# Rubber Agroforestry System (RAS) Practices in Southern Thailand towards Policy Recommendations to Promote the Practices in Cambodia

**Bunnarith Chhiev**

**A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Agricultural Development**

**Prince of Songkla University**

**2020**

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## ABSTRACT

For rubber agroforestry system (RAS) practices in Southern Thailand and Eastern Cambodia, this study aims to investigate techniques of the RAS plot management, measure the RAS plant community structures and crown covers related to soil erosion, examine economic margin of the RAS plots, and evaluate situation of RAS practices and formulate policy for recommendation in Cambodia. The study results, in Eastern Cambodia, 3 RAS plots are planted with rubber trees at 6 × 3 m planting distance. 2 of the 3 plots are rubber-based annual intercrop plots, and the intercrops were planted at 0.5 × 0.5 m planting distance in lower 5 years old rubber plantation in 2018. The rest is rubber-based chicken raising plot, chickens were raised 300 heads in 2018. Then, 11 RAS plots in Southern Thailand have been divided in five systems of RAS. Rubber planting distance was used by 6 × 3 m, 6.5 × 3.5 m, 7 × 3 m, 7 × 3.5 m, 8 × 3 m, and 10 × 2.5 m. 5 plots have been applied with chemical and organic fertilizer, 4 plots have been applied with only organic fertilizer, and 2 plots have not been applied any fertilizer. Furthermore, the economic margin from 2018 to 2024 of 12 RAS plots in this study (excluding the two rubber-based annual intercrop plots of Eastern Cambodia), show that rubber-based stingless bee raising with bamboo (shoot product) plot, rubber-based sala fruit with neem tree plot, rubber-based champadak fruit with phakleang vegetable plot have highest level of ability to overcome low rubber price. Whereas, rubber-based ironwood plot and rubber-based eaglewood plot are low level of ability to overcome low rubber price, but Ironwood and Eaglewood in the RAS plots will provide high income in the future. Therefore, RAS practices are an alternative to improve household livelihood of RAS farmers although rubber price is degreased. Moreover, the plant community structure and crown cover are composed of rubber trees with upper canopies as well as intercrops with lower canopies. The crown covers of rubber trees and intercrops in representative area of RAS plots are about 86% to 99.5% of the area. Therefore, the crown cover in plots have a great potential to prevent soil erosion and moisture in the RAS plots are kept due to multiple levels of vertical stratification and crown cover percentages of plant species. Finally, policy recommendation to promote the RAS practices in Cambodia as the track of strategies by SWOT reveal that the government should associate the RAS knowledge, rubber processing (rubber sheet) knowledge, and good agricultural practice technique into policy of agricultural extension for rubber farmers, encourage rubber farmers to cultivate RAS and participate with farmer group, and create experimental RAS plots at farmers' farm and laboratory field. Also, farmers should follow the policy of government to be successful in RAS practice and to improve household income.

*Keywords:* Rubber agroforestry system, Economic, Soil erosion, Southern Thailand

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# CHAPTER I

# INTRODUCTION

## 1.1 Background of Study

Rubber trees originated in Amazonia and have been introduced rapidly in many parts of mainland Southeast Asia where rubber trees were not traditionally grown. Now, more than 90% of rubber products in global market come from tropical Asia. Over the last several decades, more than one million hectare of land in China, Indonesia, Malaysia, Laos, Thailand, Vietnam, Cambodia, and Myanmar have already been planted rubber trees (Li & Fox, 2012). Natural rubber product is an important economic part of countries and has countless important roles in human daily life. Many products made from natural rubber plays crucial roles in development of societies (Somboonsuke & Wettayaprasit, 2009). Thailand is classified as the largest producer and exporter of rubber product in the world. Thailand produced 4.5 million tons of rubber products equal to 36% of total in the world in 2016 (Thailand Board of Investment, 2017). Rubber smallholders are sources of rubber products for 95%, so the key role of farmers' income came from rubber plantation (Jongrungrot *et al.*, 2014).

Rubber plantations produced a satisfactory income when natural rubber price was high. However, rubber price in global market was not stable. When rubber price decreased, low rubber price had affected livelihoods and living conditions of rubber farmers who depended on single income from single product of rubber plantations (Nambiar & Balasubramanian, 2016). In addition, part of conversion of natural forests to agricultural land and rural development has impacted climate, social, economic and environmental systems (Liu *et al.*, 2018; Jongrungrot, 2016). The forests have become to buildings, open area, and mono-cropping systems. These agricultural practices as mono-cropping systems have faced price instability and have been responsible for negative environmental impacts such as loss of biological diversity (Rukyutitham, 2004). The natural vegetation coverage which had helped to topsoil has been lost, so soil erosion increases during the rainy season. Rubber mono-cropping systems are applied frequently agrichemicals for agricultural practice which has resulted in soil acidification (Jongrungrot *et al.*, 2014).

Alternatives include planting integrated crops or associated economic plants and livestock with rubber plantations which can support the farmers in crisis periods because the incomes can be diversified by the integrated products of crops and/or livestock. This alternative also benefits farmers by giving them a cushion to volatile rubber prices in the specific period and in the future. (Simien & Penot, 2010). Furthermore, a research by Liu *et al.* (2016) indicated that amount of splash erosion was controlled by large sub-canopy with small sub-canopy of rubber trees and intercropping plants which was much more effective than the rubber mono-cropping system. Also, RAS can improve plant nutrient cycling, organic matter in the soil, and product efficiency. The main benefits of RAS practices are product efficiency, various products, environmental services, carbon sequestration, and microclimate improvement (Joshi *et al.,* 2003). Then the integrating various cash plants and/or livestock into rubber plantations take advantage of utilization of limited land, diversify vegetation within a limited area, increase income from single land, and avoid the risks of obtaining income only from rubber products. This practice is necessary at present and in the future, (Malaysian Rubber Board, 2009).

In Southern parts of Thailand, the average of annual rainfalls varies with ranging from 99 mm to 4,603 mm of precipitation and the average of temperature ranging from 24.4°C to 29.3°C (76°F to 85°F) where environmental conditions are favorable for rubber trees (Fair Rubber Association, 2016). Southern Thailand is the first place that rubber trees were introduced in 1900, and more than 90 percent of rubber farmers practice rubber mono-cropping system. In 1960s, a small amount of Thai rubber farmers in the South started to plant other crops with rubber trees on the same land management with maintaining rubber as the main crop while other crops were mainly grown for family consumption (Somboonsuke & Wettayaprasit, 2009). Nowadays, in Southern Thailand famers still practice different types of RAS such as rubber-based other crops, rubber-based fruit trees, rubber-based timber trees, and rubber-based livestock (Romyen *et al.,* 2018).

## 1.2 Problem Statements

Many Thai rubber farmers have practiced RAS on their open lands or areas of cultivation (Jongrungrot *et al.,* 2014). This is one strategy to reduce the risks of economic crisis and negative environmental impacts. Many strategies for integrating other cash crops and/or raising livestock are being applied on their RAS with different techniques (Jongrungrot, 2013). Furthermore, RAS in the South of Thailand has been traditionally practiced in different ways such as rubber-other crops, rubber-fruit crops, rubber-timber trees, and/or rubber-livestock (Somboonsuke *et al.,* 2011). The provinces in Eastern Cambodia currently consist of rubber plantation for 111,457 hectares. Most of these rubber farmers practice rubber monoculture system. However, there are some practices of RAS by planting annual crops between rows of under 4-year-old young rubber trees. During this last decade of low rubber price, rubber monoculture farmers' livelihood has been hardly hit, especially farmers who depend on single income from rubber product (Nambiar & Balasubramanian, 2016). Cambodian Rubber Research Institute (CRRI) has been mainly practicing rubber agroforestry systems (Table 1) on laboratory field as the experiment (MAFF, 2018). Therefore, the study of techniques of RAS plot management, and the economic and environmental aspects of RAS in Southern Thailand and Eastern Cambodia will be a great lesson for promotion of rubber agroforestry system practices in Cambodia.

**Table 1** The Types of Plants and Livestock Practice in Rubber Plantations in Cambodia

| No. | Laboratory field of CRRI | Smallholders' Rubber Plantations |
|---|---|---|
| 1 | - *Musa,* Banana | - *Glycine max,* Soybean |
| 2 | - *Mangifera indica,* Mango | - *P. vulgaris,* Green bean |
| 3 | - *Artcarpus heterophyllus,* Jackfruit | - *Legume,* Peanut |
| 4 | - *Ananas comosus,* Pineapple | - *Zea mays,* Corn |
| 5 | - *Anacardium occidentale,* Cashew | - *Manihot esculenta*, Cassava |
| 6 | - Cover crop types | - *Ananas comosus,* Pineapple |
| 7 | - Timber tree types | - Chicken |

**Source:** Ministry of Agriculture Forestry and Fisheries of Cambodia (2018)

## 1.3 Research Questions

Research questions for this study:

- What rubber agroforestry systems (RAS) are farmers practicing?
- What techniques have farmers applied in their RAS plots?
- How have economic and environment effects resulted in RAS plots?
- What is the situation of RAS practices?

## 1.4 Objectives of Study

The specific objectives of this study:

1) To investigate the different techniques of RAS plot management,
2) To examine the economic margin of rubber agroforestry system plots
3) To measure plant community structure and crown cover that result in soil erosion in rubber agroforestry system plots, and
4) To evaluate situation of rubber agroforestry system practices and formulate policy for recommendation in Cambodia.

## 1.5 Expected Benefits

The expected benefits of this study:

- Knowledge and understanding of RAS in Southern Thailand and Eastern Cambodia will be investigated to promote and support a policy formulation for promoting RAS practices to rubber farmers in Cambodia.
- Knowledge of RAS will be published and promulgated.

## 1.6 Definitions of Key Terms

The definitions of key terms of this study:

- Rubber Agroforestry System (RAS): The association of trees, crops, plants, and/or raising animals in rubber plantation.
- The economy of RAS: The profitable margin study of RAS plots.
- The plant community structure and crown cover of RAS plots of a given environment: The vertical stratification and canopy covers of all plants that result in soil erosion in RAS plots.

# CHAPTER II

# LITERATURE REVIEWS

## 2.1 The Situation of Natural Rubber Production in Thailand

### 2.1.1 The Dynamics of Rubber Smallholder Farm Development

Rubber plantations were introduced in southern part of Thailand in 1900s. At present, Thailand is the number one producer of natural rubber by the large natural rubber plantation areas (Table 2) (Thailand Board of Investment, 2016). Thai rubber smallholder sector has been viable economically, and farmers have developed production and technologies for nearly four decades. The evolution of Thai rubber smallholder farms can be divided into five stages. First, the period before 1960 can be called the Conventional Rubber Production System. The second stage, which started in the 1960s, has been named the Green Revolution of the Initial Modernized Rubber Production System. The third stage was during the 1970s known as the Modernized Rubber Production Systems. The fourth, from the 1980s, was the Alternative Rubber Production System. The fifth stage starting in the 1990s was the Industrial Rubber Systems. This was based on the Thai rubber development period (Somboonsuke, 2009).

**Table 2** Rubber Plantations Areas (rai) in Thailand (2008 to 2017)

| Years | Rubber Plantations | Rubber Tapping Areas |
|---|---|---|
| 2008 | 18,660,000 | 11,371,400 |
| 2009 | 19,600,000 | 11,508,100 |
| 2010 | 20,300,000 | 12,049,100 |
| 2011 | 21,510,000 | 12,765,600 |
| 2012 | 22,870,000 | 15,599,800 |
| 2013 | 23,350,000 | 16,487,300 |
| 2014 | 16,930,000 | 11,087,250 |
| 2015 | 17,600,000 | 12,145,007 |
| 2016 | 19,560,000 | 18,466,489 |
| 2017 | 22,866,000 | 19,056,223 |

**Source:** Rubber Authority of Thailand (2018)

**Note:** 1 rai = 1,600 square meters

### 2.1.2 Natural Rubber Market

Rubber plantation started in Thailand in 1900s with rubber seedlings in Kuntrang District, Trang Province. Throughout the last decade, global natural rubber production was 12.3 million tons, 92% of which was produced in Asia-Pacific. Thailand has been the largest rubber producer and exporter in the world. Thailand exported rubber products to Japan, China, U.S.A, Malaysia, South Korea, and Europe (Thailand Board of Investment, 2016). Rubber product has hugely increased reaching 4,902,634 tons with 20,111,359 rai of rubber tapping area in 2018. Southern Thailand region accounted for 12,216,920 rai which is 60% of tapping areas in country (Oxford Business Group, 2018). Thailand's rubber product contributed about one-third in the world. Rubber is the main raw material for tires, surgeons' gloves, condoms, balloons, and other relatively high-value products (Praktikantin, 2018). Thailand has a strong manufacturing sector for producing a great variety of value-added rubber products and contributing substantially to country's economy (Win, 2017). The tire industry in Thailand has consumed over 50% of rubber, and there are expectations that the demand will increase in the future. The main tire brands operating in country are Bridgestone, Michelin, and Goodyear. Other brands include Sumitomo, Yokohoma, and Continental (Research and Market, 2016). Table 3 shows rubber product, exports, imports, and domestic consumption (2010-2017).

**Table 3** Thai Natural Rubber Production from 2008 to 2017 (Unit/Metric Ton)

| Years | Products | Exports | Imports | Domestic Consumption | Stocks |
|---|---|---|---|---|---|
| 2008 | 3,089,751 | 2,675,283 | 4,048.49 | 397,595 | 251,721 |
| 2009 | 3,164,379 | 2,726,193 | 3,135.73 | 399,415 | 293,659 |
| 2010 | 3,252,135 | 2,866,447 | 6,504.44 | 458,637 | 227,252 |
| 2011 | 3,569,033 | 2,952,381 | 4,357.64 | 486,745 | 361,557 |
| 2012 | 3,778,010 | 3,121,332 | 3,239.84 | 505,052 | 516,675 |
| 2013 | 4,170,428 | 3,664,941 | 2,606.60 | 520,628 | 502,855 |
| 2014 | 4,323,975 | 3,770,649 | 4,108.43 | 541,003 | 516,756 |
| 2015 | 4,473,370 | 3,749,456 | 5,583.69 | 600,491 | 642,895 |
| 2016 | 4,342,935 | 3,599,698 | 3,682.57 | 627,884 | 568,813 |
| 2017 | 4,507,013 | 3,660,711 | 2,662.31 | 642,995 | 669,802 |

**Source:** Rubber Research Institute Department of Agriculture of Thailand (2018)

## 2.2 The Situation of Natural Rubber Production in Cambodia

Cambodia is a small country but is quite a player on the world's rubber market. In 2018, Cambodia exported 217,499 tons of rubber products, and it was the 19th largest rubber exporter in the world. Country's exports have increased year by year from 2009 to 2018. Cambodia's 2018 rubber exports grew by 15% that equaled to 28,667 tons in 2017 to 2018. The rise in exports was caused by increasing the rubber tapping areas. Cambodia is a rubber exporter instead of being a rubber consumer. The plantation increases every year with more products are produced, and all go to export (GDR, 2018).

In 2018, total rubber plantation areas were 436,682 hectares. 201,949 hectares was harvested, with a total production of 193,286 tons. Table 4 shows the statistics of rubber plantations and product between 2009 and 2018. Rubber production in the future will be substantially higher than present because of current rubber plantation and new tapping rubber plantations (MAFF, 2018).

**Table 4** Statistics of Rubber Plantations and Production from 2009 to 2018

| Years | Rubber Plantations (hectare) | Tapping Areas (hectare) | Productions (tons) |
|---|---|---|---|
| 2009 | 127,720 | 34,100 | 37,400 |
| 2010 | 181,433 | 38,406 | 42,250 |
| 2011 | 214,104 | 45,163 | 51,339 |
| 2012 | 280,355 | 55,361 | 64,525 |
| 2013 | 328,771 | 78,493 | 85,244 |
| 2014 | 357,809 | 90,545 | 97,054 |
| 2015 | 388,955 | 111,232 | 126,861 |
| 2016 | 432,126 | 127,292 | 145,000 |
| 2017 | 436,339 | 170,230 | 193,286 |
| 2018 | 436,682 | 201,949 | 217,499 |

**Source:** General Directorate of Rubber of Cambodia (2018)

**Note:** 1 hectare = 10,000 square meters

## 2.3 Price of Natural Rubber

The natural rubber price continuously fluctuates and escalated in 2011. But rubber price had decreased in Thailand, Cambodia, and the global rubber market during 2008 to 2018 (Figure 1). There are many factors affecting the price of natural rubber such as oversupply, low consumption, and large stock pile of natural rubber, price of crude oil, price of synthetic rubber, currencies of the world's markets, and state of the global economy (Win, 2017). The price of natural rubber rose until 2011 due to raising demand in the world and the Thai government's intervention supported the industry from 2004 to 2006. This intervention encouraged farmers to increase rubber cultivation even on unsuitable lands and switch from growing rice to rubber trees. More rubber productions led to an oversupply situation in the market and the eventual drop in the natural rubber price (Praktikantin, 2018). The excess of natural rubber product is a big issue in the global market. The large stockpiles and lacking demand have been the current facing sectors. The surplus supply has caused prices to steadily decrease. In 2020, rubber product is expected that the excess of natural rubber will be about 1 million tons and synthetic rubber will be approximately 3 million tons on the global market. Also, low crude oil prices affected the price of synthetic rubber (Televisory, 2018). World demand of natural rubber is primarily used to manufacture tires though demand is falling due to the economic downturn in China. China is the world's largest consumer of natural rubber, while the second and the third largest consumers are India and the United States, respectively. The fall in demand in China led rubber prices to fall approximately 30% in 2014 and continues to down fall. Rubber producers have been seeing a fall in revenue. Increasing consumption of tires and industrial rubber products is expected to maintain the global demand for natural rubber (Research and Market, 2016). Furthermore, the price of crude oil directly impacts the natural rubber price all over the world. Natural rubber prices have generally followed the trend of crude oil prices. The price of crude oil is an issue concerned with natural rubber price in the world. Thus, the natural rubber price is always determined by the direction of crude oil prices (Table 5). The high price of synthetic rubber is indicated by the high price of crude oil. Ultimately, a high synthetic rubber price affects the natural rubber price. The low crude oil price has made synthetic rubber competitive with natural rubber putting pressure on the price of natural rubber. The entire economy is negatively affected when the crude oil price goes up. This is because most industrial productions in the world use crude oil. Examples include the production of steel, aluminum, plastics, rubber, and fabrics. Crude oil is also used in transportation and food processing (Khin *et al.*, 2012). Additionally, the situation of global economy has impacted on the natural rubber price. The consumption dropped while demand recovery was slow because of the global financial crisis in 2008-2009. Global financial crisis pushed the rubber product into surplus (2011-2013) which made the natural rubber price decline from USD 4,817 per ton in 2011 to USD 2,795 per ton in 2013 for a downward slope of 42% (Televisory, 2018). The profitability of exports and discouraging imports were enhanced by the immediate impact of fall in the currency of the country or exchange rate fluctuations seriously. Thailand relies on exports and tourism as macroeconomic staples and benefits from a high THB/USD exchange rate. Danielsen (2017) asserted that the Thai Baht was "undervalued".

**Table 5** Natural Rubber, Crude Oil, and Rubber Synthetic Prices ('USD) (2008 to 2017)

| Years | Natural Rubber | Crude Oil | Synthetic Rubber |
|---|---|---|---|
| 2008 | 258.67 | 99.67 | 109.90 |
| 2009 | 191.92 | 61.95 | 100.63 |
| 2010 | 365.42 | 79.48 | 113.06 |
| 2011 | 480.00 | 94.88 | 129.67 |
| 2012 | 337.67 | 94.05 | 131.24 |
| 2013 | 279.50 | 97.98 | 134.22 |
| 2014 | 195.17 | 93.17 | 139.35 |
| 2015 | 157.17 | 48.72 | 128.51 |
| 2016 | 160.50 | 43.58 | 118.47 |
| 2017 | 199.67 | 50.84 | 122.27 |

**Source:** IndexMundi (2018)

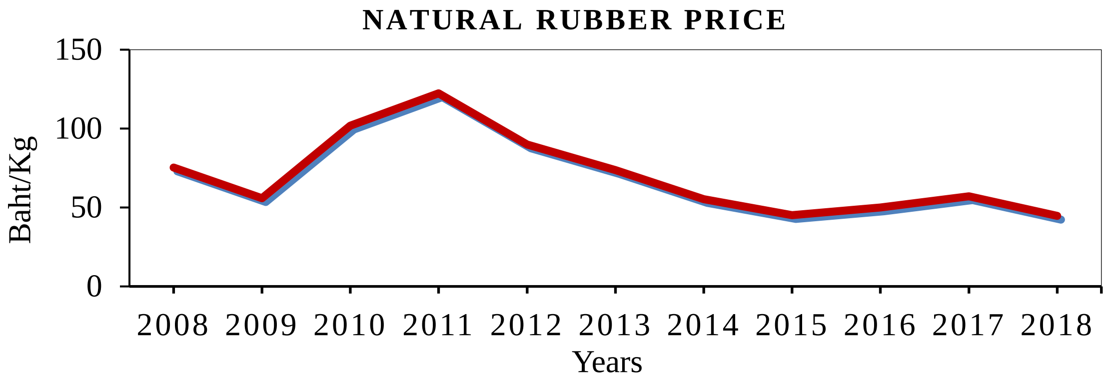



**Figure 1** Natural Rubber Price of Thailand from 2008 to 2018

**Source:** Rubber Authority of Thailand (2018)

### 2.4 Impact of Low Price of Natural Rubber on Rubber Farmers

In the last decade, natural rubber industry has seen for rapid and fundamental changes. Rubber plantations in countries such as Thailand, Laos, Vietnam, Cambodia, Myanmar, and China had expanded more than one million hectares during the price peaks in 2011 (Li & Fox, 2012). The current low rubber price has had adverse impacts on incomes and livelihoods of rubber farmers and tappers. The Association of Natural Rubber Producing Countries (ANRPC) has declared that many of rubber smallholders are only going to suffer if rubber farmers must continue to harvest rubber at current low price of natural rubber. This low-price issue has resulted on high harvesting frequency, reducing field maintenance, increasing disregard of quality standards, and increasing frequency of tapping system with a risk for productivity in the future. Rubber smallholders' livelihoods are attached to their rubber price and often without alternative income opportunities. Smallholders have been led into poverty. Poor market entrance of rubber products also has negatively affected smallholders' incomes. Farmers have been generally unaware of rubber prices in global market, and they deliver their natural rubber products to processing factories. Furthermore, low rubber price also has impacted wages of rubber tappers and daily or permanent workers work at large-scale rubber estates and rubber smallholder farms. All natural rubber producing countries, rubber companies, and rubber smallholders have been reluctant to pay tappers the minimum wage. Rubber tappers have a strong incentive to look for work in other sectors if their wages are not enough to secure a decent living (Fair Rubber Association, 2016).

Rubber plantations in urban and peri-urban areas lack labor because would-be tappers are close to more secure and better-paying jobs. Therefore, the low tapping frequency is attractive to the younger generation who work on rubber farms (Tongkaemkaew & Chambon, 2018). Lack of labor issue in rubber plantations by various countries has been compensated for by forced labor from Myanmar, Cambodia, Indonesia, Liberia, and the Philippines (U.S. Department of Labor, 2010). Family members including children are necessary for help to work because of combination of low wages and high harvesting quotas. In 2011 and 2012, many cases had been observed of basic labor rights violations: insufficient safety standards, inappropriate use of toxic chemicals, discrimination, and persistently long working hours (Danwatch, 2013).

**2.5 Environmental Impacts of Monoculture Rubber Plantation**

Wild animals, birds, invertebrates, and biodiversity were negatively impacted by forests converted to rubber monocultures (Warren-Thomas *et al.*, 2015). Single-species monoculture plantations typically lead to some negative environmental impacts. Large-scale monoculture plantations affect environment in various ways including soil erosion, low soil fertility, loss of soil moisture, soil carbon, pests, and diseases encouragement (Liu *et al.*, 2018). By focusing on a single species, namely rubber, these plantations deplete via soil erosion. The trees' roots are above the surface, so these roots will not take up nutrients efficiently during tapping period. Thus, trees may lack nutrients in the tapping sites. The roots obtain nearly the surface, so nutrients will not be efficiency in trapping period of rubber trees, and it maybe lack nutrient in the tapping sites. The strong rainfall improved risk of storm damage in monoculture plantations facilitate soil erosion (Ahrends *et al.*, 2015). Also, especially on sloping land and terraces, topsoil erosion is more likely because the vegetation which had held the soil in place was removed during preparation for rubber tree planting. This increased likelihood of erosion persists until the crowns of rubber trees have spread enough to protect the soil from rainfall. Stream flow and depletion of soil moisture are diminished in rubber monocultures. Rubber trees consume more water than other plants in natural forests. In a short dry season, the leaves of rubber trees fall and start new growth in late March, before the arrival of the first monsoon rainy season, which is the very hottest and driest time of year. A lot of water is consumed during this period for rubber trees' new leaves and buds to grow which depletes deep reserves of soil moisture. That event, the dryness will be appeared in rubber plantation areas because rubber trees used high water at the peak of dry season (Fox *et al.,* 2014). Overall, the annual water balance is reduced by about 3% in the water basin's average yield especially in the dry season period (Wangpimool, 2016). In addition, land transformation of forest into rubber monoculture cultivation has reduced the amount of soil carbon. The total carbon biomass in once-forested areas has reduced by approximately 212 grams because forestry areas have converted the forests to open land, other mono-cropping plantations and rubber mono-cropping plantations. The total carbon stock has decreased to 81 grams, which is a too-low level of carbon in the total ecosystem. Nearly 20% of carbon has been lost in a total soil depth of 1.2 meters. The application of fertilizers and eradication of weeds have affected soil carbon stock in rubber monoculture plantations (He & Martin, 2016). Rubber monocultures are also susceptible to insect pests and pathogens because rubber trees provide a huge habitat of uniform genetic closeness of tree species (Liu, 2018).

**2.6 Sustainable Economic Development**

Development means general progress towards meeting requirements of society including process of evolving from insufficient or inadequate conditions to enough or adequate conditions counting community development and national development. The development process from period to period is dynamic. Therefore, development relates directly to process of creating and refining plans with aim that situation will be better than the situation was before (Chaiworamukkul, 2012). Economic sustainability is a long-term project of sustainable economic growth which based on preservation of natural resources for present and future generations. Economic sustainability is necessary to improve production and consumption structure and to develop technologies without damaging the environment and natural resources (National Economic and Social Development Board, 2003). Sukhothai Thammathirat University (2014) defined sustainable development as improving the quality of human life within potential of global environment. The economic and social development of country is concerned with conservation of country's natural resources and environment. The people in society aim for development in order to live happily with food security, adequate housing, clothing, medicine, and other necessities for a good life quality. Having simultaneous economic growth and improved quality of life in community means that goals of development have been met. Quantitative economic growth is increasing a nation's revenue while qualitative goal improves quality of life by reducing poverty and increasing household incomes. Sustainable development has been classified into 2 types: 1) social development is main sustainable aim development and is based on poverty alleviation. Development should also focus on education, health, housing, and appropriate population policy measures for people's living conditions and 2) natural resources can be used efficiently to achieve economic goals, but this requires adherence to ethical development at all levels and sectors of society with an emphasis on protection and enhancement of natural resources (Fahasitkaew, 2003).

## 2.7 Rubber Agroforestry Systems (RAS)

The term rubber agroforestry system was defined by Jongrungrot (2016) that the one or more economic crops or plants and/or livestock integrated in a rubber plantation in various systems, and there are possibly many products with the main rubber product from the same land-management and temporal sequence. Otherwise, RAS can be defined simply as rubber trees + other crops, plants, and livestock. Another simple definition, RAS is associated diverse crops, plants, and livestock in a rubber plantation. RAS has four main characteristics in the South of Thailand based on the criteria of separate agricultural production of farm activities, socio-economic structures, and agro-ecozones (Somboonsuke *et al.,* 2011).

### 2.7.1 The Four Main Characteristics of RAS in Southern Thailand

#### 2.7.1.1 Rubber-based Timber Tree System

Normally, income of rubber smallholders who operate this type of farming is high because income is from both rubber and wood products at the same time. Wood price is presently high. The most common timber species grown are neem, teak, etc. (Figure 2). When asked for their opinions, these smallholder farmers were generally satisfied with various input-output aspects. However, many farmers were less satisfied with family incomes and savings (Somboonsuke *et al.,* 2011).

**Figure 2** Rubber-based Timber Tree System

**Source:** Jongrungrot (2018)

**2.7.1.2 Rubber-based Fruit Tree System**

Intercropped fruits including durian, rambutan, longkong, champadak, etc. are economically valuable in southern Thailand. Normally, fruit trees are mixed cultivation in the same land management with rubber trees (Figure 3). These fruit trees are grown between rubber rows called RAS. Objective is to benefit from fruit product at the same time as rubber product. Farmers tend to can postpone or continue harvesting rubber if rubber price is low, and fruit price is higher than that of rubber. These farmers are normally more experienced and skilled of fruit tree cultivation than farmers in previous planting pattern (rubber mono-crop) (Somboonsuke et al., 2011).

**Figure 3** Rubber-based Fruit Tree System

**Source:** Jongrungrot (2018)

### 2.7.1.3 Rubber-based Other Crops System

Most farmers practice this style includes those who have participated in the Office of Rubber Replanting Aid Fundus (ORRAF) replanting program. Support is provided during unproductive periods (0-36 months). Normally, intercropped varieties include pineapple, rice, corn, vegetables, and other annual crops (Figure 4). The decision to intercrop depends on several factors such as soil and terrain condition, marketing, and labor availability. When rubber trees are more than 36 months old, small holders change their farm cultivation patterns to other types of rubber-based farming to sustain their family incomes (Somboonsuke *et al.*, 2011).

**Figure 4** Rubber-based Other Crops System
**Source:** Jongrungrot (2018)

### 2.7.1.4 Rubber-based Livestock System

Livestock is normally reared within both immature and mature rubber areas. Types of livestock include cows, poultry, swine, goat, sheep, etc. (Figure 5). The main constraints are the high cost of production and a deficiency in farm labor and feed. In immature rubber plantations, the trees normally are above 2 meters high and at least 18 months old for raising livestock. Usually, the average number of livestock per hectare in rubber areas ranges from 6 to 8. Smallholders in these systems have years of experience in raising livestock. The income derived from selling the livestock and/or their products is only supplemental (Somboonsuke *et al.*, 2011).


**Figure 5** Rubber-based Livestock Farming System
**Source:** Jongrungrot (2018)

### 2.7.2 Plant Species of Rubber Agroforestry System

Jongrungrot & Thungwa (2013) showed that farmers had intercropped timber trees, fruit trees, and/or other crops in association with rubber trees (Table 6). Farmers choose intercropped species depending on their own observations, experience, advice from neighbors, and the availability of varieties distributed by public institutions. The rubber-based agroforestry systems are based on three different strategies: (1) grow fruit trees as a mono-crop at first and then gradually turn to rubber-based agroforestry; (2) growing timber trees as a monoculture and then change to rubber-based agroforestry; (3) convers from rubber monoculture to rubber-based agroforestry by intercrops to fill up empty spaces of land and increase their income (Jongrungrot *et al.*, 2014).

**Table 6** Plant Species of Rubber Agroforestry System

| Plant Species of Rubber Agroforestry System | | |
|---|---|---|
| Timber Trees | Fruit Crops | Other Crops |
| - Ta Khian Thong, *Hopea odorata* Roxb. | - *Artocarpus integer* Merr, Champedak | - *Gnetum gnemon* Linn, Miang |
| - Kritsana, *Aquilaria crassna* Pierre ex H. Lec. | - *Lansium domesticum* Corr, Longkong | - *Bambusa sp,* Bamboo |
| - Champa, *Michelia champaca* Linn. | - *Durio zibethinus* Linn, Durian | - *Licuala paludosa* Griff, Ka Pho |
| - Payom, *Shorea roxburghii* G. Don. | - *Archidendron jiringa*, Niang | - *Cyrtostachys renda Blume*, Mak Daeng |
| - Yang, *Dipterocarpus alatus* Roxb. | | |
| - *Anthocephalus chinensis* Lam, Tak Ku | | |
| - *Azadirachtaexcelsa* (Jack) Jacobs, Neem | | |

**Table 6** Plant Species of Rubber Agroforestry System (Continued)

| Timber trees | Fruit crops | Other crops |
|---|---|---|
| - *Swietenia macrophylla* King, Mahogany<br>- *ToonaCiliata* M. Roem, Yom Hom<br>- *Listsea grandis*Hook.f, Thang<br>- *Lumnitzera littorea* Voigt, Fat Daeng<br>- *Garcinia merguensis* Wight, Nuan<br>- *Syzygium cumini* (L.) SkeelsIronwood, *Hopea,* Jambolan Plum *odorata* Roxb.<br>- *Litsea grandis* L, Tung<br>- *Aquilaria crassna* Pierre, Eaglewood<br>- *Intsia palembanica* Miq, Malacca teak<br>- *Shorea roxburghii* G. Don, White Meranti<br>- *Michelia champaca* Linn, Champaka<br>- *Toona ciliata* M. Roem, Mouimein Cear<br>- *Anthocepalus chinensis* Lamk, Bur-flower<br>- *Justicia gendarussa* Burm. F, Gendarussa<br>- *Garcinia merguensis* Wight, Bastard garcinia<br>- *Lumnitzera littorea* (Jack) Voigt, Black Mangrove<br>- *Eugenia grandis* Wight, Sea apple<br>- *Ilex cymosa* Blume, Ilex<br>- *Microcos tomentosa* Smith, Cenderai<br>- *Schima wallichii* (DC.) Korth, Needle Wood<br>- *Cordia globifera* W.W. Smith, Suk-hin<br>- *Alstonia macrophylla*, Hard alstonia | - *Zalacca edulis* Reinw, Sala<br>- *Nephelium lappaceum* Linn, Rambutan<br>- *Lansium domesticum* Serr, Lansium<br>- *Garcinia mangostana* L, Mangosteen<br>- *Artocarpus integer* Merr, Champeak<br>- *Nephelium lappaceum* Linn, Rambutan<br>- *Cocos nucifera* Linn, Coconut<br>- *Archidendron jiringa* I. C. Nielsen Jerin<br>- *Parkia speciosa* Hass, Stink bean<br>- *Salacca edulis* Reinw, Salacca<br>- *T. cacao,* Cocoa<br>- *Coffea Arabica, and Robusta,* Coffee | - *Johannesteijsmannia altifrons* H.E. Moore, Bang Sun<br>- *Cyrtostachys renda* Blume, Sealing wax palm<br>- *Johannesteijsmannia altifrons* (Rchb. & Zoll.) H. E. Moore, Litter Collecting Palm<br>- *Pandanus amaryllifolius* Roxb, Pandanus palm<br>- *Licuala paludosa* Griff, Fan Palm<br>- *Livistona speciosa* Kurz, Livistona<br>- *Chrysalidocarpus lutescens* H. Wendl. Yellow palm<br>- Flowers and ornamental plant |

**Source:** Jongrungrot & Thungwa (2013); Jongrungrot *et al.* (2014)

## 2.8 Plant Community Structure and Crown Covers

The canopies of plants are used to divide height of trees' crown cover in rainforest or tropical rain forest. The canopies of plants in forests grow to 20 meters high with many branches, leaves, and fruits providing suitable shelter wildlife. Canopy may be likened to a net above ground below to provide shade to vegetation and soil and to protect trees from too much sunlight and rain. The community structure of the rainforest is classified into the following 4 layers: the bottom or forest floor, the understory layer, the canopy layer, and the emergent layer. Each layer has different flora and fauna dependent on the amount of rain and sunlight (Science Museum, 2018). Kittithornkun *et al.* (2014) studied the plant community structure in rubber agroforestry and rubber monoculture by using a vertical and horizontal structure of plants to study 40 × 40 m representative area and selecting 5 × 40 m as a sample area. The study used botanical terminology such as branching, leaf groups, and plants' shape to express meanings which represented the ecosystem and structure of the vegetation and to include the social plant groups at all canopy levels of plant social. The gray image level was used to illustrate the image group and height of plants. Subsequently, data regarding plant societies was collected from field and prepared in a vertical and horizontal image in the laboratory. The RAS society is the same as the plant community in the rainforest. There are many canopies and canopy steps of plants which protect against ultraviolet radiation to prevent micro-organisms. The acting fungi and bacteria produce great objects for plants such as micro-organisms under the trees. The micro-organisms and fallen leaves and branches of trees work together continuously to produce organic matter for the soil fertility. When the soil was collected at a depth of 0-15 cm. for analysis, the amounts of organic matter were read that organic matters accounted respectively for 3.72, 2.82, 2.51, and 2.41%. While the same depth of land under the mono-rubber plantation in the same area had only organic matters 1.74% - 2.04% (Somsak, 2016). The natural capital of the RAS farmers was higher than that of the monocropping rubber plot farmers in terms of diverse plant species and multiple vertical stratification and crown cover percentage. These could help to reduce soil erosion in area. In RAS, area was mainly comprised top layer of rubber trees with a height around 26 meters and the middle layer comprised other crops around10 meters in height. The average covers of plant species in the RAS was over 80%, respectively. Analysis of the RAS profiles on the sampling plot of 5×40 meters showed that the tree structures had great potential to preserve water and soil due to the multiple levels of vertical stratification of plant species. The quantity of moisture in the RAS were higher than these in the monocropping rubber plots (Kittitormkool *et al.*, 2019). The popular measurement of plant community structure and crown cover is observed by looking from the highest part and the spreading canopy flat of plants in forest. The evaluation of values of crown cover per unit area of plants can separate canopy of plants into layer level according to the heights of trees that has already been identified from the profile diagram (Figure 6). Therefore, sum of results of measuring crown cover areas may be great for presenting soil erosion because canopy is overlapped (Dokrak Marod, 2011).

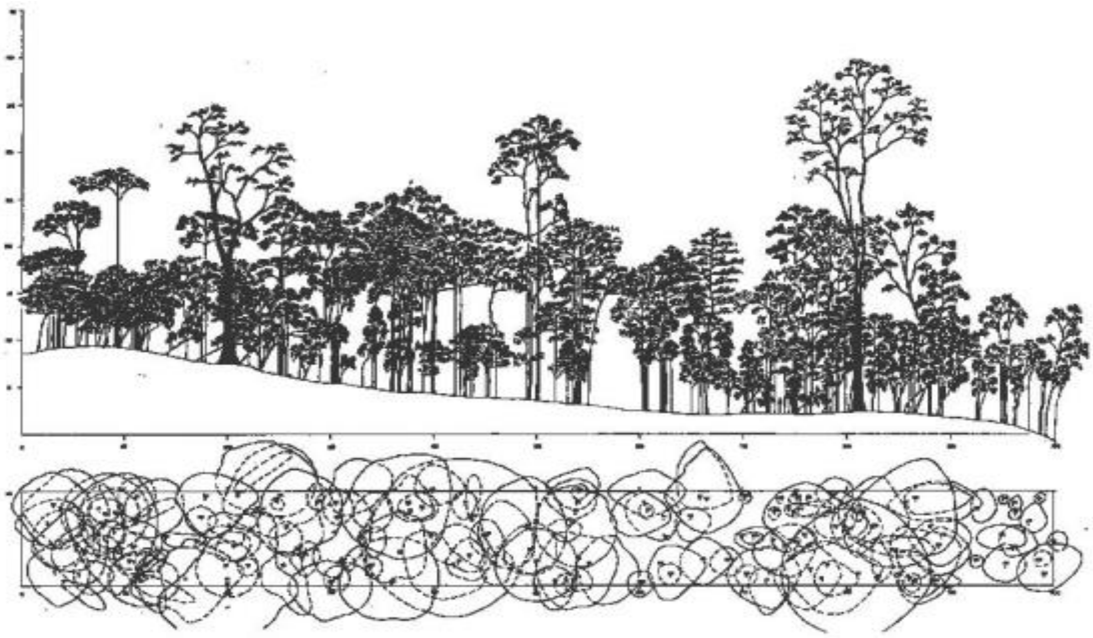


**Figure 6** Profile and Crown Cover Diagram of a Forest in Thailand
**Source:** Ruangpanit (1985)

## 2.9 Planting Method

The economic crops and other crops which grow well with rubber trees are suitable for RAS, and density of planting is a crucial factor in enabling all crops to survive and thrive. Kaewwongsri (2017) indicated that rubber agroforestry plantation could be done in many ways for example, 1) planting other crops in rows of rubber trees, 2) Planted as a line against of rubber plantation, 3) Mixed planting of many different plants in between rubber rows, and 4) planting rubber trees as double rows design. Moreover, also revealed that there were some new RAS planting designs such as:

- alternating rows 3 × 8 m, 42 rubber trees, and 42 other perennial plants per rai,
- planting a pair of rows, 3×8 m, 56 rubber trees, and 28 other plants per rai,
- planted design in 4 × 8 m, 44 rubber trees, and 12 perennial trees per rai,
- planted into a strip of 4 × 8 m, 48 rubber trees, and alternating rows of 15 plants per rai,
- planting double rows, 5×4×14m, 54 rubber trees, and alternating rows of 16 plants,
- and planting in double rows, 5 × 33 × 10 m, 54 rubber trees, and 32 trees per rai.

The intended area for intercrop is determined in the planting design, which comprises three types (Figure 7): 1) the single hedge design has 6 meters of distance between rows of rubber trees (2.5 meters between trees within rows), with 2 rows of intercrops 2 meters apart (planting density affords 555 rubber trees per hectare); 2) the double hedge design has two rows of rubber trees 3 meters apart (2.5 meters between trees within rows), with the inner row of rubber trees separated by 16 meters to allow for intercrops (planting density affords 500 rubber trees per hectare); and 3) the triple hedge design has three rows of rubber trees with 3 meters between each row, (2.5 meters between trees within rows), again with the inner row of rubber trees separated by 16 meters to allow for intercrops (planting density affords 545 rubber trees per hectare). Planting design type is dependent on intercropping species and clone of rubber tree (Malaysian Rubber Board, 2009). The study by Wibawa *et al.* (2006) revealed that PB 260, RRIC 100, and BPM1 were good rubber clones for RAS because all grow well and could be tapped at 5-7 years after planting with adapt to conditions of long-term intercrops.

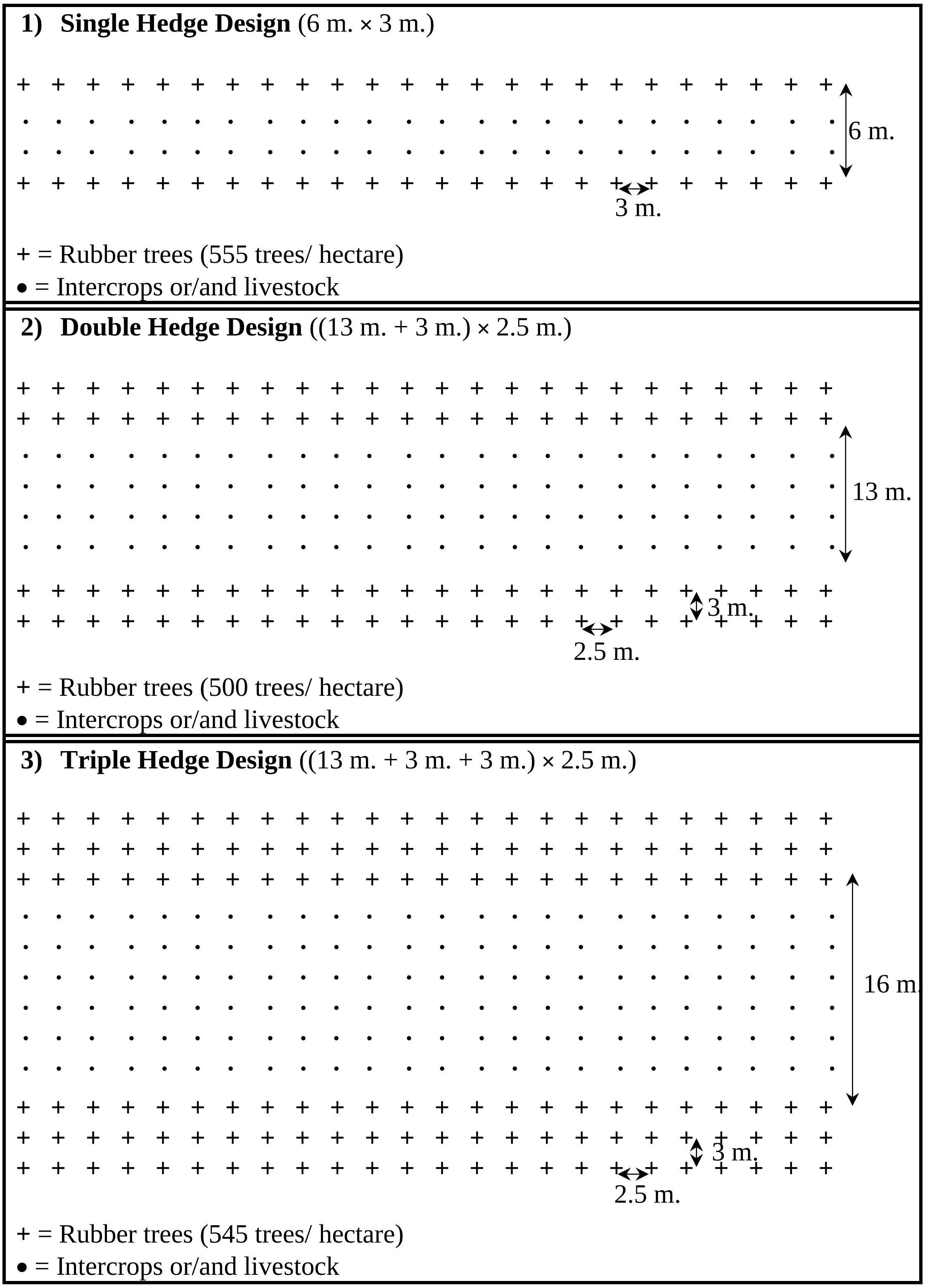



**Figure 7** Planting Design Types of Rubber Agroforestry Systems

**Source:** Malaysian Rubber Board (2009)

## 2.10 Sustainability of Rubber Agroforestry System

Rubber Agroforestry System (RAS) is integrations of various crops and/or raising animals on the same plot with rubber trees sequence of tense. RAS is an alternative agriculture practice for rubber smallholders to improve ecological integrity and crop diversity (Somboonsuke *et al.,* 2011). RAS was identified by scientists as "jungle rubber" and carried out various functions. For example, RAS is the main income source for many rubber farmers, maintains forest biodiversity, sequesters soil carbon, and conserves soil and water (Wibawa *et al.,* 2008). Jongrungrot *et al.* (2014) indicated that the economic and environmental benefits of RAS were supported to improve rubber farmers in Southern Thailand in coming decade. RAS is the most resistant form of rubber cropping against risks of economic fluctuation and climate change and helps to increase social harmony in community. The benefits of RAS are divided into economic, environmental, and social aspects (Figure 8) (Jongrungrot, 2016).

### 2.10.1 Economic Security Function

Various and resilient incomes are derived by RAS. Intercropping plants and livestock can provide a significance of additional income source during the long non-tapping period, as well as when rubber trees are harvested. When rubber products fetch a low price, the products of intercrops and livestock provide a mental cushion to farmers because many products in the single land management are less susceptible to the impacts of price fluctuations (Stroesser *et al.,* 2018). Almost all rubber smallholders from all farming groups are involved with rubber cultivation either doing the daily on-farm labor or in permanent positions at rubber processing plants. Farmers have allowed the raising intercrops and/or livestock in rubber plantations, and farmers have been also available to keep a sharing from rubber product (Nath *et al.,* 2005). A study by Rodrigo *et al.* (2005) had demonstrated that the growth of young rubber trees are not adversely affected by intercrops. Associated young rubber trees with banana resulted in increased growth and a reduction in period of the unproductivity of rubber trees. In RAS, product efficiency is improved when farmers gain non-rubber product from farm, and farm expenses are reduced, because the intercrops, livestock, and rubber trees co-exist and support each other in growth and yield. RAS need to apply organic matter and manure without chemical fertilizers, due to recycling of nutrients via fallen leaves and branches. The products of intercrops, e.g. roofing materials, bags, mats, and so on can be used by the farmers. Thus, farmers increase internal inputs and reduce family expenses (Jongrungrot, 2016). Intercrops and livestock contribute to reducing financial risk when rubber price is low and the farm labor wage is high because they are sources of income (Jongrungrot *et al.*, 2013).

### 2.10.2 Environmental Security Function

The RAS has provided several environmental benefits on RAS farms such as: 1) more soil organic matter and higher soil humidity, 2) less soil erosion and fewer weeds, 3) softer rubber tree bark yielding more latex, and 4) more biological diversity creates a more resilient ecosystem which prevents damage caused by storms (Jongrungrot *et al.*, 2014). The study by Jongrungrot (2016) showed that the topsoil damaged by rain drops falling directly on soil in upland area. Therefore, more canopy levels in RAS conserve soil by preventing rain drops directly hitting the soil and root systems of the various crops hold topsoil in place. Then, soil is protected by roots of plants in RAS. Particularly canopy levels and various roots help to reduce destruction of watersheds losing topsoil of downstream areas. The intercrops and rubber trees in upland areas are more able to resist climatic uncertainties by retaining soil moisture. In dry season, water under soil drains into water sources thereby reducing risks of flood and drought. Soil fertility maintained through plant organic matter falling and decomposing into soil and through planting diverse indigenous species. Some farmers cultivate diverse annual and perennial crops in their rubber farms which fosters both ecological and socioeconomic biodiversity (Nath *et al.*, 2005). Additionally, floral biodiversity promotes ecological sustainability. Specifically, RAS provides more diverse habitats and food sources for wildlife than rubber mono-system does due to various plant species with different heights and canopy layers. RAS can better resist fires and are more able to stock large amounts of organic carbon in soil (Bumrungsri, 2012).

### 2.10.3 Social Security Function

Some intercrops are called “culture plants” by farmers because intercrops help conserve local cultures for future generations. Such crops include banana, kor, herbs, bamboo and fanpalm. For example, fan palm leaves are used to wrap sticky rice mixed with coconut milk, sugar, and salt, and flagpoles are made from bamboo stems for monks’ boats for the annual Shuk-Pra tradition of Southern Thailand. RAS does not use agrichemicals, so RAS is ideal for health food products, clean air, and less on-farm agrichemical contact which is good for the health of the farmers and their families as well as their neighbors. Farmers, students, and academics can learn and practice at successful RAS farms which can be a source of knowledge or as a community learning center. Moreover, farmers create social networks to share as broadly as possible of knowledge and experience of RAS in rural communities. Sometimes these networks partner with other networks to develop and scale up RAS farms (Jongrungrot, 2016). In addition, social cohesion of rubber agroforestry system farmers helps to strengthen their rural communities in many ways. In the future, promoting rubber agroforestry system will be a measure used to complete government’s social welfare program in many rubber farmer communities (Jongrungrot, 2015).

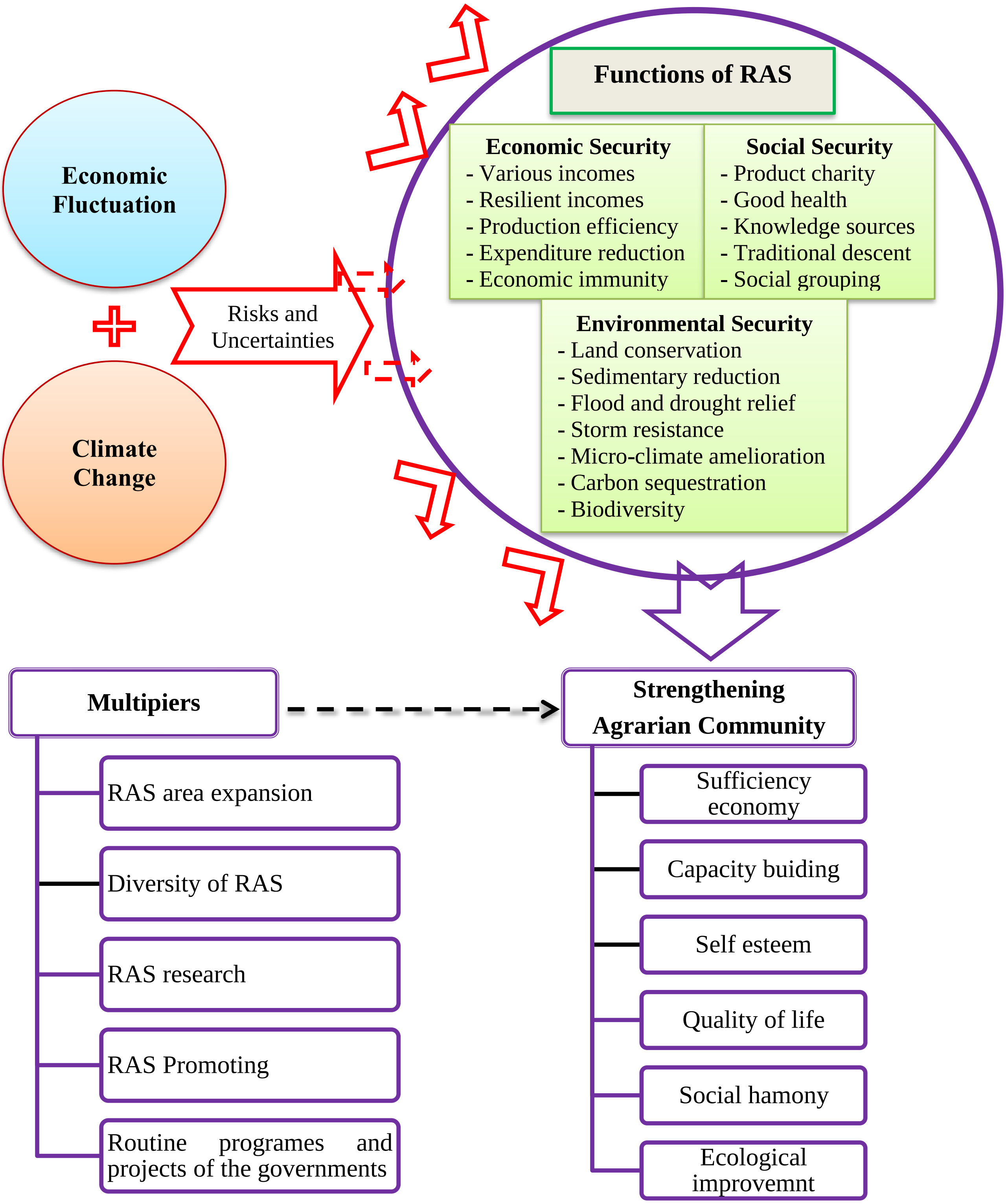



**Figure 8** RAS Can Resist Risks and Uncertainties and Strengthen Agrarian Communities

**Source:** Jongrungrot (2016)

**2.11 Related Research**

Jongrungrot *et al.* (2014) studied the rubber-based timber tree plantations that featured diverse income sources for rubber smallholder in Southern Thailand. This study investigated four different patterns: 1) planting fruit trees as a monocrop then converting to RAS, 2) planting timber trees as a monocrop then converting to RAS, 3) converting from rubber monocrop to RAS and 4) practicing RAS from the beginning. The results revealed that the farmers had obtained numerous economic and environmental advantages from RAS such as 1) more soil organic matter and soil humidity, 2) condensed soil erosion and weed, 3) much shady in the plots, so the bark of rubber trees were soft that resulted in more latex, 4) the product quality in RAS was higher, 5) the biological diversity had been increased and helped to balance ecosystem, and 6) all plants in RAS plots minimized storm damage.

Jongrungrot & Thungwa (2013) studied the resilience of RAS in Southern Thailand. Results were extracted from 5 RAS plots with three hypothetical scenarios: 1) lower rubber price from 2017 to 2021, 2) the farm labor was high wage from 2013 to 2021, and 3) RAS farmers reduced threats and insecurities by selling products of intercrop. Three plots were given a high resilience level (income of RAS plots after reducing operational expenses) while one RAS plot revealed the medium level and low level was shown in one plot. Main factors affected the levels of resilience were quantities and types of timber intercrop, appropriate harvesting timber period, efficiency of plot management by RAS farmers to improve yields of intercrops, and production of other plants in RAS plots to improve household income. A high amount of off-farm income was considered helpful in reducing some adverse impacts from a low price of rubber and high wage of farm labor.

Nath *et al.* (2005) studied about smallholder agro-forestry for upland community development in Chittagong Hill Tracts, Bangladesh. Results indicated that smallholder agro-forestry interventions had shown such benefits of increasing farmers' income through selling farm products, improving ecological conditions in these areas through decreasing soil erosion, increasing in plant coverage, and improving soil fertility. The adoption in different RAS was facilitated mainly by the interest of farmers to accept the techniques, farmers' ability to work on land in the approved manner, and demand of RAS products in the market.

Tongkaemkaew *et al.* (2016) studied about rubber farmers' income diversification through RAS practices: how to overcome rubber price volatility in Southern Thailand. This study focused on RAS that developed in mature rubber plantations in order to understand extent to which RAS contribute to income stability and financial resilience. The economy of the farm was characterized by weak income due to price instability. RAS farmers diversify their incomes through cultivation of intercrops as fruit trees and/or timber trees with rubber trees in the same plantation, and they do off-farm work in order to supplement their incomes. The result of prospective modeling revealed that most farms could resist rubber price fluctuations in both terms of land and labor valorization.

Rodrigo *et al.* (2005) concluded that the rubber's growth and yield at maturity was improved by banana intercrop during initial stage of rubber cultivation. Intensive intercrop with young rubber trees does not result in a substantial gain in the growth and yield of rubber trees only, but also in a reduction in the duration of the unproductive immature phase. The rubber trees in intercropping treatment were ready to be tapped 4 months earlier than the rubber trees in rubber monoculture plantation. Although girth and height of rubber trees grew better in the RAS plantations, bark thickness was not different than those of the rubber monoculture plantations. Moreover, the rubber yield per hectare was greater than those in the rubber monoculture treatments due to a higher number of rubber trees that could be tapped.

Wibawa *et al.* (2006) studied about RAS as alternatives to rubber monoculture systems and revealed that rubber trees' girth in double row spacing (14 + 2 m) × 6 m. and with intercrops were grown for tapping size in five years old. Growth of rubber trees in association with *Acacia mangium* was very fast. Moreover, results of clone comparison in RAS of trial (maintenance only on rubber rows) showed more varied growth of rubber trees because of the variations of plots and frequencies of weeding. PB 260, RRIC 100, and BPM1 rubber clones were able to adapt RAS conditions and were ready for tapping at 5 to 7 years after planting. These findings are evidence of alternatives for farmers, environmentally friendly and diverse systems.

Zeng (2012) studied about the improving planting patterns of rubber trees for intercrops in the whole production life. RAS farms had conducted two kinks of planting patterns with rubber clone Reyan 7-20-59 such as 1) single row (SR) avenue planting pattern 3 × 7 m. apart, and 2) double row (DR) avenue planting pattern (20 + 4 m.) × 2 m. apart. Results of study revealed that rubber trees' girths in the DR planting pattern at the first year were slightly bigger than these of the rubber trees' girths in the SR planting pattern. There were only a relatively small number of rubber trees being tapped per unit area in the DR planting pattern. The 98% of yield per hectare in SR planting pattern had not been significantly that affected yield per tree. In addition, the DR planting pattern had a larger full-sun area of land with high light penetration providing suitable conditions for the long-term intercrops.

Romyen *et al.* (2018) investigated rubber agroforestry system (RAS) in Southern Thailand. The results pointed to size of plantation as a significant factor in adoption of either rubber monocropping system (RMS) or rubber agroforestry system. Following were some significant factors that positively influenced RMS farmers toward adopting RAS: number of members in the household, RAS knowledge level, attendance in RAS workshop, and rubber cultivating experience. These findings suggested that promotion, expansion, and adoption of RAS are the driving force behind RAS tutorials. Though this seemed to be a main purpose for promoting the RAS area expansion in the future, this would be quite challenging to achieve in practice, if RAS were left to occur naturally. There would be positive measures adoption for promoting RAS expansion.

## 2.12 Conceptual Framework

The rubber agroforestry system (RAS) practices as the sampling plots for this study were divided into four categories such as 1) rubber-based timber trees, 2) rubber-based fruit tree, 3) rubber-based other crops, and 4) rubber-based livestock.

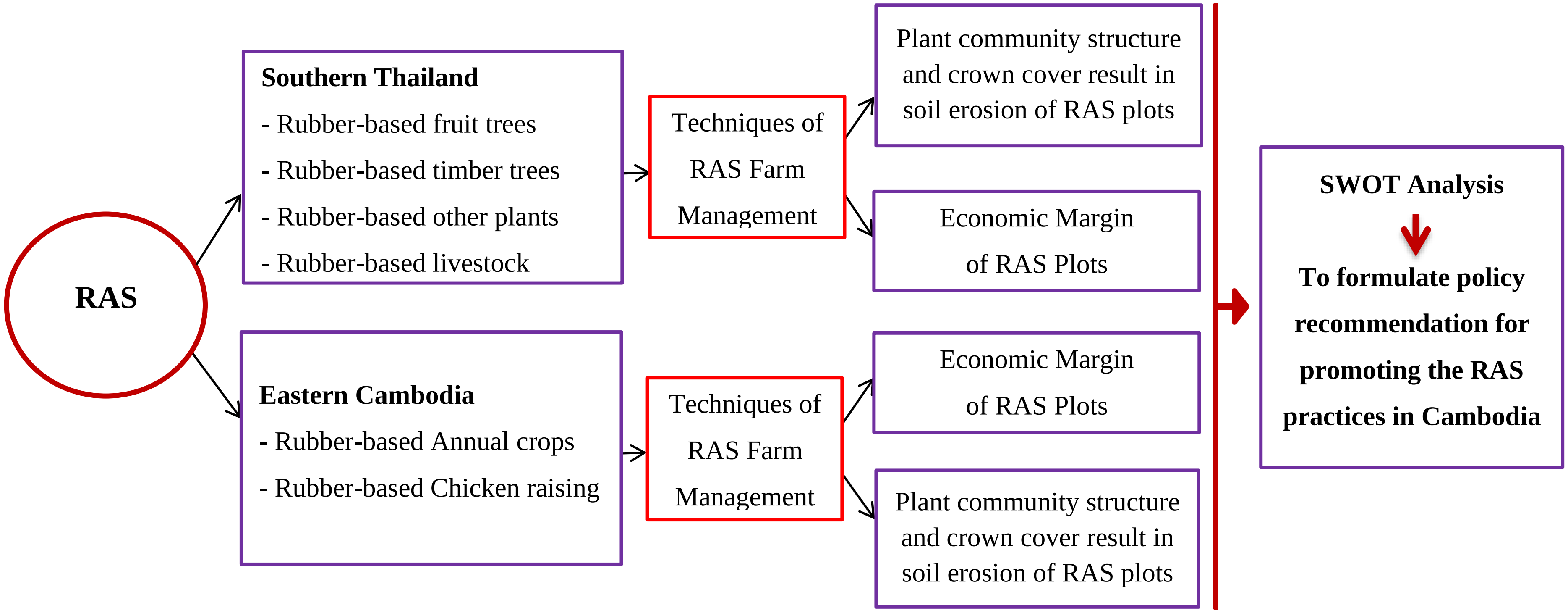



**Figure 9** Conceptual Framework of Study

# CHAPTER III

# MATERIALS AND METHODS

## 3.1 The Study Area

The study areas are purposefully conducted in Thailand and Cambodia (Figure 10). In Thailand, southern region is selected because there are many rubber farmers who have practiced rubber agroforestry system (Romyen *et al.,* 2018). In Cambodia almost all rubber farmers have practiced only growing annual intercrops and raising chicken in rubber plantations as RAS. Provinces in Eastern Cambodia are the largest and old rubber plantation areas and the oldest rubber plantation (Table 7). Rubber farmers have cultivated annual intercrops in young rubber plantations and raising chickens in rubber plantations as RAS (General Directorate of Rubber, 2018).

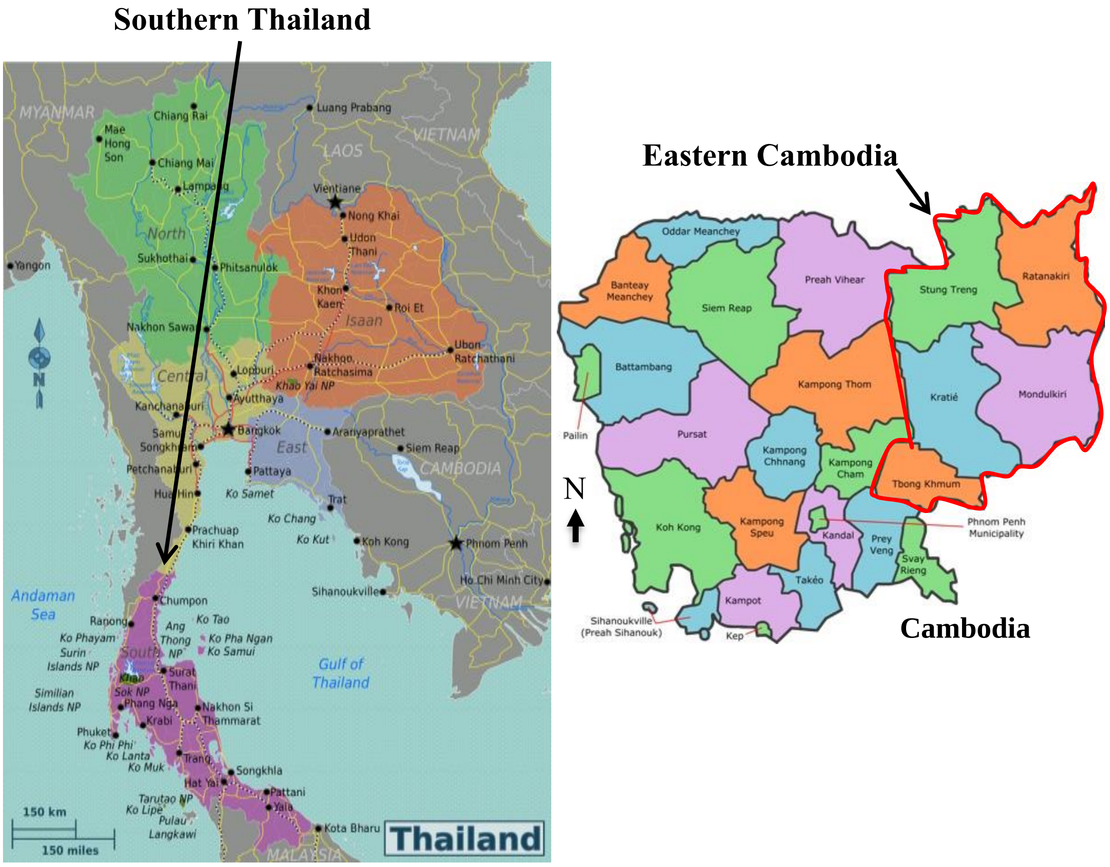



**Figure 10** Map of Study Area

**Source:** Wikipedia (2019)

**Table 7** Smallholding Rubber Plantations (hectare) and Number of Rubber Farmers by the Province in Eastern Cambodia in 2018

| Provinces | Farmers | Rubber Plantations | Rubber Tapping Areas |
|---|---|---|---|
| Tbong Khmum | 18,800 | 46,378 | 41,699 |
| Kratie | 4,075 | 13,322 | 9,368 |
| Stung Treng | 564 | 4,103 | 1,847 |
| Mondulkiri | 1,796 | 11,305 | 2,649 |
| Ratanakiri | 1,997 | 36,349 | 28,022 |
| Total | 27,232 | 111,457 | 83,585 |

**Source:** General Directorate of Rubber (2018)

### 3.2 The Sampling of Study

Purposive sampling was used for selecting farmers. In Southern Thailand, 11 farmers who were practicing rubber agroforestry systems were chosen in four categories such as a) rubber-based fruit trees, b) rubber-based timber trees, c) rubber-based other plants, and d) rubber-based livestock. In Eastern Cambodia, 3 farmers who had cultivated annual intercrops and raised livestock in rubber plantations as rubber agroforestry system were chosen as the samples in this study. The kinds of plants and livestock cultivated with rubber trees in the same land managements in this research are shown in table 8.

**Table 8** Types of Intercrops and Livestock in This Study

| RAS | Southern Thailand | Eastern Cambodia |
|---|---|---|
| Fruit trees | - *Zalacca edulis* Reinw. Sala (2 plots)<br>- *Garcinia mangostana* L. Mangosteen<br>- *Artocarpus integer* Merr. Champadak<br>- *Coffea Arabica*, Coffee<br>- *Lansium domesticum* Corr, Longkong | none |
| Timber trees | - *Hopea odorata* Roxb. Ironwood<br>- *Aquilaria crassna* Pierre. Eaglewood | none |
| Other crops | - Bamboo (shoot product)<br>- Bamboo (Stem product) | - Peanut (*Legume)*<br>- Soybean (*Glycine max.*) |
| Livestock | - Raising Bee | - Raising Chicken |

## 3.3 The Data Collection and Analysis

### 3.3.1 Data Collection

In this study, data collection was divided into two types of data:

1) Secondary data: data was collected from book, research reports, academic articles, online data, and so on.
2) Primary data: data was collected in the field using the following two approaches:

(A) Questionnaire has designed in accordance with the study objectives composed of 4 parts: 1) basic personal data, 2) techniques of rubber agroforestry system practices, 3) economic data of the each plot collected as primary data in 2018 and estimated 6-year data from 2019 to 2024. The changing products and inputs in farms from 2019 to 2024 are based on farmers' experiences and planning as well as academic data, such as the amount of dried rubber product by age shown in table 9. Also, the related price of all products and inputs from 2019 to 2024 was fixed in 2018, and 4) SWOT (Strengths, Weaknesses, Opportunities, and Threats) information of rubber agroforestry farming systems and related organization to promote the RAS practices in Cambodia.

**Table 9** Amount of Dried Rubber Products, Divided by Age of Rubber Plantation

| Age of Rubber Plantation (year) | Amount of Dried Rubber Products (Kg/hectare/year) | Amount (100%) |
|---|---|---|
| 7-9 | 1,531 | 64 |
| 10-12 | 2,375 | 100 |
| 13-15 | 1,900 | 80 |
| 16-18 | 1,575 | 66 |
| Over 19 | 1,350 | 57 |

**Source:** Gunalasiri *et al.* (2007)

The questionnaire was drafted in two key steps as follows:

a) Formulated the questions to be consistent with the study objectives

b) Sent experts the draft questionnaire to evaluate the questionnaire via the Index of Item Objective Consistency (IOC) as the following formula

$$\mathrm{IOC} = \frac{\sum \mathrm{R}}{\mathrm{N}}$$

IOC = Index of Item Objective Consistency

$\sum$R = Sum Score of Expert Comments

N = Number of Experts

If result of IOC calculation is equaled to or more than 0.50 indicates, so question is consistent with objectives and can be used. Conversely, if result of IOC calculation is lower than 0.50, so question is not consistent with objectives, and question must be deleted until IOC value is acceptable. In this study, questionnaire consists of 55 items of question. After IOC calculation, questions scored 0.67-1.00 which were used equaled 49 questions, questions scored 0.33 which were not used equaled 6 questions, but 2 questions scored 0.33 had been used because of thesis advisor's comment for using, other 4 questions had been taken out by scores of IOC experts, and some questions had been mixed together into a question. Then, the questionnaire had been reduced some questions after revision. Due to this reason, the questionnaire had remained 48 items of questions in research questionnaire for using in this study (Table 10).

**Table 10** The Result of IOC Calculation of Research Questions

| Question Items | IOC Score 0.67-1.00 | IOC Score 0.33 | Unused Question Items | Used Question Items |
|---|---|---|---|---|
| 55 | 49 | 6 | 4 | 48 |

(B) The measurement and record of data to study the plant social structures and crown cover of rubber agroforestry system plots was done in the fields (*i.e.* on real farms) by measuring and drawing the plant profile and crown cover (Table 11). After drawing plant community structure and crown cover in the rectangular (5 × 30 m) representative area (Figure 11), the density of crown cover was measured, and percentage of crown cover density was calculated by the formula as follows:

$$\text{Percentage of crown cover density} = \frac{\text{crown cover density} \times 100}{\text{Plot size}}$$

The plant community structure and crown covers are related to reduction of soil erosion. If the crown cover density is not less than 70%, this means that soil erosion is insubstantial (Ruangpanit, 2014). This is one measure for evaluating the controlling or preventing of soil erosion. Kheowvongsri (2008) asserted that loss of soil in a cultivated land is inversely proportional to crown cover of canopies. This measure is used as a criterion to analyze the impact on soil conservation in RAS plots for this study.

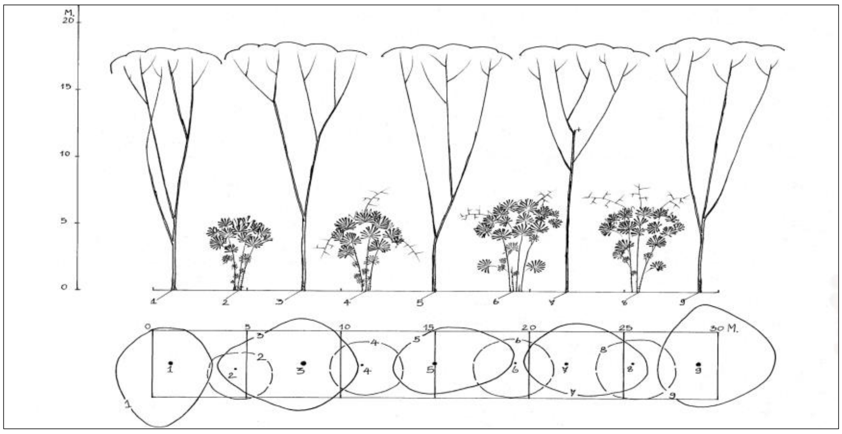


**Figure 11** The Plant Community Structure and Crown Cover of RAS
**Source:** Kaewwongsri (2018)

**Table 11** Technique of Measuring and Drawing the Plant Profile and Crown Cover

| Stage No. | Activities | Materials/Instrument |
|---|---|---|
| Stage 1. | Observation of the plot sample | Rubber agroforestry system plantations |
| Stage 2. | Identifying a rectangular area (5 × 30 m.) as a representative RAS plot | Tape measure, cables, poles, and hammer |
| Stage 3. | Determination of plant's number | Stickers |
| Stage 4. | Collecting data of plants in the rectangular area **(**Canopy radius, girth at breast height: G.B.H., and Height**)** | Tape measure and forestry pro Laser range finder (height meter) |
| Stage 5. | Drawing plant community structure and crown cover in the rectangle area | Pencil, ruler, eraser, and paper (A2) |

**Source:** Kaewwongsri, P. (March 12, 2019). Personal interview.

### 3.3.2 Data Analysis

There are some tools of data analysis used to analyze the data as follow by each objective in this study such as:

1) To achieve Objective 1, content analysis was applied to categorize and investigate different techniques applied in RAS management plots in Southern Thailand and Eastern Cambodia. Content analysis is a technique for analyzing documents, papers, and communication objects which could be texts of various structures, images, pictures, video, or audio. Social scientists apply content analysis to assess patterns of communication in a replicable and systematic manner. A key importance to apply content analysis for assessment of social phenomena that is non-invasive nature of content analysis in difference with social experience simulation or survey answer collection. Content analysis practices and philosophies vary among of academic disciplines and involves systematic scanning or studying texts or objects which are designated labels or codes to reveal the interesting and meaningful content. In the content systematic label of a set of texts, researcher can use statistical or qualitative methods to analyze the patterns of content in texts. Computers has been increased for applying in content analysis to automate text label code and can provide descriptive data like word frequencies and document lengths (Zikmund *et al.*, 2013).

2) To achieve Objective 2, Olympe software was used to analyze the economic margins of rubber products, intercrop products, and livestock products of different RAS plots in Southern Thailand and Eastern Cambodia to simulate and analyze economic margins of a 6-year period, 2018 to 2024. For this quantitative data processing, Olympe© software was used to analyze cost reduction, technical, and economic modeling of farms. Olympe software also had been utilized to compare the different farm types based on the economic aspects and total annual income of households. Olympe is a software used to simulate farming system’s future which permits a potential analysis over a period based on present farm data. Olympe can be used to create the scenarios and feature strategies of farms to discover potential development to help farmers make correct decisions (Penot, 2004).

3) To achieve Objective 3, descriptive statistics was used to determine the effect of soil erosion via plant community structure and crown cover of RAS plots. The descriptive statistics means the summary of statistical data or quantitative

feature description of information, and it can be used to describe or summarize a sample instead of using the population that the sample represents. Descriptive statistics can provide some information concerning time distribution, regional distribution, and economic crises performance. The quantitative data is described percentages, frequencies, modes, mean, medians, standard deviation, variance, range, etc. by descriptive statistics (Zikmund *et al.,* 2013).

4) To achieve Objective 4, SWOT and content analysis were used to evaluate situation of RAS practices and formulate policy recommendations in Cambodia. SWOT analysis is a technique to analyze an organization internally as well as externally. Results of SWOT show the organization's strengths, weaknesses, opportunities, and threats, and results are used as part of strategies for planning, organizing, and developing. An analysis of strategy progress of development helps to solve the problem, to have good achievement for development. Moreover, the results can be used to make predictions in the future especially if the strategies that are decided on likely to bring successful outcomes. Or if strategies are not implemented, SWOT will be used to find the effects that may occur in different aspects. The results of these effects will be controlled and used to solve the problems or obstacles in the future. Strategies for dealing with unexpected events can be flexible and depend on the specifics of each situation (Pickton & Wright, 1998).

# CHAPTER IV

# RESULTS AND DISCUSSION

## 4.1 The Rubber Agroforestry System Practices in Eastern Cambodia

### 4.1.1 Rubber-based Soybeans (*Glycine max.*)

#### a) The Techniques of Plot Management

The topography condition of this plot is upland area, and soil is red clay loam type (basaltic soil). This plantation has been cultivated rubber trees (PB 260 clone) since 2015 by 6 × 3 m planting distance equaling to single row, 6 m inter-rows, and 3 m inter-trees in the same row. The rubber density is 555 trees per hectare. This plot has been applied chemical fertilizer (20-20-15+TE) 166 kg per hectare once a year. Weeding has been practiced by spraying herbicide 2 times per year. Pruning shoot of rubber trees has been practiced 2 times per year during raining season. Moreover, soybean also has been planted in the rubber inter-rows by 0.5 × 0.5 m planting distance equaling to single row, 0.5 m inter-rows, and 0.5 m inter-trees in the same row equaling to 26,664 trees per hectare in 2018. Before planting soybean, land was prepared 1 time by plowing. One month after soybean planting, farmer applied chemical fertilizer about 100 kg per hectare one time per a crop cycle, 3.5 months. Weeding has been practiced 2 times by spraying herbicide, and pest control has been practiced 1 time by spraying pesticide. During the initial 3 years of immature period of rubber trees, the area of rubber plantation is about 80% that is used potentially for annual intercropping. This intercrops can provide a significant additional income during immature period of rubber and soil organic matter, reduce density and biomass of annual weeds in inter-rows of rubber trees and cost of management, increase land productivity, and prevent soil erosion also (Lim *et al.,* 2015).

**b) The Economic Margin**

There are 2 produces as rubber and soybean in this plantation. In 2018, this plantation was expended for the total cost equal to 351.71 USD per hectare. Income from soybean products was 738.22 USD per hectare, and rubber trees were still young which was not ready for harvesting. Rubber trees will be started the first tapping in 2021 or 2022. Farmer had gotten the total margin from this plantation per hectare equaled to 386.51 USD in 2018. The soybean is an annual crop, so soybean can be cultivated in rubber plantation only when rubber trees are still young under 4 years old. The livelihood of farmers cannot be success if the rubber price is still low and continues low price in the future.

### 4.1.2 Rubber-based Peanut (*Legume)*

**a) The Techniques of Plot Management**

The topography condition of this plot is upland area, and soil is red clay loam type (basaltic soil). Rubber trees (PB 260 clone) have been cultivated in 2015 by 6 × 3 m planting distance equal to single row, 6 m inter-rows, and 3 m inter-trees in the same row. The rubber density is 555 trees per hectare. These rubber trees have been applied with chemical fertilizer (20-20-15+TE) 166 kg per hectare once a year. Weeding has been annually practiced 2 times during the raining season. Pruning shoot of rubber trees has been annually practiced 2 times during the raining season. Moreover, at rubber inter-rows peanut has been planted by 0.5 m × 0.5 m planting distance equal to single row, 0.5 m inter-rows, and 0.5 m inter-trees in the same row equal to 26,664 trees per hectare in 2018. Before planting peanut, land was prepared 1 time by plowing. One month after planting peanuts, farmer applied chemical fertilizer about 100 kg per hectare one time. Weeding has been practiced 2 times by spraying herbicide. The peanut's product was harvested at fourth month after planting. Rubber-based legume, rubber trees were growing well with intercrop legume in shallow soil. Rubber-based intercrop provides more leaf nutrient content and healthier root length density in the deepest soil layers. In deep soils, water and soil profile and water potential indicated that rubber trees and intercrops had advanced to improved water extraction in depth below 1.10 m. Rubber trees' root traits could be controlled via intercrops increased drought resistance (Clermont-Dauphin *et al.*, 2018).

**b) The Economic Margin**

In this plantation, there are 2 produces such as rubber and peanut. In 2018, this plantation was expended for the total cost equal to 380.98 USD per hectare. Income from peanut products was 738.05 USD per hectare and rubber trees were still young which were not ready for harvesting. Rubber trees will be started the first tapping in 2020 or 2021. Farmer got the total margin from this plot per hectare equal to 386.34 USD in 2018. The peanut crop is an annual crop, so peanut can be cultivated in rubber plantation only the first 3 years of rubber plantation during rubber trees are still young under 4 years old.

### 4.1.3 Rubber-based Chicken Raising

**a) The Techniques of Plot Management**

The topography condition of this plot is upland area, and soil texture is red clay loam type (basaltic soil). Rubber trees (GT1 clone) have been cultivated by 6 × 3 m planting distance equal to single row, 6 m inter-rows, and 3 m inter-trees in the same row in 2009. The rubber density is 555 trees per hectare. This rubber plantation has been applied chemical fertilizer (20-20-15+TE) about 150 kg and organic fertilizer about 1,200 kg per hectare once a year. Weeding has been practiced 3 times per year during the raining season. The rubber trees were started tapping in 2015 when rubber trees were 6 years old. The harvesting used tapping system as S/2 d3 98/120 Pa 2 (2) 10/y ET 2.5%. In 2018, girth of the rubber trees at 1.70 m high from the ground surface was 59.2 cm on average, and rubber coagulum product was 2940 kg per hectare. Moreover, in this rubber plantation, the farmer has raised chicken since 2018. The chicken cage was designed with 12 m long × 3 m wide and 3 m high. Cage was built on a rubber inter-row. Farmer had raised 300 chickens in 2018. Chicken cage was cleaned every month. Farmer always feed food and water chickens every morning. Also, rubber plantation had source of food and shade of rubber trees was good place for raising chicken especially in dry season. Every 3.5 months, the chickens were-sold following the next cycle of raising. Farmer got free chicken manure from chickens to be fertilizer material for applying on rubber trees and other plants.

**b) The Economic Margin**

There are 2 products from planting rubber trees and raising chickens in this RAS plot. In 2018, this plot was expended the total cost per hectare equal to 1,404 USD. Income of this plot was composed of 1,764 USD per hectare from rubber products and 2,025 USD from chicken products. Meanwhile, rubber wood will provide income in 2049. Therefore, farmer got the total margin from this plot equal to 2,385 USD per hectare in 2018. By simulating for 6-year period from 2019 to 2024 and the related prices are fixed in 2018 (Figure 12), the farmer would get increasing of rubber margin until 2021. Then, rubber margin will start decreasing until the end year of simulation because of product fluctuation by old age of rubber trees. Besides, the chicken products margin will increase in 2019 because farmer will add number of raised chickens. In 2024, last year of the simulation, rubber product will share the margin 871 USD per hectare, and chicken product will share the margin 2,695 USD. The total margin of this plot in 2024 equal to 3,566 USD per hectare higher than the total margin of plot in 2018 about 33.11%. Therefore, the farmer of rubber-based chicken plot can overcome economic fluctuation even though rubber price has been still low and rubber product has been decreased by old age of rubber trees. Somboonsuke *et al.* (2019) indicated that in 10-year economic model (2017 to 2026) of farmers who practiced two different agricultural systems had gotten the dissimilar total income. Farmers practice rubber mono-farming system had gotten the lowest income and those practiced RAS had gotten high income, so livelihood of RAS farmers is success. Jongrungrot (2016) had revealed that RAS was the most resistant to uncertainties and risks of economic fluctuation because various products of other plants and/or animals had been provided numerous income sources during long none-tapping period of rubber trees as well as improved more income during rubber trees have been harvesting also (Stroesser *et al.*, 2018). Moreover, the plot still has rubber wood whose economic values will be accumulated by age, and all rubber trees can give greatly environmental services.

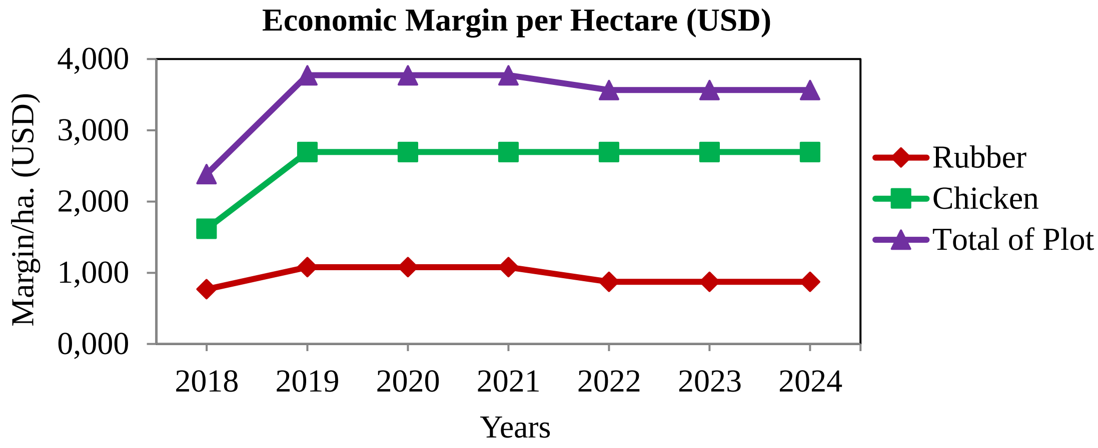
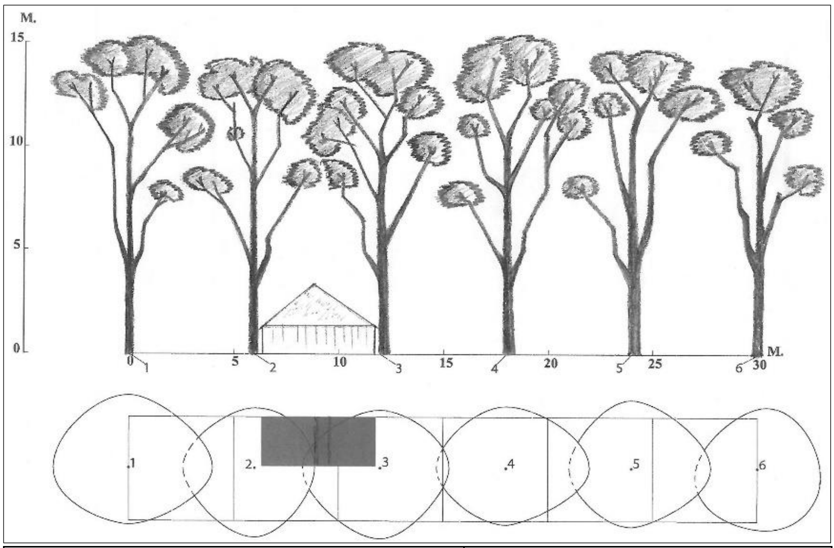



**Figure 12** Margins of Rubber-based Chicken Raising Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 13 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based chicken plot. The plant community structure is composed of rubber trees with upper canopies as well as chicken cage with lower canopies, respectively. The rubber trees and chicken cage have heights range from 14.5 to 15.2 m and 3 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. The rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground covered with grass as well as fallen and decayed leaves and branches of the rubber trees. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and chicken cage in the representative area which is about 86% of the area. For the area where is without chicken cage in this plot, the cover of canopies of rubber trees is only about 75%. Meanwhile, Ruangpanit (2014) found that soil cover by having a canopy density, not less than 70% can reduce soil erosion. Then, the crown cover with multiple levels of vertical stratification and crown cover percentages of rubber trees and chicken cage in rubber-based chicken plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot. Kittitormkool *et al.*, (2019) revealed that the average crown cover of all plants in rubber agroforestry system plots were over 80% and the plant community structures were great potential to preserve water and soil due to the multiple levels of vertical stratification of plant species. Bumrungsri *et al.* (2012) studied the environmental dimensions in the same research areas resulted that the amount of runoff in rubber mono-cropping plots had been 0.3 to 5 times higher than those in the RAS plots. The quantity of moisture in the RAS plot had been 1.4% higher than those in the rubber mono-cropping plots. Litter fall in the rubber agroforestry system had been 1.5 to 1.8 times higher than those of the rubber mono-cropping plots. Also, various roots of all plats have grown following crown cover, so roots can hold topsoil to preserve soil erosion in plots (Kittitornkool *et al.,* 2014).




| | |
|---|---|
| Rubber trees | 1,2,3,4,5, and 6 |
| Chicken cage | House |

**Figure 13** The Plant Community Structures and Crowns Cover in Representative Rectangular area (5 × 30 m) of Rubber-based Chicken Raising Plot

### 4.1.4 The SWOT of RAS Practices in Eastern Cambodia

SWOT analysis indicates a background for helping the government and farmers to identify the strategies for achieving goals. This is a technique used to analyze the internal factors (strengths and weaknesses) and external factors (opportunities and threats) of RAS practice in Eastern Cambodia. The rubber farmers in Cambodia practice only annual intercrops and raising chicken in rubber plantations as planting RAS.

Internal factors are the factors of RAS practices that indicate the strengths and weaknesses. Firstly, strengths of RAS practices, famers have practiced RAS on their own agricultural lands. Farmers used family labor and sharing labor of farmer group in all activities of RAS farms without hiring labor. The RAS practice provides biodiversity, soil moisture, cool temperature, self-sustaining fertilizer via plant nutrient cycling, much shade of trees, mitigated soil erosion in upland area, high land equivalent ratio of productivity, divers income via variety of products in plot, weeding expenditure, good society due to sharing experience and products to neighbors and friends, and well co-existence of various plants and animals in plots. RAS gives more rubber yield than rubber mono-cropping plantation due to the fallen leaves decompose into fertilizer and RAS practice helps keep moisture in area. Especially, the intercrops, livestock and rubber trees can live co-existence in single RAS plot. However, RAS practices have some weaknesses too. RAS is divided into four main characteristics based on the criteria of separating agricultural production of farm activities such as rubber-timber tree system, rubber-fruit tree system, rubber-other crop system, and rubber-livestock farming system (Somboonsuke et al., 2011). Cambodian rubber famers practice only planting annual intercrops and raising chicken as RAS, so farmers lack some knowledge and experience of RAS. Most of the farmers practice rubber mono-cropping system. Also, the most of rubber farmers have gotten loan from banks for practicing rubber plantation, so farmers lack capital account for cultivating RAS. Finally, famers also lack knowledge of RAS products processing, marketing RAS products, and some knowledge, e.g., how to produce the fruit products in different season. In addition, in Cambodia, the concerned institutions are insufficient for current rubber agroforestry system research works.

External factors are the factors of RAS practices that indicate the opportunities and threats. Firstly, those are opportunities of RAS practices. The rubber development department of General Directorate of Rubber (GDR) in Cambodia has policy to extend the rubber smallholders' planting area throughout organizing workshop for extension about technique of planting rubber and intercrop for only annual and covered crop every year. Some farmers have participated in community enterprise. Farmers can bargain the price in market, hunts good market for their products for their RAS product and get loan with low interest rate through participate with this enterprise. Rubber price in the country follows the rubber price of global market, so this enterprise cannot negotiate to raise the rubber price in local market level. This enterprise also is the central rubber market, rubber processing rubber sheet product, and the center for farmers sharing the agricultural technique and experiences with each other. There are high demands of fruits and livestock in Cambodian market. Farmers can plant fruit trees and raise livestock in rubber plantations as RAS toward supporting the market in Cambodia. In the end, this is an opportunity also that the RAS practice complied with standard of Forest Stewardship Council (FSC) according to Principle 6: environmental values and impacts, the area of the management unit shall be maintained, conserved and/or restored ecosystem services and environmental values of the management unit, and shall be avoided, repaired or mitigated negative environmental impacts. Secondly, those are threats of RAS practices. Most of fruit and livestock products in Cambodian market have been imported from other countries around Cambodia such as Thailand, Vietnam, etc., meanwhile, the local fruit and livestock products are still more expensive than these of the oversea products (Table 12). The rubber product is low price. Alternatively, the farmers can change the rubber mono-cropping system practice to rubber agroforestry system practice, participate with farmer group, avoid selling the latex or cup lump, and alternative to make the rubber sheet for surviving themselves when rubber price is dropping. Besides, climate change such as drought, storm, flood and unpredictable rainfall affects the growth and products of rubber trees and intercrops, and it destroyed the plantation, e.g., the storm caused plant trees to fall. The four main Strengths, Weaknesses, Opportunities, and Threats of RAS practices in Eastern Cambodia were determined at the end of the thematic analysis and strategic suggestions of the study indicated in Figure 14.

**Table 12** Some Agricultural Products' Price per Kg (USD) in Cambodian Market

| No. | Products | Cambodian Products | | Oversea Products | | Demand of Market |
|---|---|---|---|---|---|---|
| | | Price in Local | Price in Market | Cost | Price in Market | |
| 01 | Rambutan | 1,50 | 2.00 | 1.25 | 2.00 | High |
| 02 | Mangosteen | 2.25 | 3.00 | 1.75 | 3.00 | High |
| 03 | Pomelo | 1.62 | 1.87 | - | - | Medium |
| 04 | Guava | 1.12 | 1.38 | - | - | Medium |
| 05 | Durian | 4.00 | 5.75 | 3.50 | 5.00 | High |
| 06 | Passionpruit | 1.50 | 2.50 | 1.25 | 2.00 | High |
| 07 | Jackfruit | 0.62 | 1.00 | - | - | Medium |
| 08 | Champedak | 1.00 | 1.75 | - | - | Medium |
| 09 | Orang | 0.75 | 1.25 | 0.62 | 1.25 | High |
| 10 | lemon/Limes | 1.00 | 1.75 | - | - | High |
| 11 | Papaya | 0.70 | 0.88 | - | - | High |
| 12 | Avokado | 2.12 | 3.00 | 1.75 | 3.00 | High |
| 13 | Sweetsop | 1.25 | 2.00 | - | - | High |
| 14 | Soursop | - | - | 1.25 | 2.00 | Medium |
| 15 | Salak fruit | - | - | 1.50 | 3.00 | High |
| 16 | Longkong | - | - | 1.25 | 1.75 | Medium |
| 17 | Coffee | 1.00 | - | - | - | High |
| 18 | Cocoa | 0.30 | - | - | - | High |
| 19 | Beef | 8.75 | 1.05 | - | - | High |
| 20 | Pork | 4.65 | 5.50 | 3.00 | 4.25 | High |
| 21 | Chicken | 5.25 | 7.00 | 2.00 | 3.25 | High |
| 22 | Duck meat | 3.00 | 4.50 | 3.00 | 3.50 | Medium |
| 23 | Goat meat | 4.00 | 10.00 | - | - | Medium |

**Source:** Ministry of Commerce of Cambodia (2018)

Not* Oversea products come from Thailand and Vietnam.

| Internal Factors / External Factors | **Strengths (S)** | **Weaknesses (W)** |
|---|---|---|
| | $S_1$: Famers have land property and family labors<br>$S_2$: RAS practices provide biodiversity, moisture, much shade, increasing income, reducing expenditure in plots, and high land equivalent ratio of productivity etc.<br>$S_3$: Intercrops, livestock and rubber trees can live co-existence in RAS plots. | $W_1$: Famers lack knowledge and experience of RAS, RAS products processing and marketing<br>$W_2$: Farmers lack capital account for cultivating RAS<br>$W_3$: Insufficient current RAS research works by concerned institutions |
| **Opportunities (O)**<br>$O_1$: The RAS practice is complied with standard of Forest Stewardship Council (FSC), Principle 6: environmental values and impacts<br>$O_2$: The district agricultural extension office and GDR have policy for RAS extension (only annual intercrop)<br>$O_3$: The farmer group helps farmers to bargain the price in market, hunts good market for their products and be a central rubber processing (rubber sheet).<br>$O_4$: Farmers who participate with farmer group get loan with low interest rate in farmer groups<br>$O_5$: Local product price is higher than that of oversea product | **SO Strategies**<br>$SO_1$: The group of farmers should ask the certificate from FSC for products of RAS practices<br>$SO_2$: The rubber farmers should cultivate RAS and participate with farmer group | **WO Strategies**<br>$WO_1$: The government should associate the good agricultural practice (GAP), skills of processing RAS products, and RAS technique into policy of extension for rubber farmers<br>$WO_2$: The RAS research should be practiced in all rubber producing provinces<br>$WO_3$: The government should seriously implement the policy of RAS and GAP extension in all rubber producing provinces |
| **Threats (T)**<br>$T_1$: Rubber product price is low<br>$T_2$: Competition of fruit and livestock's products by other countries in the market<br>$T_3$: Climate change effects such as drought, storm, flood and unpredictable rainfall affected the growth and products of intercrops and rubber trees.<br>$T_4$: Shortage of agricultural labor (tapper) wages.<br>$T_5$: Banks' loan is high interest rate | **ST Strategies**<br>$ST_1$: The government should have policy to encourage or support rubber farmers to cultivate RAS and participate with farmer group<br>$ST_2$: RAS farmers should select the intercrops and/or livestock which match market demand | **WT Strategies**<br>$WT_1$: Commercial ministry should create the policy to find market for RAS farmers' agricultural products<br>$WT_2$: Farmers should participate with famer group for sharing RAS knowledge each other<br>$WT_3$: GDR and CRRI should create experimental and demonstrative RAS plots at farmers' farms and laboratory files |

**Figure 14** SWOT Matrix of RAS Practices in Eastern Cambodia

## 4.2 The Rubber Agroforestry System Practices in Southern Thailand

### 4.2.1 Rubber-based Fruit Tree

#### 4.2.1.1 Rubber-based Sala Fruit and Yangsain Tree Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIM 600 clone), yangsain timber tree (*dipterocarpus alatus* Roxb.), and Sala fruit trees (*Zalacca edulis* Reinw.). Topography condition of this plot is plain area, and the soil is silt loam type. Firstly, rubber trees were planted in 2005 by 7 × 3 m planting distance equal to single row, 7 m inter-rows, and 3 m inter-trees in the same row. The rubber density is 476 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation was used for the plot harvesting. In 2018, girth growth of rubber trees at height 1.70 m from ground surface was 67.2 cm on average, and rubber product was 2,100 kg per hectare. The rubber wood in this plot will be harvested in 2045. Secondly, Yangsain trees was planted in 2010 after planting rubber trees by 7 × 6 m planting distance equal to 238 trees per hectare. Girth of yangsain trees at 1.30 m high from ground surface was 40.3 cm on average in 2018, and timber wood will be harvested in 2045. Finally, Sala fruit trees also was planted in this plot also by (4 + 3 m) × 2 m planting distance equal to double row, 4 and 3 m inter-rows, and 2 m inter-trees in the same row in 2013. The Sala density is 1,428 trees per hectare. There were 888 female Sala trees and 540 male Sala trees per hectare. Sala had been harvested since 3-years old, and Sala fruit product was 2,662.50 kg per hectare in 2018. Farmers always combined Sala pollens by pollinating male pollen on female flower to produce fruits after male genitalia were produced by male Sala trees. Pollen fruit products would be harvested in 6-7 months after breeding. 10 female Sala trees need the supporting pollen of 5 male Sala trees for producing fruit products per year. If farmers keep pollen of male Sala in refrigerator for using, pollen can be used for 2 years. The Sala trees always have been pruned every time after harvesting. This RAS plantation has not been applied fertilizer for 10 year ago and weeding often has been practiced 2 times per year at only tapping way in RAS plantation. Sala trees were not irrigated water because RAS plot have enough moisture for all plants. Farmer reported that there were many birds in plot. The fallen leaves with other organic materials composed to become organic fertilizer in this RAS plots. Chen *at el.* (2019) showed that the RAS had significantly improved the soil physical and hydrological properties, and soil nutrients had been improved by all plants in plots also. The total soil porosity, initial soil moisture, soil mean weight diameter, and soil hydraulic conductivity in RAS systems increased on average by 13.3%, 54.7%, 31.5%, and 246.4%, and the nutrients of C, N, P, Ca, and Mg increased on average by 38.8%, 38.5%, 48.2%, 47.9%, and 31.4%, respectively.

**b) The Economic Margin**

There are 3 products as rubber, yangsain trees, and Sala fruits in this RAS plot. In 2018, this plot was expended for the total cost equal to 109 USD per hectare. The income from rubber products was 2,898 USD per hectare. Sala fruit was 5,272 USD per hectare. Especially, yangsain and rubber wood will provide income in 2045. Therefore, farmer got the total margin from this plot equaled to 8,061 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 15), farmer will get lower income from rubber in sequence until replanting rubber trees via rubber product has been decreased by old age of rubber trees. In 2024, the last year of the simulation, the farmer will get decreasing of rubber margin in order every year because of low product by old age of rubber trees. Rubber product per hectare will share margin 1,961 USD. Farmer will get more products of Sala from year by year, so the income from Sala has been increased in order by age. Sala product will share margin 7,064 USD per hectare. The total margin from this plot in 2024 equal to 9,025 USD per hectare higher than total margin of plot in 2018 about 10.68%. Therefore, farmer of rubber-based Sala fruit and yangsain trees plot can overcome economic fluctuation even though rubber product is decreased, and rubber price is still low. Somboonsuke *et al.* (2019) indicated that in 10-year economic model (2017-2026) of farmers who practiced two different agricultural systems had gotten the dissimilar total income. Farmers practiced rubber mono-farming system had gotten the lowest income, and those practice RAS had gotten high income, so livelihood of RAS farmers is success. Jongrungrot (2016) had revealed that RAS had been the most resistant to uncertainties and risks of economic fluctuation because various products of other plants and/or animals had been provided numerous income sources during long none-tapping period of rubber trees as well as improved more incomes during rubber trees had been harvesting also (Stroesser *et al.*, 2018). Moreover, the plot still has yangsain and rubber wood whose economic values will be accumulated, and all trees can be greatly used for environmental services.

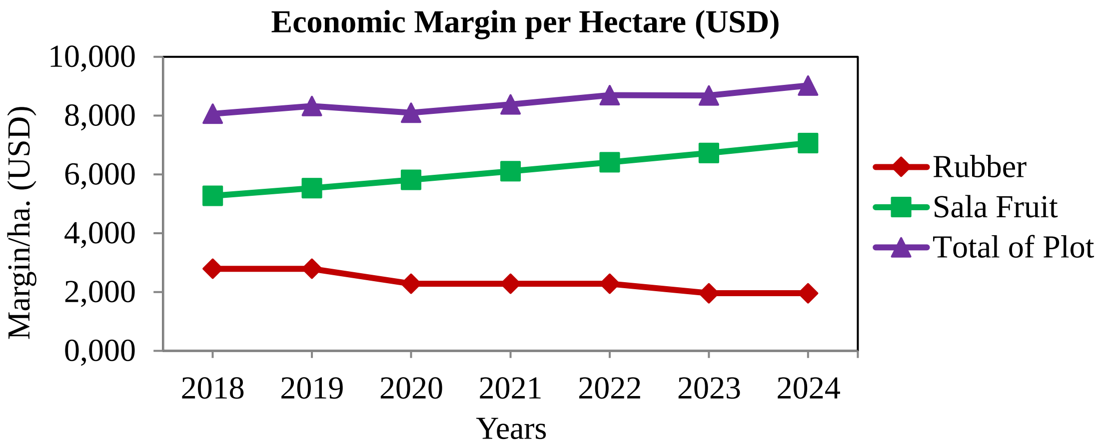
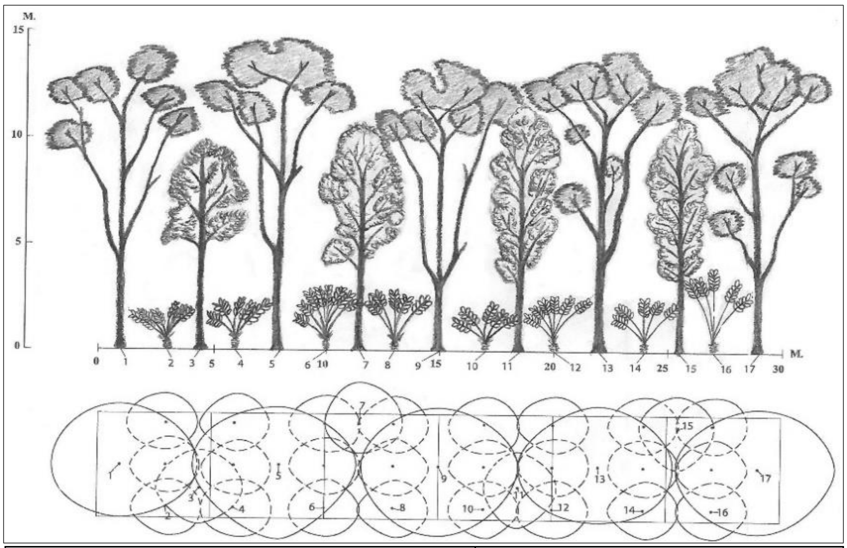



**Figure 15** Margins of Rubber-based Sala Fruit and Yangsain Tree Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 16 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based Sala fruit and yangsain tree plot. The plant community structure is composed of rubber trees with upper canopies as well as yangsain and Sala with lower canopies. The rubber trees, yangsain, and Sala have heights range from 14 m to 14.90 m, 10.10 m to 12 m, and 2.50 m to 3.10 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers, yangsain, and Sala. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees, yangsain and Sala in the representative area which is about 99.5% of the area. Meanwhile, Ruangpanit (2014) found that soil covered by having a canopy density, not less than 70% could reduce soil erosion. Then, the crown cover in rubber-based Sala fruit and yangsain tree plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species. The averages of crown cover of all plants in rubber agroforestry system plots were over 80%, so the plant community structures were great potential to preserve water and soil, due to the multiple levels of vertical stratification of plant species (Kittitormkool *et al.*, 2019). Bumrungsri *et al.* (2012) studied the environmental dimensions in the same research areas found that the amount of runoff in mono-cropping rubber plots had been 0.3 to 5 times higher than those in RAS. The quantity of moisture in the rubber agroforestry system had been 1.4% higher than those in the rubber mono-cropping plots. Litter fall in the RAS had been 1.5 to 1.8 times higher than those of the rubber mono-cropping plots. Also, various roots of all plats have grown following crown cover, so roots can hold topsoil to preserve soil erosion in plots (Kittitornkool *et al.*, 2014).




| | |
|---|---|
| Rubber trees | 1, 5, 9, 13 and 17 |
| Yangsain trees | 3, 7, 11, and 15 |
| Sala plants | 2, 4, 6, 8, 10, 12, 14 and 16 |

**Figure 16** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Sala Fruit and Yangsain Tree Plot

**4.2.1.2 Rubber-based Mangosteen Fruit Plant Plot**

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated mangosteen (*Garcinia mangostana* L.) with rubber trees (RRIM 600 clone) on the same land management. The land topography of this plot is plain area, and the soil is sandy loam type. Rubber trees were planted in 2002 by 7 × 3 m planting distance equal to single row, 7 m inter-rows, and 3m inter-trees in the same row. The rubber density is 476 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system S/3 3d/4 183/273 nil stimulation was used for the plot harvesting. The rubber wood will be harvested in 2042. Besides, mangosteen was planted in 2005 by 8 × 7 m planting distance equal to 178 trees per hectare. Mangosteen was started for harvesting fruit products when mangosteens were 5 years old, and they would be always harvested 1 time per year in September. Mangosteen trees will be cut down in 2042. This RAS plantation is applied with chemical fertilizer (15-15-15) 250 kg and organic fertilizer 300 kg per hectare 2 times per year. The weeding would be practiced 2 times before applying fertilizer. The farmer had reported this RAS plantation that the fallen leaves and chemical fertilizer has been decomposed into fertilizer, and this RAS practice provided shade and moisture in plot especially in dry season and the fallen leaves period of rubber trees. As a result, rubber trees provide much latex than those rubber trees in rubber mono-cropping plots. In 2018, girth of rubber trees at 1.70 m high from ground surface was 72.4 cm on average, and rubber product was 1,875 kg per hectare. Girth of mangosteen trees at height 1.30 m from ground surface was 38.4 cm on average, and mangosteen fruit product was 1,000 kg per hectare.

**b) The Economic Margin**

There are 2 products which are rubber and mangosteen fruit in this RAS plot. In 2018, this plot was expended the total cost equal to 482 USD per hectare. The income from rubber product was 2,588 USD per hectare, and mangosteen fruit was 500 USD per hectare. Especially, rubber wood will provide income in 2042. Therefore, farmer got the total margin from this plot equal to 2,606 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 17), farmer will get lower income from rubber in sequence until replanting rubber trees via rubber product has been decreased by old age of rubber trees. In 2024, last year of the simulation, rubber product per hectare will share margin 1,998 USD. Farmer will get more products of mangosteen from year by year, so the income from mangosteen has been increased in order by age, and in 2024 mangosteen product will share margin 641 USD per hectare. The total margin from this plot equaled to 2,640 USD per hectare higher than the total margin of plot in

2018 about 1.28% in 2024. Therefore, farmer of rubber-based mangosteen fruit plot can overcome economic fluctuation even though rubber product has been decreased and rubber price is still low. Moreover, the plot still has rubber wood which economic values will be accumulated, and all trees can be greatly used for environmental services.

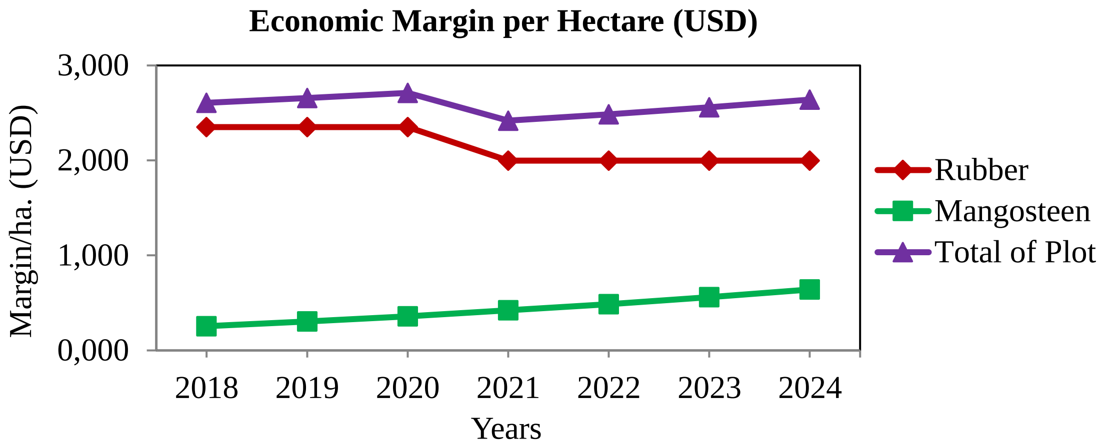
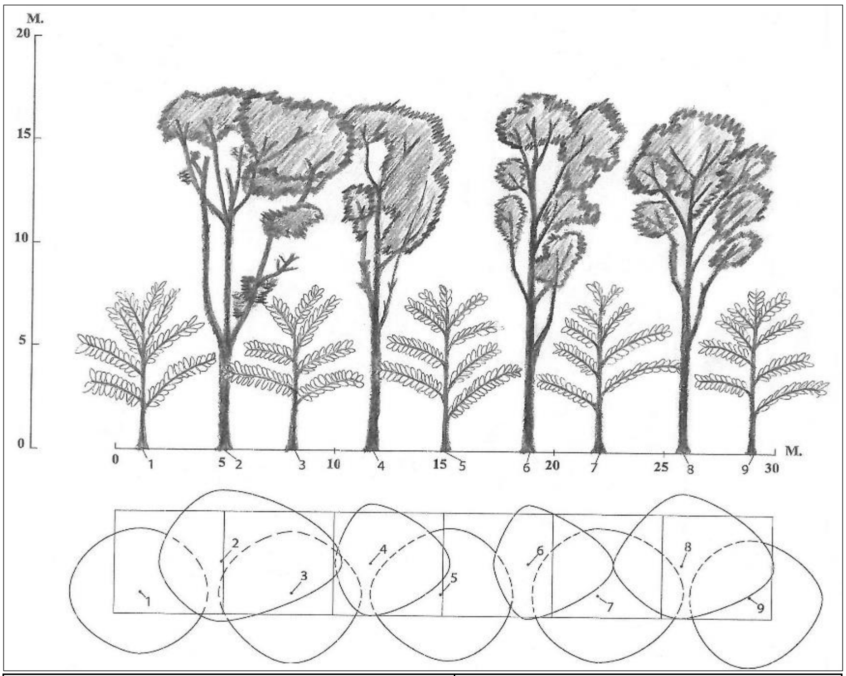



**Figure 17** Margins of Rubber-based Mangosteen Fruit Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 18 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based mangosteen fruit plot. The plant community structure is composed of rubber trees with upper canopies as well as mangosteen plants with lower canopies. The rubber trees and mangosteen plants have heights range from 16 to 17.5 m and 8 to 8.5 m, respectively. When raining season is coming, all canopies will do firstly “interception” by absorbing rain drops until saturated. Then, the rest of raindrops will be “stemflow” and “throughfall” to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers and mangosteen plants. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and mangosteen plants in the representative area which is about 95% of the area. Then, the crown cover in rubber-based mangosteen fruit plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species.




| | |
|---|---|
| Rubber trees | 2, 4, 6 and 8 |
| Mangosteen | 1, 3, 5, and 9 |

**Figure 18** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Mangosteen Plant Plot

#### 4.2.1.3 Rubber-based Longkong Fruit Tree Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated longkong (*lansium domesticum Corr.*) with rubber trees (RRIM 600 clone) on the same land management. Land topography of this plantation is plain area, and the soil is sandy loam type. Longkong trees were planted in 2006 by 9 × 6 m planting distance equal to single row, 9 m inter-rows, and 6 m inter-trees in the same row. The longkong density is 185 trees per hectare. Longkong products were started for harvesting fruit products when trees were 6 years old, and trees are always harvested once a year in September. Longkong trees will be cut down in 2049. Besides, rubber trees were planted on the same area with longkong in 2008 by 6 × 3 m planting distance equal to 555 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system S/3 3d/4 130/273 nil stimulation was used for the plot harvesting. Rubber trees will be harvested timber wood in 2049. This RAS plantation has been applied with chemical fertilizer (15-15-15) 212 kg per hectare and organic fertilizer 312 kg per hectare, a time in May per year. Weeding has been practiced before applying fertilizer. Farmer reported that the fallen leaves and fertilizer blended and decomposed into fertilizer in this RAS plantation, so there were many nutrients in plot for all plants. This practice provides shade, low temperature, and moisture in plot especially in dry season and fallen leaves period of rubber trees. As a result, rubber trees provided much latex. The girth of rubber trees at 1.70 m high from ground surface was 70.2 cm on average, and rubber product was 2,600 kg per hectare. The girth of longkong trees at 1.30 m high from ground surface was 46.6 cm on average, and longkong's fruit product was 1,456.25 kg per hectare in 2018.

**b) The Economic Margin**

There are 2 products as rubber and longkong fruit in this RAS plot. In 2018, this plot was expended the total cost equal to 302 USD per hectare. The income from rubber products was 3,588 USD per hectare, and longkong fruit was 1,019 USD per hectare. Especially, rubber wood will provide income in 2049. Therefore, farmer got the total margin from this plot equaled to 4,305 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 19), farmer will get lower income from rubber in sequence after 2020 because rubber product has been decreased by age of rubber trees. In 2024, last year of the simulation, rubber product per hectare will share margin 2,190 USD. Farmer will get more products of longkong from year by year, so the income from longkong has been increased in order by age. In 2024, longkong product will share margin 1669 USD per hectare. The total margin from this plot equaled to 3,868 USD per hectare lower than the total margin of plot in 2018 about 11.32% in 2024. Therefore, farmer of this plot has longkong fruits to increase the plot margin even though rubber product has been decreased and rubber price is still low. Moreover, the plot still has rubber wood and longkong wood which economic values will be accumulated, and all trees can be greatly used for environmental services.

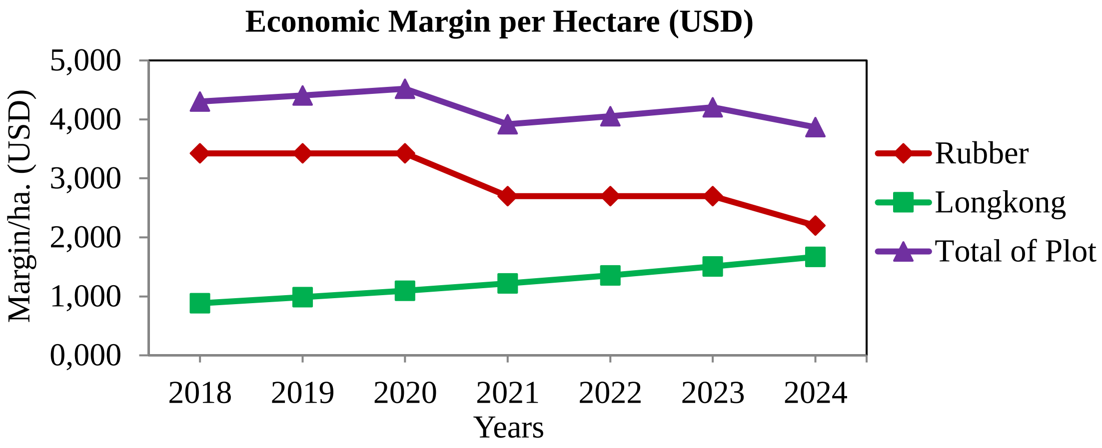
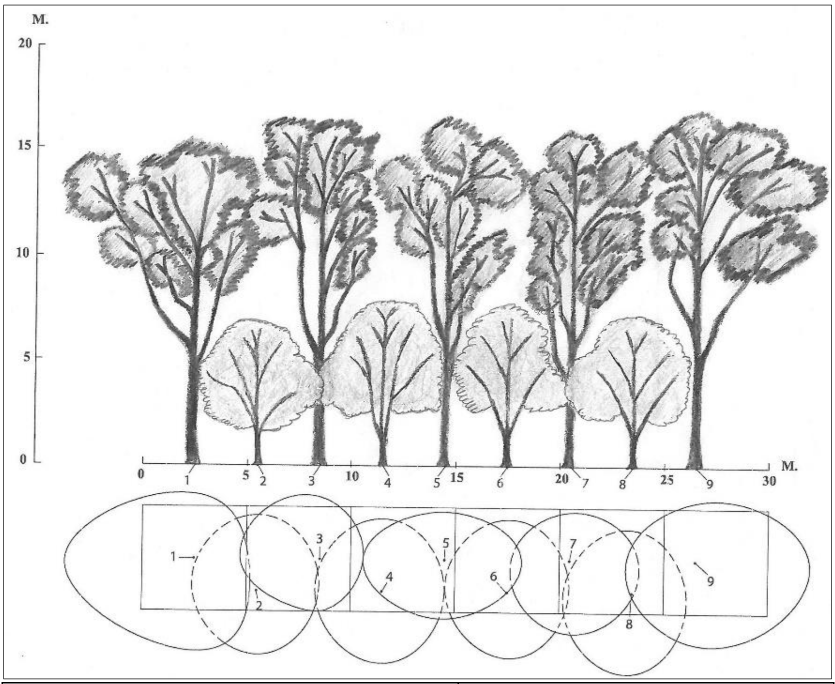



**Figure 19** Margins of Rubber-based Longkong Fruit Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 20 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based longkong fruit plot. The plant community structure is composed of rubber trees with upper canopies as well as longkong plants with lower canopies. The rubber trees and longkong plants have heights range from 15.5 to 16.5 m and 6 m to 7 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers and longkong plants. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and longkong plants in the representative area which is about 94.5% of the area. Then, the crown cover in rubber-based longkong fruit plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species.




| | |
|---|---|
| Rubber trees | 1, 3, 5, and 9 |
| Longkong | 2, 4, 6 and 8 |

**Figure 20** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Longkong Fruit Plot

#### 4.2.1.4 Rubber-based Coffee Fruit Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees, RRIM 600 clone and coffee (*Arabica)* on the same land management. The topography condition of this plot is upland area, and the soil is sandy loam type. Rubber trees were planted in 2007 by 7 × 3 m planting distance equal to single row, 7 m inter-rows, and 3 m inter-trees in the same row. The rubber density is 476 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation is used for the plot harvesting. These rubber trees will be harvested the wood in 2047. Furthermore, coffee fruit trees were planted on the same area by (5 + 2 m) × 2.5 m planting distance equal to double rows, 5 and 2 m inter-rows, and 2.5 m inter-trees in the same row between the rubber rows in 2013. The Coffee density is 1,142 trees per hectare. Coffee fruit products have been harvested since coffee fruit trees were 4 years old. Coffee fruit will be always harvested 1 time per year in October, and coffee plantation will be replanted in 2047. This RAS plantation has been applied with organic fertilizer (6-3-3) 2 times per year in May and October with 312 kg per hectare at a time. Weeding often has been practiced 2 times before applying the fertilizer. Farmers reported RAS plantation that weeds could not grow well as the same as weeds in rubber mono-cropping plots, and the rubber trees provided much latex than those in rubber mono-cropping plots because there were more shade, moisture, and organic matter in plot. In 2018, the girth of rubber trees at 1.70 m high from ground surface was 62.9 cm on average, and rubber product was 2,419 kg. Coffee fruit product was 625 kg per hectare.

**b) The Economic Margin**

There are 2 products which are rubber and coffee fruit in this RAS plot. In 2018, this plot was expended the total cost per hectare equal to 382 USD. The income from rubber products was 3,338 USD per hectare, and coffee fruit was 844 USD per hectare. Especially, rubber wood will provide income in 2049. Therefore, farmer got the total margin from this plot equaled to 3,800 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 21), farmer will get lower income from rubber in sequence because rubber product has been decreased by old age of rubber trees. In 2024, last year of the simulation, rubber product per hectare will share margin 1,894 USD. Farmer will get more products of coffee from year by year, so the income from coffee has been increased in order by age, and in 2024 coffee product will share margin 1422 USD per hectare. The total margin from this plot equaled to 3,316 USD per hectare lower than the total margin of plot in 2018 about 14.60% in 2024. Therefore, the farmer of this plot has coffee products to increase the plot margin even though rubber product has been decreased, and rubber price is still low. Moreover, the plot still has rubber wood which economic values will be accumulated, and all trees can be greatly used for environmental services.

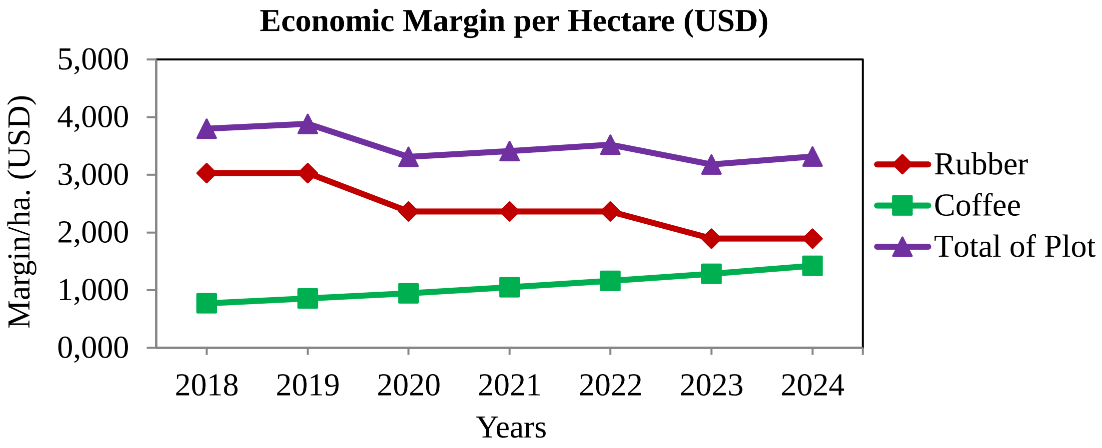
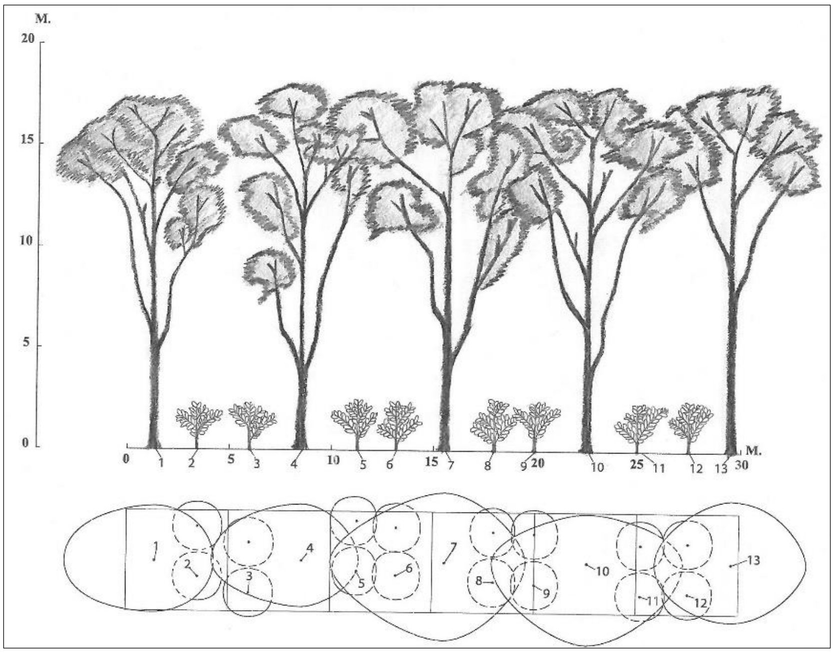



**Figure 21** Margins of Rubber-based Coffee Fruit Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 22 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based coffee fruit plot. The plant community structure is composed of rubber trees with upper canopies as well as coffee trees with lower canopies. The rubber trees and coffee trees have heights range from 18 to 18.5m and 2.20 to 2.5 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers and coffee trees. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of rubber trees and coffee trees in representative area which is about 95.5% of area. Then, the crown cover in rubber-based coffee fruit plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of plant species.




| | |
|---|---|
| Rubber trees | 1, 4, 7, 10 and 13 |
| Coffee plants | 2, 3, 5, 6, 8, 9, 11 and 12 |

**Figure 22** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Coffee Fruit Plot

**4.2.1.5 Rubber-based Sala Fruit and Neem Tree Plot**

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIM 600 clone), neem timber tree (*Azadirachta indica*.) and Sala fruit trees (*Zalacca edulis* Reinw.). The topography condition of this plantation is upland area, and the soil is sandy clay loam type. Rubber trees were planted in 2007 by 6 × 3 m planting distance equal to single row, 6 m inter-rows, and 3 m inter-trees in the same row. The rubber density is 555 trees per hectare. The farmer started tapping when rubber trees were 4 years old. Tapping system as S/3 3d/4 130/273 nil stimulation is used for the plot harvesting. In 2018, girth of rubber trees at 1.70 m high from ground surface was 54.5 cm on average, and rubber product was 940 kg per hectare. Neem timber trees have been planted on the same area with rubber trees by (4 + 2 m) × 6 m planting distance equal to double row, 4 and 2 m inter-rows, and 6 m inter-trees in the same row in 2009. The neem density is 554 trees per hectare. Girth of neem trees at 1.30 m high from ground surface was 69 cm on average, and wood of neem and rubber trees will be harvested in 2047 at the same time. Furthermore, Sala fruit plants also had been planted at the middle of inter-row by 6 × 1.5 m planting distance equaling to 1,111 trees per hectare in 2009. There are 90% female and 10% male Sala trees in plot. Sala fruits have been harvested since sala trees were 2 years old. Farmers always combine pollen of Sala by pollinating male pollen on flower of female to produce Sala fruits. The fruit products will be harvested in the sixth to seventh month after breeding. Sala fruits were harvested 5,000 kg per hectare in 2018. Farmer mixed pollens of male Sala with powder and kept them in bottle for 2 years. Sala trees always will be pruned every time after harvesting. This RAS plantation has been applied with organic fertilizer for 250 kg once per year in October, and weeding has been practiced before applying the fertilizer and after weed growing well. Sala trees always were irrigated 2 times per week during Sala fruits had appeared until nearly harvesting.

**b) The Economic Margin**

There are 3 products which are rubber, neem timber trees, and Sala fruits in this RAS plot. In 2018, this plot was expended the total cost per hectare equal to 682 USD. The income from rubber products was 1,297 USD per hectare, and Sala fruit was 9,900 USD per hectare. Especially, neem and rubber wood will provide income in 2047. Therefore, farmer got the total margin from this plot equaled to 10,515 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 15), farmer will get lower income from rubber in sequence because rubber product has been decreased by old age of rubber trees. In 2024, last year of the simulation, rubber product per hectare will share the margin 689 USD. Farmer will get more products of Sala from year by year, so the income from Sala has been increased in order by age. In 2024, Sala product will share margin 12,806 USD per hectare. The total margin from this plot in 2024 equaled to 13,495 USD per hectare higher than the total margin of plot in 2018 for about 22.08%. Therefore, farmer of rubber-based Sala fruit and neem timber trees plot can overcome economic fluctuation even though rubber product is decreased, and rubber price is still low. Moreover, the plot still has neem and rubber wood which economic values will be accumulated, and all trees can be greatly used for environmental services.

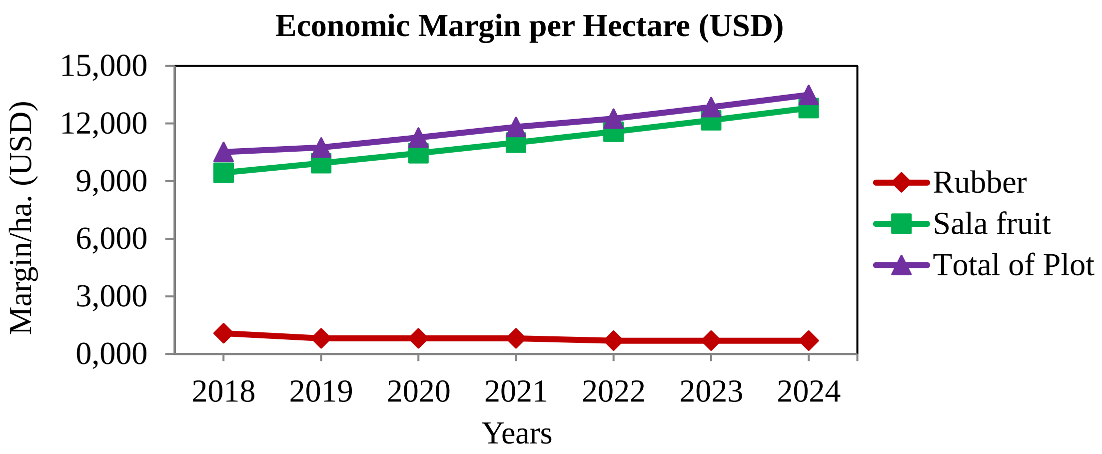
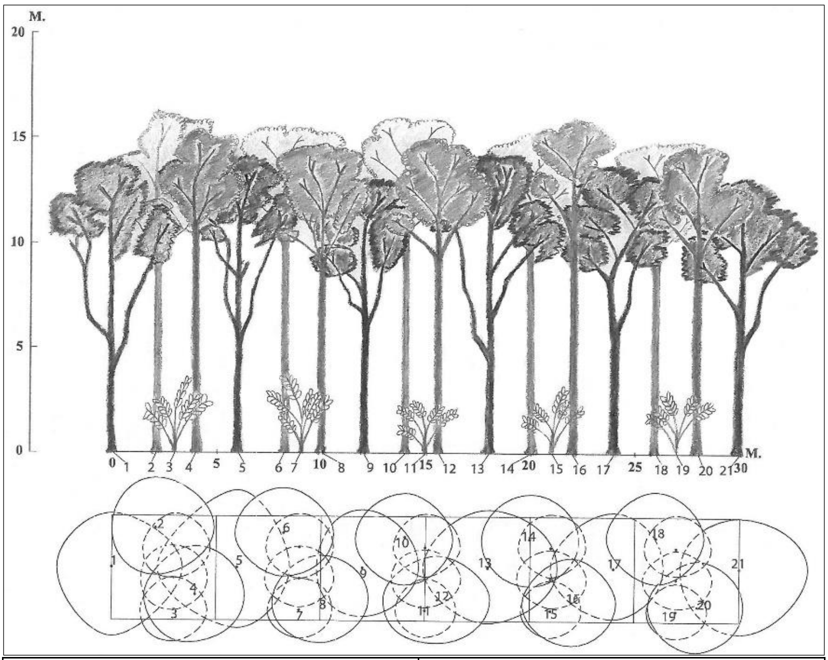



**Figure 23** Margins of Rubber-based Sala and Neem Tree Plot from 2018 to 2024

### c) The Plant Community Structure and Crown Cover

Figure 24 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based Sala fruit plot. The plant community structure is composed of rubber trees with upper canopies as well as neem timber trees and Sala plants with lower canopies. The rubber trees, neem trees, and sala plants have heights range from 13 m to 14 m, 15.20 m to 16.0 m, and 3 m to 3.50 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers, neem trees and Sala plants. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees, neem trees and Sala plants in the representative area which is about 98.5% of the area. Then, the crown cover in rubber-based Sala fruit plot has a great potential to protect soil from directly rainfalls and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species. Also, various roots of all plants have grown following crown cover, so roots can hold topsoil to preserve soil erosion in plots.




| | |
|---|---|
| Rubber trees | 1, 5, 9, 13, 17 and 21 |
| Neem trees | 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 |
| Sala fruit plants | 3, 7, 11, 15 and 15 |

**Figure 24** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Sala and Neem Trees Plot

**4.2.1.6 Rubber-based Champadak Fruits and Phakleang Vegetable Plot**

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIM 600 clone), champadak (*Artocarpus integer* Merr.) phakleang (*Gnetum gnemom var.*), longkong, durian, and mangosteen on the same area. Topography condition of land is upland area, and the soil is sandy loam type. Firstly, rubber trees were planted by 10 × 2.5 m planting distance equaling to single row, 10 m inter-rows, and 2.5 m inter-trees in the same row in 1997. The rubber density is 400 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 2d/4 120/182 nil stimulation was used for the plot harvesting. The rubber timber wood will be harvested in 2037. Secondly, in the same year of planed rubber tree, champadak fruit trees (136 trees per hectare), longkong fruit trees (10 trees per hectare), durian fruit trees (10 trees per hectare), and mangosteen fruit trees (10 trees per hectare) were planted at the same area with rubber tree by 10 × 6 m plant distance equaling to single row, 10 m inter-rows, and 6 m inter-trees in the same row. Then, their density is 166 trees per hectare. Longkong, durian, and mangosteen have been planted for consumption in household only. Champadak fruit trees have been harvested since trees have been 6 years old. Thirdly, phakleang vegetable plant were planted in the middle of rubber inter-row by 5 × 2.5 m planting distance in 2017. Then, the phakleang density is 800 trees per hectare. The farmer had harvested phakleang products since they were 6 months old. The frequency of harvesting phakleang is amount 40 weeks per year. This RAS plantation has not been applied any fertilizer and weeding often has been practiced 2 times every year. Farmers reported that this RAS plantation did not need to apply with chemical fertilizer because the fallen leaves and organic matters decomposed into fertilizer. The RAS helps to reduce the requirement of external input fertilizer management so those result in regulating C and nutrient cycles implying. RAS gave higher levels of tendency for plant part decomposition than those in rubber mono-cropping system. Macrofauna and nutrient content in the topsoil had been also observed at higher levels density in RAS. Calcium dominated the intra-couples. This could regulate physical properties and soil processes and further help C and nutrient cycles that value against low external input fertilizer management (Tongkaemkaew et al., 2018). All plants and fallen leaves of rubber trees in plots help keep moisture especially in dry season period. RAS practice is better way because there are microorganisms, biodiversity, and many birds in plot also. RAS helps to reduce fallen leaves period of rubber trees. In 2018, stem girth of rubber trees at 1.70 m high from ground surface was 79.4 cm on average. Rubber product was 1,518.75 kg per hectare. Girth of champadak trees at height 1.30 m was 68.6 cm from surface ground on average, and champadak product was 7,437.50 kg per hectare. Also, phakleang's product was 3,000 kg per hectare.

**b) The Economic Margin**

There are 3 main products which provide economic income of this RAS plot as rubber products, champadak fruits, and phakleang vegetable products. In 2018, this plot was expended the total cost per hectare equal to 104 USD. The income from rubber products, champadak fruit, and phakleang vegetable per hectare 2,096 USD, 5,206 USD, and 2,550 USD., respectively. Rubber wood will provide income in 2037. As a result, farmer got the total margin from this plot equal to 9,748 USD per hectare and future income of wood also. For simulation for 6-year period during 2019-2024 and related prices are fixed in 2018 (Figure 7), the farmer will get low and stable rubber margin per hectare every year because of low and stable products by old age of rubber trees. In 2024, rubber product will share the margin 1,992 USD per hectare. Farmer will get more products of champadak and phakleang from year by year. Champadak will share the margin 6,976 USD per hectare. Phakleang vegetable product will share the margin 3,417 USD per hectare. The total margin from this plot equaled to 12,385 USD per hectare higher than the total margin in 2018 about 21.29% in 2024. Therefore, rubber-based champadak fruit and phakleang vegetable plot owner can overcome economic fluctuation even though rubber product has been decreased and rubber price is still low. Moreover, the plot still has wood products of four kinds of fruits and the rubber trees which economic values will be accumulated by age, and all trees can be greatly used for environmental services.

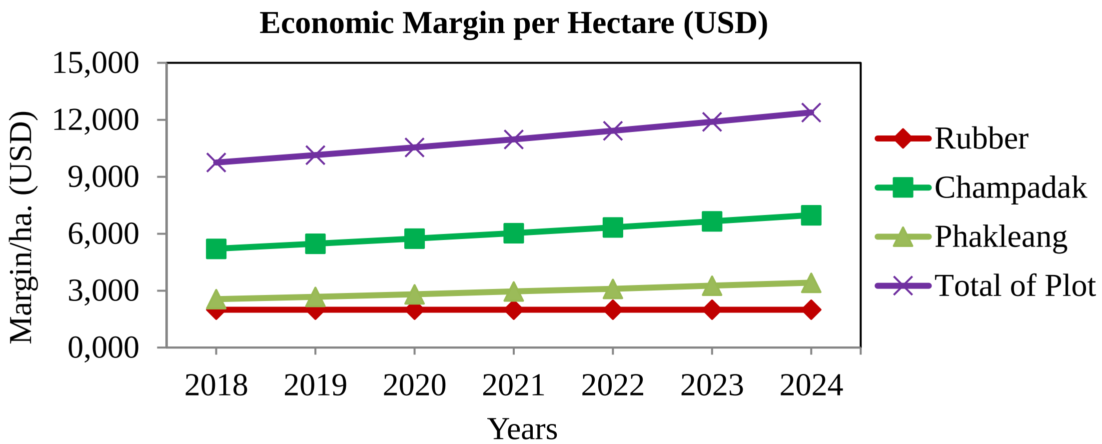
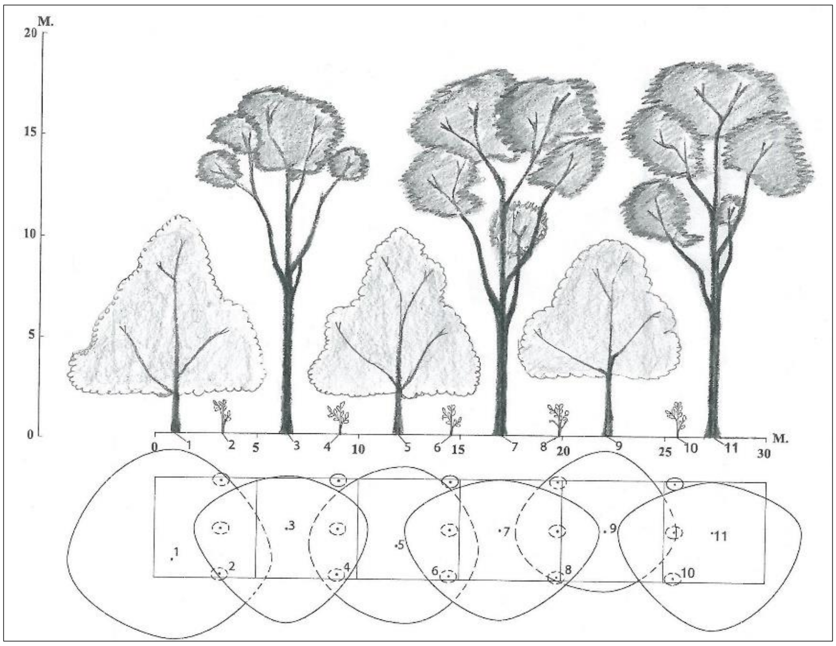



**Figure 25** Margin of Rubber-based Champadak Fruits and Phakleang Vegetable Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 26 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of this plot but will present only the co-existing area of three main economic plants. The plant community structure is composed of rubber trees with upper canopies as well as champadak and phakleang with lower canopies, respectively. The rubber trees, champadak trees, and phakleang crops have heights range from 17 m to 18 m, 9 m to 10.5 m, and 1.50 m to 1.70 m., respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubber trees. All the plants in this plot that had fallen and decayed. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees, champadak trees and phakleang plants in the representative area which is about 98% of the area. Then, the crown cover in this plot has a great potential to protect soil from direct rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of plant species. Also, various roots of all plants have grown following crown cover, so they can hold topsoil to prevent soil erosion in plots. Zhu *et al.,* (2019) revealed that the various roots in RAS be role to contribute the water to deeper drainage and recharge. Different soil hydraulic properties with different parts in a RAS make the spatial sharing surface and belowground water with improving water availability for various plants as well as different root systems. Reducing runoff generation and soil erosion, promoting groundwater recharge, and increasing water storage that reduce the effect of the intervention and transpiration losses from rubber trees which donate to the water resources' management by association of intercrops with rubber trees is better infiltration and increased preferential. The cooperative hydraulic recontribution in RAS could reorganize water in soil well along the slope and below ground. Thus, soil drought on a flat raised area can be mitigated during dry season (Wu *et al.,* 2017).




| | |
|---|---|
| Rubber trees | 3, 7 and 11 |
| Champadak trees | 1, 5 and 9 |
| Phakleang plants | 2, 4, 6, 8, and 10 |

**Figure 26** The Plant Community Structure and Crown Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Champadak fruit and Phakleang Vegetable Plot

### 4.2.2 Rubber-based Timber Tree

#### 4.2.2.1 Rubber-based Ironwood Timber Tree Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIT 251 clone) with ironwood trees (*Hopea odorata* Roxb.) on the same land management. The land topography of this plantation is plain area, and the soil is silt loam type. Rubber trees were planted by 6.5 × 3.5 m planting distance equaling to single row, 6.5 m inter-rows, and 3.5 m inter-trees in the same row in 2006. The rubber density is 439 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 d2 6d/7 86/182 nil stimulation was used for the plot harvesting. Moreover, Ironwood trees also were planted in the same land by 6 × 6 m planting distance equaling to single row, 6 m inter-rows, and 6 m inter-trees in the same row in 2008. The ironwood density is 277 trees per hectare. The rubber trees and ironwood trees will be harvested for the timber wood at the same time in 2046. This RAS plantation has been applied with chemical fertilizer (15-15-15) 437.50 kg per hectare a time every year and applied organic fertilizer 625 kg per hectare every three year per time. After weed grow very well, weeding often has been practiced every time a year. Besides, farmer reported that this RAS plantation needed to practice a little weeding in a year because weeds could not grow as well as weeds in rubber mono-cropping plots. Rubber trees provide more constant latex than those in rubber monoculture plots because RAS plot has more shape, moisture, and organic matters. In 2018, the stem girth of rubber trees at high 1.70 m from surface of ground was 61.8 cm in average, and rubber product was 1,509 kg per hectare. The girth of ironwood trees at high 1.30 m from surface of ground was 34.2 cm in average. This plot also has 8 ironwood trees planted at the same time as rubber trees in 2006, the girth was 60 cm in average in 2018. On other hand, tapping panels take long time to dry after raining in this RAS plots, so rubber trees are lately tapped. But if rubber trees were equipped with the rain guard, the tapping panels of rubber trees would dry early than before.

**b) The Economic Margin**

There are 2 products which were rubber and ironwood trees in this RAS plot. In 2018, this plot was expended total cost per hectare equal to 1,835 USD. This plot farmer expended much cost because he expended 40% of rubber products for tapping service. Income of rubber products was 3,470 USD per hectare. Ironwood and rubber wood will provide income in 2037. Therefore, farmer got the total margin from this plot equal to 1,635 USD per hectare. For simulation for 6-year period during 2019-2024 and related rubber price is fixed in 2018 (Figure 27), the farmer will get low rubber margin per hectare every year because of decreased products in sequence by old age of rubber trees, and rubber price is still low also. In 2024, rubber product will share the total margin about 928 USD per hectare lower than the total margin of plot in 2018 about 43.24%. Therefore, rubber-based ironwood tree plot owner gets single income from rubber product in present and will get additional income from ironwood and rubber wood in the future, and the trees can be greatly used for environmental services.

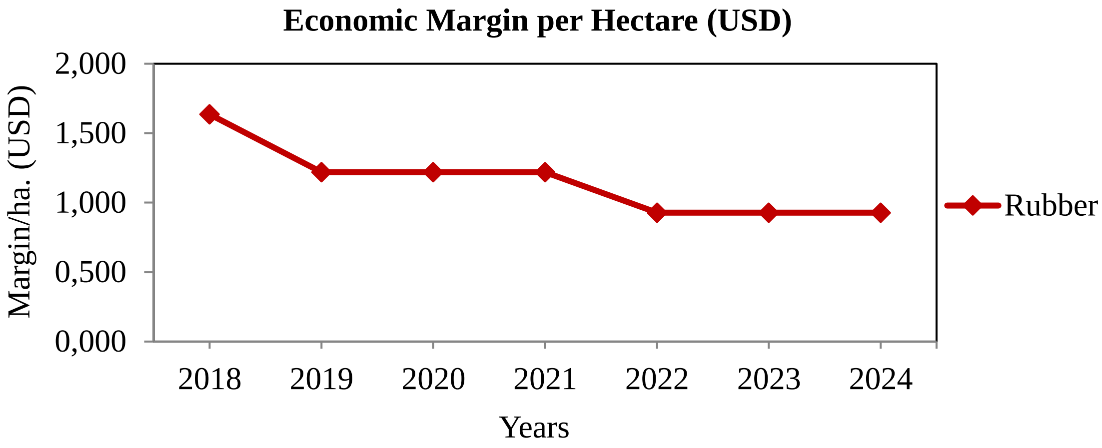
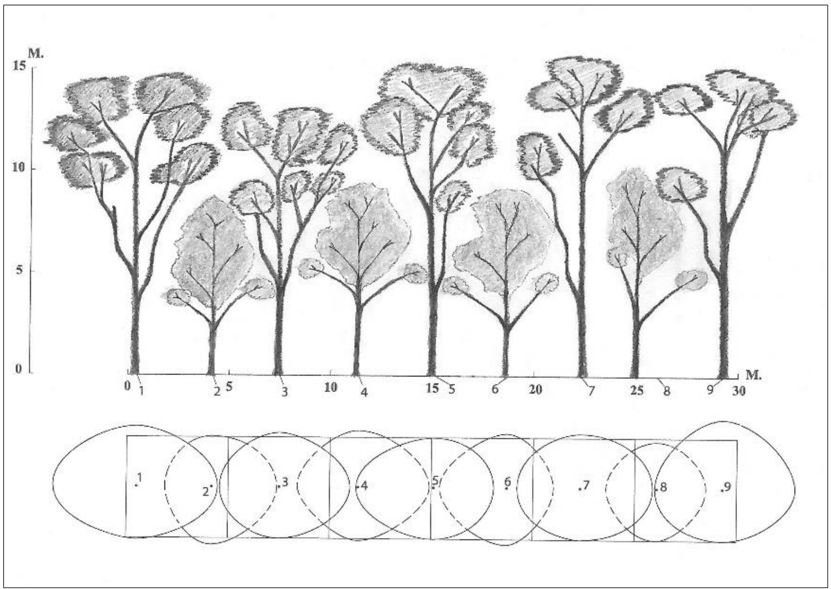



**Figure 27** Margins of Rubber-based Ironwood Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 28 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based ironwood timber trees plot. The plant community structure is composed of rubber trees with upper canopies as well as ironwood with lower canopies. The rubber trees and ironwood have heights range from 14.5 m to 15.5 m and 9 m to 10 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers and ironwood. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and eaglewood in the representative area which is about 95% of the area. Then, the crown cover in rubber-based ironwood timber trees plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species as well.




| | |
|---|---|
| Rubber trees | 1, 3, 5, 7 and 9 |
| Ironwood trees | 2, 4, 6 and 8 |

**Figure 28** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Ironwood Plot

#### 4.2.2.2 Rubber-based Eaglewood Tree Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIM 600 clone) and eaglewood trees (*Aquilaria crassna*). The topography condition of this plantation is upland area, and soil is sandy loam type. Rubber trees were planted by 8 × 3 m planting distance equal to single row, 8 m inter-rows, and 3 m inter-trees in the same row in 1997. The rubber density is 416 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation was used for the plot harvesting. Also, Eaglewood trees were planted on the same area with rubber trees by 8 × 3 m planting distance equaling to 416 trees per hectare in 2004. This RAS plot has been applied chemical fertilizer (30-30-68) once a year in June; with applying 300 kg per hectare of organic fertilizer alternate yearly. Weeding often has been practiced one time yearly before applying fertilizer. The Eaglewood and rubber trees will be harvested the timber wood at the same time in 2037. Moreover, farmers reported that this RAS plantation needed to practice weeding only once a year because weeds could not grow as same as weeds in rubber mono-cropping plots. The rubber trees in RAS provide more latex than those in rubber monoculture plots because RAS plot has more shade, moisture, and organic matters. The comparison of latex yield from RAS and rubber monoculture plantation in demonstration plots, the latex yield in RAS plots was higher productivity or appeared 70% than rubber monoculture plots, however it depended on the well farm management of farmers also. Rubber farmers who got the RAS knowledge from this demonstration plots started to accept RAS practice as alternative to both low rubber price and intensive jungle rubber. The combined RAS practice of new technology using clonal rubber with traditional RAS practice has been successful. RAS practice also provides more benefits to environment and biodiversity contrasted to rubber monoculture system (Wibawa *et al.,* 2008). In 2018, girth of rubber trees at height 1.70 m from surface of ground was 78.8cm on average. Rubber product was 1,575 kg per hectare. The girth of eaglewood trees at height 1.30 m from surface of ground was 65.7 cm on average.

**b) The Economic Margin**

There are 2 products which are rubber and eaglewood trees in this RAS plot. In 2018, this plot was expended total cost per hectare equal to 1,040 USD. This plot farmer expended much cost because 40% of rubber product was expended for tapping service. Income of rubber products was 2,173 USD per hectare. Eaglewood and rubber wood will provide income in 2037. Therefore, farmer got the total margin from this plot equal to 1,133 USD per hectare. For simulation for 6-year period during 2019-2024 and related rubber price is fixed in 2018 (Figure 29), the farmer will get low and stable rubber margin per hectare every year because of low and stable products by old age of rubber trees. In 2024, rubber product will share the total margin 1,133 USD per hectare which is same the total margin in 2018. Therefore, the rubber-based eaglewood tree plot owner get single income from rubber product in present and will get additional income from eaglewood and rubber wood in the future. All trees can be greatly used for environmental services as well.

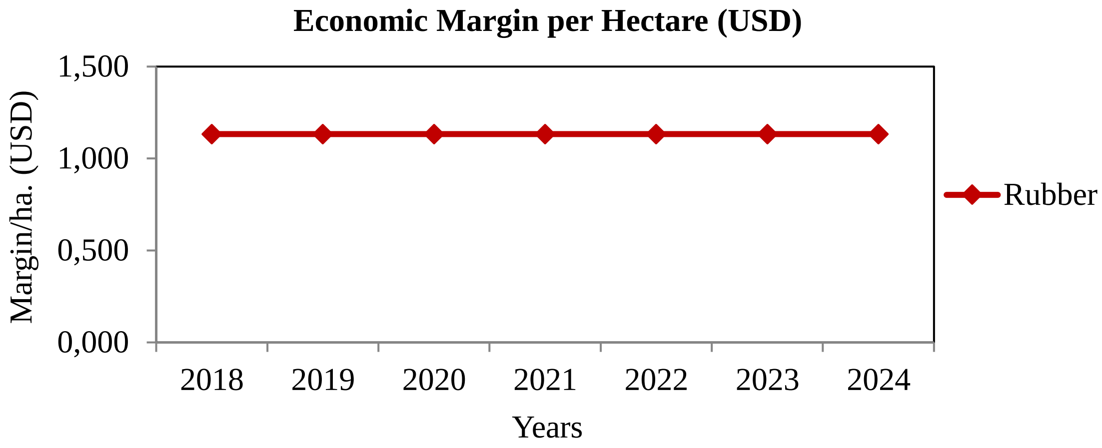
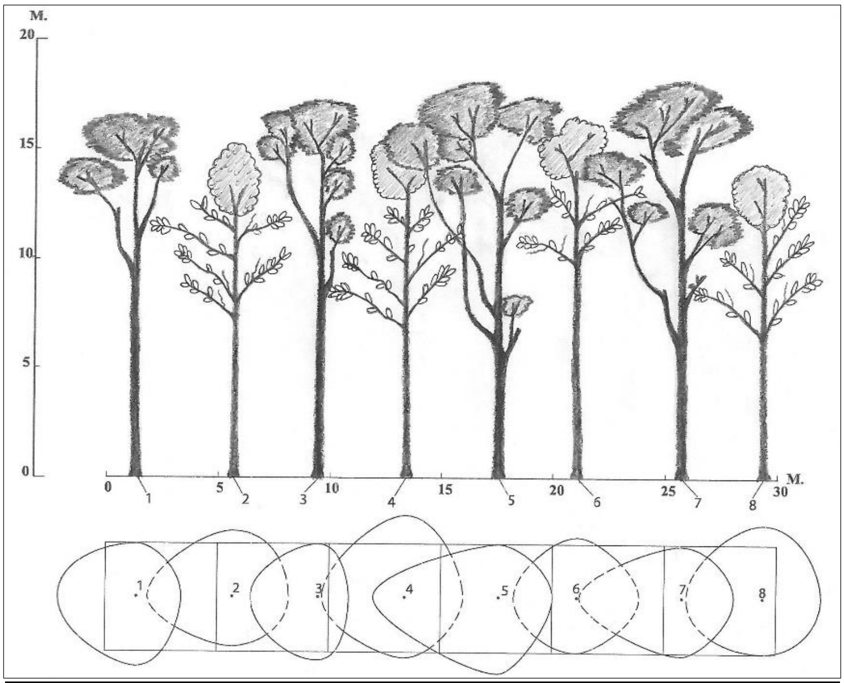



**Figure 29** Margins of Rubber-based Eaglewood Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 30 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based eaglewood trees plot. The plant community structure is composed of rubber trees with upper canopies as well as eaglewood with lower canopies. The rubber trees and eaglewood trees have heights range from 17 m to 19 m and 16 m to 17 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers and eaglewood. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and eaglewood in the representative area which is about 95% of the area. Then, the crown cover in rubber-based eaglewood trees plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species as well.




| Rubber trees | 1, 3, 5 and 7 |
| --- | --- |
| Eaglewood trees | 2, 4, 6, and 8 |

**Figure 30** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Eaglewood Plot

### 4.2.3 Rubber-based Other Plants and Livestock

#### 4.2.3.1 Rubber-based Bamboo (shoot product) and Queen Bee Raising Plot

**a) The Techniques of Plot Management**

This RAS plantation has been cultivated rubber trees (RRIM 600 clone), bamboo (*Bambusa sp.)*, and queen bees raising. The Topography condition of this plot is lowland area, and the soil is sandy loam type. Firstly, rubber trees were planted by 7 × 3 m planting distance equaling to single row, 7 m inter-rows, and 3 m inter-trees in the same row in 2004. The rubber density is 476 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation was used for the plot harvesting. These rubber trees will be harvested timber wood in 2044. Secondly, bamboo plant also was planted on the same plot by 7 × 15 m planting distance equal to 93 bushes per hectare between rubber rows in 2013. The bamboo shoots had been harvested since bamboo plants were 2 years old, 2 times per week for 9 months (in June to February next year). bamboo also often have been pruned after harvesting yearly. In a bamboo bush, farmers kept 5 to 7 stems for providing farmer the bamboo shoot products. The last product in this plantation was honey from queen bee. Raising queen bee was started in 2016, there were 6 beehives in this RAS plantation in 2018 also. Farmers arrange vitality of beehive and bee every rubber tapping day. In this RAS plantation, bees do not have only source of food from rubber trees in there, but bees have found some food from other plants around there also. Honey is always harvested annually during February to April, and bees provide honey about 3 liters per beehive box. This RAS plantation has been applied with chemical fertilizer (15-15-15) about 350 kg per hectare 1 time per year in June. Weeding often has been practiced 4 times after weed growing well and before applying fertilizer yearly. Bamboo bushes have been applied with salt 1 kg per bush once a year for improving the soil and preventing product of bamboo and applied annually with 22 kg chicken manure fertilizer 2 times per bush per time. Farmers reported that in this RAS plantation the fallen leaves and organic materials decomposed into fertilizer. All plants help keep much moisture in plot, especially in dry season which are the periods of the fallen leaves period of rubber trees also. In 2018, the stem girth of rubber trees at height 1.70 m from surface of ground was 66.7 cm on average. Rubber product was 2,258 kg per hectare. Bamboo product was 4,500 kg per hectare. Queen bee product (honey) was 18 liters per 6 beehive boxes.

**b) The Economic Margin**

There are many products from rubber, queen bee, and bamboo shoot in this RAS plot. In 2018, this plot was expended the total cost per hectare equal to 403 USD. The income of this plot was composed of 3,116 USD per hectare from rubber products, 475 USD from queen bee’s products (honey) 6 beehive boxes per hectare, and 2,250 USD per hectare from bamboo products. Meanwhile, rubber wood will provide income in 2044. Therefore, farmer got the total margin from this plot in 2018 equal to 5,841 USD per hectare. For simulation for 6-year period from 2019 to 2024 and related prices are fixed in 2018 (Figure 31), the farmer will get low rubber margin per hectare every year because of decreasing products by old age of rubber trees. Meanwhile, bamboo margin per hectare will increase every year owing to continuously increasing of bamboo shoots by age. And annual queen bees’ honey margin per hectare will rise outstandingly because the farmer will add the beehives and high price of honey every year also. In 2024, last year of the simulation, rubber product will share the margin 1,941 USD, bamboo product will share the margin 2,878 USD, and honey product will share the margin 7,802 per hectare. The total margin from this plot equal to 7,802 USD per hectare higher than the total margin of plot in 2018 about 30.31% in 2024. Therefore, the farmer of this RAS plot can overcome economic fluctuation even though rubber product and rubber price are still low. Moreover, the plot still has rubber wood which economic values will be accumulated by age. Queen bees help pollinate various flowers, and all trees can give greatly environmental services.

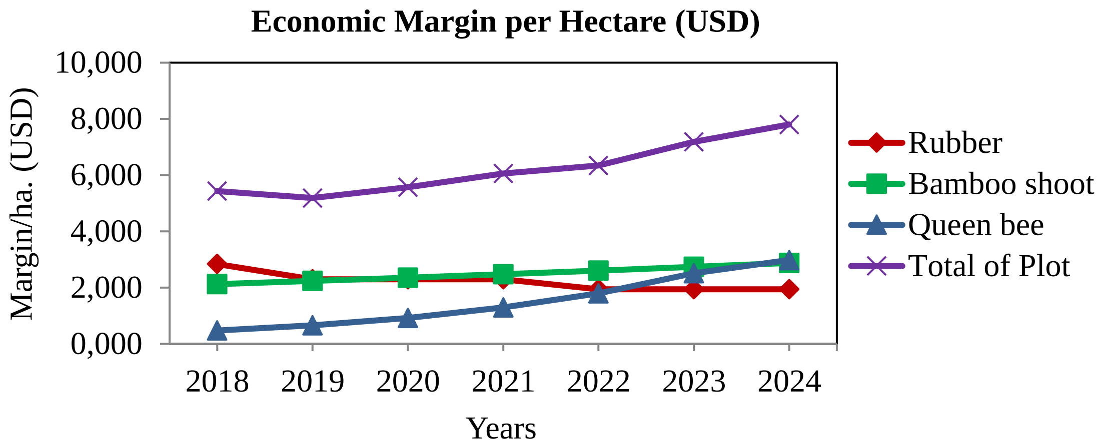
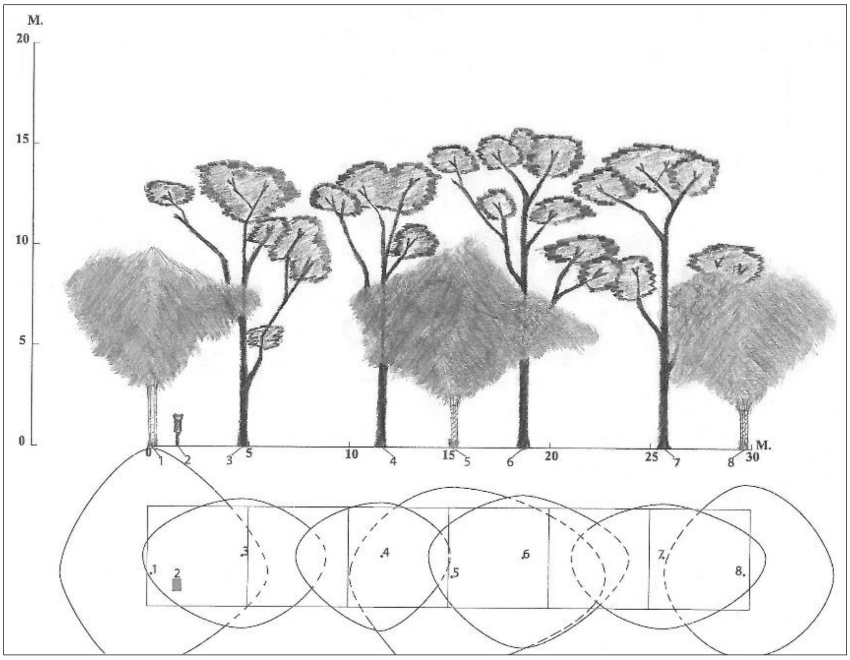



**Figure 31** Margins of Rubber-based Bamboo (shoot product) and Queen Bee Raising plot from 2018 to 2024

#### c) The Plant Community Structure and Crown Cover

Figure 32 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based bamboo plants plot. The plant community structure is composed of rubber trees with upper canopies as well as bamboo plants with lower canopies. The rubber trees and bamboo plants have heights range from 15 m to 15.8 m and 14.5 m to 10.50 m, respectively. When raining season is coming, all canopies will do firstly “interception” by absorbing rain drops until saturated. So, the rest of raindrops will be “stemflow” and “throughfall” to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubber trees and bamboo plants. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and bamboo plants in the representative area which is about 98.5% of the area. Then, the crown cover in rubber-based bamboo plant plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species as well.



| | |
|---|---|
| Rubber trees | 3, 4, 6, and 7 |
| Bamboo plants | 1, 5, and 8 |
| Beehive | 2 |

**Figure 32** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Bamboo (shoot product) and Queen Bee Raising plot

#### 4.2.3.2 Rubber-based Bamboo (stem product) and Queen Bee Raising Plot

##### a) The Techniques of Plot Management

This RAS plantation has been cultivated rubber trees (RRIM 600 clone), bamboo plant (*Bambusa sp.)*, and queen bees raising. The topography condition of this plot is lowland area, and the soil is sandy loam type. Rubber trees were planted by 7 × 3.5 m planting distance equal to single row, 7 m inter-rows, and 3.5 m inter-trees in the same row in 2011. The rubber density is 408 trees per hectare. These rubber trees have been applied with chemical fertilizer (15-15-15) 350 kg per hectare 1 time per year in June. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation was used for the harvesting. These rubber trees will be harvested for timber wood in 2051. Secondly, bamboo plant also was planted in rubber plantation by 7 × 9 m planting distance equaling to 158 bamboo bushes per hectare in the middle of rubber tree inter-rows in 2013. Bamboo bushes have been applied chicken manure fertilizer about 22 kg per bush for 2 times per year. The products of bamboo (bamboo stems) have been harvested once a year in April since bamboo stems were 2 years old. After harvesting, farmers prune bamboos and keep 10-15 bamboo stems of each bamboo bush for providing farmers the bamboo stem products next year. The last product in this plantation is honey from queen bee. Raising queen bee was started for cultivation in 2016, and until 2018 there were 8 beehives in RAS plantation. Farmers arrange vitality of beehive and bee every rubber tapping day. In this RAS plantation, bees do not have only source of food from rubber trees in there, but bees have found some food from other plants around there also. Rubber plantation has been called the Hevea honey because rubber trees are the source of bees' food. The food in rubber plantation is not only from the rubber flower but much is secreted by the extrafloral nectaries also (on young leaf petioles and fleshy scales of young shoots) (Priyadarshan, 2011). The farmer always harvests honey product during February to April. Weeding often has been practiced 4 times after weed growing well and before applying fertilizer. Farmers reported that this this RAS plantation had the fallen leaves and organic materials decomposed into fertilizer, all plants helped keep much moisture in plot especially in dry season which was the fallen leaves period of rubber trees also. In 2018, the stem girth of rubber trees at height 1.70 m from surface of ground was 56.4 cm on average. Rubber product was 1,657 kg per hectare. Bamboo product was 18,750 stems per hectare. Queen bee product (honey) was 24 liters per 8 beehive boxes per hectare.

**b) The Economic Margin**

There are many products from rubber, queen bee, and bamboo stem in this RAS plot. In 2018, this plot was expended the total cost per hectare equal to 465 USD. The income of this plot was composed of 2,287 USD per hectare from rubber products, 739 USD from queen bee's products (honey) 8 beehive boxes per hectare, and 1,313 USD per hectare from bamboo products. Meanwhile, rubber wood will provide income in 2044. Therefore, farmer got the total margin from this plot equal to 3,874 USD per hectare in 2018. For simulation for 6-year period during 2019-2024 and related prices are fixed in 2018 (Figure 33), the farmer will get increasing rubber margin per hectare in 2020-2022 and start to decrease in 2023 because of product fluctuation by old age of rubber trees. Meanwhile, bamboo margin per hectare will increase every year owing to continuously increasing of bamboo' product by age. And annual queen bees' honey margin per hectare will rise outstandingly because the farmer will add the beehives and high price of honey every year also. In 2024, last year of the simulation, rubber product will share the margin 2,328 USD per hectare, bamboo product will share the margin 1,567 USD per hectare, and honey product will share the margin 5,412 USD per hectare. The total margin from this plot equaled to 9,307 USD per hectare higher than the total margin in 2018 about 58.37% in 2024. Therefore, the farmer of RAS plot can overcome economic fluctuation even though rubber product and rubber price have been still low. Moreover, the plot still has rubber wood which economic values will be accumulated by age. Queen bees help pollinate various flowers, and all trees can give greatly environmental services.

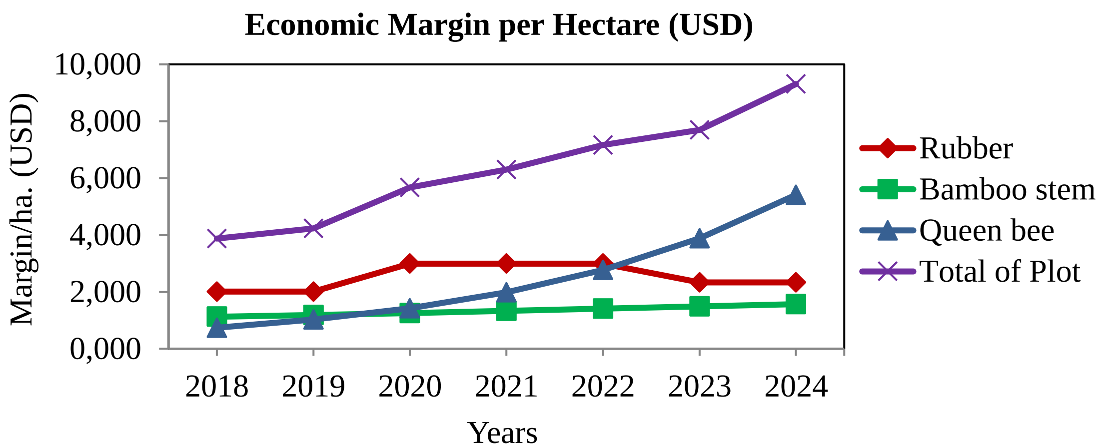
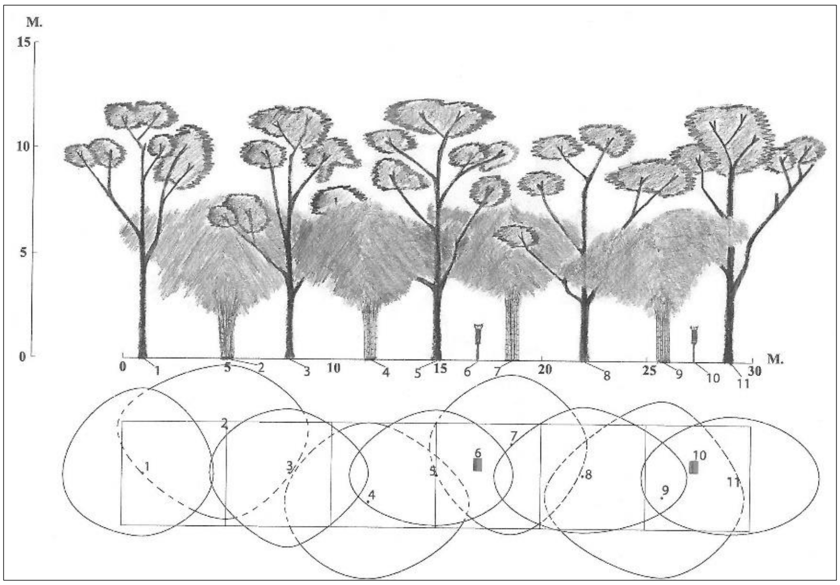



**Figure 33** Margins of Rubber-based Bamboo and Queen Bee Raising Plot (2018 to 2024)

### c) The Plant Community Structure and Crown Cover

Figure 34 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based bamboo and queen bee raising plot. The plant community structure is composed of rubber trees with upper canopies as well as bamboo plants with lower canopies. The rubber trees and bamboo plants have heights range from 11.50 m to 12.50 m and 7 m to 8 m, respectively. When raining season is coming, all canopies will do firstly “interception” by absorbing rain drops until saturated. Then, the rest of raindrops will be “stemflow” and “throughfall” to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubber trees and bamboo plants. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of the rubber trees and bamboo plants in the representative area which is about 98% of the area. Then, the crown cover in rubber-based bamboo plants plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species.




| | |
|---|---|
| Rubber trees | 1, 3, 5, 8 and 11 |
| Bamboo plants | 2, 4, 7, and 9 |
| Beehives | 6 and 10 |

**Figure 34** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Bamboo and Queen Bee Raising Plot

#### 4.2.3.3 Rubber-based Stingless Bee Raising, Ironwood Timber Tree and Bamboo (shoot product) Plot

**a) The Techniques of Plot Management**

There are many produces such as rubber trees (RRIM 600), ironwood trees (*Hopea odorata* Roxb.), stingless bee (*Trigona.*), and bamboo shoot (*Bambusa sp.)* in a RAS plantation. The topography condition of this plot is plain area, and the soil is silt loam type. Firstly, Rubber trees were planted by 7 × 3 m planting distance equaling to single row, 7 m inter-rows, and 3 m inter-trees in the same row in 1999. The rubber density is 476 trees per hectare. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation was used for the plot harvesting. Secondly, Ironwood trees also were planted in the middle of rubber inter-row by 7 × 3.5 m planting distance in 2014. Then, the Ironwood density is 408 trees per hectare. Their branches have been pruned once a year. Ironwood trees and rubber trees will be harvested for timber wood at the same time in 2039. Thirdly, bamboo plant has been planted in the middle of rubber inter-rows in 2015 by 14 × 12 m planting distance. So, the bamboo density is 59 bushes per hectare. The farmer will prune bamboo branches once a week after harvesting bamboo shoots. Fourthly, stingless bee raising was started in 2007. In 2018, there were 30 beehives per hectare in this area which farmers took care of every rubber tapping day. Bees do not only find food from all plants in RAS plantation but also from other plants around there. Association of bee raising with RAS or rubber plantation, bees have food from nectar which had produced by inflorescence and tips of young rubber and other intercrops' flowers. The bee apis cerana species was observed that it is appropriate producing honey about 3 kg per colony per harvest (Tajuddin, 1986). Honey is always harvested 3 times during March to May yearly. This RAS plantation have been applied with organic fertilizer about 1,070 kg per hectare per year in June, and weeding has been practiced three times per year after weed growing well. Farmer asserted that this RAS plantation did not need chemical fertilizer because the fallen leaves of rubber and intercrops decomposed into organic fertilizer. RAS practice is better than rubber monoculture also because RAS helps keep moisture in plot especially in dry season and the fallen rubber leaves period. In 2018, stem girth of rubber trees at 1.70 m high from ground surface was 79.7 cm on average. Rubber product was 1,880 kg per hectare. The girth of ironwood trees at 1.30 m high was 25.9 cm on average. Bamboo shoot product was 6,075 kg per hectare. Stingless bee product (honey) was 54 liters per 30 beehives per hectare.

**b) The Economic Margin**

There are many products from rubber, ironwood trees, bamboo, and stingless bee in this RAS plot. In 2018, this plot was expended the total cost equal to 283 USD per hectare. The income of plot was composed of 2,594 USD per hectare from rubber products, 1,782 USD per 30 beehive boxes from bee's products (honey), and 3,038 USD from bamboo products. Meanwhile, ironwood and rubber wood will provide income in 2039. Therefore, farmer got the total margin from this plot equal to 7,131 USD per hectare in 2018. For simulation for 6-year period during 2019-2024 and related prices are fixed in 2018 (Figure 35), farmer will get low and stable rubber margin per hectare yearly because of low and stable products by old age of rubber trees. Meanwhile, bamboo margin per hectare will increase yearly owing to continuously increasing of bamboo shoots by age. And annual stingless bee honey margin per hectare will rise outstandingly because farmer will add the beehives yearly and high price of honey. In 2024, last year of the simulation, rubber product, bamboo product, and honey product will share the margin 2,333 USD, 4,041 USD, and 10,692 per hectare. The total margin from this plot in 2024 will equal to 11,720 USD per hectare higher than the total margin in 2018 about 39.15%. Therefore, farmer of this RAS plot can overcome economic fluctuation even though rubber product and rubber price have been still low. Moreover, in plot still has ironwood and rubber wood which economic values will be accumulated by age, stingless bees help pollinate various flowers, and all trees can give greatly environmental services. Pollen distribution in March to June showed the highest varieties when the plants start to flower, and stingless bee has specific preference for flower such as *Ixora coccinea*. Small flowers with less or no petals are most preferred by stingless bees (Md Zaki *et al.,* 2018).

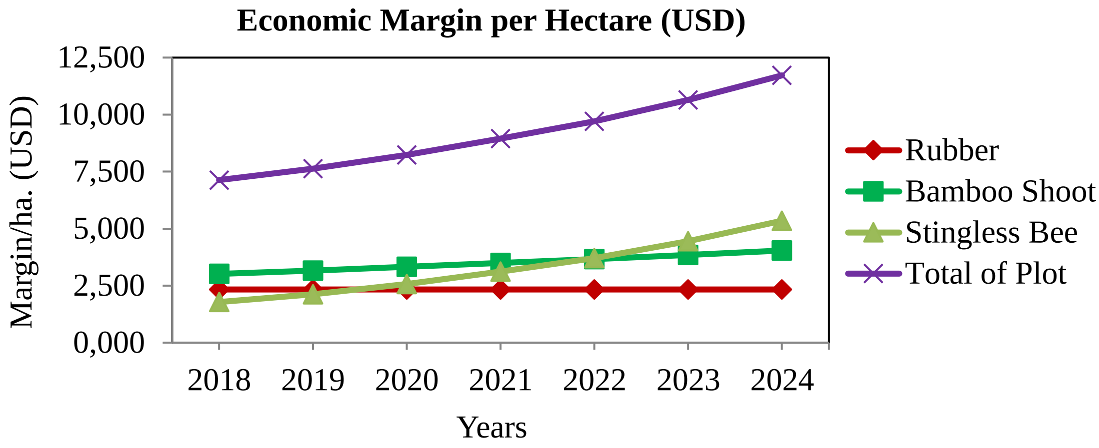
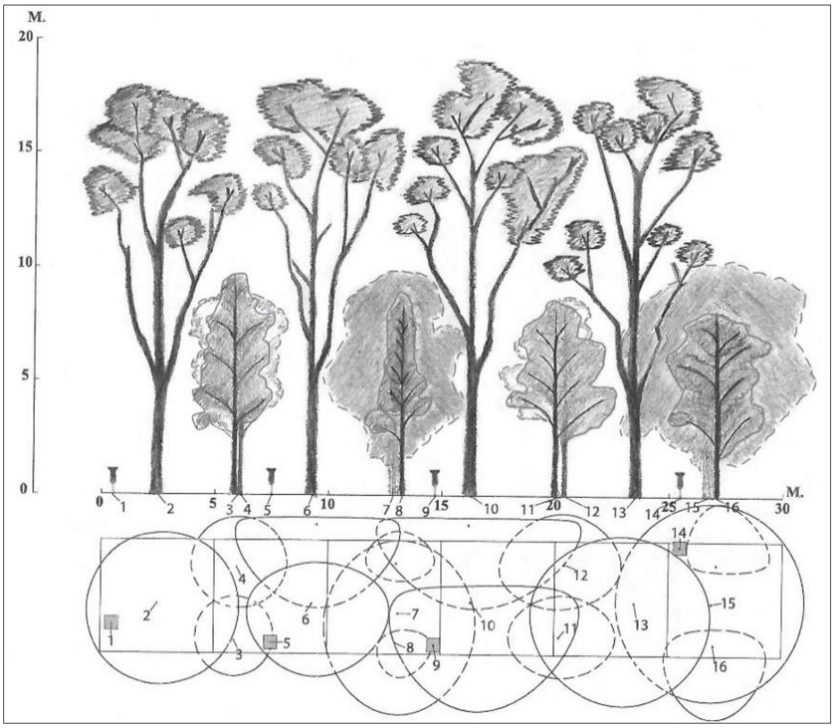



**Figure 35** Margins of Rubber-based Stingless Bee Raising, Ironwood Timber Tree and Bamboo (shoot product) Plot from 2018 to 2024

**c) The Plant Community Structure and Crown Cover**

Figure 36 shows the vertical plant community structure and crown cover in representative 5 × 30 m rectangle area of rubber-based stingless bee raising plot. The plant community structure is composed of rubber trees with upper canopies as well as Ironwood and bamboos with lower canopies. The rubber trees, Ironwoods and bamboos have heights range from 17 m to 19 m, 7.5 m to 9.5 m, and 8 m to 11 m, respectively. When raining season is coming, all canopies will do firstly "interception" by absorbing rain drops until saturated. Then, the rest of raindrops will be "stemflow" and "throughfall" to the lower canopies and the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubbers, Ironwood and bamboos. These layers help prevent soil erosion caused by rainfall. For the crown cover, this means the cover of canopies of rubber trees, Ironwoods and bamboos in the representative area which is about 99% of the area. Then, the crown cover in rubber-based raising stingless bee plot has a great potential to protect soil from directly rainfalls in raining season and has ability to keep moisture in plot also due to multiple levels of vertical stratification and crown cover percentages of the plant species. In the end, the soil of RAS displayed better soil physical properties (high field capacity, high saturated water-holding capacity, and high saturated hydraulic conductivity). That is a successful approach for conserving water and reducing runoff and soil erosion (Jiang *et al.*, 2019).




| | |
|---|---|
| Rubber trees | 2, 6, 10, and 13 |
| Bamboo plants | 1, 5, 9, and 14 |
| Ironwood trees | 3, 5, 8, 11 and 12 |
| beehives | 7 and 15 |

**Figure 36** The Plant Community Structures and Crowns Cover in Representative Rectangular Area (5 × 30 m) of Rubber-based Stingless Bee Raising, Ironwood Timber Tree and Bamboo (shoot product) Plot

### 4.2.4 SWOT of RAS Practices in Southern Thailand

SWOT analysis indicates a background for helping the government and farmers to identify the strategies to achieve goals. This is a technique used to analyze the internal factors (strengths and weaknesses) and external factors (opportunities and threats) of RAS practice in Southern Thailand.

Internal factors are the factors of RAS practices that indicate the strengths and weaknesses. Firstly, strengths of RAS practices are as follows. Famers have mostly practiced RAS on their own agricultural lands and used family labor in all activities of RAS farms without hiring labor. There are some farmers who have succeeded in practicing RAS already, so other farmers have opportunity to get RAS knowledge and experience from his practice. The RAS practice provides biodiversity, moisture in soil mainly during dry season, cool temperature, self-sustaining fertilizer via plant nutrient cycling and much shade of trees, decreased soil erosion in upland area, high land equivalent ratio of productivity, increasing income via variety of products in same land, reducing the weed in plot and weeding expenditure, future income from timber wood, and good society due to sharing experience and products to neighbors and friends, and well co-existence of various plants and animals. RAS gives more rubber yield than that of rubber mono-cropping plantation due to the fallen leaves decompose into fertilizer which helps keep moisture in area. Especially, the intercrops, livestock, and rubber trees can live co-existence in the same RAS plot. Nevertheless, RAS practices have some weaknesses too. Most of rubber famers lack some knowledge and experience of RAS, and farmers are not interested in RAS practices. Farmers lack capital account for cultivating RAS, knowledge of RAS products processing, and marketing RAS products. Moreover, famers use high frequency of tapping system for harvesting rubber plantation, so the rubber tapping system needs many tappers per one-unit area. Also, the tapping panels of rubber trees without rain guard in RAS plantation take long time to dry after raining, so tapping panels rest for a long time waiting for the rubber trees to dry for tapping. When all the intercrops and rubber trees were young about 1 to 2 year's old, farmers needed to apply a great deal of fertilizer and water and protect trees from damage of insect also. Finally, famers also lack some knowledge, e.g., how to produce the fruit products in different season, processing product, and prevent and treat the tapping panel dryness (TPD) and some diseases of rubber trees. In addition, the concerned institutions have insufficient current rubber agroforestry system research works.

External factors are the factors of RAS practices that indicate the opportunities and threats. Firstly, these are opportunities of RAS practices. Rubber Authority of Thailand (RAOT) has a policy to subsidize rubber farmers during their rubber trees had not been harvested yet and encouraged rubber farmers to practice RAS. Some RAS farmers have participated in community enterprise. This group helps farmers to bargain the price in market, hunts good market for their products, and shares the agricultural knowledge and experiences with each other. The district agricultural extension office and RAOT have policy for RAS extension, but there are not many farmers who have gotten the knowledge and experience of RAS and practice RAS. The knowledge of RAS which farmers have practiced on their agricultural lands is passed down from old experience and gain from the farmer experiences, neighbors, members of farmer group, and other RAS farmers. Some famers have decided to practice RAS because farmers would like to use land efficiently, get additional income, make a balance for ecosystem, and support the policy of RAOT. In addition, this is an opportunity also that the RAS practice complied with standard of the Forest Stewardship Council (FSC), Principle 6: environmental values and impacts, the area of the management unit shall be maintained, conserved and/or restored ecosystem services and environmental values of the management unit, and shall be avoided, repaired, or mitigated negative environmental impacts. After that, these are threats of RAS practices. RAS famers have reported that the products of rubber and some intercrops had low price. The intercrops' products by other countries are competitive in the markets such as Longkong, Mangosteen, Durian, Champadak produccts etc. Besides, climate change such as drought, storm, flood, and unpredictable rainfall affect the growth and products of rubber trees and intercrops, and climate destroyed the plantation. For instance, the flood and storm destroyed rubber plantations. The four main Strengths, Weaknesses, Opportunities, and Threats of RAS practices were determined at the end of the thematic analysis, and strategic suggestions of the study have been indicated in figure 37.

| Internal Factors / External Factors | Strengths (S) | Weaknesses (W) |
|---|---|---|
| | $S_1$: Famers have land property and family labors<br>$S_2$: RAS practices provide biodiversity, moisture, much shade, increasing income, reducing expenditure in plot, and high land equivalent ratio of productivity etc.<br>$S_3$: Intercrops, livestock and rubber trees can live co-existence in RAS plot.<br>$S_4$: There are some farmers who succeed in RAS practice, so farmers have chance to get RAS knowledge and experience | $W_1$: Famers lack knowledge and experience of RAS, RAS products processing and marketing<br>$W_2$: Farmers have lack capital account for cultivating RAS<br>$W_3$: Tapping panels of rubber trees in RAS plantation take long time to dry after raining<br>$W_4$: Insufficient current RAS research works by concerned institutions |
| **Opportunities (O)**<br>$O_1$: A policy of RAOT to support the subsidy and encourage farmers to practice RAS<br>$O_2$: The RAS practice is complied with standard of Forest Stewardship Council (FSC), Principle 6: environmental values and impacts<br>$O_3$: The district agricultural extension office and RAOT have policy for RAS extension<br>$O_4$: The farmer group helps farmers to bargain the price in market and hunts good market for their products. | **SO Strategies**<br>$SO_1$: Farmers should cultivate RAS<br>$SO_2$: The group of farmers should ask the certificate from FSC for products of RAS practices | **WO Strategies**<br>$WO_1$: Farmers should register with RAOT and district agricultural extension office<br>$WO_2$: Associating the good agricultural practice (GAP), skills of processing products, and RAS knowledge into policy of extension for rubber farmers<br>$WO_3$: The RAS research should be practiced in all rubber producing provinces<br>$WO_4$: The government should implement the policy of RAS extension in all rubber producing provinces |
| **Threats (T)**<br>$T_1$: Products of rubber and some intercrops price are low<br>$T_2$: Competition of intercrops' products by other countries in the markets<br>$T_3$: Climate change effects such as drought, storm, flood and unpredictable rainfall affect the growth and products of intercrops and rubber trees<br>$T_4$: Shortage of tapper because rubber famers use high frequency of tapping system. | **ST Strategies**<br>$ST_1$: The government should have policy to encourage and support farmers to cultivate RAS<br>$ST_2$: Farmers should select the intercrops and/or livestock which match market demand | **WT Strategies**<br>$WT_1$: Commercial ministry should create the policy to find market for RAS farmers' agricultural products<br>$WT_2$: Farmers should participate with famer group for sharing RAS knowledge each other<br>$WT_3$: RAOT or agricultural research institutions should create experimental RAS plots |

**Figure 37** SWOT Matrix of RAS Practices in Southern Thailand

# CHAPTER V

# CONCLUSION AND RECOMMENDATIONS

## 5.1 The Summary of Study Findings

### 5.1.1 The Techniques of Plot Management

In the Eastern Cambodian, all 3 RAS plots of this study are planted with rubber trees by 6 × 3 m planting distance equal to single row, 6 m inter-rows, and 3 m inter-trees in the same row. The rubber densities are 555 trees per hectare. Topography condition of these plots are upland area, and the soils are red clay loam type (basaltic soil). For rubber-based soybean and rubber-based peanut plot, when the rubber trees were under 5 years old, rubber trees had been associated by annual crops as intercrops equal to 26,664 trees per hectare. Then the last plot has been raising chicken in rubber plantation 300 heads in 2018. In 2015 when they were 6 years old, the rubber trees were opened tapping. Tapping system as S/2 d3 98/120 Pa 2 (2) 10/y ET 2.5% is used for the harvesting of these rubber trees in plot 3. All three RAS plots have been applied with chemical fertilizer, and weeding has been practiced by spraying herbicide.

In other hand, there are 11 RAS plots in Southern Thailand of this study. Also, rubber agroforestry systems have been divided into five systems as follows: a) rubber-based fruit trees, b) rubber-based timber trees, c) rubber-based other plants, d) rubber-based livestock, and e) rubber-based mixed products. Rubber-based mixed products in this study are 4 categories such as rubber-based other plant with livestock and timber tree, rubber-based fruit tree with other plant, rubber-based timber tree with fruit plant, and rubber-based other plant with livestock. Rubber trees in all 11 RAS plots of this study are planted with rubber trees by 6 × 3 m, 6.5 × 3.5 m, 7 × 3 m, 7 × 3.5 m, 8 × 3 m, and 10 × 2.5 m planting distance. The farmers of 10 plots started tapping when rubber trees were 7 years old, and only 1 plot of rubber-based Sala fruit and neem tree plot was started tapping when rubber trees were 4 years old. Tapping systems as S/3 3d/4 183/273, S/3 3d/4 130/273, S/3 d2 6d/7 86/182, and S/3 2d/4 120/182 nil stimulation was used for the plot harvesting. The other plants and livestock have been planted and raised in rubber plots under RAS. The 5 RAS plots have been applied with chemical and organic fertilizer, and 4 RAS plots have been applied only organic fertilizer. Only rubber-based Sala fruit and yangsain trees and rubber-based champadak fruit and phakleang vegetable plots have not been applied with any fertilizer. The farmers said that there were much humidity and all plants could recover nutrients in plots via the fallen leaves of all plants decomposed into organic fertilizer.

**5.1.2 The Economic Margin**

The 3 RAS plots in Eastern Cambodia in this study, rubber-based soybean plot (Cambodian plot 1) and rubber-based peanut plot (Cambodian plot 2) provided the total margin per hectare equal to 386.51 USD and 386.34 USD in 2018. The intercrops of these plots are annual crops, so crops can be cultivated in rubber plantation for the first 4 years during rubber trees are still young. Rubber-based chicken plot (Cambodian plot 3) provided mostly total margin per hectare equal 2,385 USD in 2018. Furthermore, for the 11 RAS plots in Southern Thailand in 2018, rubber-based Sala fruit and yangsain trees plot (Thai plot 1) provided the total margin per hectare equal 8,061 USD. Rubber-based mangosteen fruit plot (Thai plot 2) provided the total margin equal 2,606 USD. Rubber-based longkong fruit plot (Thai plot 3) provided the total margin equal 4,306 USD. Rubber-based coffee fruit plot (Thai plot 4) provided the total margin equal 3,800 USD. Rubber-based Sala fruit and Neem tree plot (Thai plot 5) provided the total margin equal 10,515 USD. Rubber-based champadak fruit and phakleang vegetable plot (Thai plot 6) provided the total margin equaled 9,748 USD. Rubber-based ironwood timber trees plot (Thai plot 7) provided the total margin equal 1,635 USD. Rubber-based eaglewood trees plot (Thai plot 8) provided the total margin equaled 1,133 USD. Rubber-based bamboo (shoot product) and queen bee plot (Thai plot 9) provided the total margin equal 5,437 USD. Rubber-based bamboo (stem product) and queen bee plot (Thai plot 10) provided the total margin equal 3,874 USD. Rubber-based raising stingless bee and bamboo (shoot product) plot (Thai plot 11) provided the total margin equal 7,131 USD per hectare. Therefore, the total costs, total incomes, and total margin of RAS plots in 2018 (Table 13) and the simulation for 6-year period of all 11 Thai and 1 Cambodian plots in this study demonstrate that the level of ability to overcome low rubber price has been divided in to 4 levels from 2019 to 2024 (Figure 38) as follows:

1) Highest level: There are three plots ranked at the highest level. Rubber-based stingless bee raising and bamboo (shoot products) plot (Thai plot 11), rubber-based Sala fruit and neem tree plot (Thai plot 5) and rubber-based champadak fruit and phakleang vegetable plot (Thai plot 6) are at the highest level of ability to overcome the low rubber price.

2) High level: There are three plots for the high level. Rubber-based sala fruit and yangsain trees plot (Thai plot 1), rubber-based bamboo (stem products) and queen bee plot (Thai plot 10), and rubber-based bamboo (shoot products) and queen bee plot (Thai plot 9) are at the high level.

3) Medium level: There are four plots ranked at the medium level. Rubber-based longkong fruit plot (Thai plot 3), rubber-based coffee fruit plot (Thai plot 4), rubber-based chicken (Cambodian plot 3), and rubber-based mangosteen fruit plot (Thai plot 2) are at the medium level.

4) Low level: There are two plots ranked at the low level. Rubber-based ironwood timber trees plot (Thai plot 7) and rubber-based eaglewood trees plot (Thai plot 8) are at the low level of ability to overcome the low rubber price, but Ironwood and Eaglewood trees in plots will provide the additional income in the future beyond this simulation period, so farmers can compensate the low income in the future.

However, RAS practices are an alternative practice to improve household livelihood of RAS farmers though rubber price is decreased because products of other plants and livestock shared the economic margin on farms. Then, livelihood of RAS farmers is success. The rubber-based fruit tree and livestock systems provided the best trade-off between return to land and/or to labor. Rubber-based timber tree is a labor-saving alternative with high income in the harvesting period, but the timber provides late income. Simulations of RAS be grateful to flexibility and a higher gross margin, the RAS had offered a higher resilience of the farms when the rubber price does not only drop but rises as well.

**Table 13** The Costs, Incomes, and Margin (USD) of RAS Plots per Hectare in 2018

| No. | RAS Plots | Techniques of Plot Management | | | Costs | Incomes | Margins |
|---|---|---|---|---|---|---|---|
| | | Rubber Planting Distance | Rubber Harvesting Systems | Applying Fertilizer | | | |
| **Eastern Cambodia, 3 RAS plots** | | | | | | | |
| 01 | Rubber-based Soybeans (*Glycine max.*) | 6 × 3 m | None | Chemical fertilizer | 351.71 | 738.22 | 386.51 |
| 02 | Rubber-based Peanut (*Legume)* | 6 × 3 m | None | Chemical fertilizer | 380.98 | 738.05 | 357.07 |
| 03 | Rubber-based Chicken raising | 6 × 3 m | S/2 d3 98/120 Pa 2 (2) 10/y ET 2.5% | Chemical and organic fertilizer | 1,404 | 3,789 | 2,385 |
| **Southern Thailand, 11 RAS plots** | | | | | | | |
| 01 | Rubber-based Sala fruit and Yangsain tree | 7 × 3 m | S/3 3d/4 183/273 nil stimulation | None | 109 | 8,170 | 8,061 |
| 02 | Rubber-based Mangosteen fruit tree | 7 × 3 m | S/3 3d/4 183/273 nil stimulation | Chemical and organic fertilizer | 482 | 3,088 | 2,606 |
| 03 | Rubber-based Longkong fruit tree | 6 × 3 m | S/3 3d/4 130/273 nil stimulation | Chemical and organic fertilizer | 302 | 4,607 | 4,305 |
| 04 | Rubber-based Coffee fruit | 7 × 3 m | S/3 3d/4 183/273 nil stimulation | Organic fertilizer | 382 | 4,182 | 3,800 |
| 05 | Rubber-based Sala fruit and Neem tree | 6 × 3 m | S/3 3d/4 130/273 nil stimulation | Organic fertilizer | 682 | 11,197 | 10,515 |
| 06 | Rubber-based Champadak fruit and Phakleang vegetable | 10×2.5 m | S/3 2d/4 120/182 nil stimulation | None | 104 | 9,852 | 9,748 |
| 07 | Rubber-based Ironwood timber trees | 6.5×3.5m | S/3 d2 6d/7 86/182 nil stimulation | Chemical fertilizer | 1,835 | 3,470 | 1,635 |
| 08 | Rubber-based Eaglewood timber tree | 8 × 3 m | S/3 3d/4 183/273 nil stimulation | Organic fertilizer | 1,040 | 2,173 | 1,133 |
| 09 | Rubber-based Bamboo shoot and Queen bee raising | 7 × 3 m | S/3 3d/4 183/273 nil stimulation | Chemical and organic fertilizer | 403 | 5,841 | 5,438 |
| 10 | Rubber-based Bamboo stem and Queen bee raising | 7 × 3.5 m | S/3 3d/4 183/273 nil stimulation | Chemical and organic fertilizer | 465 | 4,339 | 3,874 |
| 11 | Rubber-based Bamboo shoot, Ironwood tree and Stingless bee raising | 7 × 3 m | S/3 3d/4 183/273 nil stimulation | Organic fertilizer | 283 | 7,414 | 7,131 |

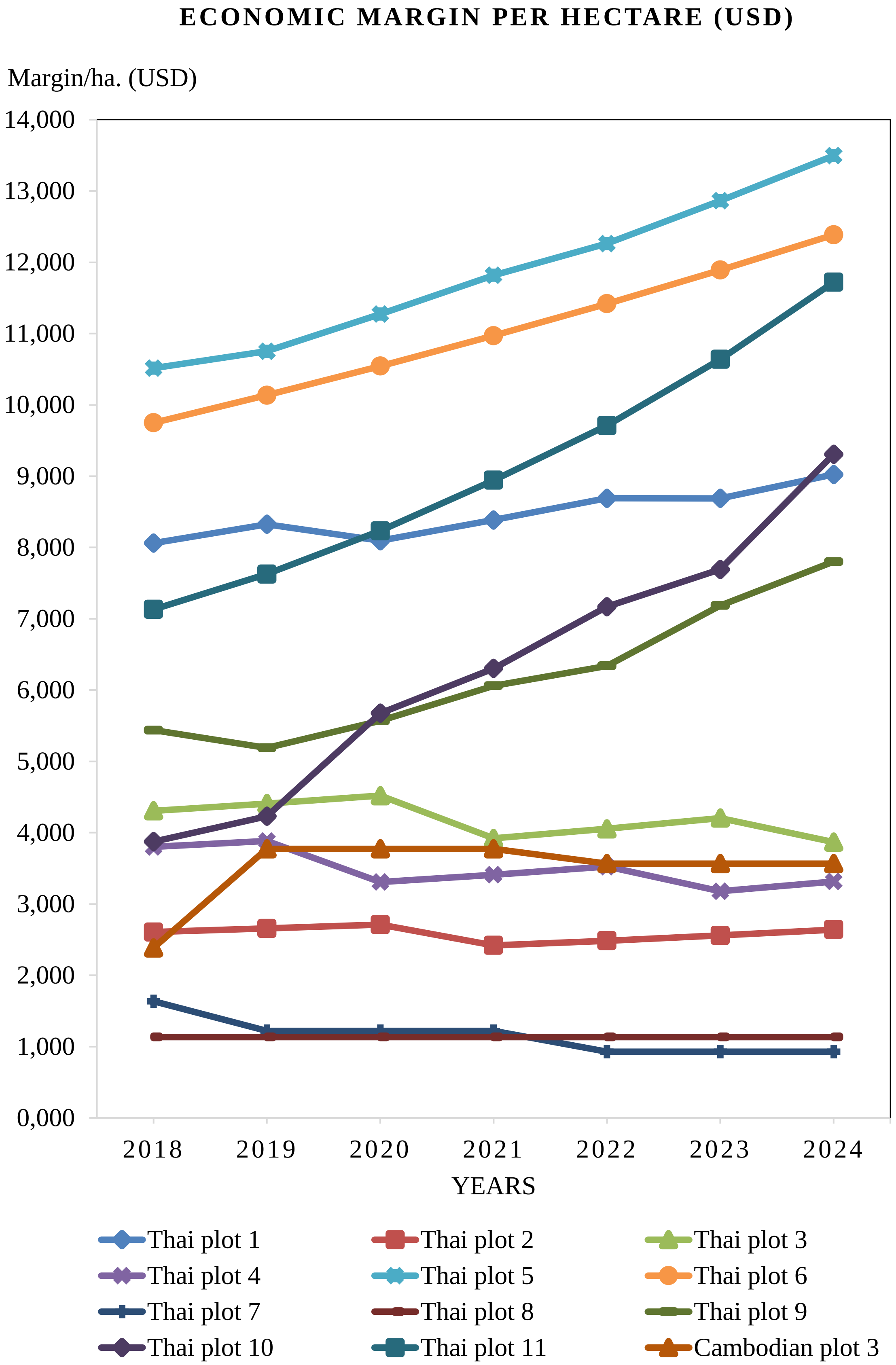



**Figure 38** Total Economic Margin of 12 RAS Plots from 2018 to 2024

### 5.1.3 The Plant Community Structure and Crown Cover

The plant community structure is composed of rubber trees with upper canopies as well as intercropping plants with lower canopies. When raining season is coming, all canopies will reduce the strength of raindrops. Then the ground that covered with some grass as well as fallen and decayed leaves and branches of the rubber and intercropping trees will receive the rest of raindrops. In rubber-based mixed products plots in this study such as rubber-based other plant and livestock, rubber-based timber tree, fruit tree and other plant, and rubber-based timber tree, other plant, and livestock have multiple levels of vertical stratification and crown cover percentages of plant species. These stratification, crown cover percentages, and layers of all plant species help to prevent soil erosion caused by reducing strength of directly rainfall. The soil is covered (crown cover) by having a canopy density not less than 70% in plot can reduce soil erosion. In this study, cover of canopies of rubber trees and other plants in representative area of all plots are about 86 to 99.5% of the area. Therefore, the crown cover in all plots had a great potential to protect soil from directly rainfalls in raining season and have ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of plant species.

### 5.1.4 The SWOT of Rubber Agroforestry System Practices

SWOT analysis indicates a background to identify the strategies of RAS practices in Eastern Cambodia and Southern Thailand. This is a technique used to analyze the internal factors (strengths and weaknesses) and external factors (opportunities and threats). The four main Strengths, Weaknesses, Opportunities, and Threats of RAS practices were determined and analyzed, and the result has been revealed the strategic suggestions of RAS practices.

In Eastern Cambodia, there are some strategies of RAS practices that were determined by SWOT analyze:

- The government should associate the RAS technique, good agricultural practice (GAP) technique, and skills of processing RAS products into policy of extension for rubber farmers, have policy to encourage farmers to cultivate RAS and participate with farmer group, and should seriously implement the policy of RAS and GAP extension in all rubber producing provinces.

- Commercial Ministry should create the policy to find market for RAS farmers' agricultural products or implement this policy seriously.
- The rubber farmers should cultivate RAS and select the intercrops and livestock which serve the demands of market and participate with farmer group following the policy of government.
- The group of RAS farmers should ask the certificate from Forest Stewardship Council (FSC) for products of RAS practices.
- GDR and CRRI should create RAS experimental plots at farms of farmers and laboratory fields.

In Southern Thailand, there are some strategies of RAS practices that were determined by SWOT analyze:

- The government should have policy to encourage and support farmers to cultivate RAS, and should associate GAP technique, skills of processing RAS products, and RAS knowledge into policy of extension for rubber farmers.
- Commercial Ministry should create the policy to find market for RAS farmers' agricultural products or implement this policy seriously.
- RAOT or agricultural research institutions should create RAS experimental plots at farms of farmers and laboratory fields and implement the policy of RAS extension in all rubber producing provinces.
- Farmers should register to be members with RAOT and district agricultural extension office, cultivate RAS with selecting the intercrops and livestock which are high demands in market. Especially, rubber farmers should participate with famer group for sharing RAS knowledge among each other, and the group of farmers should ask for the certificate from FSC for products of RAS practices.

**5.2 Recommendations of Study**

All plants undergo photosynthesis with the help of sunlight, but the amount of sunlight required vary with plant species. Those plants, which require less amount of sunlight for photosynthesis should be associated with rubber trees in the same land management as RAS. Some rubber clones which grows in straight and upward direction such as RRIM 728, RRIM805, RRIM901, PB217, PB260, PB254, RRIC100, BPM1, etc. are good for excellent RAS practice (Wibawa, G. et al. 2007; Board, M. R. 2009). As well, maintaining distance while planting rubber trees is flexible depending on intercrop species. The intercrops sala fruit, bamboo (shoot product), and champadak fruit provided farmers more income because the market value is high for the products. Sala and bamboo (shoot product) are good intercrops for association with rubber trees because sala is small plant and they requires less sunlight for photosynthesis. Farmers who practiced rubber-based timber tree and rubber-based fruit tree, suggested that rubber planting distance in RAS should expand line spacing of rubber rows such as 9 × 3 m, 10 × 3 m, 10 × 2.5 m, (12 + 4 m) × 2 m, (13 + 4 m) × 2.5 m, etc. Zeng (2012) reported that the rubber trees' girth in the planting distance (20 + 4 m) × 2 m at the first year was slightly bigger than those of the rubber trees' girth in the 3 × 7 m planting distance. The planting distance (20 + 4 m) × 2 m had a larger full-sun area of land with high light penetration providing suitable conditions for the long-term open-air intercrops. Additionally, livestock provided good income on farms. According to the result of this study, raising bees and chickens in RAS plot provided high profit to farmers by products, such as bee is the good insect which plays an important role in pollination and manures from chickens raising help reduce fertilizer expenditure in farm. The RAS practice should be associated with livestock as the third or fourth product on RAS farms to increase household economy. Rubber-based mixed products systems such as rubber-based other plant with livestock, rubber-based timber tree with fruit tree and other plant, and rubber-based timber tree with other plant and livestock are good strategy to improve household economy of farmers and to prevent soil erosion in plots. Furthermore, agricultural extension officers, General Directorate of rubber (GDR) of Cambodia, and RAOT should associate the knowledge of RAS into the policy of extension for rubber farmers, implement the policy of RAS and GAP extension in all rubber producing provinces, encourage rubber farmers to cultivate RAS and participate with farmer group, create experimental RAS plots at farmers' farm and laboratory field, and build policy to find market for RAS farmers' agricultural products. Farmers should cooperate with agricultural extension officers and GDR in advance such as register with farmer group, pay attention with agricultural workshop and report the agricultural data to government.

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# APPENDIX

## Appendix I

**Research Questionnaire**

**Rubber Agroforestry System (RAS) Practices in Southern Thailand towards Policy Recommendations to Promote the Practices in Cambodia**

---

I am carrying out a master's degree study at faculty of Natural Resources. The collection of information and data via this questionnaire is a component of the study. Thank you for taking the time to fill in this questionnaire. Your answers will be treated with complete confidentiality.

**Section A: Personal Background**

1. Name: ..........................................................................................................
2. Address: ................................................................Tel:....................................
3. Gender: ☐ male ☐ female
4. Marital Status: ☐ single ☐ married ☐ divorced
5. Age: .................... years
6. Nationality: ☐ Cambodian ☐ Thai
7. Religion: ☐ Buddhism ☐ Islam
8. Education: ☐ Uneducated ☐ Primary school
   ☐ Secondary school ☐ Bachelor's degree
   ☐ Master's degree or Higher ☐ Other...........................
9. How many members of family in your house?
10. How many members of your family who working off farm?
11. How many members of your family who working on farm?
12. Do you hire agricultural labors?
    ☐ No, ☐ Yes, number and job description......................................................
13. Experience of Rubber plantation: ..................years
    Intercropping: ..................years
    Raising animal: ..................years

**Section B: Techniques and economic data of RAS Practice in the selected plot**

**Part 1: Other Plants with Rubber Trees**

**1.1 Planting Techniques**

1.1.1 The plot area.....................hectare/rai,

1.1.2 Topography of plot area: ☐ Rolling ☐ Plain ☐ Other...........................

1.1.3 Soil texture ☐ Clay ........... ☐ Sand........... ☐ Silt .............

1.1.4 Rubber trees

| No. | Rubber Clone | Planting Year | Planting System (Land & Materials preparation, inter-row & inter-tree distance, etc.) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

1.1.5 Tree Crops

| No. | Kind of Tree Crop | Planting Year | Planting System (Land & Materials preparation, inter-row & inter-tree distance, etc.) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

1.1.6 Multiannual Crops (more than 1 to 5 years)

| No. | Kind of Multiannual Crop | Planting Year | Planting System |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

1.1.7 Annual Crops

| No. | Kind of Annual Crops | Planting Year | Planting System |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

**1.2 Techniques of Plant Maintenance**

| Activities | Activity Time Number per Year | | | | | | Quantity of Input[1] used per Time per Hectare/rai | | | | | | Input Price per Unit | Hired Labor Number | Hired Day Number per Year | Hired Labor Cost/Day/ Person |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2018 | 2018 | 2018 |
| Rubber …………… | | | | | | | | | | | | | | | | |
| Applied organic fertilizer | | | | | | | | | | | | | | | | |
| Applied chemical fertilizer | | | | | | | | | | | | | | | | |
| Weeding | | | | | | | | | | | | | | | | |
| Disease management | | | | | | | | | | | | | | | | |
| Stimulation | | | | | | | | | | | | | | | | |
| Other …………… …………… | | | | | | | | | | | | | | | | |

[1] Input for this study means variable costs such as fuel, fertilizer, medicine, water, etc.

| Activities | Activity Time Number per Year | | | | | | Quantity of Input[1] used per Time per Hectare/rai | | | | | | Input Price per Unit | Hired Labor Number | Hired Day Number per Year | Hired Labor Cost/Day/ Person |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2018 | 2018 | 2018 |
| Intercrop (1) …………… | | | | | | | | | | | | | | | | |
| Applied organic fertilizer | | | | | | | | | | | | | | | | |
| Applied chemical fertilizer | | | | | | | | | | | | | | | | |
| Weeding | | | | | | | | | | | | | | | | |
| Watering | | | | | | | | | | | | | | | | |
| Pest control | | | | | | | | | | | | | | | | |
| Disease management | | | | | | | | | | | | | | | | |
| Pruning plant | | | | | | | | | | | | | | | | |
| Other …………… | | | | | | | | | | | | | | | | |

| Activities | Activity Time Number per Year | | | | | | Quantity of Input[1] used per Time per Hectare/rai | | | | | | Input Price per Unit | Hired Labor Number | Hired Day Number per Year | Hired Labor Cost/Day/ Person |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023-2024 | 2018 | 2018 | 2018 | 2018 |
| Intercrop (2) …………… | | | | | | | | | | | | | | | | |
| Applied organic fertilizer | | | | | | | | | | | | | | | | |
| Applied chemical fertilizer | | | | | | | | | | | | | | | | |
| Weeding | | | | | | | | | | | | | | | | |
| Watering | | | | | | | | | | | | | | | | |
| Pest control | | | | | | | | | | | | | | | | |
| Disease management | | | | | | | | | | | | | | | | |
| Pruning plant | | | | | | | | | | | | | | | | |
| Other …………… …………… | | | | | | | | | | | | | | | | |

### 1.3 Techniques of Plant Harvesting

| | Plot Area (hectare/ rai) | Number of Tapping Trees per Plot | Type of Tapping Panel | Tapping Age of Rubber Trees | 2018 | | | | | | Age of Rubber Tree Cut Down |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Frequency of Tapping | All Rubber Latex (kg.) per Day | Rubber DRC (%) | RSS per Year | Coagulum per Year | Price/ kg. | |
| **Rubber** | | | | | | | | | | | |

| Kind of Intercrop | Plot Area (hectare/ rai) | All Intercrop Number per Plot | Frequency of Harvesting and When? | Harvested Age of Intercrops | Quantity of Product per Year | | | | | | | 2018 Price per Unit | 2019 Price per Unit | Age of Intercrop Cut Down |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | | | |
| Intercrop (1) …………… | | | | | | | | | | | | | | |
| Intercrop (2) ………….. | | | | | | | | | | | | | | |

### 1.4 Processing Products

1.4.1 What is rubber product called?

1.4.2 How do you process the rubber product?

1.4.3 What is intercropping product called?

1.4.4 How do you process this intercropping product?

## Part 2: Raising Livestock with Rubber Trees

### 2.1 Raising Livestock

| No. | Kind of Animal | Starting Year of Raising | Cycle of Raising Animal (raising to selling) | All Animal Number | Reasons for Raising Animals in Rubber Plot |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | |
| | | | | | |
| | | | | | |

### 2.2 Livestock activity and Labors for a Raising Cycle in year 2018

| Activity (2019 if possible) | Months | Day Number per Month for the Activity | Family Labor Number | Hired Labor Number | Hired Labor cost/day /person | Total Hired Labor Cost |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**2.3 Annual Input Costs in 2018 (2019 if possible)**

| Kind of Input | Time Number per Year | Used Input Quantity per Time | Price per Unit | Total Input Cost |
|---|---|---|---|---|
| Animal feed ………... | | | | |
| Medicine…………… | | | | |
| Mineral ……………. | | | | |
| Other……………….<br>……………………… | | | | |
| ……………………… | | | | |

**2.4 Outputs** (this question may be suitable for some animal but not for other one)

- Mother head .............. head Local price................. Baht/head
- Father head................ head Local price................. Baht/head
- Male child ................. head Local price................. Baht/head
- Female child............. head Local price................. Baht/head
- The mother gives birth..................... litter per year
- How many dead children per litter ............ head?
- As mother for................ year before discard
- As father for.................. year before discard

| All Output Number | Sold Output Number | Total Weight or Heads | Price/Unit | Total Revenues | Where is the market? |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**2.5** Processing livestock products practice ☐ Yes ☐ No

**2.6** How do you process your products of livestock?

**Part 3: Off-farm Income**

3.1 Do you have off-farm income ☐ Yes ☐ No

3.2 How much have you earned income of off farm per year?

3.3 What is the source of your off-farm income?

**Section C: SWOT Analysis (Strengths, Weaknesses, Opportunities, and Threats) for Promoting Rubber Agroforestry System Practice in Cambodia**

**SWOT of Rubber Agroforestry System Practice**

1. What strengths do you have to be available for practicing RAS?
2. What knowledge, talent, or resources of RAS do you have?
3. What are advantages of your RAS? (Environment, income, etc.)
4. How are the growths of all plants and animal in your RAS?
5. How are products of all plants and animal in your RAS?
6. What knowledge, skills and/or resources are you lacking for RAS practice?
7. What are disadvantages of your RAS?
8. Do you participate in farmer group? Why?
9. Does your Agricultural Ministry have policy to support the RAS? What is it?
10. What is the opportunity of your RAS practice?
11. What obstacles do you face with RAS practice?
12. Who and what might cause your problems on RAS practice in the future? How?
13. Are there any standards, policies, and/or legislation changing that might negatively impact on your RAS practice?

## Appendix II

## IOC Calculation of Research Questions

| Contents | Items of Question | Experts | | | IOC Calculation | IOC Results |
|---|---|---|---|---|---|---|
| | | Expert 1 | Expert 2 | Expert 3 | | |
| **Section A:** Personal Background | | | | | | |
| | 1 | -1 | 1 | 1 | 0.33 | Used |
| | 2 | 0 | 1 | 1 | 0.67 | Used |
| | 3 | 0 | 1 | 1 | 0.67 | Used |
| | 4 | 0 | 1 | 0 | 0.33 | Used |
| | 5 | 0 | 1 | 1 | 0.67 | Used |
| | 6 | 1 | 1 | 1 | 1.00 | Used |
| | 7 | 0 | 1 | 1 | 0.67 | Used |
| | 8 | 0 | 1 | 1 | 0.67 | Used |
| | 9 | 0 | 1 | 1 | 0.67 | Used |
| | 10 | 0 | 1 | 1 | 0.67 | Used |
| | 11 | 0 | 1 | 1 | 0.67 | Used |
| | 12 | 0 | 1 | 1 | 0.67 | Used |
| **Section B:** Techniques and economic data of RAS Practice in the selected plot | | | | | | |
| **Part 1:** Other plants with rubber trees | 1.1.1 | 1 | 1 | 1 | 1.00 | Used |
| | 1.1.2 | 1 | 1 | 1 | 1.00 | Used |
| | 1.1.3 | 1 | 1 | 1 | 1.00 | Used |
| | 1.1.4 | 1 | 1 | 1 | 1.00 | Used |
| | 1.1.5 | 1 | 1 | 1 | 1.00 | Used |
| | 1.1.6 | 1 | 1 | 1 | 1.00 | Used |
| | 1.2 | 1 | 1 | 1 | 1.00 | Used |
| | 1.3 | 1 | 1 | 1 | 1.00 | Used |
| | 1.3.1 | 1 | 1 | 1 | 1.00 | Used |
| | 1.3.2 | 1 | 1 | 1 | 1.00 | Used |
| | 1.3.3 | 1 | 1 | 1 | 1.00 | Used |
| | 1.3.4 | 1 | 1 | 1 | 1.00 | Used |
| | 1.4.1 | 1 | 1 | 1 | 1.00 | Used |
| | 1.4.2 | 1 | 1 | 1 | 1.00 | Used |
| | 1.4.3 | 1 | 1 | 0 | 0.67 | Used |

| Contents | Items of Question | Experts | | | IOC Calculation | IOC Results |
|---|---|---|---|---|---|---|
| | | Expert 1 | Expert 2 | Expert 3 | | |
| **Part 2:** Raising animals in rubber plantation | 2.1 | 1 | 1 | 1 | 1.00 | Used |
| | 2.2 | 1 | 1 | 1 | 1.00 | Used |
| | 2.3 | 1 | 1 | 1 | 1.00 | Used |
| | 2.4 | 1 | 1 | 1 | 1.00 | Used |
| | 2.5 | 1 | 1 | 0 | 0.67 | Used |
| | 2.6 | 1 | 1 | 1 | 1.00 | Used |
| | 2.7 | 1 | 1 | 1 | 1.00 | Used |
| | 2.8 | 1 | 1 | 0 | 0.67 | Used |
| **Part 3:** Off-farm income | 3.1 | 1 | 1 | 1 | 1.00 | Used |
| | 3.2 | 1 | 1 | 1 | 1.00 | Used |
| | 3.3 | 1 | 1 | 1 | 1.00 | Used |
| **Section C:** SWOT questions for promoting RAS practice in Eastern Cambodia | | | | | | |
| **SWOT of RAS** | 1 | 1 | 1 | 1 | 1.00 | Used |
| | 2 | 0 | 1 | 1 | 0.67 | Used |
| | 3 | 1 | 1 | 1 | 1.00 | Used |
| | 4 | 1 | 1 | 1 | 1.00 | Used |
| | 5 | 1 | 0 | 1 | 0.67 | Used |
| | 6 | 1 | 1 | -1 | 0.33 | Unused |
| | 7 | 1 | 1 | 1 | 1.00 | Used |
| | 8 | 1 | 1 | 1 | 1.00 | Used |
| | 9 | 1 | 1 | -1 | 0.33 | Unused |
| | 10 | 1 | 1 | -1 | 0.33 | Unused |
| | 12 | 1 | 1 | -1 | 0.33 | Unused |
| | 13 | 1 | 1 | 1 | 1.00 | Used |
| | 14 | 1 | 0 | 1 | 0.67 | Used |
| | 15 | 1 | 1 | 1 | 1.00 | Used |
| | 16 | 1 | 1 | 1 | 1.00 | Used |
| | 17 | 1 | 1 | 1 | 1.00 | Used |
| | 18 | 1 | 1 | 0 | 0.67 | Unused |

## Appendix III

### Research Plan

The experiment was conducted for two years. It was started in August 2018 and finished in July 2020. The research plan specifies the schedule, with each step as the table of research activities schedule of the research plan below.

| Activities | 2018 | | | | | 2019 | | | | | | | | | | | | 2020 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Semester 1 | | | | | Semester 2 | | | | | | | Semester 3 | | | | | Semester 4 | | | | | | |
| | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Research proposal preparation | | | | | | | | | | | | | | | | | | | | | | | | |
| Literature review | | | | | | | | | | | | | | | | | | | | | | | | |
| Proposal examination | | | | | | | | | | | | | | | | | | | | | | | | |
| Data collection in Eastern Cambodia | | | | | | | | | | | | | | | | | | | | | | | | |
| Data collection in Southern Thailand | | | | | | | | | | | | | | | | | | | | | | | | |
| Data preparing and Analysis | | | | | | | | | | | | | | | | | | | | | | | | |
| Writing thesis | | | | | | | | | | | | | | | | | | | | | | | | |
| Thesis revision | | | | | | | | | | | | | | | | | | | | | | | | |
| Writing article, submission, and approval | | | | | | | | | | | | | | | | | | | | | | | | |
| Thesis defense | | | | | | | | | | | | | | | | | | | | | | | | |
| Thesis submission and approval | | | | | | | | | | | | | | | | | | | | | | | | |