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Feasibility of Integrating Sheep and Crops with Smallholder Rubber Production Systems in Indonesia

Nu Nu San and Brady J. Deaton

Diversified production systems are considered important tools for stabilizing the income of smallholder rubber producers in Indonesia. Based on empirical data collected from smallholder rubber producers in the Nucleus Estate Smallholder (NES) development project, estimations were made of the economic feasibility of integrating sheep and selected crops into smallholder rubber production plantations. The dynamic optimization procedure is used as an evaluation technique. This study finds that integration of sheep and crops into smallholder rubber production is economically feasible, particularly for those who utilize family labor for hand harvesting grass and grazing sheep. Integrating sheep alone increases the net present value of future income by 20%. The combination of sheep and soybeans with smallholder rubber production increases the net present value of future income by 38%.

Key Words: bioeconomic model, diversification, dynamic optimization, Indonesia, rubber, sheep, smallholder

Productivity, efficiency, and income stabilization are key issues for the sustainability of smallholder rubber producers in Indonesia. Consequently, investigation of possible diversified production systems may provide helpful information for improving productivity and stabilizing the small farmer's income. A promising diversified production system for smallholder rubber producers is the integration of sheep and crops into their plantation.

Most of the rubber plantations in Indonesia are located in Sumatra, where local breeds of sheep are small, have some unused wool, and are highly reproductive—but their growth rates are slow. To improve sheep production, the Small-Ruminant Collaborative Research Support Program (SR-CRSP) at the Sei-Putih animal research

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Nu Nu San is post-doctoral fellow, Agricultural and Resource Economics Program, Division of Resource Management, West Virginia University, Morgantown. Brady J. Deaton is provost and professor of agricultural economics, University of Missouri, Columbia.

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station was begun in 1985 to include projects emphasizing genetics and breeding, nutrition, animal health, and management. Testing and performance of new technologies in sheep production have been continuously evaluated in both on-farm and research station projects. In on-farm projects, participant farmers initially received four ewes and one ram. Farmers are required to return eight weaned ewes within five years after they obtain the animals. Returned ewes are then distributed to other farmers. By 1993, the number of participant farmers had increased from 12 to 77 (Soedjana; Sirait et al.). The concurrent success of credit repayment systems formulated by the SR-CRSP and improved technology transfer prompts the research question of whether or not smallholder rubber producers can integrate sheep into an already existing production system of crop and rubber.

Earlier studies have found that there is economic potential for integrating sheep and crops among smallholder rubber producers in Sumatra (Amir et al.; Karo-Karo et al.). However, comprehensive research which considers the dynamic nature of latex and sheep production is still required to provide guidelines for the effective implementation of an integrated program of rubber and sheep production.

Kaimen and Schwartz defined an economic system as truly dynamic if the present production level affects not only the current profit, but also profits in later periods. Therefore, in a sense, a dynamic production system reflects the existence of multiple decisions in each time period. Decisions regarding production and input use in earlier periods influence their productivity in future periods. In latex production, while natural causes are given, intertemporal decisions (such as the intensity of exploitation, applications of fungicides, fertilizers, and weed control) determine the economic life of the plantation and the amount of latex produced in each time period.

In sheep production, intertemporal decisions on capital and labor investments, and inventory adjustments such as the number of sheep sold and the number retained in each time period, determine the farmers' projected profit in subsequent periods. These intertemporal decisions are influenced by farmers' expectations toward market conditions as well as biological characteristics of sheep such as lambing interval, reproduction rate, and survival rate, which contribute partially to the optimal flock size for a given level of family resources.

While it would be useful to include measures of changing crop productivity over time due to soil, water, pests, diseases, and other natural factors, these data were not available during the process of this research project. Therefore, annual crop production will be considered in this study not to be affected by time variations.

The Conceptual Theory

The primary objective of this study is to determine whether or not integrating sheep into smallholder rubber plantations is profitable. The target group of farmers in this analysis consisted of smallholder rubber producers, with individual households forming the basic unit of study. These households are assumed to be semi-subsistence

farm households who produce and consume goods, and sell or buy the difference between production and consumption. Family labor is used for their production activities. Their principal crop, rubber, will continue producing for approximately 16 years after initial production at six years of age. Therefore, the beginning period in this study is the first year of tapping (which is the sixth year after planting), and goes through the completion of one production cycle (i.e., years 6–21).

In analyzing the intertemporal decision process, the optimal control approach provides an estimate of the optimal time path for control variables and state variables. In this household analysis, intertemporal decisions regarding the rate of latex extraction (bark consumption), the repayment schedule of borrowed money, and the number of sheep sold qualify as control variables, whereas the state variables are bark left on the tree for later-period tapping, remaining credit to be returned, and sheep stock. The initial number of rubber trees and flock size are also included in the decision variables for the beginning point.

Data

One rubber planting cycle takes approximately 20–30 years. To establish the productivity of smallholders for an entire production cycle of a rubber plantation within a limited time period, we preferred a study area offering as many production stages as possible, with the least variations in planting technology factors such as cloning, planting density, management practices during the grace period, etc. Therefore, a study area was selected for latex production patterns and socioeconomic activities of smallholders based on minimum variations in planting and production technology across the age of the rubber plantation. Nucleus Estate Smallholder (NES) development projects[1] in Alue-Ie-Merah, Aceh, North Sumatra, were selected because of the accessibility of eight different stages of tree growth with the same GT-1 clone in one contiguous area.

Data were collected on family characteristics, labor utilization, expenditures, yield per two hectares during a year, and number of trees tapped in different stages of life of the tree. Planting dates ranged from 1977–78 to 1986–87, excluding 1984–85 and 1985–86, when no trees were planted. We conducted a total of 85 surveys, completed during the last weeks of October and November 1993. The surveys incorporated responses from at least 10 households from each planting period over eight different years.

Data on small-farm sheep production performance, including measures of input use, sources of labor, animal feed, and productivity, were taken from the survey and

[1] An NES development project is a type of government project where participant farmers receive two hectares of high-yielding-clone rubber plantation, 0.75 hectare for food crop production, and 0.25 hectare for their home-yard. Recipient farmers are required to sell their latex to the government. After one or two years of tapping, 30% of the latex is collected as a credit repayment. All participant farmers must sell their latex to PTP (the government-owned Plantation Company, Ltd.), with the price determined by PTP, until the loan is cleared.

the long-time extension records from both on-farm and research station testing of new technology of sheep production in the Galang district of North Sumatra.

Empirical Estimation

In the literature, economic analyses of agricultural production systems with dynamic characteristics are sometimes referred to as bioeconomic models. In their respective studies, Standiford, and Lambert and Harris utilized a dynamic nonlinear optimization method to determine the optimal path for decision variables in integrated production systems. Both studies considered the whole production period of 10 to 14 years in one equation system. Hence, the production systems of each period are consecutively evaluated for the whole period. Accordingly, the optimal production path for each enterprise is determined in considering expected prices and interest rates over the entire production period. Therefore, we use this method to address our research question of whether or not smallholder rubber farmers should integrate rubber, sheep, and crops.

Objective Function

The objective is to maximize the discounted net revenue resulting from each enterprise over the time period of one production cycle of 16 years, as specified by equation (1) below:

$$\text{(1)} \qquad \text{Max} \sum_{t=1}^{T} Df_t \Big[\big(SELSHEEP_t^g * YSHEEP^g + E(PSHEEP_t) \big) - PAY_t^s - FEEDC_t - VCOST_t^s - VBARN_t - GRASS_t - DEP_t \Big] + \Big[LATEX_t * PLATEX_t - PAY_t^R - RCOST_t \Big] + \Big[SOYBEAN_t * YSOY_t * E(PSOY_t) - SOYCOST_t \Big],$$

where

Df_t	=	discount factor for time t,
$SELSHEEP_t^g$	=	number of sheep sold in year t,
$YSHEEP^g$	=	yield in kg per type of sheep,
$E(PSHEEP_t)$	=	per unit price of sheep meat in year t,
PAY_t^s	=	payment made in year t for sheep loan,
$FEEDC_t$	=	total cost for feed supplement in year t,
$VCOST_t^s$	=	total sheep health cost in year t,
$VBARN_t$	=	total sheep housing cost in year t,
$GRASS_t$	=	cost for cut grass,
DEP_t	=	depreciation for sheep housing,

$LATEX_t$ = dry rubber production in year t,
$PLATEX_t$ = price of latex in year t,
PAY_t^R = payment made for rubber plantation loan in year t,
$RCOST_t$ = operating costs for rubber plantation in year t,
$SOYBEAN_t$ = area grown to soybeans in year t,
$YSOY_t$ = yield of soybeans in year t,
$E(PSOY_t)$ = expected price of soybeans in year t, and
$SOYCOST_t$ = operating costs for soybeans in year t.

The system of equations is grouped as follows: credit policy, equations of motion, family labor, resource constraints, marketing balance, and net revenue. For purposes of this study, detailed presentations are provided only for equations of motion.

Credit Policy Equations

Credit policy equations are constructed to determine the capital recovery rate of investment on the two primary enterprises—rubber and sheep. Initial investments for rubber and sheep are assumed to be borrowed from a bank through the government-owned Plantation Company, Ltd. (PTP). The credit repayment schedule designed in this analysis is based on the current policy conducted in the NES Alue-Ie-Merah development project area. This program allows approximately seven years as a loan-deferral period for rubber, including five years for the interest-free grace period and the first two years of initial latex production. The first year of tapping (year 6) marks the beginning of the analysis period for this research. Therefore, both rubber and sheep credit repayment schedules are allowed to start at the end of the third year of production.

The costs of developing a rubber plantation include land clearing, growing nurseries, grafting with high-yielding clones, regular weeding, and fertilizing during the grace period. Similarly, the starting investment for sheep production includes the initial flock, fixed cost for sheep housing, health cost, supplemental feed cost, and other operating costs.

The equations of motion to determine the optimal path of the loan repayment schedule begin with equation (2.1), in which each year's balance is based on the previous year's balance plus the interest charge for the previous year, minus the payment made for the previous year:

$$BALANCE_t^c = BALANCE_{t-1}^c + INT_{t-1}^c - PAY_{t-1}^c, \tag{2.1}$$

where

$BALANCE_t^c$ = credit balance at beginning of year $(t \geq 3)$ for a commodity (c = rubber, sheep),
$BALANCE_{t-1}^c$ = credit balance at beginning of year $t-1$ $(t \geq 3)$,

INT_{t-1}^{c} = interest charge for plantation loan in year $t-1$, and
PAY_{t-1}^{c} = payment for plantation loan in year $t-1$.

The upper limit for repayment is set as 30% of the revenue from each particular enterprise per year [equation (2.2)]:

$$PAY_t^c \leq REV_t^c * PHI, \tag{2.2}$$

where

PAY_t^c = payment for commodity loan in year *t*,
REV_t^c = revenue from commodity in year *t*, and
PHI = percent (%) of revenue (credit repayment policy).

The level of interest charged to the farmer from the third year on depends upon how much the farmer paid on the principal each year. Therefore, in equation (2.3), the interest charge equals the yearly interest rate on the beginning-year balance:

$$INT_t^c = BALANCE_t^c * SIGMA, \tag{2.3}$$

where

INT_t^c = interest charge for commodity loan in year t $(t \geq 3)$,
$BALANCE_t^c$ = credit balance at beginning of year t $(t \geq 3)$, and
$SIGMA$ = annual interest rate.

The principal paid for each year is derived by subtracting the interest charge from the payment made in the same year [equation (2.4)]:

$$PPAY_t^c = PAY_t^c - INT_t^c, \tag{2.4}$$

where

$PPAY_t^c$ = principal paid for plantation loan in year *t*,
PAY_t^c = payment for plantation loan in year *t*, and
INT_t^c = interest charge for plantation loan in year *t*.

Equations of Motion for Rubber and Sheep

The equations of motion for latex production are based on the number of trees planted, the change in number of tapped trees due to the smallholder's exploitation technology, and associated productivity per tree per year. In equation (3.1), the

amount of latex harvested in time *t* is calculated as the number of trees in production during the last time period multiplied by the parameter determined by the rate of changes in tapped trees, and the yield per tree:

$$LATEX_t = (TAPTREE_{t-1} * TECH_t) * YLATEX_t, \tag{3.1}$$

where

$LATEX_t$ = total dry rubber production in year *t*,
$TAPTREE_{t-1}$ = number of tapped trees in year $t-1$,
$TECH_t$ = parameter for changes in number of trees, and
$YLATEX_t$ = dry rubber yield in kg per tree in year *t*.

The equations of motion for sheep production (ewe, ram, ewelamb, and ramlamb) at each time period are built from biological data of survival rates and growth rates of offspring, probability of female and male offspring, and reproduction rate [equation (3.2)]. Fertility rate is the percentage of pregnant ewes per time period. Data used here are drawn from Gatenby et al. and from Verwilghen et al.

$$GROLAMB_t^i \leq GROEWE_t * REP * SVI * PROB^s * FERTILITY, \tag{3.2}$$

where

$GROLAMB_t^i$ = number of lambs grown in year *t* (*i* = sex),
$GROEWE_t$ = number of ewes grown in year *t*,
REP = reproduction rate,
SVI = survival rate of offspring,
$PROB^s$ = probability of being female, and
$FERTILITY$ = rate of fertility.

The population of rams in year *t* is a function of the previous year's ramlambs minus the number of ramlambs sold in the previous year, and the survival rate [equation (3.3)]:

$$GRORAM_t \leq (GRORAML_{t-1} - SELRAML_{t-1}) * SVI^r, \tag{3.3}$$

where

$GRORAM_t$ = number of rams grown in year *t*,
$GRORAML_{t-1}$ = number of ramlambs grown in year $t-1$,
$SELRAML_{t-1}$ = number of ramlambs sold in year $t-1$, and
SVI^r = survival rate of ramlambs.

The population of ewes in year *t* is a function of the past year's ewe and ewelamb numbers in the stock, the number of ewes sold, and the survival rates of ewes and ewelambs [equation (3.4)]:

$$GROEWE_t \leq (GROEWE_{t-1} - SELEWE_{t-1}) * SVI^e + (GROEWEL_{t-1} - SELEWEL_{t-1}) * SVI^e, \tag{3.4}$$

where

$GROEWE_t$ = number of ewes grown in year t,
$GROEWE_{t-1}$ = number of ewes grown in year $t-1$,
$SELEWE_{t-1}$ = number of ewes sold in year $t-1$,
SVI^e = survival rate (e = ewe, ewelamb),
$GROEWEL_{t-1}$ = number of ewelambs grown in year $t-1$, and
$SELEWEL_{t-1}$ = number of ewelambs sold in year $t-1$.

Family Labor Constraint

Based on our survey of the study area and the literature review of family labor allocation for rubber farmers and sheep farmers, the following generalizations can be made: (*a*) daily labor utilization for latex production, which includes tapping, collecting, and weeding, is performed mainly by adult males (with labor commencing at approximately 7:00 a.m. and ending at 1:00 p.m.); (*b*) growing rice or soybeans is normally carried out in the afternoon and is performed mainly by adult males with the help of family and friends or by hiring wage workers; and (*c*) sheep production responsibilities are assigned to children under 14 years of age, usually working in the afternoon.

Family Labor for Latex Production

The average labor availability per household for latex production, as derived from the survey, is 2,000 hours for one year—obtained from two family members working five hours per day (from 7:00 a.m. to 12:00 p.m.). One tapping hour of labor by a male head of household is assumed to be equal to 0.75 hour worked by a second family member. Therefore, with 240 tapping days per year, a total of 2,000 hours is assumed to be available from a household to work on the rubber plantation.

Family Labor for Sheep Production

Family labor requirements for sheep production will likely vary with the type of feeding system assumed. The sheep production system applied in the base model is a combination of the grazing and cut-and-carry systems, used by most of the on-

farm-research farmers in North Sumatra's Galang district. Combinations of systems demand daily labor input, with at least one person for grazing and another for cutting grass. Approximately four hours per day are required to accompany the animals while they are grazing.

In the base model, children of the household between the ages of 8 and 14 are the primary source of labor for cutting grass and grazing. The assumption of 900 hours per year of family labor available to cut grass is calculated based on three hours per day needed to cut grass and 300 working days. The opportunity cost for labor in cutting grass is combined into the model as wages for cut grass per sheep. The carrying capacity for grazing is assumed to be 100 head per family. Therefore, the base model assumes that there are at least two family members, possibly children between the ages of 8 and 14, to work at sheep production. When children grow older and leave the home, housewives take over the grazing and other chores for sheep production.

Family Labor for Soybean Production

With an average crop land size of 0.8 hectare, soybean production is one cash crop possibility (among other annual crops such as paddy rice, chili, etc.). In the study area, soybeans are widely grown as a cash crop, rice is generally grown for own consumption, and chili and other crops are grown in a mixed cropping system. The input, production, and price data for soybeans are relatively well recorded by farmers. Therefore, soybeans are used as a possible annual cash crop in this analysis.

Annual rainfall in the study area allows crops to be grown throughout the year. Soybeans can be grown as many as three times a year. However, planting three times a year for consecutive years may cause yield variations resulting from varying levels of soil fertility, pests, and diseases. Hence, this analysis allows for one growing season, approximately four months in a year, with an average yield of 563 kg per 0.8 hectare. The family labor constraint is presented for soybean production, where labor required is assumed to be available also from evening time labor hours of the male head of the household.

Other Resource Constraints

In investigating the potential benefits of diversified production systems for the smallholder rubber plantations in this study, the additional resource constraints of capital, facilities, and land must also be considered. We briefly address each of these constraints below.

Capital Constraint

In considering the capital constraint for a rubber plantation, each family received various numbers of trees (from 200 to 700) on two hectares of land. PTP computed

the credit in accordance with the number of trees that each family received. Therefore, a capital constraint for the rubber plantation is not included in the model. For sheep production, the first-year available capital is assumed to be one million Rupiah.

Facility Constraint

The initial size of a barn is 5m × 10m, and costs 250,000 Rupiah. The facility capacity is 25 head. This type of housing is subsidized by the SR-CRSP for on-farm research in the Galang district. As the flock size gets larger, an extension unit can be built adjacent to the initial barn. In this model, the initial barn cost is entered as a fixed cost in year one. Thereafter, each additional head above 25 costs 1,000 Rupiah per year, and is included in the model as an operating cost for sheep housing.

Land Constraint

The plantation land area for each family is two hectares, wherein the number of trees planted will vary with their spacing. Research on plant density and yield association suggests that high plant density produces higher yield per hectare among alternative methods tested. However, research also reveals that trees in the high-density fields are more susceptible to plant diseases. Therefore, based on the past experience of growers and the recommendation of experiment station personnel, a spacing of 5m × 5m seems most reasonable for a high-density maximum. Accordingly, a total of 800 trees is the maximum number a family can receive from PTP.

Marketing Balance

On average, rams are marketed when they reach 30 kg, which is usually at 9–10 months after their birth. In this analysis, rams are assumed to be raised only for meat purposes. Thus, the number of rams ready for marketing in time t is the number of ramlambs in the flock at time $t-1$, accounting for the survival rate of ramlambs.

Ewes are raised for both reproductive purposes and meat consumption. In this base model, the culling rate for ewes is 30%, and reflects that the oldest ewe in the flock is approximately three years of age.

Net Revenue Discount Rate

In solving the above equation system, the net revenue resulting from each enterprise over the 16-year time period is discounted to the present time period. Then, the enterprise combination which yields the maximum positive net present value will be selected as the optimal solution. Consequently, the discount rate is a critical factor in determining the amount of net present value. A lower discount rate provides

higher net present value of the future cash flow. In this study, the primary enterprises are considered as complementary rather than competitive. The enterprises do not compete for the same resources. Hence, the level of discount rate will not have an impact on optimal levels, once the feasible solution is found. The net present value reported here utilizes the 10% discount rate unless noted otherwise.

Model-Solving Techniques

The objective function for maximizing net revenue to a family farm over the 16-year time period considers resource constraints. The estimation period in the base model is from 1995 to 2011. Therefore, farmers' price expectations for 16 years must be forecast and combined into the equation system. The autoregressive integrated moving average (ARIMA) process is utilized to forecast farmers' price expectations for the two primary enterprises: rubber and sheep.

Our programming model is specified as linear and is solved by GAMS/MINOS software developed by Brooke, Kendrick, and Meeraus. This software uses the primal simplex method (Dantzig) to solve the model described above. The solution is reached by performing a sequence of iterations until the maximum net present value is found for a given set of constraints. The results provide the optimal number of trees, the initial sheep flock size, and the optimal trajectory of latex produced for a given exploitation technology, number of sheep sold in each time period, and soybean production. The results of our analysis are presented in the following section.

Results

Results of the base model indicate that for a given level of resources, technology, and credit repayment policy, the optimal number of trees for a smallholder producer is 593. Initial flock size is eight ewes for a family, and annual soybean production is included in the solution. That is, the most profitable farm operation is found to be rubber production combined with both soybeans and sheep.

The net revenue streams for a smallholder rubber producer for the base model are presented in figure 1. Integrating sheep production activity into rubber plantations increases net present value of future income by 20%. Integrating both sheep and soybeans into a rubber plantation can provide a 38% increase in net present income.

Sensitivity Analysis

In the discussion that follows, we first address the results of assuming different lengths of economic life of a rubber plantation. We then report our findings when a low-intensity exploitation (LIE) system is substituted into the model instead of a high-intensity exploitation system (HIE) to observe the changes in net revenue streams.

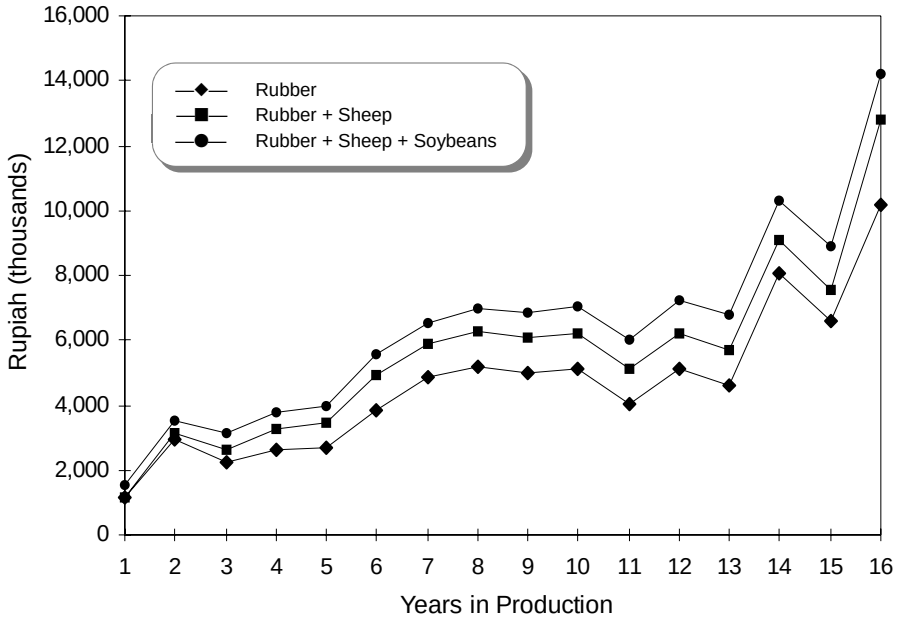

Figure 1. Potential net revenue for a smallholder rubber producer in Aceh

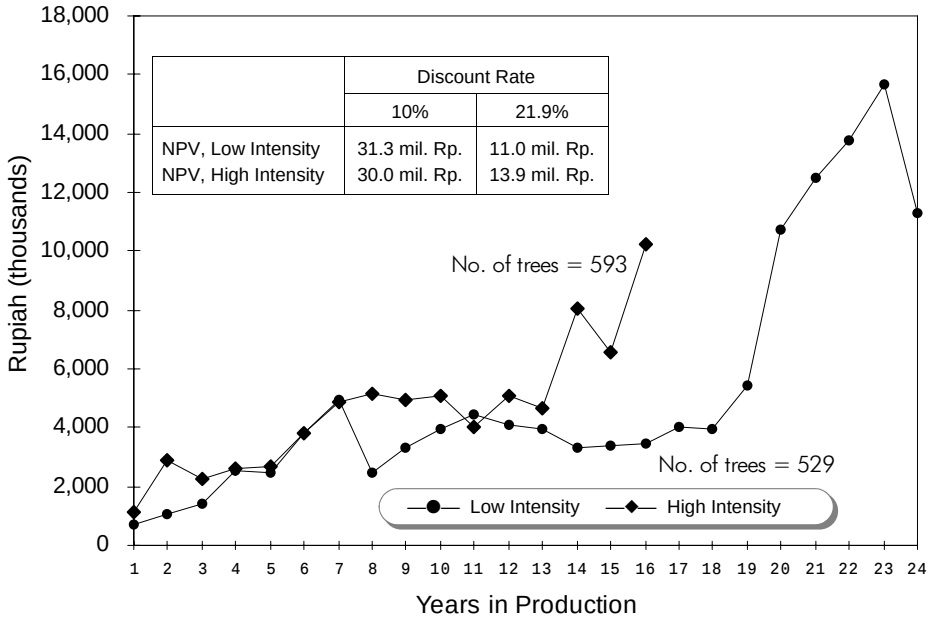

Figure 2. Comparison of net revenue streams for low- and high-intensity exploitation systems

Duration of Plantation's Economic Life

To provide a comparison for the 16-year estimation period used in the base model, we consider two reasonable alternative scenarios of the economic life of rubber plantations. The alternative scenarios of 14 years and 12 years were evaluated and compared with the solution of the base model. The shorter productive life of a rubber plantation is most likely due to an HIE system and poor management. The results of our sensitivity analysis reveal that the credit policy which requires collection of 30% of the revenue from sales is no longer feasible for rubber production with the 14-year and 12-year scenarios of productive life. Simulation results indicate that if the economic life is 14 years, the credit policy would have to be 32% of the sales revenue, and 38% of the revenue if the life of the plantation is 12 years.

Exploitation System Used

The base model rubber production system is representative of the HIE system, which the majority of the farmers in the study area are practicing. In contrast, LIE systems are generally applied at the private estates. The data on LIE systems (tap every other day, half spiral cut) of a private estate from North Sumatra are used in the sensitivity analysis.

The illustration of comparative net revenue streams for high and low exploitation systems in figure 2 captures the dynamic character of the latex production system. The optimal number of trees for a family under the LIE system is 529, compared to 593 in the HIE system. The economic life of an LIE system is eight years longer than that of an HIE system, and the net present value is approximately 1.3 million Rupiah higher under the LIE system at a 10% discount rate. However, when the discount rate is 21.9% (lending rate to reflect the opportunity cost of capital), the net present value of the LIE system is 2.9 million Rupiah lower than that of the HIE system. A longer time period is required to repay the loan for rubber production under an LIE system, where the loan is repaid after 19 years of production. Under the HIE system, the loan is repaid after 15 years of production.

Price Risk Analysis

As a simulation, the risk associated with price uncertainty is incorporated as a chance constraint in evaluating the economic feasibility of integrating sheep and crops into smallholder rubber plantations. The chance constraint imposes a condition that the net revenue is to be greater than or equal to the certain value calculated from the quantity sold and the variance of expected prices. The results suggest that there is a low probability of net loss due to input and output price fluctuations in rubber and sheep production. Farmers' income from soybeans is found to be very vulnerable to either output or input price variations (see San for details).

Discussion

This study found that the integration of sheep and soybeans into smallholder rubber farms can help stabilize farm income within the year and over the production cycle, especially for farms with low numbers of trees. Including sheep production on rubber plantations is primarily motivated by the symbiotic nature of the two enterprises. Rubber plantations benefit from organic fertilizer and reduction in weeding cost, while grazing land provided by plantations is essential for growing sheep. Additionally, using family labor with the low opportunity cost of housewives or children plays a significant role in sheep production in Indonesia. This tradition makes small-farm sheep production more economically feasible.

The base model assumes a family uses its own labor for both grazing and cutting grass, with a low opportunity cost (i.e., the wage rate). The solution reveals the optimal initial flock size for ewes to be eight. In the case where a farm needs to hire a helper and there is a cost associated with cutting grass, the initial flock size is reduced to six, and a positive net revenue will occur only during the fourth year of growing sheep. The net present value of a farm that does not hire a helper is approximately 4 million Rupiah higher than those that hire a helper. This information indicates that for a small farm where capital is limited, family labor availability is a critical factor in the profitability of sheep production.

The operating costs for sheep production consist principally of feed supplement costs, although feed supplements are industrial by-products and considered to be fairly cheap. Therefore, unless farmers are convinced by their experience of a potential marginal profit with feed supplement, they may rely only on grazing and cut grass for feed.

In this stage of technology transfer, operating costs for cut grass are relatively inexpensive, primarily because only a few farmers are sharing the free-access-land feed resources. In the solution of the base model, the steady-state flock size is 43 with 16 ewes per family, with the assumption of one family member devoted to cutting grass. This carrying capacity depends on the assumption that sheep growers are able to procure unlimited amounts of cut grass at a certain price. The adjustment of flock size will depend heavily upon the availability of feed resources and health services, in addition to market conditions, labor cost, and the risk preference of the individual farmer.

When sheep farmers need to grow their grass, the carrying capacity will shift appropriately with the area of land a family has for cultivation. For example, if cut grass from one hectare of land carries 45 sheep per year, then the maximum carrying capacity is 45 sheep per year, and the cost to grow the grass must be considered in the evaluation. Additionally, the opportunity cost of land and labor must be considered for alternative uses of land.

If sheep are raised during the grace period, the mapping of the net income stream could be as shown in figure 3. The net income streams plotted in that figure are the results from the base model. Therefore, the net revenue from rubber can account for

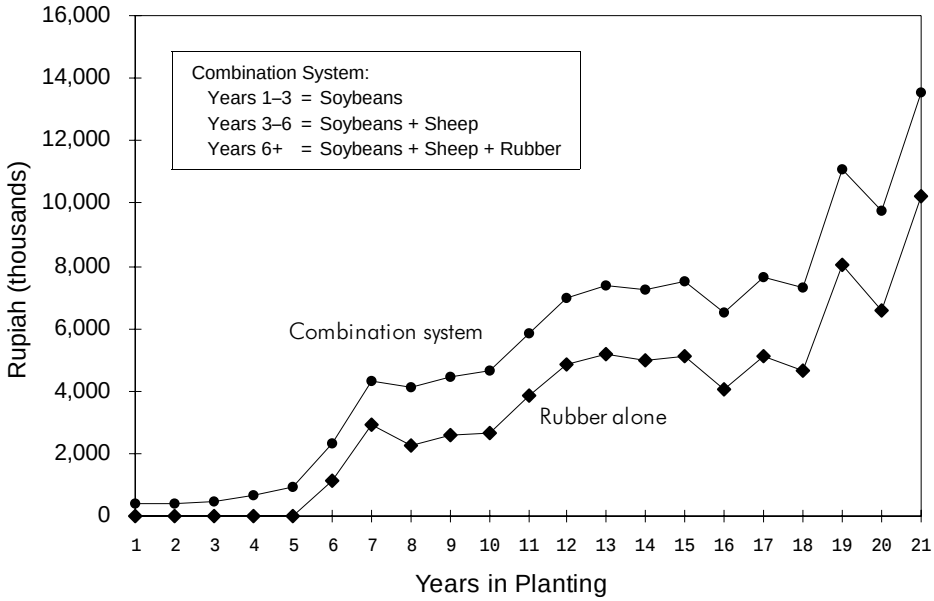

Figure 3. Alternative mapping of net revenue for a combination system and for rubber alone

loan repayment for home yard, crop land, and rubber plantation. This illustration shows that the integration of sheep and crops (the "combination system" plot in figure 3) by smallholder producers can increase their net income stream.

If the grazing area is not free-access land, and farmers are limited to their own land of two hectares of rubber plantation for grazing, the optimal flock size will be determined by the carrying capacity of two hectares of rubber plantation. A stocking rate study conducted in North Sumatra by Sanchez reported that one hectare of mature rubber plantation can carry up to five adult sheep. Chong and Tajuddin found that immature rubber plantations in Malaysia can carry up to 17 sheep per hectare. In their study comparing dry matter yield over different ages of mature plantations in Malaysia, Mohamed and Embong reported that the carrying capacities across these plantations are generally the same.

Based on the findings of the above stocking rate studies, a family with two hectares of rubber plantation might be able to sustain as many as 34 sheep during the third/fourth/fifth years of the grace period. When the rubber canopy closes during the mature period, a family probably could raise only 10 adult sheep per year for the remainder of the production period.

The sensitivity analyses for the 14-year and 12-year scenarios of the plantation's economic life show that the current arrangements for rubber production programs with housing and crop land is not economically feasible for these shorter production periods—due mainly to the credit policy which requires repayment of 30% of

revenue from each year's sales. Such a system will need 15 years to clear the loan. Therefore, if the productive life is expected to be shorter than 16 years, the repayment terms must be increased above 30% of sales in order to recover the capital investment.

Concluding Remarks

The solution for the optimal initial flock size is determined by performing a sequence of iterations for given levels of family resources and expected prices. In identifying the initial flock size in sheep production, the model enables us to consider inventory changes, the biological cycle, expected prices, and interest rates through time. Hence, this analysis provides a helpful guide to the animal research institution in Sei-Putih for determining the optimal flock size required for an economically feasible number of sheep for a given level of family resources.

Results of the price risk analysis show that net revenues from rubber and sheep are not as volatile as that of soybeans. However, incomes from rubber and sheep are susceptible to price changes as well. Enterprise diversification that includes these three production activities could bring more income stability than might be experienced otherwise. However, a successful sheep farming enterprise requires stable and adequate supplies of forage, and effective health and extension services.

In concluding this article, we note here some caveats pertaining to the limitations of this research. A weakness of this study is the limited availability of original data on the rubber production segment. Also, the determinants of the economic life of rubber plantations have not been well established. The economic life of a rubber plantation could be 11–25 years depending upon the exploitation system employed. The oldest NES plantation in Aceh, Indonesia, is about 16 years old, with 10 years in production. We estimated the remaining economic life and productivity, and established the potential latex production pattern of smallholder rubber producers. Consequently, any policy decisions based on this research should be cautiously interpreted with respect to productivity, which determines the potential income of smallholder rubber producers in the later time period of the production cycle.

As we have observed from the field research, smallholder rubber producers from the NES project in Aceh are practicing high-intensity exploitation systems, whereas plantations managed by private or government estates are applying relatively low-intensity exploitation systems. The impact of tapping intensity on yield over time is captured in this analysis by incorporating measures of rates of change in tapped trees and latex yield in kg per tree per year. Alternatively, the latex production pattern measured by gram per tree per tap in successive time periods for different exploitation systems would have more fully captured the impact of exploitation systems on productivity.

Finally, family labor availability for all enterprises was assumed in this study to be a constant for the one production cycle of rubber production. Incorporating

family-specific labor dynamics into the enterprise combination would provide a better understanding of the economic feasibility of integrating sheep and crops into smallholder rubber production enterprises.

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