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Community forest management: Comparison of simulated production and financial returns from agarwood, tengkawang and rubber trees in West Kutai, Indonesia

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Abstract. *Lahjie AM, Isminarti, Simarangkir BDAS, Kristiningrum R, Ruslim Y. 2018. Community forest management: Comparison of simulated production and financial returns from agarwood, tengkawang and rubber trees in West Kutai, Indonesia. Biodiversitas 19: 126-133*. Research was conducted in planted forests of agarwood (*Aquilaria* spp.) and tengkawang (*Shorea macrophylla*) and in plantations of natural rubber (*Hevea brasiliensis*) in West Kutai District, East Kalimantan Province, Indonesia. The research aimed (i) to find out the productivity of agarwood and tengkawang trees in mixed plantings (ii) to measure their rate of development in order to estimate the maximum Mean Annual Increment (MAI) for agarwood and tengkawang and (iii) to carry out a comparison with natural rubber production of the investment feasibility of planted forests of these trees using a financial analysis of Pay Back Period, Net Present Value (NPV), Net Benefit/ Cost (B/C) Ratio and Internal rate of Return (IRR). The research was based on measurements carried out in plots, 0.25 ha in extent, selected by systematic random sampling from three model plantations. Plantation **Model I** was a combination of agarwood and tengkawang in one piece of land in which the agarwood trees were planted at a spacing of of 5m x 2.5m and the tengkawang tree were also planted at a spacing of 5m x 2.5m. This means that there were a total of 200 agarwood saplings and 200 tengkawang saplings in the plot. **Model II** was the combination of agarwood and tengkawang in one piece of land, in which 167 agarwood saplings were planted and 166 tengkawang saplings were planted in a different planting arrangement (at the planting distance of 5m x 3 m). **Model III** was rubber trees in an area of 0.25 ha with 119 saplings. The data for natural rubber were collected in series from the farmers. The measurement variables for agarwood and tenkawang included the diameter and height of trees using series measurement until they reached 30 years and then the results were simulated. The research findings showed that in **Model I**, agarwood was found to have higher maximum MAI while in **Model II**, tengkawang was found to have higher maximum MAI. This was the result of a silvicultural technique in which thinning, maintenance and intermediate harvest were carefully controlled. These two models were feasible for business because the values of their IRR were 14% and 13.3% respectively, while in **Model III**, rubber cultivation was not feasible for business because the value of its IRR was only 4.7%.

Keywords: *Aquilaria* spp., production, *Shorea macrophylla*, simulation

INTRODUCTION

Agarwood and tengkawang are economically valuable forestry trees grown in Indonesia, particularly in West Kutai, Kalimantan, the focal area of the study reported in this paper. Agarwood is commonly known in Indonesia as '*gaharu*', and belongs to the genus *Aquilaria* Lam. in the family Thymelaeaceae. Its mature trees produce a prized fragrant wood. Tengkawang is the Indonesian name given to several timber-producing tree species in the genus *Shorea* Roxb.ex C.F. Gaertn. of the Dipterocarpaceae family (Kettle 2010). The natural distribution area for tengkawang includes India, Thailand, Malaysia, Indonesia, Sarawak, Sabah, and The Philippines (Kettle 2010; Saner et al. 2012; Widiyatno et al. 2014). The tengkawang tree can be found in Kalimantan and Sumatera islands (Purwaningsih 2004; Kettle 2010).

In contrast to these species, plantations of natural rubber (*Hevea brasiliensis*), a native of the tropical rainforest of the Amazon Basin, are these days often seen as problematic, competiting with the planted forest species both in economic terms and in terms of conservation goals (Wu et al. 2016).

Forest destruction and resulting land degradation in East Kalimantan is of serious concern. This condition arises as the result of forest fires, illegal logging, human population pressures, forest function conversion, as well as unsustainable forest management practices (Gonner and Seeland 2002). These factors together accelerate the process of forest decline and land degradation (Sunandar 2005). Analysis of satellite imagery reveals that the total land area of critical concern in East Kalimantan is as much as ± 6.4 million ha, which consists of ± 4.3 million ha located inside forest areas and 2.1 ha located outside the forest areas (Edwards et al. 2014).

Fire is a major threat to production forests, especially following desiccation from sustained droughts (Wilcove et al. 2013). The canopy disruption and trail networks that result from logging promote forest desiccation, while fine slash from logging is highly flammable when dry. Burnt production forests are also vulnerable to further disturbance, such as from subsequent fires, salvage-logging (Van Nieuwstadt et al. 2001), invasion by grasses (Veldman et al. 2009), and even conversion to persistent *Imperata* grasslands (Van Nieuwstadt et al. 2001). Fortunately, if a logged forest is not subject to burning soon after extraction, then susceptibility to fire can diminish within a few years (Blate 2005).

Forests both natural and planted are of considerable environmental and economic value at the local, regional and global scale, providing many goods and service to a growing population (Kettle 2010). The extent of critical land in West Kutai has reached 1 million ha. In 1995, the extent of critical land in all of East Kalimantan was approximately 3.5 million ha. Relevant to this figure, the rate of forest and land destruction in East Kalimantan has been estimated to reach 290 thousand ha year^{-1} (Sunandar 2005). The demand for timber products will continue to increase in future, so the development of more effective ways for managing the timber-harvesting system is paramount to the continued protection of diversity in tropical forestry (Ruslim et al. 2016).

In two catchments in Indonesian Borneo, it has been estimated that there is a 10-fold higher runoff from skid trails and roads, than from harvest control plots which differed in runoff only marginally (Hartanto et al. 2013). In Southeast Asia, the additional runoff after logging was assessed by Chan and Parker (1996) to be insufficient to produce detectable flooding downstream. However, complete forest conversion results in 100-800% increase in annual water flow (Bruijnzeel 2004) because of enhanced runoff in rainstorms, with peak flows being 185% higher and water levels rising nearly twice as quickly as under forest cover (Douglas 1999), and with greatly increased evapotranspiration. In Indonesian Borneo alone, such flood displaced 1.5 million people between 2009 and 2012, especially in the deforested middle reaches of rivers (Wells et al. 2013).

Rubber cultivation is another form of land-use in West Kutai. It was developed in the 1980s, funded by soft loans from the Asia Development Bank with the purpose of increasing the people's income and welfare. Rubber trees (*Hevea brasiliensis)*, though originally an imported species from South America, are a source of great economic and social value throughout Southeast Asia. But compared with primary tropical forests, areas of rubber monoculture have significantly lower biodiversity, lower total biomass carbon stocks, rapidly fluctuating microclimate temperatures and negative hydrological effects (Fox et al. 2014; Liu et al. 2017: Ziegler et al. 2009). Improved rubber-based agroforestry systems, which combine agricultural, ecological and forestry techniques to create more diverse, productive, healthy, and sustainable land use, provide a promising solution to these problems and have been applied in practice in some cases (Feng 2007; Fox et al. 2014; Parham 2000). But not all of these agroforestry systems were designed with a comprehensive consideration of ecological principles. Below-ground interactions and associations between rubber trees and other intercropped species remain poorly documented, particularly regarding water-use (Ziegler et al. 2009). Rubber trees have been referred to as 'water pumps' because rubber trees can deplete water sources at the basin scale (Tan et al. 2011).

Since rubber trees can produce latex for one hundred days in a year, rubber tree plantations can support the daily economic needs for farmers. Rubber is called a cash-crop, but today, this commodity has dropped in popularity and does not attract the attention of the people because the price of rubber has decreased by 5.7% every year. In the last decade, some farmers have replaced rubber plantations with forest plants because the costs are cheaper and developement can be carried out by the farmers themselves by collecting seed from the forests (Mulyoutami et al. 2003). This does not need a big investment compared with rubber plantation. The investment is mainly in the form of manpower (Saner et al. 2012). Therefore, some Dayak people have tended to return to their original farming practices, developing the natural resources that exist around them, although at present, it is only only a limited number of people who have returned to this type of cultivation.

It is because of this, that we undertook the research reported in this paper. Our aims were (i) to determine the productivity of this kind of cultivation based on the forest species agarwood and tengkawang, compared with that of rubber trees (ii) to measure the rate of development of agarwood and tengkawang, in order to obtain estimates of the maximum value for the Mean Annual Volume Increment MAI of the these species in model plantations (iii) and to find out the investment feasibility of such plantation models using financial analysis through estimation of Pay Back Period, Net Present Value (NPV), Net Benefit/Cost Ratio (B/C ratio) and Internal Rate of Return (IRR). Measurements of the agarwood and tengkawang plantations were based on a systematic random sampling of plantation model areas of 2,500 m^2.

MATERIALS AND METHODS

Study area

The research was located in Desa Galeo Asa, Barong Tongkok Sub-district, Province of East Kalimantan, Indonesia. The study sites were located in the vicinity of 0° 09' 14.48" S – 115° 44' 16.53" E (Figure 1).

Data collection

Both direct and indirect approaches were adopted to analyse incremental growth of trees from 2005 to 2015. Specifically, the direct approach was based on observation of the increment in volume production by trees. However, due to limited data, simulations were then carried out using a law of diminishing returns model**.**

In economics, diminishing returns is the decrease in the marginal (incremental) output of a production process as the amount of a single factor of production is incrementally increased, while the amounts of all other factors of production stay constant. Probably the best way to illustrate this principle of diminishing returns as it applies to risk reduction is by reference to a case study such as that of Mold et al. (2010).

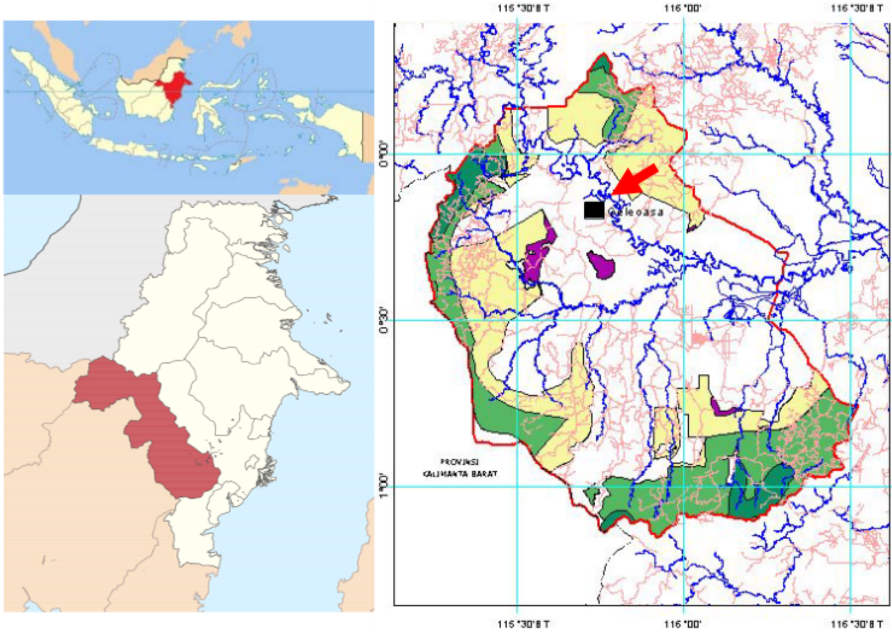

Figure 1. Location studies of Barong Tongkok Sub-district (■), West Kutai District of East Kalimantan, Indonesia

Table 1. Research plots of agarwood and tengkawang in Desa Galeo Asa, East Kalimantan, Indonesia (Isminarti et al. 2016)

Model	Objects	Planting distance			Total number of trees in 0.25 ha
		Agarwood	Tengkawang	Rubber	
I	Agarwood + tengkawang	5m x 2.5m	5m x 2.5m	-	400
II	Agarwood + tengkawang	5m x 3m	5m x 3m	-	333
III	Rubber with monoculture cultivation	-	-	7m x 3m	119

The simulation determined the potential wood production in a one hectare scale area, facilitating comparison between plantation models. The research was carried out based on three model plantation areas. **Model I** included agarwood stands and tengkawang (*Shorea* spp.) stands in combination, planted initially at a spacing of 5m x 2.5m for each species (making a total number of 400 trees within 0.25 ha-^{1}, i.e. 200 agarwood and 200 tengkawang); **Model II** also included agarwood stands and tengkawang stands, but with a different arrangement and a planting spacing 5m x 3 m (making a total number of 333 trees within 0.25 ha^{-1}) (Lusseti et al. 2016). **Model III** included rubber which was cultivated in a monoculture system with a tree spacing of 7m x 3m (with 119 tree in a 0.25 hectare plot^{-1}). Table 1 shows details of the three models. **Model I** consisted of agarwood and tengkawang with a spacial arrangement of agarwood-tengkawang-agarwood-tengkawang and so forth. **Model II** had a spacial arrangement of agarwood-tengkawang-agarwood-tengkawang-tengkawang, repeated with agarwood-tengkawang-agarwood-tengkawang-tengkawang, and so forth.

The variables measured within the plots to obtain estimates of the potential production of agarwood and tengkawang were as follows: Tree Volume, Total Volume, Mean Annual Volume Increment (MAI), and Current Annual Increment (CAI) (Van Gardingen et al. 2003).

We calculated the Mean Annual Increment and Current Annual Increment using the Van Gardingen et al. (2003) formula:

$$\mathrm{MAI} = \frac{V_t}{t}$$

In which: MAI = Mean Annual Increment (m^3 ha^{-1}year^{-1}), V_t = total volume at age t (m^{3}ha^{-1}), t = tree age (in years)

$$\mathrm{CAI} = \frac{V_t - V_{t-1}}{T}$$

Where:
CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$)
V_t = Total volume at age t (m^3 ha^{-1})
V_{t-1} = Previous total volume (m^3 ha^{-1})
T = Second age minus the first age (in years)

Due to the page limitation, details of the methods used in the third task, the financial feasibilty analysis, are not included in this paper, but are available as an internal report by contacting the authors. The financial feasibility analysis compared the Pay Back Period (APP), Net Present Value (NPV), Net Benefit Cost B/C Ratio and (Internal Rate of Return) IRR for the three plantation models.

RESULTS AND DISCUSSIONS

The simulation of potential production of agarwood trees in Model I

The agarwood cultivation at a planting distance 5m x 2.5 m can carry 800 trees ha^{-1} with replanting around 20% ha^{-1} in the first and second years of growth. Cultivation of agarwood combined with tengkawang (**Model I**) took the form of agarwood – tengkawang, agarwood – tengkawang, and so forth. Simulation based on the results of measurement showed that the maximum production of agarwood was achieved at the age of 15 years, with a total volume (V_t) of 97.97 m^3ha^{-1}, an average diameter of trees (D) of 20 cm and a branch-free height (H) of 8 meters. The potential production of agarwood based on its potential life-cycle is presented in Table 2. According to this simulation, at age 15 years when maximum production is reached, the mean annual increment (MAI) is 6.53 m^3 ha^{-1} $year^{-1}$ and the current annual increment (CAI) is 6.63 m^3 ha^{-1} $year^{-1}$.

Table 2 shows that the number of trees declines year by year. This is due to natural death of trees. which occurs naturally. Replanting activity is conducted only up to the age of 2 years; after that, there is no replacement of trees that die. The average diameters of agarwood at age of 8, 10 and 15 years is 13.5 cm; 16 cm and 20 cm respectively. This means that the diameter accretion from time of planting decreases every year, namely 1.69 cm $year^{-1}$; 1.60 cm $year^{-1}$ and 1.33 cm $year^{-1}$ respectively.

The graph of the mean annual increment (MAI) and current annual increment (CAI) of agarwood trees in **Model I** against time in years, based on the data in Table 2, is presented in Figure 2. It shows that the intersection point of the maximum annual increment and current annual increment curves for agarwood in the **Model I** plantation (i.e. with a planting distance of 5m x 2.5m) occurs at 15 years of age with the total volume being 97.97 m^3 and with MAI and CAI values of 6.53 m^3 ha^{-1} $year^{-1}$ and 6.63 m^3 ha^{-1} $year^{-1}$ respectively. T

The distribution of agarwood trees at the age of 15 varies, ranging from 14 cm to 24 cm, but the most frequent diameter at that age is 20 cm.

The simulation of potential production of tengkawang trees in Model I

The planting distance of tengkawang cultivation was 5m x 2.5m or 800 trees ha^{-1} with replanting around 20% ha^{-1} in the first and second years of growth. Tengkawang was planted in combination with agarwood stands, with a planting pattern of agarwood – tengkawang, agarwood – tengkawang, and so forth. The results of simulation based on our measurements, showed that the maximum production of tengkawang would be reached at the age of 40 years based on its life cycle. At 40 years of age, the maximum total volume (V_t) would reach 150.31 m^3 ha^{-1}; the average tree diameter (D) would be 38 cm and the branch-free height (H) would reach 17 m according to the data in Table 3. The results of our simulation indicate that the maximum production of tengkawang is reached at the age of 40 years, at which time the mean annual increment (MAI) reaches 3.76 m^3 ha^{-1} $year^{-1}$ and the current annual increment (CAI) is 3.83 m^3 ha^{-1} $year^{-1}$.

Table 3 shows that the number of trees declines year by year. This is due to natural death of trees. which occurs naturally. Replanting activity is conducted only up to the age of 2 years; after that, there is no replacement of trees that die. The average diameter of the tengkawang trees (in mixed plantation with agarwood) at age of 10, 30, and 40 years reaches 11.2 cm; 28 cm and 38 cm respectively. This means that the diameter accretion from time of planting decreases every year, namely 1.12 cm $year^{-1}$; 0.93 cm $year^{-1}$ and 0.90 cm $year^{-1}$ respectively.

Figure [illegible] shows that the intersection point of the maximum annual increment and current annual increment curves for tengkawang in the **Model I** plantation (i.e. with a planting distance of 5m x 2.5m) occurs at 40 years of age, with the total volume being 150.31 m^3 and with MAI and CAI values of 3.7[illegible] m^3 ha^{-1} $year^{-1}$ and 3.83 m^3 ha^{-1} $year^{-1}$ respectively. The diameter of tengkawang trees at the age of 40 years (in the **Model I** plantation) varies, ranging from 32 cm to 42 cm, but the most frequent diameter at that age is 38 cm.

The simulation of potential production agarwood trees in Model II

The planting distance of agarwood cultivation was 5m x 3m or 666 trees ha^{-1}, plus 20% replanting. The pattern of planting of agarwood combined with tengkawang in **Model II** was as follows: agarwood-tengkawang-agarwood-tengkawang-tengkawang, repeated with agarwood-tengkawang-agarwood-tengkawang-tengkawang, and so forth. Simulation based on the results of measurement showed that the maximum production of agarwood was achieved at the age of 15 years, with a total volume (V_t) of 61.36 m^3 ha^{-1} an average diameter of trees (D) of 18.4 cm and a branch-free height (H) of 7.4 m. The potential production of agarwood in the **Model II** plantation based on a simulation of the tree life cycle is presented in Table 4.

The results of our simulation indicates that the maximum production of tengkawang is reached at the age of 15 years, at which time the mean annual increment (MAI) reaches 4.09 m^3 ha^{-1} $year^{-1}$and its current annual increment (CAI) is 5.07 m^3 ha^{-1} year^{-1}. The graph of the mean annual increment (MAI) and current annual increment (CAI) of tengkawang trees in **Model II** against time in years, based on the data in Table 4, is presented in Figure 4 (Isminarti et al. 2016).

The diameter of agarwood trees at the age of 15 years (in the **Model II** planting) varies, ranging from 11 to 24 cm, but the most frequent diameter is 18 cm.

Table 2. Simulated potential wood production of agarwood trees in **Model I,** based on a planting distance of 5m x 2.5m (Isminarti et al. 2016)

Ages	N	D	H	F	V_t	MAI	CAI
3	750	5.5	4.0	0.75	5.34	1.78	-
5	730	8.5	5.5	0.73	16.62	3.32	5.64
8	680	13.5	6.5	0.71	44.90	5.61	9.42
10	650	16	7.3	0.68	64.84	6.48	9.97
15	600	20	8.0	0.65	97.97	6.53	6.63
20	520	23	8.5	0.62	113.80	5.69	3.17
25	480	24.5	9.0	0.60	122.13	4.89	1.67
30	440	25.5	9.5	0.59	125.89	4.20	0.75

Note: N: Population of agarwood (trees ha^{-1}); D: Tree Diameter (cm); H: Branch-free Height (m); V_t: Total Volume (m^{3}ha^{-1}); MAI: Mean Annual Increment (m^3 ha^{-1}year^{-1}); CAI: Current Annual Increment (m^3 ha^{-1}year^{-1})

Table 3. The simulated potential wood production of tengkawang trees in **Model I**, at a planting distance of 5m x 2.5m (Isminarti et al. 2016)

Ages	N	D	H	F	V_t	MAI	CAI
3	650	4.6	3.3	0.83	2.96	0.99	-
5	580	6.5	4.5	0.82	7.10	1.42	2.07
8	440	9.4	6.0	0.77	14.10	1.76	2.33
10	380	11.2	7.0	0.75	19.64	1.96	2.77
15	300	15.5	9.0	0.72	36.66	2.44	3.40
20	240	19.8	11.0	0.70	56.87	2.84	4.04
25	200	24.0	13.0	0.69	81.12	3.24	4.85
30	180	28.0	14.6	0.66	106.75	3.56	5.13
35	150	33.2	16.3	0.62	131.16	3.75	4.88
40	130	38.0	17.0	0.60	150.31	3.76	3.83
50	120	41.5	18.0	0.5[illegible]	169.37	3.39	1.91

Note: N: Population of tengkawang (trees ha^{-1}); D: Tree Diameter (cm); H: Branch-free Height (m); V_t: Total Volume (m^3 ha^{-1}); MAI: Mean Annual Increment (m^3 ha^{-1} year^{-1}); CAI: Current Annual Increment (m^3 ha^{-1} year^{-1})

Table 4. Simulated potential wood production of agarwood trees in **Model II** (Isminarti et al. 2016)

Ages	N	D	H	F	V_t	MAI	CAI
3	640	5.5	3	0.78	3.56	1.19	-
5	620	8.8	4.3	0.73	11.83	2.37	4.14
8	600	12.6	5.5	0.71	29.20	3.65	5.79
10	500	15.5	6.3	0.69	40.99	4.10	5.90
15	480	18.4	7.4	0.65	61.36	4.09	4.07
20	440	21	8	0.63	76.77	3.84	3.08
25	400	23.4	8.5	0.61	89.15	3.57	2.48
30	380	25.5	9	0.57	99.51	3.32	2.07

Note: N: Population of agarwood (trees ha^{-1}); D: Tree Diameter (cm); H: Branch-free Height (m); V_t: Total Volume (m^{3}ha^{-1}); MAI: Mean Annual Increment (m^3 ha^{-1}year^{-1}); CAI: Current Annual Increment (m^3 ha^{-1}year^{-1})

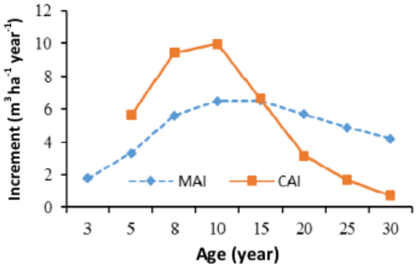

Figure 2. Trend over time (in years) for MAI and CAI of agarwood trees in **Model I**

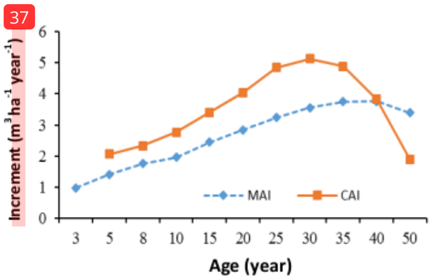

Figure 3. Trend over time (in years) for MAI and CAI of tengkawang trees in **Model I**

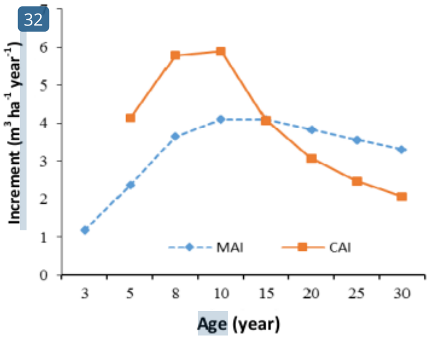

Figure 4. Trend over time (in years) for MAI and CAI of agarwood trees in **Model II**

Simulation of potential production and of diameter distribution for tengkawang trees in the Model II plantation

The results of the simulation in Table 5 show the production of tengkawang trees peaks at the age of 40 years, at which time the mean annual increment (MAI) reaches 5.43 m^3 ha^{-1} year^{-1}, when current annual increment (CAI) is 5.27 m^{3}ha^{-1} year^{-1}.

The total volume of tengkawang at the age of 10, 30, 40 years is estimated to be 27.66 m^3 ha^{-1}; 153.15 m^3 ha^{-1} and

217.16 m^3 ha^{-1} respectively. The values for MAI of tengkawang in **Model II** at the age of 10, 30, 40 years are 2.77 $m^3 ha^{-1} year^{-1}$, 5.11 m^3 ha^{-1} $year^{-1}$ and 5.43 m^3 $ha^{-1} year^{-1}$ respectively. The total volume and mean annual increment from 10 to 40 years increases because tengkawang increases in volume accretion. However, based on Table 5 after the age of 40 years, the rate of growth of tengkawang trees declines. This means that the maximum for the mean annual increment of tengkawang is reached at the age of 40 years, at which time tengkawang trees in **Model II** are ready to be harvested.

The graph of mean annual increment (MAI) and current annual increment (CAI) of wood production for tenkawang trees in Model II based on this data is presented in Figure 5 (Isminarti et al. 2016).

In Figure 5 it can be seen that the intersection of the mean annual increment (MAI) curve with the current annual increment curve (CAI) for tengkawang in Model II occurs at 40 year of age, at which time the total volume (V_t) is 217.16 m^2 and the MAI and CAI values are 5.43 $m^3.ha^{-1}.year^{-1}$ and 5.27 $m^3.ha^{-1}.year^{-1}$, respectively.

Production of natural rubber trees in a monoculture plantation

The rubber trees in monoculture cultivation (**Model III**) started to produce latex at the age of 3 years and continued through to 25 years of age, with a total production of latex rising from 900 kg ha^{-1} to 3,600 kg^{-1} after 25 years (Table 6). The average production rose from 121.43 kg $ha^{-1}year^{-1}$ to 176.47 kg $ha^{-1}year^{-1}$ between 7 years and 17 years after planting.

Table 6 shows that rubber was able to produce natural rubber/latex at the age of 3 years with a total production of 300 kg ha-$^{-1}$. This means that the average annual production of rubber over the first three years was 100 kg ha^{-1} $year^{-1}$. The natural rubber plantation reached its maximum production at age 17 years with a total production of 3,000 kg ha^{-1}, the average production of 176.47 kg $ha^{-1}year^{-1}$ over the first 17 years and an average current annual production of 175 kg ha^{-1} $year^{-1}$ in the 17th year. However, the rubber trees continued to produce latex until they reached 25 years, but with a declining annual production of latex after the 17th year. Average annual production and current annual production of rubber at the age of 25 years was144 kg ha^{-1} $year^{-1}$ and 50 kg ha^{-1} $year^{-1}$, respectively. Rubber farmers commonly harvest their natural rubber (latex) from trees aged 7 through to 25 years, although the peak production of natural rubber is reached at the age of 17 years and after this age, rubber production tended to decrease until the age of 25 years. Graphically, the production of natural rubber under monoculture cultivation can be seen in Figure 6 (Isminarti et al. 2016).

Figure 6 showed that the time series curves for average annual production (AP) and current annual production (MP) intersect at 17 years of age, the age of optimum production. However, after 17 years, the average annual production and marginal production decreased as can be seen in the graph.

Table 5. Simulated potential wood production of tengkawang trees in **Model II**

Ages	N	D	H	F	V_t	MAI	CAI
3	580	4.8	4.4	0.88	4.06	1.35	-
5	570	6.5	5.5	0.86	8.94	1.79	2.44
8	500	9.0	7.3	0.83	19.26	2.41	3.44
10	390	11.6	8.5	0.79	27.66	2.77	4.20
15	320	16.0	10.4	0.78	52.17	3.48	4.90
20	300	19.0	12.5	0.77	81.83	4.09	5.93
25	240	24.0	14.0	0.76	115.46	4.62	6.73
30	210	28.0	15.8	0.75	153.15	5.11	7.54
35	190	33.0	17.8	0.66	190.82	5.45	7.53
40	140	40.0	19.0	0.65	217.16	5.43	5.27
50	130	45.0	20.5	0.60	254.18	5.08	3.70

Note: N: Population of tengkawang (trees ha^{-1}); D: Tree Diameter (cm); H: Branch-free Height (m); V_t: Total Volume (m^3ha^{-1}); MAI: Mean Annual Increment (m^3 ha^{-1} $year^{-1}$); CAI: Current Annual Increment (m^3 $ha^{-1}year^{-1}$)

Table 6. Production of natural rubber (latex) in monoculture cultivation **Model III** (Isminarti et al. 2016)

Ages	TP (kg)	AP (kg ha^{-1} $year^{-1}$)	MP (kg $ha^{-1}$$year^{-1}$)
3	300	100.00	-
7	850	121.43	137.50
10	1450	145.00	200.00
13	2170	166.92	240.00
15	2650	176.67	240.00
17	3000	176.47	175.00
20	3350	167.50	116.67
25	3600	144.00	50.00

Notes: TP: Total Production (kg ha^{-1}); AP: Average Product (kg $ha^{-1}year^{-1}$); MP: Marginal Product/Average Current Annual Product (kg ha^{-1} $year^{-1}$)

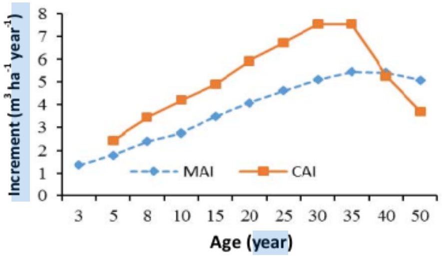

Figure 5. Trend over time (in years) for MAI and CAI of tenkawang trees in **Model II**

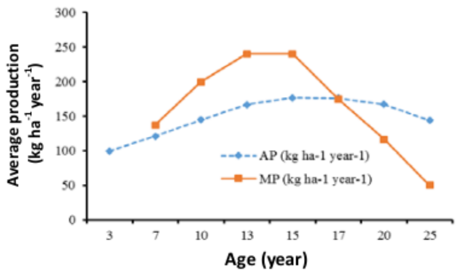

Figure 6. Natural rubber latex production from plantation trees (*Hevea brasiliensis*) under monoculture cultivation (**Model III**)

Financial analysis for wood production from mixed agarwood and tengkawang cultivations (Model I and Model II) compared with the cultivation of rubber trees for their latex (Model III).

The product prices required for financial modeling of the forest tree plantings and rubber plantations are listed as follows: the price for agarwood wood was taken to vary between Rp. 3,000 and Rp. 7,000 kilogram^{-1} based on current markets: the price for tengkawang wood was taken as Rp. 3,000 m^{-3}; while the price for natural latex was taken as Rp. 5,000 kg^{-1}, a much lower price compared to the price of rubber 15 years ago which reached Rp. 11,500 kg^{-1}. The financial analysis of the forest tree plantings was based on a 40 year cycle.

As pointed out in the Material and Methods section, it is not possible in the limited space available here to describe the full details of the methods used in the financial analysis. Here, we just present the results of the analysis.

*Financial analysis of agarwood and tengkawang cultivation (**Model I**)*

The financial analysis for agarwood cultivated in combination with tengkawang (**Model I**) at an interest rate of 5%, estimated the Pay Back Period is 9.7 years, Net Present Value (NPV) is Rp 160,668,000 and Net Benefit/Cost (B/C) Ratio is 6.4. The model analysis estimated the Internal Rate of Return (IRR) is 14%. The results indicate that agarwood and tengkawang cultivation (Model I) based on a 40 year cycle and and an interest rate of 5% is a feasible business of because its positive NPV, indicating that the cultivation of agarwood combined with tengkawang would be profitable. In addition, the value of the net B/C Ratio for this business was estimated to reach 6.4, which means that the value in rupiah obtained from the investment would be 6.4 times as much as the value of rupiah that had been invested. A value for the Net B/C Ratio > 1 is another indicator that this business is profitable. The value of its IRR (14%) is higher than the Minimum Acceptability Rate (MAR = 5%).

*Financial analysis of agarwood and tengkawang cultivation (**Model II**)*

The financial analysis for agarwood cultivation combined with tengkawang (**Model II**) at an interest rate of 5%, estimated the Pay Back Period is 14.3 years, Net Present Value (NPV) is Rp 155,796,000 and Net Benefit/Cost (B/C Ratio is 6.0. The model analysis estimated the Internal Rate of Return (IRR) is 13.3%. The results indicate that agarwood and tengkawang cultivation (**Model II**) based on a 40 year cycle and an interest rate of 5% is a feasible business because of its positive NPV, indicating that agarwood cultivation combined with tengkawang would be profitable. In addition, the value of the net B/C for this business was estimated to reach 6.0, which means that the value in rupiah obtained from the investment would be 6.0 times as much as the value of rupiah that had been invested. A value for Net B/C Ratio > 1 is another indicator that this business is profitable. The value of its IRR (13.3%) is higher than the Minimum Accessibility Rate (MAR = 5%).

Table 7. Recapitulation of financial analysis of agarwood, tengkawang, and rubber (Isminarti et al. 2016)

Models	Cycle (year)	PBP (Year)	NPV (Rp.)	Net B/C	IRR (%)
Agarwood + Tengkawang (**Model I**)	40	9.7	+160,668,000	6.4	14
Agarwood + Tengkawang (**Model II**)	40	14.3	+155,796,000	6.0	13.3
Rubber monoculture cultivation (**Model III**)	25	18.7	-1,772,000	0.95	4.7

Note: PPB: Pay Back Period (year); NPV: Net Present Value (Rp.); Net B/C: Benefit/Cost Ratio; IRR: Internal Rate of Return (%)

*Financial analysis of natural rubber produced under monoculture cultivation (**Model III**)*

The financial analysis for rubber cultivation (**Model III**) at an interest rate of 5%, estimated the Pay Back Period is 18.7 years, Net Present Value (NPV) is negative Rp. 1,772,000 and Net Benefit/Cost B/C Ratio is 0.95. The model analysis estimated the Internal Rate of Return (IRR) is 4.7%. The results indicate that monocropped rubber cultivation (**Model III**) at an interest rate of 5% is not a feasible business because the value of its NPV was negative, its Net B/C Ratio was less than 1, and its IRR was lower than the Minimum Accessibility Rate (MAR = 5%).

Recapitulation of the financial analyses

A summary of the results of the financial analysis for cultivation of agarwood, tengkawang, and rubber is outlined in Table 7. The data in Table 7 show that both models of agarwood and tengkawang cultivation (**Model I** and **Model II**) are feasible businesses, because the results of their financial analysis indicate that their NPV values were higher than zero; their Net B/C Ratios were higher than one, and their IRR values exceeded the value of MAR = 5%. On the other hand, the results for the financial analysis indicate that natural rubber produced as a monoculture (Model III) is not a feasible business, because the value of its NPV was negative, its net B/C Rasio was less than zero and its IRR which was smaller than MAR.

The results of the financial analysis showed that agarwood and tengkawang forestry production is economically more viable than plantation production of natural rubber. The values for IRR in **Model I** (agarwood – tengkawang) and **Model II** (agarwood-tengkawang-agarwood-tengkawang-tengkawang) were significantly higher than MAR (5%). In another comparable study, Winarni et al. 2017 obtained an estimate of 9.52 m^3/ha^{-1} year^{-1} for the MAI of tengkawang monoculture trees at 40 year of age growing in West Kalimantan. However, in our study we obtained an MAI value of 5.43 m^3/ha^{-1} year^{-1} for tengkawang combine with agarwood trees at the age of 40 years. This growth difference of 4.09 m^3/ha^{-1} year^{-1} is likely due to the fact that rainfall is higher in West Kalimantan higher than at Sekolaq Muliaq in East Kalimantan. Growth analysis of agarwood combined with tengkawang at a planting distance of 5m x 2.5m, both in **Model I** and **Model II** showed that agarwood reaches its maximum productivity at the age of 15 years at which time it achieved a total estimated volume of 97.97 m^3 and 61.36 m^3 respectively in **Model I** and **Model II**. Tengkawang reached its peak productivity much later, at the age of 40 years, and produced a total volume at that age of 150.31 m^3 ha^{-1} and 217.16 m^3 ha^{-1} respectively in **Model I** and **Model II** (Isminarti et al. 2016).

The results of the financial analysis for producing agarwood and tengkawang, in mixed forest stands in **Model I** and **Model II** arrangements, showed that they wouldbe feasible businesses with NPV values above zero Net B/C Ratios higher than one, and their IRR values exceeding the value of MAR. Therefore, it is recommended that the government should play a role in stabilising the price of wood, in giving financial capital assistance, and in interest subsidiees to help finance the estabishment of such activities. Viewed from the results of their financial analysis, wood of agarwood and tengkawang as forestry products were superior to natural rubber as a plantation product, therefore the government should consider giving greater support to such forestry programs than it currently does to plantation programs.

The production of agarwood and tengkawang is viewed as Local Ecological Knowledge (LEK) based on relatively uncomplicated techniques in the combination of species and the maintenance of plantations. This creates sustainable production of materials of high economic value.

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