmers. Similarly, in traditional markets, chilies are collected by small traders before being distributed to next traders or traditional retail markets. Since supermarkets have centralized procurements and standards, there is an increasing need for closer coordination along the commodity chains (Ecscobal and Cavero, 2011; Hingley et al., 2006; Reardon et al., 2009). The benefits of selling to supermarket channels are higher prices than traditional markets. Besides, supermarkets provide technical assistance in order to assure the standard quality. In line with such situation, we hypothesize that:

H_7: Farmers who sell their chilies to supermarkets have closer relationships with their traders compare to those in traditional markets.

H_8: Farmers who sell their chilies to supermarkets have higher perception on price satisfaction than those in traditional markets.

H_9: Farmers who sell their chilies to supermarkets have higher perception on non-economic relationship than farmers in traditional markets.

4. Chili Area

Larger farmers may have different perception regarding to their relationships with their buyers relative to smaller farmers (Gyau et al., 2011). They might have a broader set of marketing choices (Reardon et al., 2009); therefore they can often negotiate with the buyers for specific conditions that might not be possible for small farmers (Gyau et al., 2011). For example, they can negotiate about the place of transaction, whether in farmers' gate or other places, payment time and credit. Therefore our hyphothesis is:

H_{10}: The larger the size of land that farmers have, the higher the level of their relationship with their buyers.

Based on the above hypotheses, a conceptual model of relationship quality can be illustrated in Figure 1. Relationship quality is a higher construct influenced by price satisfaction, non-economic satisfaction, supermarket participation, real price and size of farm. Participation in supermarket channel might influence the perception of farmers on non-economic satisfaction and price satisfaction. Likewise, actual chili price that farmers receive from their buyers may influence their perception on price satisfaction.

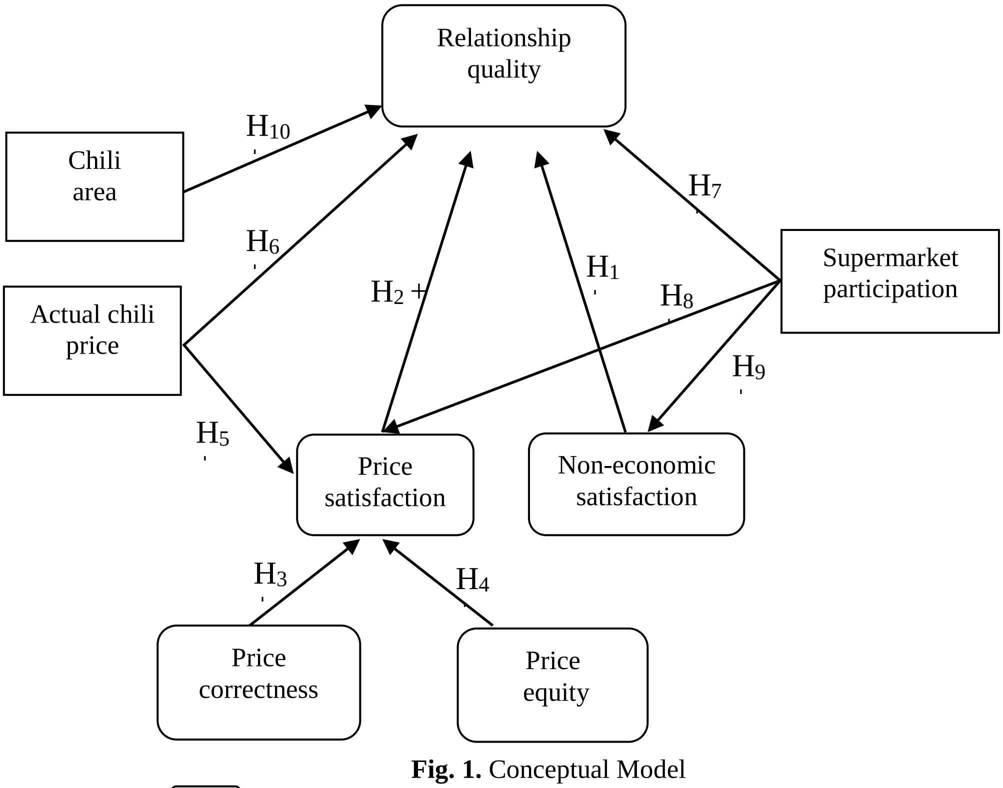


Fig. 1. Conceptual Model

Note: Latent variable that operationalize by manifest variables (see Table 1)

METHODOLOGY

Variables

The various variables in our model as outlined in Figure 1 were measured based on previous studies and were modified to the context of farmer-buyer relationship in chili commodity. The variable of relationship quality was measured through three items covering aspects of trust and commitment (Table 1). Non-economic satisfaction was explored through two items. Overall price satisfaction was explored through two items. The dimensions of price satisfaction were adapted and modified from the studies by Matzler et al. (2006b) and Matzler et al. (2007) including relative price, price quality ratio, price fairness and price transparency. We categorized price satisfaction into two dimensions. First, 'price correctness' consisted of three items covering aspects of relative price, price quality ratio and price fairness. The second is 'price equity which consisted of two items related to price transparency. A-five-point Likert scale from one (strongly disagree) to five (strongly agree) was utilized to rate the level of each item.

Table 1. Variables used in the model

Variables	Unit of Measurement
Relationship quality is a latent variable that operationalize through three manifest variables as follows:	
1. I care about the long-term success of the relationship with my buyer.	Likert Scale*
2. I receive payment on time.	Likert Scale*
3. My buyer always keeps his promises.	Likert Scale*
Non-economic satisfaction is a latent variable that operationalize through two manifest variables as follows:	
1. My buyer deals with me as expected	Likert Scale*
2. My buyer is quick to handle my complaints.	Likert Scale*
Overall price satisfaction is a latent variable that operationalize through two manifest variables as follows:	
1. The buyer offers me satisfactory prices for my chilies.	Likert Scale*
2. Based on the price my buyer offers me, I will not change buyers.	Likert Scale*
Price correctness is a latent variable that operationalize through three manifest variables as follows:	
1. In comparison to other buyers, I am satisfied with the price my buyer offers.	Likert Scale*
2. I receive a good price-quality ratio	Likert Scale*
3. The chili prices I receive are fair.	Likert Scale*
Price equity is a latent variable that operationalize through two manifest variables as follows:	
1. The prices I received are similar to the prices other farmers get.	Likert Scale*
2. The chili price information from my buyer is complete and correct.	Likert Scale*
Supermarket participation	1=farmers selling

Variables	Unit of Measurement
	through supermarket traders and 0= farmers selling through traditional market traders)
Actual chili price	IDR per kg
Chili area	Area planted with chili (ha.)

Note : *The response options for each statement are from 1=strongly disagree to 5=strongly agree)

Supermarket participation was operationalized through a dummy variable (1=farmers selling through supermarket traders and 0= farmers selling through traditional market traders). Unlike other fresh vegetable products that can be harvested at the same time, farmers can harvest chili crop weekly or fortnightly; therefore we measured actual chili price through average chili prices received by chili farmers from their buyers over the last season (in Indonesian currency for each kg chili or IDR/kg). Finally, chili area refers to the area dedicated for planting chilies (ha).

Sampling method

The 602 chili farmers were personally interviewed in a farm survey between March and April 2010. The survey was conducted in West Java Province, the largest chili production zone in Indonesia with a lot of supermarkets active in chili supply chains. The samples include farmers selling to traditional markets or supermarkets.

The traditional farmer respondents were selected by following several stages. First, three districts in West Java were selected: Garut represents the main production zone in West Java, Ciamis and Tasikmalaya Districts both represent new emerging areas with substantial modern sector activities. Second, by applying systematic random sampling procedure on the data of average chili production in 2004-2008 in the three districts, the 14 subdistricts were selected; eight subdistricts from Garut and three subdistrict from each new emerging area. Next, three villages were selected randomly from each subdistrict. Finally, in each of these villages, 12 chili farmers were selected from a list provided by the Extension office and the Land Tax Office. Overall we interviewed 506 respondents as representative sample of chili farmers. The supermarket farmer respondents were obtained from a list of 96 names of chili farmers whose chilies are sold to supermarkets in Ciamis Districts. The list was provided by a contact person in the field: supermarket suppliers, traders and local agricultural staffs.

After examining the quality of the data, we noticed that about 17 farmers from the traditional channel sample can be incorporated to supermarket channel sample. Those farmers, in fact, sell their chilies to supermarkets. Additionally, two households from the random sample (traditional channel) and one household from the supermarket sample were excluded due to incomplete information. Finally, this study came up with 487 farmers as samples in traditional markets and 112 farmers in supermarkets.

Statistical procedure

Multiple stages were involved in testing our hypotheses as outlined in Gyau *et al.* (2011) and Smith (1998). We first conducted factor analysis in each item to construct the relational variables. The second step focused on the Partial Least Square (PLS) approach.

In the factor analysis, Principal Component Analysis (PCA) was used to check the dimensionality in each latent variable (relationship quality, non-economic satisfaction; overall price satisfaction, price correctness and price equity). For each variable, only item having factor loading above 0.5 were retained (Nunnaly, 1978).

The relationships between the variables in the structural model (Figure 1) were analysed using PLS approach. This method allows simultaneous test of multiple dependent and independent variables, incorporates unobservable constructs (the latent variables) and estimates the contribution of each variable measures (Smith, 1998). In PLS approach the measurement model should be examined before testing the structural model. The fitness of the measurement model was estimated by examining outer and inner models. The outer model provides an assessment of reliabilities and convergent validity, focusing on the individual item on each variable consisting of more than one item. Meanwhile, the inner model provides an assessment of discriminant validity, focusing on each variable in the model.

RESULTS AND DISCUSSION

Description of the sample

Several differences, mostly significant at $\alpha = 0.01$, between respondents in supermarket and traditional market emerged as indicated in Table 2. Farmers who sell to supermarkets have better education level and younger age compared to farmers selling to traditional markets ($\alpha = 0.05$). Respondents both in supermarkets and traditional markets can be considered as small farmers as indicated by the average of farm size that less than one hectare. No significance difference in term of land size and irrigated land between the two categorizes of respondents. Though, in terms of area dedicated for chili crop there is a significant difference in which farmers in supermarkets have larger area for chili crop. Farmers in supermarkets receive higher price, rewarding quality differentiation. Additionally, farmers in supermarket samples receive greater income than farmers in traditional markets.

Table 2. The profile of respondents in the traditional and supermarket channels

Variable	Traditional market (n=487)	Supermarket (n=112)	Total Sample (n=599)	t-test[1]
Age of respondent (years)	46.24	43.86	45.79	2.07**
Education of respondent (years)	6.46	7.96	6.74	-4.84***
Land size (ha)	0.70	0.8	0.72	-1.14
Area planted with chili (ha)	0.34	0.48	0.36	-2.72***
Irrigated land (ha)	0.26	0.3	0.28	-0.86
Sort into different groups by size (% yes)	8.00	40.18	14.02	-9.47***
Sort into different groups by color (% yes)	14.58	54.46	22.04	-9.89***
Sort into different groups by quality (% yes)	16.22	55.36	23.54	-9.42***
Net chili income (million IDR)	6.13	13.67	7.54	4.82***

Note: ***Significant at 1% level; ** Significant at 5% level

Factors which influence relationship quality

For latent variables used in this study, the individual item reliabilities were evaluated through examining the values of factor loading of items on their respective variables. All items on the respective variables should be equal to or greater than 0.5. As shown in Table 3, the factor loadings of each item on the respective variable are above 0.5 which is on the threshold recommendation. The internal consistency was evaluated through examining the values of composite reliability (CR) (Fornell and Larcker, 1981) with the minimum recommend value should be 0.6 (Bagozzi and Yi 1988). The values of CR for all variables with multiple items in this study are acceptable (above 0.7). Fornell and Larcker, (1981) also stress the importance of convergence validity to assess whether the variable variance can be explained by the chosen items. The convergence validity was demonstrated by the values of Average Variance Extracted (AVE) with the recommend value should be equal to or greater than 0.5 (Bagozzi and Yi, 1988). All variables having multiple items in this study met this criteria with AVEs are above 0.5.

Table 3. Loadings, composite reliabilities, average variance extracted of relational variables

Variables and indicators	**Factor loading**	**Comp. Reliability**	**Average**
Supermarket participation	1.000	1.000	1.000
Actual chili price	1.000	1.000	1.000
Chili area	1.000	1.000	1.000
Relationship quality		0.765	0.520
I care about the long-term success of the relationship with my buyer.	0.765		
I receive payment on time.	0.676		
My buyer always keeps his promises.	0.721		
Non-economic satisfaction		0.811	0.682
My buyer deals with me as expected	0.810		
My buyer is quick to handle my complaints.	0.841		
Overall price satisfaction		0.811	0.683
The buyer offers me satisfactory prices for my chilies.	0.884		
Based on the price my buyer offers me, I will not change buyers.	0.765		
Price correctness		0.801	0.574
In comparison to other buyers, I am satisfied with the price my buyer offers.	0.754		
I receive a good price-quality ratio	0.693		
The chili prices I receive are fair.	0.820		
Price equity		0.819	0.693
The prices I received is similar to the prices other farmers get.	0.802		
The chili price information from my buyer is complete and correct.	0.862		

Discriminant validity was conducted to assess the inner model. In this article, we examined the correlation matrix and the square roots of AVE (Table 4). The square roots of AVE are reported along the diagonal while other values in Table 4 represent the correlation between variables. The discriminate validity for each latent variable is well specified when the square roots of the AVEs are greater than the correlation between the variable and the other variables. Table 4 shows that the discriminant validity in this study is acceptable.

Table 4. Discriminant validity of the variables

	Super-market	**Actual price**	**Chili area**	**Rel. quality**	**Non-economic satisfaction**	**Price satisfaction**	**Price correctness**	**Price equity**
Supermarket participation	1.000							
Actual price	0.208	1.000						
Chili area	0.111	0.048	1.000					
Relationship quality	0.124	0.068	0.082	0.721				
Non-economic satisfaction	0.218	0.041	0.106	0.490	0.826			
Price satisfaction	0.102	0.100	0.071	0.556	0.425	0.827		
Price correctness	0.087	0.136	0.091	0.426	0.311	0.574	0.758	
Price equity	0.083	-0.034	0.025	0.244	0.161	0.276	0.243	0.835

Note: the diagonal values indicate the square root of AVE

After checking the fitness of the measurement model, the structural model in Figure 1 was estimated by using SmartPLS software. The relative strength of structural relationship between variables were evaluated through the values of PLS path coefficients which are analogues to standardized regression coefficient. The R^2 criterion was also utilized to evaluate the ability of independent variables explain the variance of dependent variables. Finally, a bootstrap method was utilized to test the significance of the path coefficients.

Table 5 presents the estimations of the structural model. Based on the values of path coefficients and the results of bootstrap method, we accepted the hypotheses H_1, H_2, H_3, H_4 and H_9, but rejected the hypotheses H_5, H_6, H_7, H_8 and H_{10}. All path coefficients in all accepted hypotheses were significant at $\rho < 0.001$ level. Non-economic satisfaction, price satisfaction, actual chili price, supermarket participation and chili area explain 38.8 per cent the variance of relationship quality. While price correctness, price equity, actual chili price and supermarket participation explain 35.2 per cent the variance of price satisfaction.

Table 5. The results of the structural model

Hypo-theses	The influence independent variable to dependent variable	Expected sign	Path coefficient	Decision
H_1	Non economic satisfaction → relationship quality	+	0.306*	Supported
H_2	Price satisfaction → relationship quality	+	0.422*	Supported
H_3	Price correctness → price satisfaction	+	0.533*	Supported
H_4	Price equity → price satisfaction	+	0.144*	Supported
H_5	Actual price → price satisfaction	+	0.024	Rejected
H_6	Actual price → relationship quality	+	0.010	Rejected
H_7	Supermarket channel → relationship quality	+	0.010	Rejected
H_8	Supermarket channel → price satisfaction	+	0.039	Rejected
H_9	Supermarket → non economic satisfaction	+	0.218*	Supported
H_{10}	Chili area → relationship quality	+	0.018	Rejected

Note: * significant at 1%

Non-economic satisfaction and price satisfaction have positive influences on relationship quality confirming the hypotheses H_1 and H_2. We find that actual chili price does not influence the perception of chili farmers on their relationship quality, thus H_6 is rejected. Farmers give more consideration to whether prices that they receive can satisfy them based on the quality, fairness, price offered by other buyers and price transparency. This result is supported by Gyau and co-workers (2011) who proposed that actual milk price is less important in determining relationship quality in the German dairy industry. Likewise, being large farmers does not imply they will have stronger relationship with the buyers relative to smaller farmers as indicate by not significant impact of land dedicated to chili on relationship quality- rejecting H_{10}. It should be noted, however, either larger farmers in our sample can be considered as small farmers as indicated by their land size less than one hectare (Table 2).

Although previous studies demonstrate that supermarkets need closer coordination along the chain, the results in this study indicate that in the context of Indonesian chili supply chain, there is no evidence that farmers selling to supermarkets perceive a higher level of relationship quality compared to those selling to traditional markets. This is because farmers think that the buyers from supermarkets treat them similarly to farmers in traditional channel in terms of providing payment on time and keeping their promises. Likewise, there is no significant difference related to the perception of price satisfaction between the two categorizes of farmers. Farmers in supermarket samples might perceive that they should obtain higher prices for rewarding them in sorting activities. In such case, we rejected H_7 and H_8. However, farmers selling to supermarkets perceive higher non-economic satisfaction than farmers selling to traditional markets, confirming H_9. They believe that their buyers have treated them adequately as expected (*e.g.*, how mutuality and equity are exercised in their relationship) and offered quick response in handling their complaints (*e.g.,* regarding the grading system).

Considering the relative importance of price satisfaction in modeling farmer-buyer relationships in Indonesian chili supply chain, we then explore the impact of price satisfaction dimensions on overall price satisfaction. This study reveals that all two dimensions of price satisfaction strongly influence overall price satisfaction, this confirming H_3 and H_4. However, it seems that the variable of price correctness, is more important to farmers than the variable of price equity. This is because farmers may obtain price information from other sources, such as traders in wholesale markets, farmer associations, extension office, *etc*.

CONCLUSIONS AND IMPLICATIONS

This study has explored farmer-trader relationship quality in the Indonesian modern food supply chain. More specifically, we analyzed whether economic variables (actual price and farm size) or relational variables (the perception of chili price and non-economic satisfaction) have stronger influences on farmers perception on relationship quality. The results indicate that there is no significant influence of economic variables on relationship quality. It is rather the relational variables that really matter in determining farmers' perceptions of relationship quality. Similar to study by Matzler et al., 2006b; Matzler et al., 2007), this study shows that price satisfaction can be conceptualized as a multidimensional constructs, each with significant impact on overall price satisfaction.

This study also compares the perception of relationship quality, price satisfaction, and non-economic satisfaction between farmers selling to supermarkets and those selling to traditional channels. Contrary to the expectation, there is no significant difference related to their perception on relationship quality and price satisfaction. However, farmers selling to supermarkets perceive higher non-economic satisfaction than farmers selling to traditional markets. These findings suggest that to increase relationship quality between farmers and traders in supermarket and traditional supply chain, traders should more focus on relational variables instead of economic variables. Price satisfaction might be improved by providing prices based on chili quality; avoid takes advantage to the farmers by offering unfair price rather than focus on absolute price. Traders might consider to provide quick responses in handling farmers' complaints and dealing with farmers as expected in order to improve farmers' perception on non-economic satisfaction particularly when dealing with farmers selling to supermarket chains.

This study only examines some relational and economic variables in modelling farmer-buyer relationships in Indonesia chili supply chain. Future study should incorporating other variables that might determine relationship quality, such as communication, power dependency, goal compatibility as indicated in studies by (Batt, 2003; Gyau and Spiller, 2007) Also, since this study was region and commodity specifics, i.e., chili commodity in Indonesia, further research is needed to generalize the results in the context of high value agricultural commodity. Given the same method with relatively similar attributes, we notice that the variable of land size does not influence farmers' perception on relationship quality.

ACKNOWLEDGEMENTS

The data for this paper was generated by a research that was funded by the Australian Centre for International Agricultural Research (ACIAR). All views, interpretations and conclusions expressed are those of the authors and not necessarily those of the supporting or cooperating institutions.

REFERENCES

Ashnai, B., M. Smirnova, S. Kouchtch, Q. Yu, B.R. Barnes and P. Naude´. 2009. Assessing relationship quality in four business-to-business markets. Marketing Intelligence and Planning. 27: 86-102.

Bagozzi, R. and Y.Yi. 1988. On the evaluation of structural equation models. Journal of the Academy of Marketing Science. 13: 989-1006.

Batt, P.J. 2001. Building trust in the Filipino seed potato industry. Journal of International Food and Agribusiness Marketing. 13: 23-41.

Batt, P.J. 2003. Building trust between growers and market agents. Supply Chain Management: An International Journal. 8: 65-78.

Batt, P.J. and N. Rexha. 1999. Building trust in agribusiness supply chains. Journal of International Food and Agribusiness Marketing. 11: 1-17.

Bejou, D., B. Wray and T.N. Ingram. 1996. Determinants of relationship quality: an artificial neural network analysis. Journal of Business Research. 36: 137-143.

Boniface, B., A. Gyau, R. Stringer and W.J Umberger. 2010. Building long term relationship in the Malaysian fresh milk supply chain. Australian Agribusiness Review. 8: 66-84.

Boselie, D., S. Henson and D. Weatherspoon. 2003. Supermarket procurement practices in developing countries: redefining the roles of the public and private sectors. American Journal Agricultural Economics. 85: 1155–1161.

Caceres, R.C. and N.G. Paparoidamis. 2007. Service quality, relationship satisfaction, trust, commitment and business-to-business loyalty. European Journal of Marketing. 41:836-867.

Coronado, J.J.A., J. Bijman, O. Omta and A.O. Lansink. 2010. Relationship characteristics and performance in fresh produce supply chains: the case of the Mexican avocado industry. Journal on Chain and Network Science. 10: 1-15.

Dries, L,, E. Germenji, N. Noev and J.F.M. Swinnen. 2009. Farmers, vertical coordination, and the restructuring of dairy supply chains in Central and Eastern Europe. World Development. 37: 1742-1758.

Escobal, J.A. and Cavero D. 2011. "Transaction costs, institutional arrangements and inequality outcomes: potato marketing by small producers in rural Peru." World Development. 40: 329-341.

Ellram, L.M. and T.E. Hendrick. 1995. Partnering characteristics: A dyadic perspective. Journal of Business Logistics. 16: 41-64.

Fischer, C. and N. Reynolds. 2010. Collaborative advantage, relational risks and sustainable relationships: a literature review and definition. In C. Fischer and M. Hartmann (Eds). Agri-food chain relationships, CAB International.

Fornell, C. and D.F. Larcker. 1981. Evaluating structural equations with unobservable variables and measurement error. Journal of Marketing Research. 18: 39-50.

Geyskens, I. and J.E.M. Steenkamp. 2000. Economic and social satisfaction: measurement and relevance to marketing channel relationship. Journal of Retailing. 76: 11-32.

Geyskens, I., J.E.M. Steenkamp and N. Kumar. 1999. A meta-analysis of satisfaction in marketing channel relationships. Journal of Marketing Research. 36: 223-238.

Gyau, A. and A. Spiller. 2007. Determinants of trust in the international fresh produce business between Ghana and Europe. International Business Management. 1: 104-111.

Gyau, A., A. Spiller and C. Wocken. 2011. Price or relational behaviours? Supplier relationship management in the German dairy industry. British Food Journal. 113: 838-852.

Hingley, M., V. Sodano and A. Lindgrees. 2006. Differentiation strategies in vertical channels: a case study from the market for fresh produce. British Food Journal. 110: 42-61.

Holmlund, M. 2008. A definition, model, and empirical analysis of business-to-business relationship quality. International Journal of Service Industry Management. 19: 32-62.

Kaganzi, E., S. Ferris, J. Barham, A. Abenakyo, P. Sanginga and J. Njuki. 2009. Sustaining linkages to high value markets through collective action in Uganda. Food Policy. 34: 23-30.

Kalwani, M.U. and S. Narayandas. 1995. Long-term manufacture-supplier relationships: do they pay off for supplier firm? Journal of Marketing. 59:1-16.

Kwon, I.G. and T. Suh T. 2004. Factors affecting the level of trust and commitment in supply chain relationships. The Journal of Supply Chain Management. Spring: 4-14.

Matzler, K., B. Renzl and R. Faullant. 2007. Dimensions of price satisfaction: a replication and extension. The International Journal of Bank Marketing. 25: 394-405.

Matzler, K., B. Renzl and S. Rothenberger. 2006a. Measuring the relative importance of service dimensions in the formation of price satisfaction and service satisfaction: a case study in the hotel industry. Scandinavian Journal of Hospitality and Tourism. 6: 179-196.

Matzler, K., A. Würtele and B. Renzl. 2006b. Dimensions of price satisfaction: a study in the retail banking industry. International Journal of Bank Marketing 24: 216-231.

Morgan, R.M. and S.D. Hunt. 1994. The Commitment-Trust Theory of Relationship Marketing. Journal of Marketing. 58: 20-38.

Natawidjaya, R., T. Reardon T, S. Shetty, T.I. Noor, T. Perdana and E. Rasmikayati. 2007. Horticultural producer and supermarket development in Indonesia. World Bank report pp 1-178. Jakarta: World Bank.

Nunnally. 1978. Psychometric Theory, 2nd Edition. McGraw-Hill, New York.

Ӧsterberg, P. and J. Nilsson. 2009. Member's perception on their participation in the governance of cooperatives: the key to trust and commitment in agricultrual cooperatives. Agribusiness. 25: 181-197.

Parsons, A.L. 2002. What determines buyer-seller relationship quality? An investigation from the buyer’s perspective. The Journal of Supply Chain Management. Spring: 4-12.

Rao, E.J.O. and M. Qaim, M. 2011. Supermarkets, farm household income, and poverty: insights from Kenya. World Development. 39: 784-796.

Reardon, T., C.B. Barrett, J.A. Berdegué and J.F.M. Swinnen. 2009. Agrifood industry transformation and small farmers in developing countries. World Development. 37: 1717-1727.

Sabel, C.F. 1993. Studied trust: building new forms of cooperation in a volatile economy. Human Relations. 46: 1133-1170.

Sargeant, A. and S. Lee. 2004. Trust and relationship commitment in the United Kingdom voluntary sector: determinants of donor behavior. Psychology and Marketing. 21: 613-635.

Schulze, B., A. Spiller, and C. Wocken. 2006. Supplier relationship quality in the German pork and dairy sector: theoretical considerations and empirical evidence. In: 16th Annual World Forum and Symposium “Agribusiness, Food, Health, and Nutrition”, IAMA Conference, June 10 – 13, Buenos Aires, Argentina.

Smith, J.B. 1998. Buyer–seller relationships: similarity, relationship management, and quality. Psychology and Marketing. 15: 3-21.

Suryadarma, D., A. Poesoro, Akhmadi, S. Budiyati, M. Rosfadhila and A. Suryahadi . 2010. Traditional food traders in developing countries and competition from supermarkets: Evidence from Indonesia. Food Policy. 35: 79-86.

Weatherspoon, D.D. and T. Reardon. 2003. The rise of supermarkets in Africa: Implications for agrifood systems and the rural poor. Development Policy Review. 21: 333-355.

Wong, A. and A. Sohal. 2002. An examination of the relationship between trust, commitment and relationship quality. International Journal of Retail and Distribution Management. 30: 34-50.

Woo, K. and C.T. Ennew. 2004. Business-to-business relationship quality: an IMP interaction-based conceptualization and measurement. European Journal of Marketing. 38: 1252-1271.

J. ISSAAS Vol. 21, No. 1: 123-136 (2015)

LAND USE CHANGES AND ABOVE-GROUND BIOMASS ESTIMATION IN PEATLANDS OF RIAU AND WEST KALIMANTAN, INDONESIA

Syed Aziz Ur Rehman*, Untung Sudadi, Syaiful Anwar and Supiandi Sabiham

[1]Department of Soil Science and Land Resource, Bogor Agricultural University,
Jl. Raya, Darmaga Kampus IPB, Darmaga, Bogor 16680, Indonesia
*Corresponding author: syedaziz88@gmail.com

(Received: November 27, 2014; Accepted: May 1, 2015)

ABSTRACT

Indonesian peatlands are extensively managed for large-scale plantations particularly oil palm grabbing global attention due to high carbon contents in both soil and biomass. Therefore, land use changes in the peatlands of Riau and West Kalimantan provinces, Indonesia were documented by analyzing the expansion of industrial-scale oil palm plantations (OPP) and estimating changes in above-ground biomass (AGB). We used Landsat imagery to visually interpret OPP followed by intersection with peat thickness and swamp forest maps to create province-wide maps; spanning three temporal periods ranging from 1990 to 2000, 2000 to 2010 and 2010 to 2013. To assess the loss of AGB associated with each land use change, we followed the AGB estimates reported in the scientific literature for the selected land uses. The results show that in 1990, the two provinces collectively had approximately 0.31 Mha of OPP, which expanded to 3.04 Mha by 2013. The OPP grew at an approximately constant rate (11% yr^{-1}); the conversion of secondary peat swamp forest (SPSF) to wet shrublands (WSL) caused the greatest loss of AGB (85.5 M tons), followed by conversion from SPSF to OPP (47.5 M tons). Similarly, the loss of AGB from the conversion of primary peat swamp forest (PPSF) to OPP (estimated to be only 4.39 M tons) was higher than for conversions from PPSF to WSL (3.44 M tons). Our results can be used for future peatland planning and management coupled with results from social and economic surveys.

Key words: conversion, oil palm, peat swamp forest, plantation, Southeast Asia

INTRODUCTION

About 11% or 440,000 km^2 of the Earth's peatland area is found in the tropics, of which most is concentrated in insular Southeast Asia; here peat deposits in some areas are up to 20 m thick and these lands have cover around 250,000 km^2 (Page *et al*., 2011). Tropical peatlands provide a range of ecosystem functions and societal benefits. This includes the provisioning of habitat for endangered fauna because anthropogenic activities in pre-existing lowland forests with mineral soils have caused these forests to suffer extensive declines, limiting habitat for some species (Giesen, 2004).

During the mid-1980s, the Indonesian government implemented a policy of promoting the diversification of products outside the oil and gas sector, with a strong focus on the development of tree crop plantations. In the forestry sector, an industrial tree crop estate (*Hutan Tanaman Industri* or HTI) was originally proposed as a model to be established on degraded land, supposedly to reduce the demanding of natural timber. The main thrust of development in the tree crop sector, however, has been the rush to develop oil palm estates. From around 500,000 ha in 1984, the gross area under oil palm had increased to over 1.0 Mha by 1990, to approximately 2.4 Mha in 1997, and to nearly 3.0 Mha in 2000 (Pagiola, 2000). The development of plantations in previously swampy areas involved the drainage of land during site preparation; therefore, since the 1980s, there has been an increase in the distortion of landscapes and a loss of small segments of land held by poor landholders in the logged peatlands (Page *et al*., 2009).

The process of the accumulation and storage of peat in tropics is a collective function of peatland hydrology, ecology and landscape morphology (Hooijer *et al*., 2010). The conversion of peatland to agricultural use results in demands for an optimal water supply aimed to avoid flooding. This involves civil engineering work such as the development of road networks and waterways. Such development ultimately leads to lowering the ground water level, creating aerobic conditions within the peat that accelerate oxidation, nitrogen mineralization and microbial activities (Hirano *et al*., 2007). Such logging activity causes the humid tropical forests to be highly prone to forest fires and desiccation because of wood loss and the opened canopy (Siegert *et al*., 2001). These fires are potentially disastrous, causing abrupt changes in the peatland involving the burning and release of carbon stocks, which creates an enormous emission of carbon into the atmosphere (Heil *et al*., 2006).

Therefore, from the perspective of national-level resource management and policy development regarding peatlands, understanding the historical land use changes and the mechanisms involved in agriculture development is much needed. The current research study thus discusses the historical expansion of oil palm plantations (OPP) and explores the dynamics of above-ground biomass (AGB) during land use changes in peatland ecosystems. This study highlights the conversion of peat swamp forests (PSF) based on the status of primary or secondary forests. It addition, the study also documents the transitions occurring in AGB in the peatlands that have been developed for OPP by distinguishing classes of peat thickness, which in some cases (thickness > 3m) have been protected by presidential decrees[1] in Indonesia.

MATERIALS AND METHODS

Study Area

Riau

Much of the mainland of the Province of Riau, situated on the northeastern side of the island of Sumatra, is low lying and swampy, with hilly regions mainly toward the western and southern borders. Soils are either highly acidic, developed over peat, or the Podsolic and leached soils of the Sumatran peneplain. Until the 1980s, very large tracts were forested; local people practiced swidden subsistence agriculture, with cash crops of smallholder rubber plantations on the peneplain and coconuts grown in the coastal swamps (Potter *et al*., 2001).

West Kalimantan

West Kalimantan, the fourth largest province in Indonesia, covers 146,807 km^2 (7.53% of the area of Indonesia). The mainland of West Kalimantan, bordered in the north by the Malaysian state of Sarawak, consists mostly of lowlands with a few hills, while the marine area contains scores of islands. Vegetation types include coastal vegetation, mangroves, swampland and upland rain forest. West Kalimantan is predominantly occupied by pure or composite red-yellow podzolic soils. The Kapuas River, the longest river in Indonesia (1,086 km), and Sentarum Lake, with an area of 117,500 ha, dominate the hydrological regime. Hundreds of rivers flow through West Kalimantan, all originating in either the Kapuas Hulu or the Schwaner Range (Soetarto *et al*., 2001).

[1] Presidential Decree No. 32/1990 and Presidential Decree No. 80/1999.

Secondary Data

Landsat imagery (4, 5, 7 and 8) was downloaded from the US Geological Survey website: http://glovis.usgs.gov/. In addition, we obtained peatland distribution data from the Indonesian Centre for Agricultural Land Resources Research and Development (ICALRRD), which was used to obtain details related to peat thickness in the study area. The land use data for forest lands were acquired from the Indonesian Ministry of Forestry and used to locate swamp forests. Primary and secondary swamp forest polygons were intersected with peat thickness polygons to obtain the locations of PSF.

Spatial Data Analysis

Landsat satellite imagery (4, 5, 7 and 8) was processed using ArcGIS® 9.3 software by performing on-screen analysis to locate oil palm plantations. A mouse was used to trace the outlines of land cover and directly identify land cover types (Carlson *et al.*, 2012). During on-screen interpretation, multistage visual technique images were displayed as false color composites of various Landsat bands. We identified 3 (0.63–0.69 µm, red), 4 (0.76–0.90 µm, near infrared) and 5 (1.55–1.75 µm, mid-infrared)—schemes with bands 5-4-3 that were displayed as red, green and blue, respectively, and were followed with displays of a combination of the selected channels on the screen.

The OPP were identified and delineated using Landsat imagery, while the spatial extent and thickness of peat soils were taken using secondary data from ICALRRD. The peat-layer thickness information was used to determine the extent of OPP above two groups of peat soil with thickness identified as being either more or less than 3 m to separate the two groups. Similarly, the peat soil polygons were intersected with OPP and swamp forests data to circumscribe the PSF and to further distinguish between the peatlands and PSF.

The primary outputs of the data analysis were land cover change matrices. However, to better understand the dynamics of the development of OPP and to facilitate communication of the results, the output of the analysis has been presented in the form of maps and tables depicting incremental changes in the OPP over time (Broich *et al.*, 2011). Then, the results were compared with land cover maps and published statistics from other studies. To estimate the changes in AGB across selected land uses, we used the reported estimates of AGB from the scientific literature. As an exception, in the cases of Verwer *et al*. (2009), Khasanah *et al*. (2012) and Agus *et al*. (2013) we recalculated the biomass from the reported carbon stocks using C fraction data (CF = 0.50) [ton C (ton dm) $^{-1}$] following IPCC (2006). Meanwhile, studies reporting extreme high or low estimates of AGB, *i.e*. Carlson (2012), Morel *et al*. (2011), Van der Meer *et al*. (2011), Budiharta *et al*. (2014) and Ludang *et al*. (2007), were not considered. The decline in biomass was estimated by multiplying the spatial change (ha) in AGB during each land use transition based on the difference of biomass. We estimated the changes in AGB associated with the major land use changes only, *i.e*. our estimates encounter change from densely vegetated primary and secondary PSF to oil palm monocultures and wet shrublands (WSL). However, all other land uses developed above peatlands that can be classified as primary and secondary PSF have also been determined.

RESULTS AND DISCUSSION

Peatlands Distribution in Riau and West Kalimantan

Province-wide scale (1:250,000) peatland distribution maps were prepared by Wetland International (WI) in 2003/2004, followed by ICALRRD in 2011. We processed raw data obtained from ICALRRD and our results show that the total peatland area based on peat thickness in Riau and West Kalimantan was 3.83 Mha and 1.69 Mha, respectively (Table 1).

Table 1. District-level distribution of peatland based on thickness classes in West Kalimantan and Riau, Indonesia (reproduced from ICALRRD, 2011).

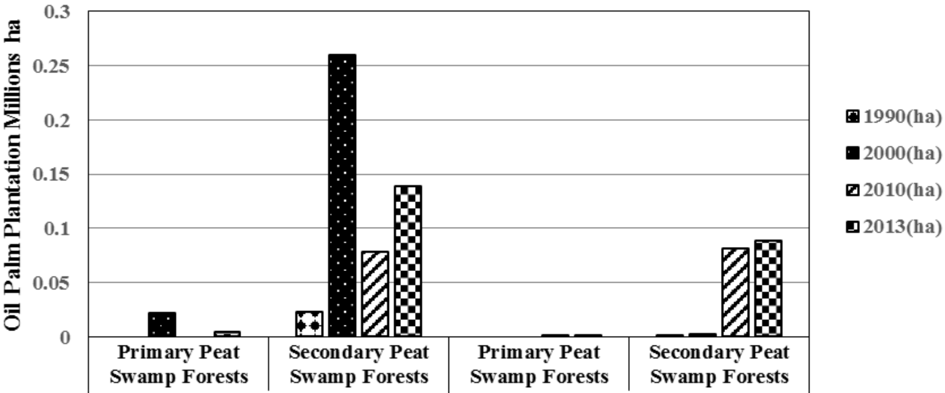
Peatland (ha)							
West Kalimantan				**Riau**			
District	**Peat thickness**		**Total**	**District**	**Peat thickness**		**Total**
	< 3m	**>3m**			**< 3m**	**> 3m**	
Bengkayang	36,520	--------	36,520	Bengkalis	657,981	387,087	1,045,069
Kapuas Hulu	198,659	71,762	270,442	Indragiri Hilir	690,737	216,112	906,848
Kayong Utara	128, 464	--------	128,464	Indragiri Hulu	66,807	138,779	205,586
Ketapang	274,753	69,465	344,219	Kampar	71,604	34,072	105,675
Kubu Raya	317,746	96,236	413,983	Kota Pekanbaru	3,792	--------	3,792
Landak	127,157	--------	127,157	Pelalawan	314,185	364,823	679,008
Melawi	2,893	--------	2,893	Rokan Hilir	248,814	182,276	431,090
Pontianak	10,343	--------	10,343	Rokan Hulu	44,351	8,470	52,820
Sambas	96,351	6,133	102,48	Siak	142,510	261,577	404,086
Sanggau	182,599	5,710	188,308				
Sintang	68, 582	--------	68,582				
Kota Pontianak	25	--------	25				
Grand Total	1,444,092	249,307	**1,693,398**	**Grand Total**	2,240,781	1,593,196	**3,833,978**

Current and Historical Oil Palm Plantations in Peatlands

Table 2 documented the OPP that have been developed over peatland in Riau and West Kalimantan since 1990 based on the peat thickness classes. Riau and West Kalimantan had 1,552,165 ha (91.60%) and 359,879 ha (80.00%) of peatland, respectively, that has been legally converted to OPP, *i.e*. with peat thickness less than 3 m. The results show that much of the peatlands that are legally available for further development and plantations from 2013 onwards in both provinces are now greatly limited. That is, Riau has 0.32 Mha and West Kalimantan has 0.79 Mha of peatland deposits remaining that can be developed legally (peatlands with thickness < 3 m). Similarly, the spatial extent of peat soils supporting OPP increased from 22,992 ha (7% of total oil palm area) in 1990 to 1.3 Mha (43%) by 2013 in both provinces, of which 1.04 Mha (30%) occurs in Riau, compared with 0.26 Mha (29%) in West Kalimantan. The use of peatlands for OPP in areas with a peat-layer thickness greater than 3 m increased in both provinces, from 26 ha and 0 ha (0.11% and 0%) in 1990 to 0.31 Mha and 24,796 ha (30% and 9%) in 2013 in Riau and West Kalimantan, respectively. The analysis revealed that the OPP expanded almost linearly in both provinces with a more drastic rise in Riau from 1990 to 2000, and from 2010 onwards. We also noticed accelerated encroachment of oil palm plantations toward areas with thicker peat deposits over time.

The Conversion of Peat Swamp Forest to Oil Palm Plantations

To extract PSF and differentiate it from swamp forests above mineral soils, we overlaid the land use change data for forests with peatland maps across each time period. Thus we assessed the conversion of PSF to OPP and other land uses. However, remember that a very minute fraction of OPP has been derived from primary peat swamp forests (PPSF); most of the OPP has been established on land previously inhabited by secondary peat swamp forests (SPSF). Our results supported the finding (Figure 1) that in both provinces the expansion took place initially using SPSF and then in the later stages (from 2010 to 2013) some portion of PPSF has also been used.



	Riau: Primary Peat Swamp Forests	Riau: Secondary Peat Swamp Forests	West Kalimantan: Primary Peat Swamp Forests	West Kalimantan: Secondary Peat Swamp Forests
1990(ha)	0	22852	0	140
2000(ha)	22136	260202	0	2142
2010(ha)	0	78026	1065	81255
2013(ha)	4288	138701	1684	88329

Fig. 1. Temporal expansion of oil palm plantations and conversion of primary and secondary peat swamp forest in Riau and West Kalimantan, Indonesia

Table 2. Oil palm plantations in peatlands based on peat thickness in West Kalimantan and Riau, Indonesia

Year	Land Use	Mineral soil	Oil Palm over Peat (ha)							% OPP over peat thickness < 3m (legal)
			D1	D2	D3	D4	Total over Peat	Over Peat (thickness < 3m)	Over Peat (thickness > 3m)	
West Kalimantan										
1990	Oil Palm	43,518	140	--------	--------	--------	140	140	--------	
2000	Oil Palm	181,498	3,193	7,035	2,490	--------	12,718	12,718	--------	
2010	Oil Palm	359,960	57,571	39,877	9,288	12,558	119,294	106,736	12,558	
2013	Oil Palm	641,799	81,449	131,287	27,549	24,796	265,081	240,285	24,796	
Total							**397,233**	**359,879**	**37,354**	**91.60**
Riau										
1990	Oil Palm	246,402	4,855	4,237	13,734	26	22,852	22,826	26	
2000	Oil Palm	845,340	59,415	147,643	130,425	25,718	363,201	337,483	25,718	
2010	Oil Palm	972,696	61,116	212,804	187,477	52,791	514,188	461,397	52,791	
2013	Oil Palm	1,087,486	66,364	268,721	395,374	310,755	1,041,214	730,459	310,755	
Total							**1,941,455**	**1,552,165**	**389,290**	**80.00**

Peat thickness classes: D1, 50–100 cm; D2, 100–200 cm; D3, 200–300 cm; D4, > 300 cm

Table 3. Land use change trajectory from PSF to OPP and other land uses in West Kalimantan, Indonesia

Primary Peat Swamp Forest(ha)				Converted to (ha)		
1990	**2000**	**2010**	**2013**	**1990-2000**	**2000-2010**	**2010-2013**
25,737	17,090	15,957	14,272	Open land (30) Other Plantation (209) Dry-land Agriculture (4) Wetland (20) Rice Paddy (5) Shrub-land (146) Wet Shrub-land (8,102)	Oil Palm Plantation (1,065) Wet Shrub-land (68)	Oil Palm Plantation (1,684)

Secondary Peat Swamp Forest(ha)				Converted to (ha)		
1990	**2000**	**2010**	**2013**	**1990-2000**	**2000-2010**	**2010-2013**
1,237,170	1,188,116	995,290	887,385	Oil Palm Plantation (2,142) Open land (261) Dry-land Agriculture (11) Agriculture cum Shrub-land (20) Wetland (223) Shrub-land (212) Wet Shrub-land (47,611)	Oil Palm Plantation (81,255) Open land (6,251) Other Plantation (34,462) Mining (122) Dry-land Agriculture (159) Agriculture cum Shrubland (593) Wetland (45) Shrub-land (1,588) Wet Shrub-land (68,354)	Oil Palm Plantation (88,329) Open land (6,388) Other Plantation (204) Dry-land Agriculture (135) Agriculture cum Shrubland (1,340) Shrub-land (69) Wet Shrub-land (10,120)

Table 4. Land use change trajectory from PSF to OPP and other land uses in Riau, Indonesia

Primary Peat Swamp Forests (ha)				**Converted to (ha)**		
1990	**2000**	**2010**	**2013**	**1990-2000**	**2000-2010**	**2010-2013**
202,918	174,145	107,911	95,433	Secondary PSF (169) Forestry Plantation (3,069) Oil Palm Plantation (22,136) Open Land (1,178) Other Plantation (406) Wet Shrub-land (1,815)	Secondary PSF (52,458) Forestry Plantation (4,521) Open Land (3,808) Other Plantation (333) Wet Shrub-land (5,113)	Secondary PSF (3,426) Oil Palm Plantation (4,288) Open Land (3,485) Other Plantation (675) Wet Shrub-land (604)
Secondary Peat Swamp Forests (ha)				**Converted to (ha)**		
1990	**2000**	**2010**	**2013**	**1990-2000**	**2000-2010**	**2010-2013**
8,673	2,075,438	1,318,421	1,081,485	Forestry Plantation (20,198) Oil Palm Plantation (260,202) Open Land (72,241) Other Plantation (113,241) Settlements (825) Mining (247) Dry-land Agriculture (11,042) Wet Shrubland (88,436) Wetland (82) Savannah (11) Rice Paddy (13,545) Shrubland (30,230) Agriculture cum Shrubland (33,112)	Forestry Plantation (155,186) Oil Palm Plantation (78,026) Open Land (142,719) Other Plantation (53,508) Dry-land Agriculture (214) Agriculture cum Shrubland (30,827) Wetland (311) Shrubland (3,822) Wet Shrubland (345,034)	Forestry Plantation (2,126) Oil Palm Plantation (13,8701) Open Land (33,827) Other Plantation (6,668) Agriculture cum Shrubland (12,193) Wet Shrubland (43,420)

Furthermore, this study revealed that the exploitation of PSF for OPP is indirect (Tables 3 and 4) and that PSF is not only being converted to OPP but also to other land uses. After analyzing all regions and temporal periods in both provinces, we observed that only 0.94% (29,137 ha) of the OPP had been created on land that had been derived directly from PPSF; 21.55% (0.67 Mha) had been established on land previously covered with SPSF. In particular, Riau had the overall highest observed magnitude of SPSF conversion from 1990–2000, while in West Kalimantan more expansion took place from 2000–2010.

An overall comparison shows that Riau had the highest spatial extent of OPP that had replaced both primary and secondary PSF, *i.e*. 26,424 ha and 499,782 ha compared to 2,749 ha and 171,865 ha in West Kalimantan, respectively. The research results are both similar to and distinct from other studies (Table 5). This outcome is expected when different studies use different types of remote-sensing data, classification methods, and criteria that are used to establish definitions when evaluating the changes occurring on complex landscape mosaics.

Table 5. Comparison of results of oil palm plantation expansion with Miettinen et al., 2012

Source	Geographic Area	Peatland	Oil Palm Plantations over Peatland					
			1990		2000		2010	
		ha	ha	%	ha	%	ha	%
Miettinen et al. 2012	Riau	4,014,076	6,134	0	264,656	6.6	475,764	12.0
	West Kalimantan	1,743,224	0	0	12,190	0.7	149,384	9.0
This Study	Riau	3,833,978	22,852	0.6	363,201	9.5	514,188	13.4
	West Kalimantan	1,693,398	140	0	12,718	0.8	119,293	7.0

Some researchers believe that the expansion of OPP in Indonesia is one of several drivers of deforestation. However, it is a misconception to allege that all OPP originate from PPSF conversion, as described by Pagiola (2000) even before the global financial crisis, Indonesia had the world's lowest production costs for oil palm oil, estimated at about 10–25% below the costs in neighboring Malaysia, and about 15% below the global average. The financial crisis has tended to further increase Indonesia's cost advantage. As a result, oil palm production has grown rapidly in recent years, expanding from 0.1 million ha in 1967 to 2.5 million ha in 1997.

Loss of Above-Ground Biomass Because of Land Use Changes

The change in AGB is an obvious outcome in various land use change scenarios. These scenarios involve a change from systems such as forests with high levels of biomass stock to less densely vegetated ecosystems such as shrublands or monocultures such as OPP. Therefore, we focused on analyzing land cover changes involving the conversion of primary and secondary PSF to WSL and OPP as a major land use change. To estimate the changes in AGB across selected land uses, we used reported estimates of the AGB from the scientific literature (Table 6).

The biomass lost from 1990 to 2013 during all time periods was estimated (Table 7) for each land use change category using the difference of biomass in each land use type per hectare. By totaling the AGB lost during all time periods and in both provinces, the highest amount of AGB loss was found to be a result of the conversion of SPSF to WSL (85.5 M tons); this was followed by 47.5 M tons from the conversion of SPSF to OPP. Similarly, the AGB loss from the conversion of PPSF to OPP was estimated to be only 4.39 M tons, which is higher than the 3.44 M tons lost by the conversion from PPSF to WSL.

Table 6. Above-ground biomass (AGB) estimation of the selected land uses and the biomass changes associated with the conversion of primary (PSF) and secondary (PSF) peat swamp forest

Land Use	AGB (t dm ha^{-1})	AGB loss from PPSF* conversion (t ha^{-1})	AGB loss from SPSF** conversion (t ha^{-1})	AGB loss from PPSF conversion (% biomass in the PPSF)	AGB loss from PPSF conversion (% biomass in the SPSF)
Primary peat swamp forest	249[a]	---------	---------	---------	---------
Secondary peat swamp forest	172[b]	77	---------	30.93	---------
Oil palm plantations	99[c]	150	73	60.30	42.52
Wet shrubland	30[d]	219	142	87.84	82.39

[a, b:] average of the AGB values reported by Istomo 2002, Astiani 2014, Engalhart 2013, Kronseder *et al*., 2012, Campbell 2013, Jubanski *et al*., 2013, Verwer *et al*., 2009[†], Wijaya *et al*., 2011; c: from Verwer *et al*., 2009[†], Khasanah *et al*., 2012[†], Wicke *et al*., 2008, Germer *et al*., 2008; d: reported AGB by Engalhart 2013, Solichin *et al*., 2011, Agus *et al*., 2013[†]; †: AGB recalculated from the Carbon reported using C fraction (CF = 0.50) [ton C (ton dm) $^{-1}$] from IPCC 2006

Table 7. Loss of above ground biomass from primary and secondary PSF conversion to oil palm plantation and other land uses in Riau and West Kalimantan

Time Period	Loss of above-ground biomass due to land use change (tons)				
	PPSF to SPSF	**PPSF to OPP**	**PPSF to WSL**	**SPSF to OPP**	**SPSF to WSL**
			West Kalimantan		
1990 to 2000	-------	-------	1,774,679	156,889	6,757,022
2000 to 2010	-------	160,115	14,881	5,951,580	9,700,927
2010 to 2013	-------	253,295	-------	6,469,717	1,436,183
			Riau		
1990 to 2000	13,010	3,328,848	397,608	19,058,732	12,550,926
2000 to 2010	4,046,240	-------	1,120,022	5,715,127	48,967,606
2010 to 2013	264,224	644,759	132,374	10,159,292	6,162,210
Total AGB loss	4,323,474	4,387,017	3,439,565	47,511,336	85,574,874

PPSF: Primary peat swamp forest; SPSF: Secondary peat swamp forest; OPP: Oil palm plantations; WSL: Wet Shrubland

During the three periods analyzed here, 1990–2000, 2000–2010 and 2010–2013, the greatest loss of AGB was estimated in areas converted from SPSF to WSL *i.e*. 19.30 M tons, 58.66 M tons and 7.59 M tons; this was followed by areas with a conversion from SPSF to OPP *i.e*. 19.21 M tons, 11.66 M tons and 16.62 M tons, respectively. During the same time periods, the estimated loss of AGB from conversion of PPSF to OPP was 3.32 M tons, 0.16 M tons and 0.89 M tons, which is higher than the loss of AGB from conversions of PPSF to WSL, which were 2.17 M tons, 1.13 M tons and 0.13 M tons, respectively.

The average time for carbon storage in an OPP is 25 years during the rotation period; applying the differences in the AGB carbon stocks, the C lost during each land use transition was estimated by multiplying the difference factor with the areal increase in each time period. We followed the time-averaged biomass stocks (Table 6) and applied C fraction (CF = 0.50) [ton C (ton dm) $^{-1}$] from IPCC 2006 for the selected land uses. Our results thus show similar trends to that of biomass losses, *i.e*. the greatest C loss in AGB was estimated to occur in areas converted from SPSF to WSL, *i.e.* 42.8 M tons; this is followed by conversion from SPSF to OPP, *i.e.* 23.8 M tons. While C loss in AGB from the conversion of PPSF to OPP was estimated to be only 2.19 M tons, this is higher than C loss in AGB from the conversion of PPSF to WSL *i.e.* 1.72 M tons.

CONCLUSION AND RECOMMENDATIONS

Land use changes have been extensively studied in humid tropical areas, particularly in Indonesia, to explore the causes of forest degradation in one way or another. This study principally aimed to investigate the source of land acquisition for large-scale OPP and targeted the loss of AGB as one consequence. Although it became obvious that OPPs have developed extensively over time, simultaneously the research revealed that OPPs replaced PSF to the extent that PSF land use became secondary in terms of the amount of land occupied by OPP. Similarly, a significant portion of PSF was converted to WSL; this led to the greatest loss of AGB when compared with all other types of land use change. In conclusion, OPP is occupying peatlands that were previously occupied by secondary forests and a substantial portion of SPSF has been converted to WSL, leading to the greatest loss of AGB. This study does not cover the social and economic aspects of the trajectory of land use change; therefore, we recommend further studies should analyze shorter time periods and use advance remote-sensing technologies other than visual interpretation to identify the economic and social factors that drive the land use change. Furthermore, special consideration should be given to exploring the causes of major and spontaneous land use changes, *e.g*. conversion of SPSF to WSL, using field surveys and the knowledge of local indigenous peoples.

ACKNOWLEDGEMENTS

The authors acknowledge the extensive help received from the scholars and team members from Bogor Agricultural University and Indonesian Peat Society (HGI). We extend our special gratitude to Prof. Dr. Shinya Funakawa from the Graduate School of Global Environmental Studies, Kyoto University, Japan for his valuable inputs. The authors are also grateful to the Indonesian Agency for Agricultural Research and Development of the Ministry of Agriculture, the Ministry of Forestry and Dr. Muhammad Ardiansyah for helping us obtain secondary data and technical support. We acknowledge the research team of the Indonesian Palm Oil Association (GAPKI) who financed this study in collaboration with HGI.

REFERENCES

Agus, F., I.E. Henson, B.H. Sahardjo, N. Harris, van Noordwijk, M. and J.K. Timothy. 2013. Review of emission factors for assessment of CO_2 emission from land use change to oil palm in southeast asia. Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia. 22 pp.

Agus, F., E. Runtunuwu, T. June, E. Susanti, H. Komara, H. Syahbuddin, I. Las and van M. Noordwijk. 2009. Carbon dioxide emission in land use transitions to plantation. Jurnal Litbang Pertanian, *28*(4):119-126.

Astiani, D. 2014. Bornean Peatlands: Forest Dynamics, Land Use and Carbon Flux. Ph.D. Thesis, Yale University, USA. 219pp.

Broich, M., M. Hansen, F. Stolle, P. Potapov, P.A. Margono and B. Adusei1. 2011. Remotely sensed forest cover loss shows high spatial and temporal variation across Sumatera and Kalimantan, Indonesia 2000–2008. Environmental Research Letters. 6(1): 014010, 9 pp.

Budiharta, S., F. Slik, N. Raes, E. Meijaard, P.D. Erskine and K.A. Wilson. 2014. Estimating the Aboveground Biomass of Bornean Forest. Biotropica, 46(5), 507-511.

Campbell, L.A. 2013. Disturbance effects on carbon content and tree species traits in tropical peat swamp forest in Central Kalimantan, Indonesian Borneo. BS (Hons) Thesis, Dalhousie University, Canada. 108pp.

Carlson, K.M, L.M. Curran, G.P. Asner, A.M. Pittman, S.N. Trigg and J.M. Adeney. 2012. Carbon emissions from forest conversion by Kalimantan oil palm plantations. Nature Climate Change. 3(3): 283-287.

Carlson, K.M. 2012. Effects of oil palm plantation development on land cover, carbon flux, and streams in Indonesian Borneo. Ph.D. Thesis, Yale University, USA. 186pp.

Engalhart, S. 2013. Monitoring restoration and aboveground biomass in tropical peat swamp forests on Borneo using multi-sensoral remote sensing data, Ph.D. Thesis, Ludwig Maximilian University of Munich, Germany. 153pp.

Germer, J. and J. Sauerborn. 2008. Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. Environment, Development and Sustainability, 10(6), 697-716.

Giesen, W. 2004. Causes of peat swamp forest degradation in Berbak National Park and recommendations for restoration. Water for Food & Ecosystems Programme, International Agricultural Centre (IAC). Wageningen. 125pp.

Heil, A., B. Langmann and E. Aldrian. 2006. Indonesian peat and vegetation fire emissions: Study on factors influencing large-scale smoke haze pollution using a regional atmospheric chemistry model. Mitigation and adaptation strategies for global change. 12(1): 113-133.

Hirano, T., H. Segah, T. Harada, S. Limin, T. June, R. Hirata and M. Osaki 2007. Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia. Global Change Biology. 13(2): 412-425.

Hooijer, A, S. Page, J.G. Canadell, M. Silvius, J. Kwadijk, H. Wösten and J. Jauhiainen. 2010. Current and future CO_2 emissions from drained peatlands in Southeast Asia. Biogeosciences. 7(5): 1505-1514.

ICALRRD (Indonesian Centre for Agricultural Land Resources Research and Development) 2011. Peta Lahan Gambut Indonesia Skala 1:250.000 *(Indonesian peatland map at the scale*

1:250,000). Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture, Republic of Indonesia. 30pp.

IPCC (Intergovernmental Panel on Climate Change) 2006. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds). Published: IGES, Japan.

Istomo. 2002. Kandungan Fosfor dan Kalsium Serta Penyebarannya pada Tanah dan Tumbuhan Hutan Rawa Gambut (Studi Kasus di Wilayah Bagian Kesatuan Pemangkuan Hutan Bagan, Kabupaten Rokan Hilir, Riau). Ph.D. Thesis, Bogor Agricultural University, Indonesia. 178pp.

Jubanski, J., U. Ballhorn, K. Kronseder, J. Franke and F. Siegert. 2013. Detection of large above-ground biomass variability in lowland forest ecosystems by airborne LiDAR. Biogeosciences. 10(6): 3917-3930.

Khasanah, N, M. van Noordwijk, A. Ekadinata, S. Dewi, S. Rahayu, H. Ningsih, A. Setiawan, E. Dwiyanti and R. Octaviani. 2012. The carbon footprint of Indonesian palm oil production. Technical Brief No 25: palm oil series. Bogor, Indonesia. World Agroforestry Centre - ICRAF, SEA Regional Office. 10pp.

Kronseder, K., U. Ballhorn, V. Böhm, and F. Siegert. 2012. Above ground biomass estimation across forest types at different degradation levels in Central Kalimantan using LiDAR data. International Journal of Applied Earth Observation and Geoinformation. 18(1): 37-48.

Ludang, Y. and H.J. Palangka. 2007. Biomass and carbon content in tropical forest of Central Kalimantan. Journal of Applied Sciences in Environmental Sanitation, *2*(1), 7-12.

Miettinen, J., A. Hooijer, D. Tollenaar, S. Page, C. Malins, R. Vernimmen and S.C. Liew. 2012. Historical analysis and projection of oil palm plantation expansion on peatland in Southeast Asia. International Council on Clean Transportation. 22pp.

Morel, A.C., S.S. Saatchi, Y. Malhi, N.J. Berry, L. Banin, D. Burslem, R. Nilus and R.C. Ong. 2011. Estimating aboveground biomass in forest and oil palm plantation in Sabah, Malaysian Borneo using ALOS PALSAR data. Forest Ecology and Management. 262(9): 1786-1798.

Page, S.E., A. Hoscilo, H. Wösten, J. Jauhiainen, M. Silvius, J. Rieley, H. Ritzema, K. Tansey, L. Graham, H. Vasander and L. Suwido. 2009. Restoration ecology of lowland tropical peatlands in Southeast Asia: current knowledge and future research directions. Ecosystems. 12(6): 888-905.

Page, S.E., J.O. Rieley and C.J. Banks. 2011. Global and regional importance of the tropical peatland carbon pool. Global Change Biology. 17(2): 798-818.

Pagiola, S. 2000. Land use change in Indonesia. Washington, DC: World Bank Environment Department. 29pp.

Potter, L. and S. Badcock. 2001. The Effects of Indonesia's Decentralization on Forest and Estate Crops in Riau Province: Case Studies of the Original Districts of Kampar and Indragiri Hulu (No. 6-7). CIFOR. 73pp.

Siegert, F., G. Ruecker, A. Hinrichs and A.A. Hofmann. 2001. Increased damage from fires in logged forests during droughts caused by El Nino. Nature. 414(6862): 437-440.

Soetarto, E., M.F. Sitorus and M.Y. Napiri. 2001. Decentralization of administration, policy making and forest management in Ketapang District, West Kalimantan (8). CIFOR. 55pp.

Solichin, L.M. and K.H. Steinmann. 2011. Tier 3 biomass assessment for baseline emission in Merang Peat Swamp Forest. In Workshop on Tropical Wetland Ecosystems of Indonesia: Science Needs To Address Climate Change Adaptation and Mitigation. Watilan Convention Center, Sanur Beach Hotel, Bali, Indonesia. 5pp.

van der Meer, P.J. and C.C. Verwer 2011. Towards a reference carbon value for peat swamp forest in Southeast Asia based on historical inventory data. In Workshop on Tropical Wetland Ecosystems of Indonesia: Science Needs To Address Climate Change Adaptation and Mitigation. Watilan Convention Center, Sanur Beach Hotel, Bali, Indonesia. 4pp.

Verwer, C.C., P.J. van der Meer and E.J.M.M. Arets. 2009. Effects of oil palm cultivation on carbon stocks and biodiversity. Poster, ALTERRA Wageningen UR.

Wicke, B., V. Dornburg, M. Junginger and A. Faaij. 2008. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass and Bioenergy. 32(12): 1322-1337.

Wijaya, A., A. Susanti, V. Liesenberg, W. Wardhana, E. Yanto, D. Soeprijadi, C. McFarlane and N. Qomar. 2011. In Proceedings of the 5th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry Hosted by ESRIN in Frascati, Italy 24-28 January 2011. 7pp.

J. ISSAAS Vol. 21, No. 1: 137-146 (2015)

FACTORS AFFECTING INCREASED EXPORT OF INDONESIAN PALM OIL AND ITS DERIVATIVE PRODUCTS TO THE UNITED STATES OF AMERICA MARKET

Nila Rifai[1], Yusman Syaukat[2], Hermanto Siregar[3], E.Gumbira-Sa-id[4]

[1]Graduate Student, Program of Agriculture Economics
[2]Department of Resource and Environmental Economics, Faculty of Economics and Management, Bogor Agricultural University (FEM-IPB), Bogor, Indonesia 16680
[3]Department of Economics, FEM-IPB), Bogor, Indonesia 16680
[4]Department of Agricultural Industry Technology, Faculty of Agricultural Technology IPB, Bogor, Indonesia 16680
*Corresponding author : nila_rifai@yahoo.com

(Received: June 8, 2014; Accepted: May 15, 2015)

ABSTRACT

The world palm oil production reached 55.7 million tons in 2013. Indonesia and Malaysia shared 86% of it with their production of 26.7 and 21.7 million tons, respectively. However, the volume of Indonesian palm oil export to USA was lower than that of Malaysia. Malaysian palm oil export had 96 percent market share, while Indonesia only had 3 percent market share in the USA. The aim of this study was to analyze the factors affecting the increased export of palm oil and its derivative products to the USA market. Annual time series data from 1992 to 2012 were used. Data were analyzed by using an econometric approach of Two Stages Least Squares (2SLS). Results showed that factors affecting the volume of export of palm oil and its derivative products to the USA market are USA CPO import, labour demand, USA economic growth, and Malaysian CPO production. Factors affecting an export price of Indonesian palm oil and its derivative products to the USA market are Indonesia economic growth, USA economic growth, Indonesian export taxes, Indonesian production value of agriculture sector, Malaysian CPO production, and Malaysian CPO export.

Key words: oil palm downstream industries, export, export duty tariff, simultaneous equation model

INTRODUCTION

The world palm oil production reached 55.7 million tons in 2013 with the contributions of Indonesia and Malaysia of 26.7 and 21.7 million tons, respectively. This has made the two countries share about 86% of the world palm oil production. It was noted that in 2013, the export volume of Indonesia's palm oil and its derivative products was 21.2 million tons equivalent to USD19.1 billion (47% international palm oil trade), while that of Malaysia was 19.8 million tons (44% international palm oil trade).

Based on data of Malaysia Palm Oil Council (MPOC), in 2010, 2011, and 2012, Asia Pacific and Africa were the biggest export destination for Indonesian and Malaysian palm oil and its derivative products. In 2012, Indonesia exported 3.67 million and 1.37 million tons of palm oil and its derivative products to Asia Pacific and Africa, respectively, while Malaysia did it by 6.38 million and 1.53 million tons. For the USA market, the export of these products from Indonesia (341,000 tons) was much lower than that from Malaysia (1.1 million tons).

In order to improve the competitiveness of added values of Indonesian oil palm products in the international market, the government has promulgated Regulation of Minister of Finance Number 128/PMK.011/2011 on the A mendment to the Regulation of Minister of Finance Number 67/PMK.011/2010 on the Stipulation of Export Goods Subjected to Export Duties and Export Duty Tariff. Based on this regulation, for CPO reference prices of up to USD750 per ton, the export duty tariff is 0% which is subject to change for every USD50 per ton increase of reference price. For CPO reference prices of USD1000-1050 per ton, the export duty tariffs of CPO and its derivative products are 15% for CPO, 7% for Refined Bleached Deodorized (RBD) Palm Olein, 5% for RBD Palm Oil, 5% for RBD Palm Stearin, and 2% for Biofuel. This progressive export duties policy was made to reduce the export volume of CPO. Promulgating this regulation, the government expected that in 2012 there would be an increase in the export volume of CPO derivative products and a development of oil palm downstream industries in Indonesia.

The export opportunity of palm oil and its derivative products is still widely open as demand for plant-based oil in the USA market is quite large. This demand is for oleochemicals and their derivative products including fatty acids, methyl esters, glycerols, fatty alcohols, and various surfactant products (SBRC, 2009). Having the third biggest population in the world, the USA is an enormous market.

Indonesia, with a production target of 40 million tons of palm oil in 2020, has to develop its downstream palm industries by enhancing its export and seeking for new markets for its palm oil and its derivative products. This is required to avoid an excess supply of palm oil. The USA is one of the prospective markets. The development of oil palm downstream industry plays an important role in the national economy, especially as foreign exchange generator contributes about 4.5% to the national GDP and work provider for about 3.3 million households, equivalent to 13.2 million people. The increasing demand for food, feed, and fuel in the future needs increasing availability of raw materials and feedstock and oil palm has a big potential for this purpose.

Several studies on the export performance of Indonesian palm oil have been conducted (Suryana, 1986; Manurung, 1993; Purwanto, 2002; Drajat et al., 2013). Suryana (1986) concluded that Indonesian palm oil was complementary to soybean and coconut oils in the USA. Manurung (1993) showed that a policy on export tax might decrease domestic palm oil production and export price which in turn lowered the amount of Indonesian palm oil export. The export behavior of Indonesian palm oil was strongly affected by production development and export tax while that of Malaysia palm oil was strongly affected by its production and stock (Purwanto, 2002). Results of a recent study by Drajat et al. (2013) showed that the implementation of duty tariff (DT) had created pros and contras among the oil palm upstream industrialists. DT was believed to bring benefits to downstream industries but losses to upstream industries producing fresh fruit bunches (FFB) and crude palm oil (CPO). The latter was found to weaken Indonesian CPO competitiveness and decrease the profit margin obtained by producers.

The study was aimed at analyzing factors affecting the increased export of palm oil and its derivative products to the USA market. This study was expected to bring benefits that could be used as considerations in the strategy planning of the export development of Indonesian palm oil and its derivative products to the USA.

METHODS

Type and Source of Data

Annual time series secondary data of 1992 to 2012 periods were used. Data were obtained from Ministry of Industry, Ministry of Agriculture, Ministry of Trade, Statistics Indonesia (BPS), Ministry of Finance, Bank of Indonesia, Indonesian Association of Palm Oil Producers (GAPKI, GIMNI, APROBI, MAKSI, IPB, PPKS), United States Department of Agriculture (USDA), United States Department of Commerce (USDC), United States Department of Treasury (USDT), and other various related institutions and associations.

Model Specification

The model specification formulated in this study was strongly related to the aims of the study to formulate an econometrical model consisting of Indonesian oil palm upstream and downstream industries, domestic consumption, international trade in relation to the opportunity of improving the export of Indonesian palm oil and its derivative products to the USA. The equation for palm oil block referred to the one resulted from the work of Hartoyo et al. (2009) and Susila and Munadi (2008) with necessary adaptation. The equation for oil palm plantation block referred to the one resulted from the work of Hartoyo et al. (2009) with some necessary adaptations.

The developed model was simultaneous equation model which was formulated consist of 11 structural equations as follows:

$$QCPO_t = a_0 + a_1DCPOR_t + a_2PTBSR_t + a_3CCPO_t + a_4QCPO_{t-1} + a_5HCPOMt + a_6DCCPOMt + U_{1t} \quad (1)$$

$$CCPO_t = b_0 + b_1PXPO_t + b_2PMGR_t + b_3QST_t + b_4DCCPOM_t + b_5HSOASt + b_6PTBSRt + U_{2t}. \quad (2)$$

$$DCPOR_t = c_0 + c_1PXPO_t + c_2QCPO_t + c_3CCPO_t + c_4PTBSR_t + c_5CPOM_t + c_6DCPOR_{t-1} + c_7XCPOM + c_8HCPOM + U_{3t} \quad (3)$$

$$PXPO_t = d_0 + d_1WOIL_t + d_2XTAX_t + d_3XCPO_t + d_4DCCPOM_t + d_5HSOASt + d_6PXPO_{t-1} + U_{4t} \quad (4)$$

$$XCPO_t = e_0 + e_1PXPO_t + e_2ER_t + e_3XTAX_t + e_4CPOM_t + e_5DCPOR_t + e_6XCPOMt + e_7DCCPOMt + e_8HSOASt + U_{5t} \quad (5)$$

$$AREA_t = f_0 + f_1DCPOR_{t-1} + f_2QCPO_t + f_3SB_t + f_4ER_t + f_5CPOMt + f_6XCPOMt + f_7HCPOM + U_{6t} \quad (6)$$

$$QTBS_t = g_0 + g_1PTBSR_t + g_2AREA_t + g_3QTBS_{t-1} + g_4CPOMt + g_5XCPOMt + g_6HCPOMt + U_{7t} \quad (7)$$

$$PTBSR_t= h_0 + h_1DCPOR_t + h_2CCPO_{t-1} + h_3CPOMt + h_4XCPOMt + h_5EGRO_t + h_6HCPOMt + h_7PTBSR_{t-1} + U_{8t} \quad (8)$$

$$PXPTI_t = i_0 + i_1PXPOt + i_2EGRO_t + i_3EGROS_t + i_4XTAX_t + i_5GDPAt + i_6CPOMt + i_7XCPOMt + i_8HCPOMt + U_{9t} \quad (9)$$

$$XCPTI_t = j_0 + j_1PXPTI_t + j_2MCPOA_t + j_3DEMLt + j_4EGROSt + j_5CPOMt + U_{10t} \quad (10)$$

$$MCPOAt = k_0 + k_1CCAt + k_2EGROSt + k_3QCPOt + k_4CPOMt + k_5XCPOMt + k_6DCCPOMt + k_7DCSOASt + U11_t \quad (11)$$

Hypothesis :

$a_1, a_3, , a_5 , a_6 > 0$; $a_2 < 0$; $0 < a_4 < 1$
$b_2 , b_4, b_6 < 0$; $b_1 , b_3, b_5 > 0$
$c_1, c_2, c_4 , c_7 > 0$; $c_3 , c_5 , c_8 < 0$; $0 < c_6 < 1$
$d_1, d_2 , d_4 , d_5 > 0$; $d_3 < 0$; $0 < d_6 < 1$
$e_3 , e_4 < 0$; $e_1 ,e_2, e_5 , e_6 , e_7 , e_8 > 0$
$f_1 , f_2 , f_4 , f_6 , f_7 > 0$; $f_3 , f_5 < 0$;
$g_1 , g_2 , g_4 > 0$; $0 < g_3 < 1$; , $g_5 , g_6 < 0$
$h_1, h_2 , h_3, h_6 > 0$; $h_5 , h_4 , h_7 < 0$
$i_4, i_2, i_3 , i_5 , i_7 , i_8 > 0$; $i_1, i_6 < 0$
$j_1 , j_5 < 0$;, $j_2, j_3, j_4 , j_6 > 0$
$k_1, k_2 , k_3 , k_5 , k_6 > 0$; $k_4, k_7 < 0$

Model Formulation

In this study, the designed model consisted of 11 equations or 11 endogenous variables and 21 predetermined variables. The predetermined variables consisted of 17 exogenous variables and 4 lag endogenous variables. Based on the criteria of order condition, each structural equation in the model was over identified. Therefore, parameter estimate could be done by using a Two Stage Least Square (2SLS) method (Koutsoyiannis, 1977). Data were processed by using SAS/ETS software.

RESULTS AND DISCUSSION

Results of the estimate of parameters over the model showed significantly high coefficient of determination (R^2) values in each equation ranging from 0.885 to 0.989 (Table 1). This meant that the R^2 values in all equations were relatively high and showed that the explanatory variables in the model were able to explain the fluctuation of every endogenous variable well. In each equation, explanatory variables collectively gave significant effects on endogenous variables. This was suggested from the F values ranging from 18.01 to 187.83. In addition, most explanatory variables were found to individually affect endogenous variables significantly in the significant levels (α) of 0.15.

Indonesian domestic real price of CPO gave positive and significant effects ($p<0.15$) on Indonesian total CPO production (QCPO). This effect show that better domestic price of CPO will push CPO producer to increase their production. Indonesian domestic demand for CPO gave positive and significant effects on Indonesian total CPO production. This means an increasing demand for CPO by downstream industries will encourage increased production of palm oil in Indonesia. Malaysian CPO price gave negative and significant effects on Indonesian total CPO production. This is due to Malaysian export taxes and its shipping costs are lower than Indonesian. Malaysian domestic consumption for CPO was found to positively and significantly affect Indonesian total CPO production. This means an increasing demand for CPO by Malaysian downstream industries will increase production of Indonesian palm oil.

Indonesian CPO export price, cooking oil price, stearin production, Malaysian domestic consumption for CPO, soybean oil price of USA and real price of Indonesian palm fresh fruit bean (FFB) had significant effects ($p<0.15$) on Indonesian domestic demand for CPO (CCPO). Increased stearin production as an indicator of the development of palm oil downstream industries will increase Indonesian domestic demand for CPO.

Indonesian total CPO production, Indonesian domestic demand for CPO, real price of Indonesian palm fresh fruit bunches (FFB) palm oil, and Malaysian CPO export gave significant effects ($p<0.15$) on Indonesian domestic CPO real price (DCPOR). Increased Malaysian palm oil export will boost Indonesia’s CPO export and reduce Indonesia domestic palm oil stocks, hence it leads to increase domestic CPO price. To protect the palm oil downstream industries, the government provides incentives for more efficient production cost.

Table 1. Results of parameter estimate of Oil Palm Derivative Product Development Equation to Export Increment of oil palm products to the USA market

VARIABLE	**Parameter Estimate**	**Pr > $\lvert t \rvert$**	**F-value**		**R^2**	**Dw**
QCPO	**Indonesia CPO Production**			150.59	0.98474	2.0607
	Intercept	-1036241	0.3512			
	Indonesian Domestic CPO Real Price (DCPOR)	1079.559	**0.0684**			
	Indonesian FFB Real Price (PTBSR)	-1696.81	0.3231			
	Indonesian Domestic Demand for CPO (CCPO)	0.896419	**0.0061**			
	CPO Lag Production (LQCPO)	0.331267	0.2397			
	Malaysian CPO Price (HCPOM)	-4323.27	**0.0897**			
	Malaysian Domestic Consumption for CPO (DCCPOM)	2499.771	**0.025**			
CCPO	**Indonesian Domestic Demand for CPO**			18.01	0.88528	2.4152
	Intercept	1823009	0.0289			
	Indonesian CPO Export Price (PXPO)	5295.635	**0.0284**			
	Palm Cooking Oil Real Price (PMGRR)	-577.651	**0.0043**			
	Indonesian Stearin Production (QST)	12742.6	**<.0001**			
	Malaysian Domestic Consumption for CPO (DCCPOM)	-1970.86	**0.0115**			
	Soybean Oil Price of USA (HSOAS)	-3416.15	**0.1382**			
	Indonesian FFB Real Price (PTBSR)	1392.406	**0.1355**			
DCPOR	**Indonesian Domestic CPO Real Price**			59.15	0.97527	1.9780
	Intercept	-1651.15	0.0584			
	Indonesian CPO Export Price (PXPO)	3.238998	0.5355			
	Indonesian CPO Production (QCPO)	0.000141	**0.1315**			
	Indonesian Domestic Demand for CPO (CCPO)	0.00037	**0.0097**			
	Indonesian FFB Real Price (PTBSR)	1.959096	**0.0038**			
	Malaysian CPO Production (CPOM)	-0.33658	0.2108			
	Lag Indonesian Domestic CPO Real Price (LDCPOR)	0.114333	0.3752			
	Malaysian CPO Export (XCPOM)	0.531697	**0.1101**			
	Malaysian CPO Price (HCPOM)	-1.01191	0.8564			

VARIABLE	Parameter Estimate	Pr > |t|	F-value	R^2	Dw
PXPO	**Indonesian CPO Export Price**		44.63	0.95031	2.2515
	Intercept	-298.35	0.0011		
	Fuel Price (WOIL)	-1.13964	0.4189		
	Indonesian CPO Export Tax (XTAX)	1.009541	**0.1462**		
	Indonesian CPO Export (XCPO)	-0.00004	**0.002**		
	Malaysian Domestic Consumption for CPO (DCCPOM)	0.215444	**0.0011**		
	Soybean Oil Price of USA (HSOAS)	0.849225	**<.0001**		
	Lag Indonesian CPO Export Price (LPXPO)	0.282754	**0.0073**		
XCPO	**Indonesian CPO Export**		133.11	0.98886	1.9339
	Intercept	-1022948	0.5184		
	Indonesian CPO Export Price (PXPO)	286.0311	0.9304		
	Rupiah to US Dollar Exchange Rate (ER)	-422.989	**0.0187**		
	Indonesian CPO Export Tax (XTAX)	13728.04	0.2796		
	Malaysian CPO Production (CPOM)	-2208.417	**0.0148**		
	Indonesian Domestic CPO Real Price (DCPOR)	1288.417	**0.0016**		
	Malaysian CPO Export (XCPOM)	2735.13	**0.004**		
	Malaysian Domestic Consumption for CPO (DCCPOM)	5096.046	**0.0012**		
	Soybean Oil Price of USA (HSOAS)	-9091.11	**0.0808**		
AREA	**Indonesian Oil Palm Plantation Area Size**		187.83	0.99021	2.1351
	Intercept	-1481138	0.0143		
	Lag Indonesian Domestic CPO Real Price (LDCPOR)	-52.5281	0.5397		
	Indonesian Palm Oil Production (QCPO)	0.174489	**0.0057**		
	Interest Rate (SB)	20548.19	**0.069**		
	Rupiah to US Dollar Exchange Rate (ER)	17.07511	0.6979		
	Malaysian CPO Production (CPOM)	-277.438	**0.1355**		
	Malaysian CPO Export (XCPOM)	722.9703	**0.0048**		
	Malaysian CPO Price (HCPOM)	-903.742	**0.0984**		
QTBS	**Indonesian Palm Fresh Fruit Bunch Production**		132.06	0.9826	2.0467
	Intercept	24501335	0.0372		
	Indonesian FFB Real Price (PTBSR)	7040.067	0.2306		
	Indonesian Oil Palm Plantation Area Size (AREA)	10.05172	**0.0038**		
	Lag QTBS (LQTBS)	0.97282	**0.0014**		
	Malaysian CPO Production (CPOM)	3151.683	0.2368		
	Malaysian CPO Export (XCPOM)	-9150.66	**0.0311**		
	Malaysian CPO Price (HCPOM)	-19106.7	0.171		

VARIABLE		Parameter Estimate	Pr > |t|	F-value	R^2	Dw
PTBSR	**Indonesian Palm Fresh Fruit Bunch Real Price**			70.57	0.9743	2.1949
	Intercept	448.7103	0.0008			
	Indonesian Domestic CPO Real Price (DCPOR)	0.164093	**<.0001**			
	Lag Indonesian Domestic Demand for CPO (LCCPO)	-0.00005	**0.0156**			
	Malaysian CPO Production (CPOM)	0.076937	**0.0931**			
	Malaysian CPO Export (XCPOM)	-0.11628	**0.0493**			
	Indonesia Economic Growth (EGRO)	-25.1178	**<.0001**			
	Malaysian CPO Price (HCPOM)	0.612403	**0.0061**			
	Lag Indonesian Palm Fresh Fruit Bunch Real Price (LPTBSR)	-0.14189	**0.0497**			
XCPTI	**Export of Indonesian CPO and its derivative Products to the USA**			38.96	0.9435	2.6237
	Intercept	886860.8	0.0009			
	Export Price of Indonesian CPO and its derivative Products to the USA (PXPTI)	-19.9009	0.2815			
	USA Palm Oil Import (MCPOA)	0.060145	**0.0013**			
	Labour Demand (DEML)	6.766185	**0.0001**			
	USA Economic Growth (EGROS)	1880.245	**0.1304**			
	Malaysian CPO Production (CPOM)	12.46634	**0.0069**			
PXPTI	**Export Price of Indonesian CPO and its derivative Products to the USA**			22.70	0.9380	1.9359
	Intercept	-70.1933	0.514			
	Indonesian CPO Export Price (PXPO)	-0.00005	0.9999			
	Indonesia Economic Growth (EGRO)	17.81659	**0.0004**			
	USA Economic Growth (EGROS)	37.46906	**0.0068**			
	Indonesian CPO Export Tax (XTAX)	2.549921	**0.0172**			
	Indonesian Production Value of Agriculture Sector (GDPA)	0.000653	**0.0897**			
	Malaysian CPO Production (CPOM)	-0.07941	**0.0381**			
	Malaysian CPO Export (XCPOM)	0.071514	**0.1098**			
	Malaysian CPO Price (HCPOM)	0.840904	0.261			
MCPOA	**USA Palm Oil Import**			118.59	0.98458	2.545
	Intercept	863905.2	<.0001			
	USA Per Capita Consumption of vegetable Oil (CCA)	-22111.3	**0.0028**			
	USA Economic Growth (EGROS)	-24114.7	**0.0068**			
	Indonesian CPO Production (QCPO)	0.015446	0.2524			
	Malaysian CPO Production (CPOM)	-77.2755	0.172			
	Malaysian CPO Export (XCPOM)	97.49563	**0.1082**			
	Malaysian Domestic Consumption for CPO (DCCPOM)	394.93	**0.0018**			
	USA Domestic Consumption for Soybean Oil	-84.3999	**0.0181**			

Indonesian export taxes of CPO, Indonesian CPO export, Malaysian domestic consumption for CPO, soybean oil price of USA, and lag Indonesian CPO export price gave significant effects ($p<0.15$) on Indonesian CPO export price (PXPO). Indonesia export taxes of CPO have positive parameter that shows increasing export taxes of CPO will increase Indonesia CPO export price. The imposition of export taxes aims to secure the needs of palm oil for the domestic industries based palm oil (Purba, 2012). Fuel oil/petroleum price gave negative and unsignificant effects ($p>0.15$) on Indonesian CPO export price. This shows that the use petroleum as fuel is a main priority and use bio-fuel is still limited.

Exchange rate, Malaysian CPO production, Indonesian domestic CPO real price, Malaysian CPO export, Malaysian domestic consumption for CPO, and soybean oil price of USA gave significant effects ($p<0.15$) on Indonesian CPO export (XCPO). Indonesian CPO exports are very responsive to Malaysian CPO production, Malaysian domestic consumption for CPO and Malaysian CPO export. This shows that Malaysia is Indonesia's main competitor in the world trade of palm oil.

Indonesian CPO production, interest rates, Malaysian CPO production, Malaysian CPO export, and Malaysian CPO price significantly affects ($p<0.15$) the size of oil palm plantation area in Indonesia (AREA). Increased Indonesian palm oil production will increase the demand for palm fresh fruit bunches (FFB) that will affect farmers and private companies to expand their palm plantation area. Exchange rates gave positive and unsignificant effects ($p>0.15$) on on the size of oil palm plantation area in Indonesia. If the Rupiah depreciated against the US Dollar, Indonesian CPO price becomes cheaper for importing countries that will increase the palm oil demand that will affect farmers or private companies to expand oil palm plantation area.

The size of oil palm plantation area in Indonesia, lag Indonesian palm FFB production, and Malaysian CPO export gave significant effects ($p<0.15$) on Indonesian palm FFB production (QTBS). For other variables gave unsignificant effects ($p>0.15$).

Indonesian domestic CPO price, lag Indonesian domestic demand for CPO, Malaysian CPO production, Malaysian CPO export, Malaysian CPO price, lag Indonesian palm FFB price, and Indonesia economic growth gave significant effects ($p<0.15$) on Indonesian palm FFB price (PTBSR). This means that increased Indonesian domestic CPO price will affect farmers to increase the selling price of their palm FFB. Indonesia economic growth less responded by Indonesian palm FFB. This means that increasing Indonesian economic growth will increase the ability of farmers and private companies to expand oil palm plantations that palm FFB production will increase. Increasing the supply of palm FFB will decrease palm FFB price.

USA CPO import, labour demand, USA economic growth, and Malaysian CPO production gave significant effects ($p<0.15$) on export of Indonesian CPO and its derivative products to USA (XCPTI). Labour demand effect on export of Indonesian CPO and its derivative products to USA, this means an increasing labour demand in palm oil industries indicate the development of palm oil downstream industries to improve its export performance. Increased USA economic growth will increase consumption of USA citizen for vegetable oils including palm oil products so that it will increase their palm oil import. This means it will increase Indonesian opportunity to export palm oil products to USA.

Indonesia economic growth, USA economic growth, Indonesian export taxes, Indonesian production value of agriculture sector, Malaysian CPO production, and Malaysian CPO export gave significant effects ($p<0.15$) on export price of Indonesian CPO and its derivative products to USA (PXPTI). Malaysian CPO production and its export gave effects on decreased export price of Indonesian CPO and its derivative products to USA. This means that Indonesian palm oil industries will increase production efficiency in order to compete with Malaysia.

USA per capita consumption of vegetable oil, USA economic growth, Malaysian CPO export, Malaysian domestic consumption for CPO, and USA domestic consumption for Soybean oil gave significant effects ($p<0.15$) on the USA import of palm oil (MCPOA). USA per capita consumption of vegetable oil gave negative effect on USA import of palm oil. This happens because the palm oil imported by USA is consumed by the oleochemical industries that many their output products are exported beyond the USA. USA economic growth gave negative effects on USA import of palm oil. This happens because USA government subsidizes their soybean oil farmers to reduce their palm oil import. Malaysian CPO export gave positive effects on USA import of palm oil. This happens due to increase their palm oil export, Malaysia routinely doing promotion to USA market to increase palm oil import by USA. USA domestic consumption for Soybean oil gave negative effects on USA import of palm oil. This happens because the soybean oil is a commodity substitution of palm oil.

CONCLUSIONS AND POLICY IMPLICATIONS

Indonesia's oil palm area and production consistently increases over time, while its domestic demand does not increase significantly. Thus, Indonesia needs to develop its export markets for palm oil and its derivative products. USA market is one of the potential destinations for such development. Indonesia has large opportunities to export palm oil products to USA market to meet its demands for food, oleochemicals and bioenergy. Indonesia export of palm oil products to USA is affected by USA CPO import, labour demand, USA economic growth, and Malaysian CPO production, while the prices of Indonesia palm oil products to USA are determined by Indonesia economic growth, USA economic growth, Indonesian export taxes, agricultural product value of Indonesia, Malaysian CPO production, and Malaysian CPO export.

Indonesia's policy to develop palm oil derivatives products, which is combined with its trade policy, is expected to boost their exports to USA and other countries. When it happens, it will increase domestic demand for CPO to be processed into its derivative products which have a high added value. The development of palm oil derivative products has to be done in Indonesia to increase added value of oil palm products domestically. To achieve that objective, first, Indonesian government should allocate revenues from palm oil export taxes to increase palm oil productivity and develop palm oil derivative products industries more efficiently by increasing research and development programs to compete with Malaysia. Second, the government should formulate an palm oil derivative product development policy to allow the absorption of over production of CPO by domestic processing industries which would further allow palm oil downstream industry to develop in Indonesia. Third, in order to make these products meet the market demand, the government should promote Indonesian palm oil derivative products overseas, especially in the USA as one of the biggest economic power in the world.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to Surfactant and Bioenergy Research Center (SBRC), Bogor Agricultural University for giving us funding to finalize this research.

REFERENCES

Drajat, et al. 2013. Menuju Kebijakan Bea Keluar CPO Yang Lebih Proposional. Pp. 343-365 dalam Prosiding Seminar Tahunan Maksi 2013, Bogor.

Hartoyo, S., E. I. Kumala Putri dan Hastuti. 2009. Dampak Perubahan Permintaan *Crude Palm Oil* Sebagai Bahan Bakar Alternatif (Nabati) Terhadap Ketersediaan Pangan dan Kebijakan yang

Terkait. Laporan Akhir Hibah Kompetitif Penelitian Sesuai Prioritas Nasional Batch II. Lembaga Penelitian dan Pengabdian kepada Masyarakat, Institut Pertanian Bogor, Bogor.

Koutsoyiannis, A. 1977. Theory of Econometrics : An Introductory Exposition of Econometric Methods. McMillan Press Ltd, London. 688 p.

Manurung, J. 1993. Model Ekonometrika Industri Komoditi Kelapa Sawit Indonesia Suatu Analisis Simulasi Kebijakan. Tesis. Institut Pertanian Bogor. 183 p.

MPOC. 2011. Malaysian Palm Oil Council Annual Report 2011. 130 p.

Purba, Jan H.V. 2012. Dampak Pajak Ekspor Crude Palm Oil Terhadap Industri Minyak Goreng Indonesia. Disertasi. Institut Pertanian Bogor. 201 p.

Purwanto, S.K. 2002. Dampak Kebijakan Domestik dan Faktor Eksternal Terhadap Perdagangan Dunia Minyak Nabati. Tesis. Institut Pertanian Bogor. 245 p.

Surfactant and Bioenergy Research Center [SBRC]. 2009. Rangkuman Bahan Simposium Nasional Bioenergi, Institut Pertanian Bogor, 23 November 2009. Pusat Penelitian Surfaktan dan Bioenergi. Institut Pertanian Bogor. Bogor. 320 p.

Suryana, A. 1986. Trade Prospects of Indonesian Palm Oil in The International Markets for Fats and Oils. Disertasi. Institut Pertanian Bogor. 139 p.

Susila, W. R. dan E. Munadi. 2008. Dampak Pengembangan Biodiesel Berbasis CPO Terhadap Kemiskinan di Indonesia. Jurnal Informatika Pertanian, 17(2): 1173-1194.

The International Society for Southeast Asian Agricultural Sciences