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Resilience, various benefits, and constraints of rubber agroforestry systems in southern Thailand

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Abstract The research finding found various margin resilience of the twelve rubber agroforestry plots, classified by resilience levels: 1) five plots with the high resilience; 2) six plots with the medium resilience; and 3) one plot with the low resilience. Timbers in rubber plots showed the high resilience and the plots had timbers left for income generation in the future. Duck and goat in rubber plots had flexible resilience. Also, they kept weeds in check by eating them and their feces acted as organic fertilizers. The sarjor-caju mushroom, vegetable fern, and straw mushroom under rubber plots generated the top three margins in 2019 and green products. Gnetums under the shade of rubber trees grew well and produced good-tasting leaves. Pineapple and sala under rubber trees grew well and were good quality fruits. However, mangosteen and longgong under rubber trees were characterized taller shapes with less harvesting than the typical monoculture. The recommendations for promoting rubber agroforestry suggested to practice in the future: 1) cut down stunted and diseased rubber trees and intercropped trees that cannot be harvested or in the case of new rubber plantings, expand rubber inter-row distances, to allow more sunlight into the plots and decrease competition of root system, 2) prune fruit intercrops to allow more sunlight entry and control the canopy, 3) choose a kind of intercrop suitable for the ecosystem in the plot and 4) choose kinds of intercrop appropriate to the farmer’s time availability, and need for income.

Keywords: Margin, Compensation, Scenario building, Simulation

Introduction

Smallholders produced more than 85% of the world’s natural rubber (Somboonsuke and Wettayaprasit, 2013). In Thailand, the first world producer of natural rubber, 95% of natural rubber was produced by smallholders, who, from the 1980s on, gradually decided to grow rubber trees as a monocrop thanks to innovative technologies and subsidy programmes (Siriaraya, 2009). In 2018, there were 22.6 million rais of rubber plantation areas in Thailand, 60% which located in the Southern region (Office of Agricultural Economics, 2019). About 90% of the rubber plantations in Thailand were monoculture (Delarue and Chambon, 2012). These rubber plantations give satisfactory income, employment and economic growth whenever the rubber price is high but sometime it causes

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negative impacts and suffer perturbations during economic and climatic uncertainties. For instance, after the rubber price was high peaked in 2011 which averaged price about 132 Baht per kg, the rubber growers suffered due to low income. There are concerned with several reasons e.g. the People's Republic of China, the biggest natural rubber importer of the world, has applied measures to slow economic growth and orient development towards balance and sustainability; European countries and the USA have experienced monetary and economic crises; and rubber planting areas in many regions and nations have increased because of high rubber price and government promotion, all of which has led to an oversupply of rubber products since 2013, and the subsequent drop in price. In addition, the World Bank data for a total of 13 years (2014-2026) indicates that the rubber price will continue to be in the low range (Figure 1).

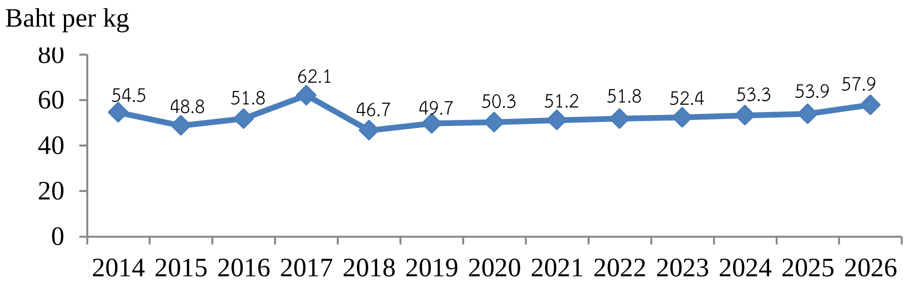

Figure 1. Rubber price forecasting during 2014-2026
Source: The World Bank, 2019.

The World Bank's rubber price forecast accords with comment of Hu (2019), an international agricultural economics expert of the Chinese Academy of Social Sciences. He sees the constant demand of natural rubber in China in the future because mode of transportation in China will shift from using cars mainly to using more environmentally friendly rail systems. Therefore, tire manufacturing industries in China will have lower growth rate. In environmental aspects, many mono rubber farmers are facing risks stemming from years of agrichemical use resulting in soil acidification, and the loss of cover crops protecting the soil surface (Jongrungrot *et al*., 2014). Externalities of rubber monoculture are the impacts that they increase sedimentation in streams and decrease biodiversity (Langenbergerb *et al*., 2016). Also, monoculture rubber trees fall in a storm more easily than nearby agroforestry rubber trees (Jongrungrot and Thungwa, 2013).

Resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation (Holling, 1973). Transferring insights from resilience thinking onto farm management would allow shifting the emphasis from predicting the specifics of future possibilities towards focusing on the factors that build the ability of the farm to respond to change (Darnhofer, 2009). Crop diversification can improve resilience in a variety of ways (Lin, 2011). Rubber agroforestry systems can generate income diversification and better resilience (Stroesser *et al*., 2016). For instance, when tapping is not possible, income from rubber associated crop is a good substitute (Kheowvongsri, 2008). Also, modeling by Stroesser *et al*. (2016) showed that most agroforestry farms were more resilient to rubber price volatility due to the flexibility of their systems. Although rubber based intercropping does not provide the plot with water directly, there is more humidity in this plot in the dry season than in mono-crop rubber plot, which is beneficial for higher latex yield (Sdoodee and Limsakul, 2012). Rubber agroforestry systems also provide environmental services, for instance, land and water conservation, micro-climate improvement (De Leeuw *et al*., 2014*)*, and soil organic carbon stocks (Pierret *et al*., 2011). In Thailand, the number of rubber agroforestry plantations which can support income diversification and resilience is limited and there is an insufficiency of research concerning the plantation's resilience to support extension of rubber agroforestry system in the future.

The research finding aimed to assess the margin resilience of twelve rubber agroforestry plots in southern Thailand following lower rubber price for last five years of a ten-year simulation, to classify resilience levels of each rubber agroforestry plot and show some benefits and constraints of the current rubber agroforestry plots with the nationwide popular rubber planting distances and give recommendations for improving and promoting rubber agroforestry practices in the future.

Materials and methods

The study locations were Chana District, Hadyai District, Namom District, and Khlonghoykhong District in Songkhla Province; Tamod District in Phatthalung Province; Thaphae District, and Manang District in Satun Province; Kabang District in Yala Province; Huaiyot District in Trang Province. All of the five provinces are in Southern Thailand. Twelve rubber agroforestry farmers were selected for research investigation. The experimental plots were arranged by purposive sampling, one plot per farmer and each plot cultivated intercropping system and/or livestock. It represented the diversity of rubber agroforestry (Table 1).

Data was collected by field survey and a structured interview that were done in 2018 and 2019 to collect technical and economic data of the sample plots. Data analysis was done by forecasting economic margins of the plots for 10 years (2017-2026) under (a) normal condition: all real prices were used for first two year (2017-2018) and all prices were fixed in 2018 for last eight year (2019-2026). Changes in quantities of farm products and inputs from 2019 to 2026 based on farmers' experiences and planning, as well as academic data (b) scenario 1: latex prices from 2022 to 2026 reduced 40% from the fixed price in 2018, and (c) scenario 2: The farmers increased or changed various products of the intercrops and livestock to compensate the lower rubber price. Olympe Program was used to calculate the margins under the normal condition, scenarios 1 and scenario 2. The margins of the plots were calculated by the formula as follows:

$$M = (Y_1 + Y_2 + Y_3) - (VC_1 + VC_2 + VC_3)$$

M = economic margin

Y_1 = rubber income

Y_2 = intercrop income

Y_3 = livestock income

VC_1 = rubber variable cost

VC_2 = intercrop variable cost

VC_3 = livestock variable cost

Table 1. Characteristics of the twelve rubber agroforestry plots in 2019

Plot No.	**Province**	**Area (rai)**	**Rubber tree age (year)**	**Intercrops and animals in the rubber agroforestry plots**			
				Timber	Fruit tree	Other intercrop	animal
1	Songkhla	3.5	17	Eaglewood (*Aquilaria crassna Pierre ex Lecomte*)			
2	Songkhla	5.5	11	Ironwood (*Aquilaria crassna Pierre ex Lecomte*)			
3	Phatthalung	13	10	Ironwood			
4	Satun	12	20			Straw mushroom (*Volvariella volvacea*)	
5	Songkhla	1	11			Sarjor-caju mushroom (*Pleurotus sajor-caju(Fr.) Sing.*)	
6	Songkhla	2.16	9			Vegetable fern (*Diplazium esculentum (Retz.)Swartz*)	
7	Yala	1	13		Pineapple (*Ananas comosus*)	Gnetum (*Gnetum gnemon var. tenerum Markgr.*)	
8	Phatthalung	9	16		Mangosteen (*Garcinia mangostana L.*)		
9	Trang	5	12		Sala (*Salacca magnifica J.P.Mogea*)		
10	Songkhla	12	15			Yellow palm (*Chrysalidocarpus lutescens H. Wendl.*)	
11	Songkhla	8	20		Longgong (*Lansium domesticum Corr.*)		Egg laying ducks (*Anas platyrhychos*)
12	Satun	5	8				Goats (*Capra hircus*)

Descriptive statistic was used to compare the margins of the plots in 2019 and explain resilience levels of the plots. Criteria to classify resilience levels are shown in Table 2 and content analysis was used to find out some benefits and constraints of the current rubber agroforestry plantations with the nationwide popular rubber planting distances and recommendations for improving and promoting rubber agroforestry practices in the future.

Table 2. Criteria to classify resilience levels of the plots

Resilience levels	***Criteria***
High	• 1-2 years for practice adjustment in the plot • Compensating for margin losses not less than 100%
Medium	• 3-5 years for practice adjustment in the plot • Compensating for margin losses not less than 100%
Low	• 3-5 years for practice adjustment in the plot • Compensating for margin losses less than 100%

Results

Plot 1: Rubber intercropped with Eaglewood

Normal condition: For the 10 year forecast, the plot margins will come from only rubber latex. In 2018, the margin decreased owing to fall of the rubber price. During 2019-2026, the margins will be stable because the old rubber trees give some stable yields. *Scenario1* (40% lower price of latex): From 2022 to 2026 (5 years), the margin will go down 17,205 Baht per rai from normal condition. *Scenario2*: In 2023. The farmer will pay for stimulating Eaglewood trees to produce dark aromatic resin embedded wood so that the margin in this year will decrease and be minus. In 2026, the farmer will sell all twenty-two-year-old Eaglewood trees. The margin in 2026 will go up to 193,208 Baht per rai which can compensate for about 1,123% of the total lower margin from scenario 1 (Figure 2).

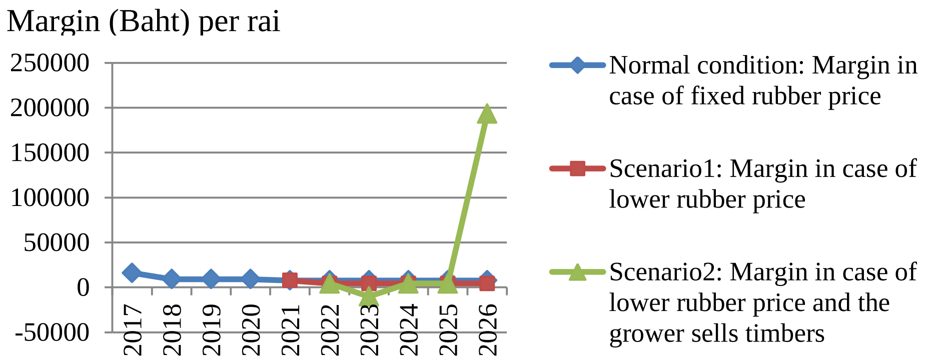

Figure 2. Margin of Plot 1 before and after built scenarios from 2017 to 2026

Plot 2: Rubber intercropped with Ironwood

Normal condition: For the 10 year forecast, the farmer will gain the margins from only rubber latex. In 2018, the margin went up because the rubber yield increased by age although the rubber price fell. During 2019-2020, the margin will be stable because of the stable rubber yield by age. From 2021 to 2026, the margins will decrease periodically because of the decrease of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will go down 18,694 Baht per rai from normal condition. *Scenario2*: In 2026, the farmer will sell only 5 fifteen-year-old Ironwood trees per rai. The margin in 2026 will be 24,141 Baht per rai, which can compensate for about 129% of the total lower margin from 2022 to 2026. This plot will still have 85 Ironwood trees per rai left (Figure 3).

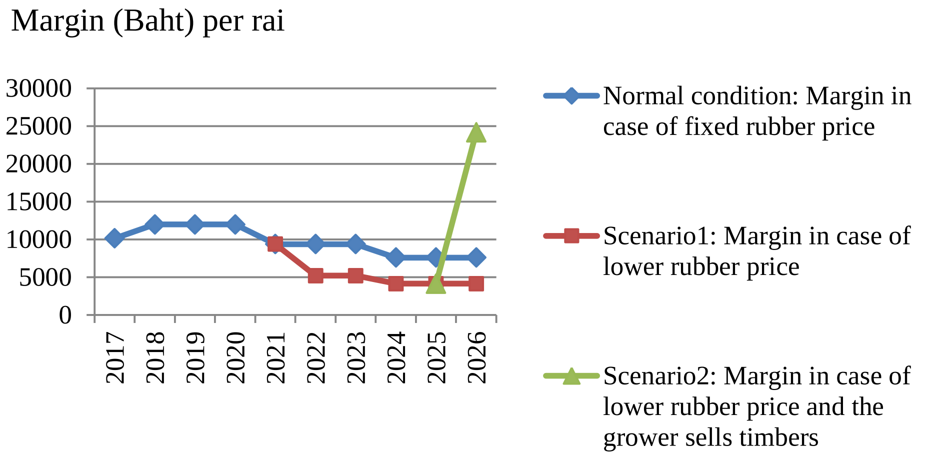

Figure 3. Margin of Plot 2 before and after built scenarios from 2017 to 2026

Plot 3: Rubber intercropped with Ironwood

Normal condition: For the 10 year forecast, the margin will come from only rubber latex. In 2018, the margin decreased owing to the fall of rubber price. In 2019-2021, the margins increase owing to the latex increase by rubber age. After that, the margin will decrease periodically because of the latex decrease by rubber age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will go down 21,767 Baht per rai from normal condition. *Scenario2*: In 2026, the farmer will sell only 4 fifteen-year-old Ironwood trees per rai. The margin in 2026 will go up to 30,788 Baht per rai, which can compensate for about 141% of the loss. This plot will still have 34 Ironwoods per rai left (Figure 4).

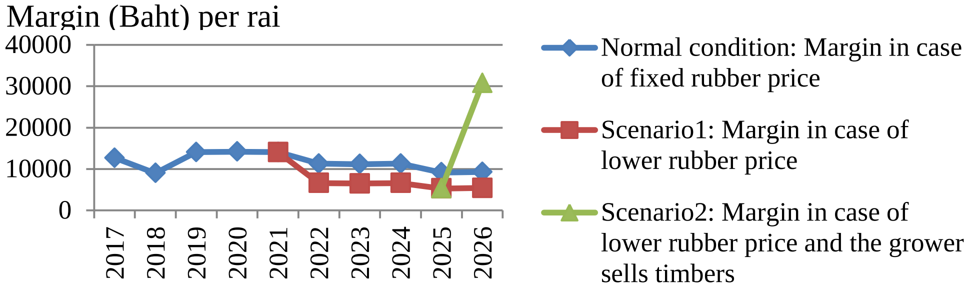

Figure 4. Margin of Plot 3 before and after built scenarios from 2017 to 2026

Plot 4: Rubber intercropped with Straw mushrooms

Normal condition: During 2017-2026, yield of the old rubber trees will be stable and amounts of Straw mushrooms will be also stable owing to the farmer management. Therefore, in 2018, the margin decreased owing to only the fall of rubber price. During 2019-2026, the margins will be stable because of the stable amounts of the rubber latex and Straw mushrooms. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will go down 10,505 Baht per rai from normal condition. *Scenario2*: During the last two years of the simulation, the farmer will increase the number of mushroom farm-huts from 8 to 9 farm-huts per rai per year. So, the margin from 2025 to 2026 will gain up to 20,270 Baht per rai, which can compensate for up to 193% of the loss (Figure 5).

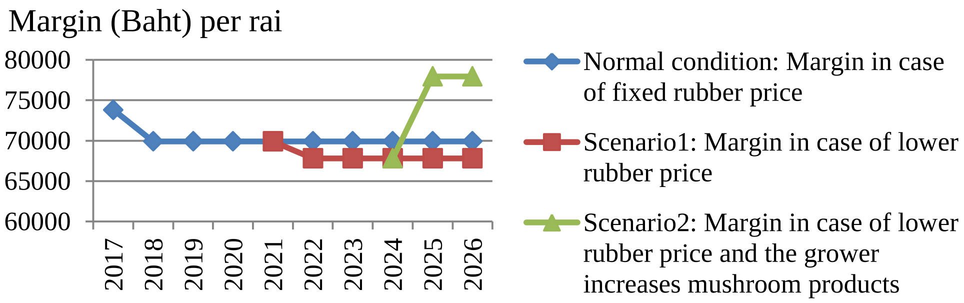

Figure 5. Margin of Plot 4 before and after built scenarios from 2017 to 2026

Plot 5: Rubber intercropped with Sarjor-caju mushrooms

Normal condition: During 2017-2026, yield of the rubber trees before old age will go up and down by age and amounts of Sarjor-caju mushroom will be stable every year. Hence, during 2018-2020, the margins would increase owing to the increase of rubber yield by age. After that, the margins will decrease periodically because the decrease of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will go down 42,041 Baht per rai from normal condition. *Scenario2*: During the last three years, the farmer will increase the number of mushroom bags from 7,000 to 7,600 bags per rai per year. So, the margin from 2024 to 2026 will go up 53,604 Baht per rai, which can compensate for up to 128% of the loss (Figure 6).

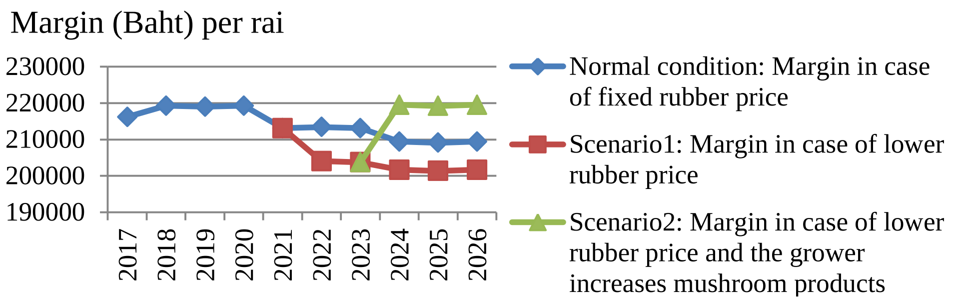

Figure 6. Margin of Plot 5 before and after built scenarios from 2017 to 2026

Plot 6: Rubber intercropped with vegetable ferns

Normal condition: In 2017, the farmer got merely the margin from vegetable fern shoots. In 2018, the margin went up because of increasing sale volume of the vegetable fern shoots. In 2019, the rubber trees started to yield and the farmer could sell the stable volume of vegetable fern shoots every year. These caused the margin increase in this year. During 2020-2022, the margin will increase because of increase of rubber yield by age. After that, the margins will go down periodically because of decrease of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will decrease 58,096 Baht per rai. *Scenario2*: During the last two years, the farmer will increase possibly the sale of vegetable fern shoots from 27,778 to 39,780 shoots per rai per year. So, the margin from 2025 to 2026 will increase to 72,012 Baht per rai, which can compensate for up to 124% of the loss (Figure 7).

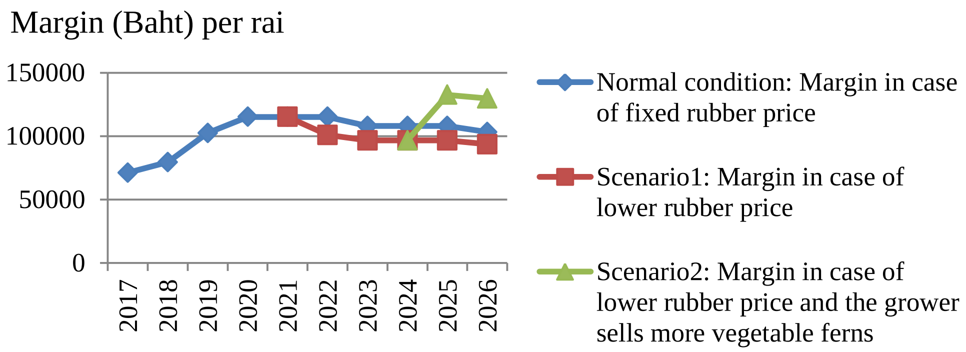

Figure 7. Margin of Plot 6 before and after built scenarios from 2017 to 2026

Plot 7: Rubber intercropped with Gnetum and pineapples

Normal condition: In 2017, the margin composed of 17% from rubber products, 74% from Gnetum leaves and grafts, and 9% from pineapples. Amount of Gnetum leaves and grafts as well as pineapples will be stable every year. During 2018-2026, the margin will decrease periodically owing to the fall of rubber price in 2018 and the decrease of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the plot margin will decrease 8,145 Baht per rai from normal condition. *Scenario2*: Starting in 2022 the farmer will increase the weight of sold Gnetum leaves from 600 to 650 kilos per rai per year and number from 90 to 108 sold Gnetum grafts per rai per year. So, the margin from 2022 to 2026 will go up to 16,777 Baht per rai, which can compensate for up to 206% of the loss (Figure 8).

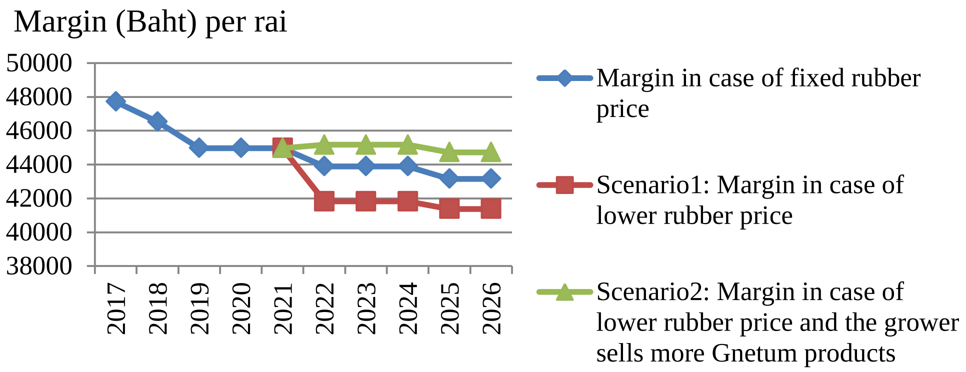

Figure 8. Margin of Plot 7 before and after built scenarios from 2017 to 2026

Plot 8: Rubber intercropped with Mangosteens

Normal condition: In 2017, the farmer gained the margin from only rubber latex while mangosteens did not fruit owing to rain during flowering. In 2018, the margin decreased because of the fall of rubber price and lower rubber yield by age. In this year, the mangosteens gave a small yield. During 2019-2020, the margin will go down owing to fertilizer cost increase. From 2021 to 2026, the margin will decrease periodically because of the fall of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will decrease 30,990 Baht per rai from normal condition. *Scenario2*: Starting in 2022, the farmer will prune the mangosteen trees and cut down all diseased and stunted rubber trees to increase sun-light in the plot to increase flowering and fruiting. So, the margin from 2023 to 2026 will gain up to 32,640 Baht per rai, which can compensate for about 105% of the loss (Figure 9).

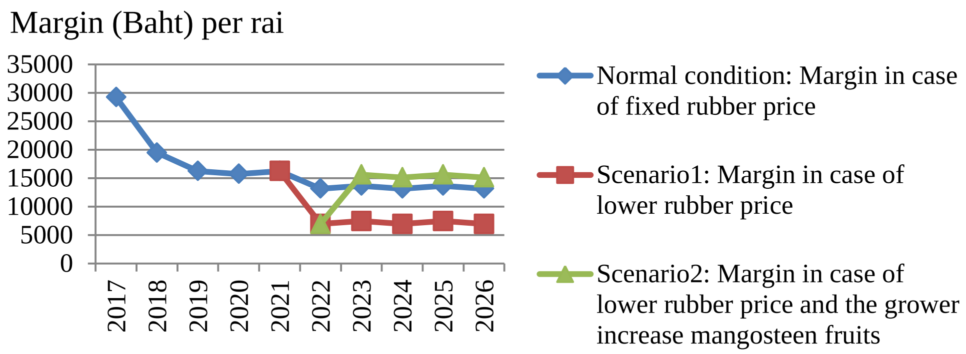

Figure 9. Margin of Plot 8 before and after built scenarios from 2017 to 2026

Plot 9: Rubber intercropped with Sala

Normal condition: In 2017, the farmer gained the margin from only rubber latex while two year old Salas did not fruit. In 2018, the margin increased because Salas started to yield that could overcome lower rubber price. In 2019, the margin increased slightly as Salas yield increase by 5% every year. After that, the margins will vary owing to decrease of rubber yield by age, increase of Sala yield by age and increase of fertilizer amount by Sala age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the plot margin will go down 45,837 Baht per rai from normal condition. *Scenario2*: In 2022 and 2023, 30% of each year's Sala fruits will be simply processed by the farmer, and from 2024 to 2026 will increase to 40, 50 and 60% per year, respectively. So, the margin for the five years will gain up to 58,790 Baht per rai, which can compensate for up to 128% of the loss (Figure 10).

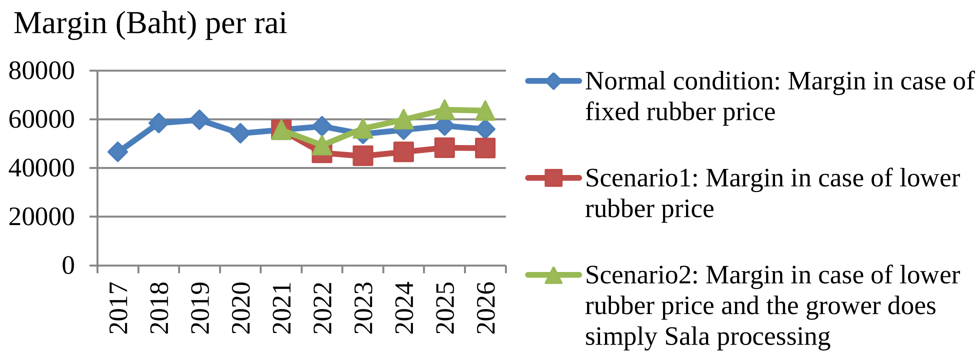

Figure 10. Margin of Plot 9 before and after built scenarios from 2017 to 2026

Plot 10: Rubber intercropped with Yellow palms

Normal condition: In 2017, the margin composed of 61.5% from rubber products and 38.5% from Yellow palm leaves. Amount of the sold leaves will be stable every year. Hence, during 2017-2026, the margin will decreased periodically owing to the decrease of rubber yield by age. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will go down 12,974 Baht per rai from normal condition. *Scenario2*: Since 2022, the farmer will increase number from 4,000 to 4,680 sold leaves of Yellow palm per rai per year. So, the margin from 2022 to 2026 will go up to 6,800 Baht, which can compensate for only 52% of the loss (Figure 11).

Margin (Baht) per rai

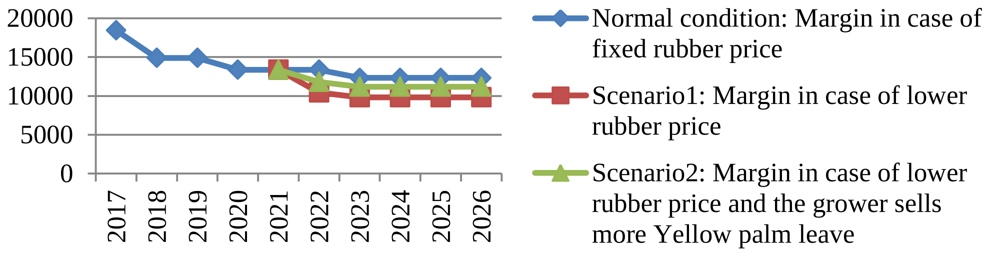

Figure 11. Margin of Plot 10 before and after built scenarios from 2017 to 2026

Plot 11: Rubber with Longgong and Egg-laying ducks

Normal condition: In 2017, the margin composed of 48.5% from rubber latex, 29.3% from Longgong, and 22.2% from duck egg. In 2018, the margin decreased because of the latex price fall and lower yield of Longgong owing to rain during flowering. Also, the rubber trees gave stable yield by old age. In 2019, the margin decreased further because of cost of buying Egg-laying ducklings and low egg yield. In this year, amount of Longgong fruit was close to that in 2017 and was set to be stable in the future. In 2020, the margin will go up because of high egg yield of adult ducks and income from sold retired ducks at the end of this year. In 2021, the margin will drop again owing to cost of buying the ducklings and low egg yield. In 2022, the margin will increase again owing to high egg yield of adult ducks and income from selling the retired ducks. From 2023 to 2026, the margin will down and up alternately, following the round of raising the ducks. *Scenario1* (40% lower price of latex): From 2022 to 2026, the plot margin will go down 25,600 Baht per rai from normal condition. *Scenario2*: Starting in 2023, the farmer will increase the number of egg-laying ducks from 200 to 280 to be replaced every two years. So, the margin from 2023 to 2026 will gain up to 27,928 Baht per rai, which can compensate for about 109% of the loss (Figure 12).

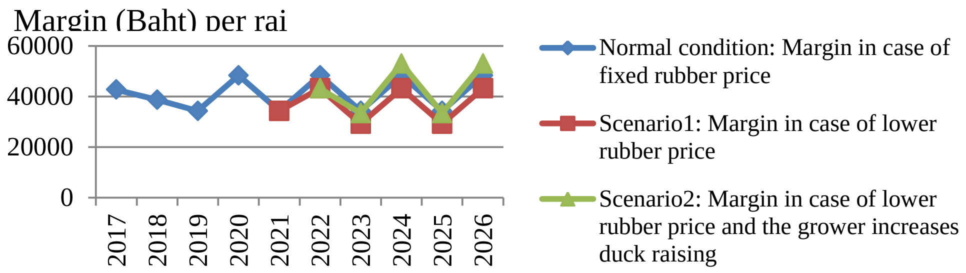

Figure 12. Margin of Plot 11 before and after built scenarios from 2017 to 2026

Plot 12: Rubber with Goats

Normal condition: In 2017, the farmer gained the margin from only rubber latex. In 2018, the margin decreased because of lower rubber price. In 2019, the margin decreased slightly because the farmer alternated from using organic to chemical fertilizer that had higher price and bought meat goats as breeders. During 2020-2023, the margin will increase continuously because of more sold live goats every year. In 2024, the margin will decrease because of lower sold live goats. In 2025, the margin will drop further owing to lower sold live goats and new bought breeders replaced the old ones. In 2026, the margin will go up again owing to new round of selling live goats. *Scenario1* (40% lower price of latex): From 2022 to 2026, the margin will decrease 57,911 Baht per rai from normal condition. *Scenario2*: Starting in 2022, the farmer will change from selling live goats to slaughtered goats. So, the margin from 2022 to 2026 will gain up to 63,000 Baht per rai, which can compensate for about 109% of the loss (Figure 13).

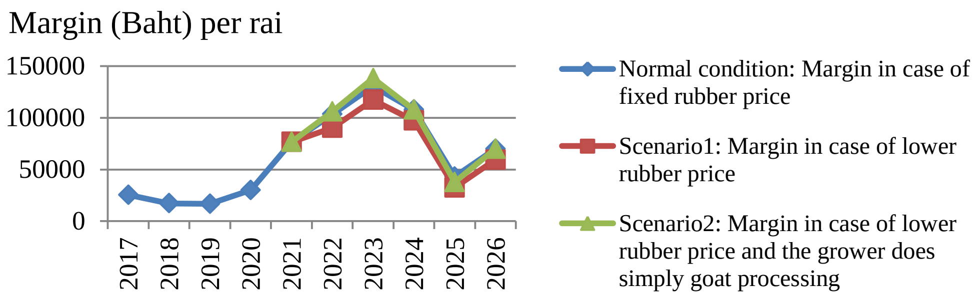

Figure 13. Margin of Plot 12 before and after built scenarios from 2017 to 2026

Resilience levels of the twelve rubber agroforestry plots

From scenario 1, the 40% reduced latex price from 2022 to 2026 has led to the decreased margins of the twelve plots. Then, the farmers adjust their practices depending on their knowledge, skill, specific intercrops, proper time for harvesting, market demand, and so on in order to increase the margins to compensate for the margin loss in scenario 2. Hence, there are various practices, margin change, and margin resilience of the plots. For this study, the resilient levels of the plots are classified in Table 3.

Table 3. The resilience levels of the twelve rubber agroforestry plots

Resilience Level	Plot Number	Kind of Intercrop and livestock	Criteria
High	Plot 1	Eaglewood	• One year for practice adjustment • Compensates for margin loss up to 1,123%
	Plot 2	Ironwood	• One year for practice adjustment • Compensates for margin loss up to 129%
	Plot 3	Ironwood	• One year for practice adjustment • Compensates for margin loss up to 141%
	Plot 4	Straw mushroom	• Two years for practice adjustment • Compensates for margin loss up to 193%
	Plot 6	Vegetable fern	• Two years for practice adjustment • Compensates for margin loss up to 124%
Medium	Plot 5	Sarjor-caju mushroom	• Three years for practice adjustment • Compensates for margin loss up to 128%
	Plot 7	Gnetum and pineapple	• Five years for practice adjustment • Compensates for margin loss up to 206%
	Plot 8	Mangosteen	• Four years for practice adjustment • Compensates for margin loss up to 105%
	Plot 9	Sala	• Five years for practice adjustment • Compensates for margin loss up to 128%
	Plot 11	Longgong and egg laying duck	• Four years for practice adjustment • Compensates for margin loss up to 109%
	Plot 12	Goat	• Five years for practice adjustment • Compensates for margin loss up to 109%
Low	Plot 10	Yellow palm	• Five years for practice adjustment • Compensates for margin loss only 52%

The twelve rubber agroforestry plots in Figure 14 are classified by the resilience levels and indicate the margin per rai in 2019. Some analysis and comparison of them are as follows:

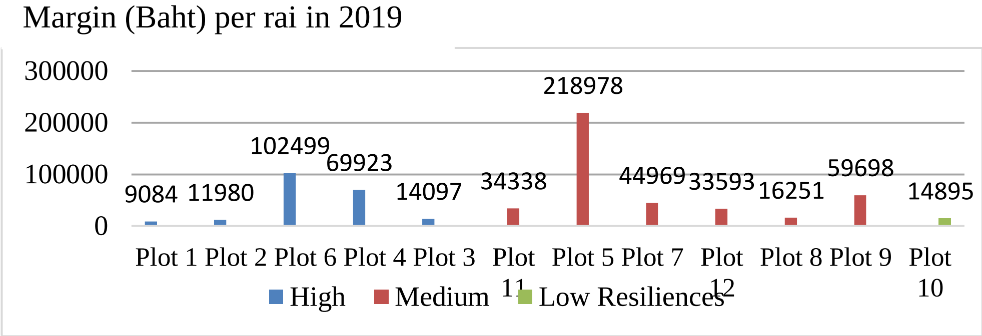

Figure 14. The twelve rubber agroforestry plots classified by resilience levels and with the margin in 2019

Five plots with high resilience

Plots 1, 2, and 3 were the rubber based timber plots with high resilience and low margins in 2019, ranging from 9,084 to 14,097 Baht per rai, because the margins were from only rubber product at low price. Meanwhile, plots 4 and 6 had high resilience and high margins in 2019, about 69,923 Baht per rai for the rubber based straw mushroom plot (Plot 4), and 102,499 Baht per rai for the rubber based vegetable fern plot (Plot 6) because each plot provided margins from rubber and intercrop product and the intercrop product had good price because it was a green product free from chemical pesticide and herbicide.

Six plots with medium resilience

Plots 5, 7, 8, 9, 11 and 12 showed medium resilience. In 2019, the six plots had a wide range of margins from 16,251 to 218,978 Baht per rai. The highest margin of the six plots (in fact of all plots in this study) belonged to Plot 5 (rubber intercropped with Sarjor-caju mushroom). The six plots generated the margin from rubber products, intercrop and/or livestock products, and had higher margins than the three rubber based timber plots with high resilience (Plot 1, 2, and 3) and the rubber based Yellow palm plot with low resilience (Plot 10).

One plot with low resilience

Plot 10 showed low resilience. The farmer had to sell more Yellow palm leaves for last five years of the 10-year simulation but was able to compensate for only 52% of the margin loss. This was due to a limited Yellow palm market and high market competition in the area. In 2019, this plot had a low margin of about 14,895 Baht per rai, ninth out of the twelve.

The twelve rubber agroforestry plots had various rubber planting distances: 5x3 m, 5.5x3 m, 6x3 m, 7x2 m, and 7x3m. These and other similar rubber planting distances are popular all over Thailand and seem to be proper for rubber monoculture. Several times in the past, when rubber prices decreased, some rubber farmers in Southern Thailand tried to introduce intercrops or livestock in the rubber plots. Some benefits and constraints of the twelve rubber agroforestry plots that use the popular nationwide rubber planting distances were shown in Figure 15.

In the last year of the 10-year simulation, the timber plots will potentially show high resilience because they will compensate for all previous margin losses, and will have timbers left for generating income and resilience in the future without any additional management or investment. Raising the egg laying ducks and meat goats in rubber plots showed some benefits in terms of 1) increased source of margins in the plots, though the margins will rise and fall in waves, owing to the life cycle of the animals, and instability of production due to the age of the animals, 2) compensation for all previous margin losses via increasing the number from 40% to 50% of ducks that the farmer can reasonably manage; changing from selling live goats to selling slaughtered goats; or adding value by making goat curry, and 3) yielding byproducts, e.g. duck and goat feces used as organic fertilizer for rubber trees and intercrops in the plots. In addition, the animals help eat or gnaw weeds in the plots, thus decreasing or eliminating the need for fertilizers and weed control by the farmer. Of all the intercrops in this study, Sarjor-caju mushrooms, vegetable ferns, and straw mushrooms gave the top three margins in 2019, respectively. Also, they produced green products daily since they did not have to deal with chemical pesticides and herbicides, which they are sensitive to. Salas grew well and gave good fruits in rubber tree shade. Also, the pineapple flesh (sarcocarp) has good texture if grown in the shade of other trees, like rubber trees. Gnetun in rubber shades grew well and had good leaf quality (i.e. the taste was not bitter). Mangosteen and Longgong trees in the shade of rubber trees were balanced and tall, and the quality of the fruit was equal to that from monocultures. However, they flowered and fruited less than in monocultures because they receive less sunlight than monocultures and there were competition for nutrient of root system. A farmer said that less flowering helped reduce time for pruning.

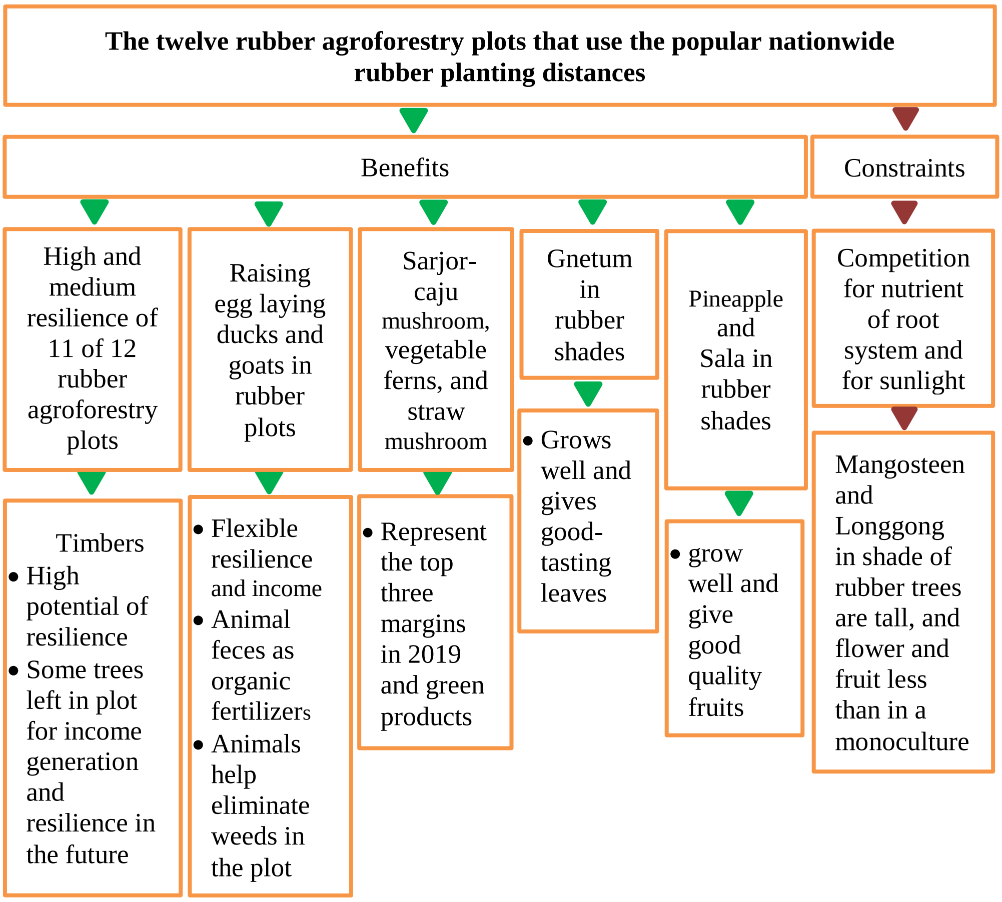

Figure 15. Benefits and constraints of the twelve rubber agroforestry plots that use the popular nationwide rubber planting distances

Discussion

The twelve rubber agroforestry plots that use the popular nationwide rubber planting distances are resilient and offer various benefits. 11 of 12 rubber agroforestry plots had high and medium resilience. After cutting down some timbers in rubber plot, the rest left for income generation and resilience in the future. Raising livestock in rubber plots provided some byproducts in the plots. Mushrooms and vegetable ferns in rubber plots gave high resilience and were green products. Gnetum, pineapple and Sala in rubber shades grew well and gave good quality products. This result accords with Simien and Penot (2011) who indicated that the bigger the share of income from the associated crop, the better it would help the farmer survive a decline in rubber price. However, due to the narrow rubber planted distance, there are some constraints. Most important are the competition for nutrient of root system and for sunlight. This result corresponds to Chiarawipa (2019) who mentioned that there is competition for nutrients of root systems and for sunlight among rubber and Longgong trees, leading to taller Longgong trees and less productivity than in mono crop systems.

Some recommendations for improving and promoting rubber agroforestry practices in the future are as follows: 1) fell stunted and diseased rubber trees and intercropped trees that can no longer be harvested. In case of newly planted rubber plots, the farmer should increase the rubber inter-row distances. For instance, 7x3 m spacings could become 14x3 m to allow more sunlight to enter the plots and to decrease competition among root systems; 2) prune the intercrops, especially fruit trees such as Mangosteen. The farmer should prune inside branches to allow more sunlight entry and trim the ends of branches to control the canopy and prevent branches from breaking; 3) choose intercrops that are suitable for the ecosystem in the plot. For instance, some wild trees such as Ironwood, and Anan (*Fagraea fragrans* Roxb.) should be planted along waterways; and 4) choose rubber agroforestry system that is appropriate for the farmer's time availability, and the required income. For example, an old farmer who has enough off-farm income and little time for farming, might be wise to choose a timber intercrop because of the low maintenance, and hire share-tappers to harvest the rubber latex.

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