Agroforestry Systems (2006) 66:117–127
DOI 10.1007/s10457-005-4676-2

Economic Analyses of rubber and tea plantations and rubber-tea intercropping in Hainan, China

Zhimei Guo[1], Yaoqi Zhang[2,*], Peter Deegen[3] and Holm Uibrig[4]
*[1]Hainan General Reclamation Bureau, Haikou, Hainan, 572000, China; [2]School of Forestry and Wildlife Sciences, Auburn University, AL 36849-5418, USA; [3]Institute of Forest Economics and Forest Management, Dresden University of Technology, Tharandt, Germany; [4]Institute of International Forestry and Forest Products, Dresden University of Technology, Tharandt, Germany; *Author for correspondence: (phone: +334-844-1041; fax: +334-844-1084; e-mail: yaoqi.zhang@auburn.edu)*

Received 16 July 2004; accepted in revised form 30 March 2005

Key words: Economic efficiency, Faustmann model, Land expectation value, Optimal rotation, Tropical land use

Abstract

This study uses land expectation value (LEV) as a criterion to conduct economic analyses of natural rubber (*Hevea brasiliensis*) and tea (*Camellia sinensis var. assamica*) monoculture, and rubber-tea intercropping. We calculated LEV by using the Faustmann model that combines annual revenue flow from latex production with final timber harvest of rubber trees. Production and cost data were collected from Xinwei Farm in Hainan, China. We found that rubber-tea intercropping generated higher LEV than rubber and tea monoculture under current socio-economic circumstances. Sensitivity analysis has been conducted to examine the impacts on land expectation value by interest rate, prices of natural rubber and tea, and labor costs.

Introduction

Although tropical crops (rubber, tea, tropical fruits) were introduced to Hainan at the beginning of last century, they were not widely planted until the 1950s. To secure the natural rubber materials supply, particularly for military demand, Hainan was selected as a national strategic region to plant natural rubber (*Hevea brasiliensis*) because its climate and natural environments are more suitable for rubber plantation than any other places in China. The Hainan General Reclamation Bureau (HGEB) was established directly under the central government in the 1950s. Rubber plantation areas increased from 10,000 ha in the 1950s to 400,000 ha in the 1990s.

The direct impact of the plantation of rubber and other tropical crops, accompanied by massive deforestation, was land degradation. In order to overcome the land degradation, rubber and tea (*Camellia sinensis var. assamica*) intercropping was developed. This agroforestry system has been popular in the mountainous regions where the land is very susceptible to soil erosion. In the 1970s, the rubber-tea intercropping was introduced to other tropical provinces (Guangdong, Guangxi, Yunnan etc.). In Hainan Reclamation System alone, more than 13,000 ha of rubber-tea intercropping, mainly in central mountainous or hilly regions and surrounding mesa regions (Long 1991).

During the 1950s–1970s, economic efficiency was not the first priority and was seldom considered by state-owned rubber plantation farms while increasing domestic supply for military and industrial uses from natural rubber was considered more important (Zhang et al. 2003). Since the 1980s, the farms have been gradually exposed to the market economy; hence economic analyses of rubber-tea intercropping became necessary. It was widely reported that rubber-tea intercropping was more profitable than rubber and tea plantations respectively (e.g., Huang 1990; Zhan 1990; Long 1991). Unfortunately, in those studies the methodology was often problematic and economic returns were evaluated based on the data of the beginning of the production cycle without consideration of capital costs, even though all three production systems have an approximate 30-year cycle.

This paper is intended to re-assess the economic return of rubber-tea intercropping, rubber monoculture and tea monoculture by considering the following new aspects. First, we choose land expectation value (LEV), which is the net present value (NPV) for bare land assuming perpetual land management regime, to measure the economic efficiency. LEV is a more appropriate method than profitability (benefit-cost ratio), internal rate of return in land evaluation. Second, it is well known that the main product of the rubber tree is latex, but timber from the rubber-tree is becoming more valuable as harvesting natural forests was banned and the processing technology of the rubber-tree wood has been improved. For this purpose, we extend the classical Faustmann Formula to accommodate annual income flow from the rubber plantation and other cultivation systems. Third, since the prices of products, the cost of labor and capital have experienced significant changes, sensitivity analyses are conducted to evaluate the impacts of LEV by interest rate, prices of natural rubber and tea, and labor costs.

Methodology

In terms of land use, efficiency is achieved when the land is used for the option which creates the highest land rent or expected land value. Different criteria can be used to evaluate investment, and land use options and agroforestry (Follis 1993; Sullian et al. 1992). The most widely used methods are net present value (Dyack et al. 1999; Ramirezl et al. 2001), benefit-cost ratio, and internal rate of return (Mehta and Leuschner 1997). Those criteria are not always consistent and may be misleading if they are not appropriately used. For example, when net present value is used and the durations of two crops differ, it is required to annualize present value or convert the value into an equivalent term at a given period of time (Rodrigo et al. 2001). Land expectation value, a special case of net present value method of infinite time of perpetual land management, does not need to consider duration differences.

The Faustmann Formula developed by Faustmann (1849), is a land expectation value maximization model. This model solved the traditional problem in forest economics – the decision of harvest time. The optimum harvesting age is when the value of forest increment, by delaying the harvest by one year, becomes equal to land capital cost for 1 year plus forest capital cost for 1 year.

The following equation is one expression of the Faustmann Formula:

$$\mathrm{NPV}_\infty = \frac{\sum_{t=0}^{T}(R_t - C_t) * (1+r)^{T-t}}{(1+r)^T - 1} - \frac{c-a}{r} \quad (1)$$

where NPV_∞ is the net present value for bare land assuming perpetual land management regime; R_t is the revenue in the year t; C_t is the cost in the year t (including afforestation cost C_0); $c-a$ is the annual cost minus annual revenue; T is the rotation age; and r is the interest rate (guiding rate of return).

The NPV_∞ is equivalent to the land expectation value (LEV), and the rotation age that can maximize the LEV is the optimal rotation age. The Faustmann model is correct in terms of neoclassical economics, and provides a good guideline of such kind of studies. Considering the needs for our purpose in this study, the Faustmann model is re-formulated in the following three forms:

$$\mathrm{NPV}_{(\mathrm{rubber})_\infty} = \frac{\sum_{t=6}^{T} R_{(\mathrm{latex})t} * (1+r)^{T-t} + R_{(\mathrm{timber})T} - \sum_{t=0}^{T} C_t * (1+r)^{T-t}}{(1+r)^T - 1} \tag{2.1}$$

$$\mathrm{NPV}_{(\mathrm{tea})_\infty} = \frac{\sum_{t=0}^{T} \left[R_{(\mathrm{tea})t} - C_t\right] * (1+r)^{T-t}}{(1+r)^T - 1} \tag{2.2}$$

$$\mathrm{NPV}_{(\mathrm{rubber}\cap\mathrm{tea})_\infty} = \frac{\sum_{t=0}^{T} \left[R_{(\mathrm{latex})t} + R_{(\mathrm{tea})t}\right] * (1+r)^{T-t} + R_{(\mathrm{timber})T} - \sum_{t=0}^{T} C_{(\mathrm{joint})t} * (1+r)^{T-t}}{(1+r)^T - 1} \tag{2.3}$$

The subscripts rubber, tea and rubber ∩ tea represent the LEV that can be generated from rubber plantations, tea plantations and rubber-tea intercropping, respectively. In Equation (2.1), we have final harvest income from rubber tree at year T, and annual income from latex. In Equation (2.2), we only have annual revenue from tea. In Equation (2.3), we have combined revenue from tea, latex and final tree harvest. These three forms will be used to analyze the LEV of the three land use options in this study.

Study area and data collection

Hainan is a tropical island of 3.4 million ha in the South China Sea. Apart from the seashore regions that are flat and suitable for agriculture, mountainous, hilly and mesa regions account for around 80% of the total area of Hainan Island. There are more than 90 state-run farms administrated by the Hainan General Reclamation Bureau and a number of collective-owned farms were used for planting rubber and other tropical crops.

Since we have no systematic experimental data, we have to collect our data from a state farm that we can meet following requirements: (1) a representative of farms in terms of socio-economic and geographic factors; (2) with significant scale of rubber and tea plantation; (3) located in mountainous regions that are more sensitive to soil erosion and runoff and has more rubber-tea intercropping. The Xinwei State Farm of Hainan Province closely matches the requirements above.

The Xinwei Farm is located between the east longitude 109°36′36″–109°44′42″ and the north latitude 18° 58′23″–19°06′54″, with an elevation of 350 m–500 m above sea level. This area is in the central part of Hainan island, north of Wuzhi Mountains (1867 m a.s.l.). Although the climate is humid, the temperatures are mild with an annual average of 22 °C. The total area of the farm was 12,250 ha, with 1333 ha of rubber plantation, 240 ha of tea plantation and 250 ha of rubber-tea cropping. The main business of the farm is to plant rubber, tea, and some fruit trees. This farm is very typical in Hainan.

Experimental spacings in intercrops of rubber trees and tea vary from place to place. The goal is to achieve about 30% shade for the tea to produce the best products (Feng 1986). For example, one possible arrangement of 30% rubber trees with 70% tea bushes could be: two rows of rubber trees with the rows separated by 2.0 m, and the trees in each row separated by 2.5 m while the lanes of rubber trees would be separated from one another by 18 m of tea bushes with the bushes separated by as little as 0.4 m or as much as 0.6 m (Zheng and He 1991). With such an arrangement, the combined vegetative cover intercepts much of the energy of raindrops, thus reducing soil erosion. In other cases, rubber trees may be spaced as close as 1.5 m apart (Feng 1986).

At the Xinwei farm, the selected rubber plantation (*Hevea brasiliensis*) was spaced by 3×7 m (480 rubber trees/ha). The selected tea plantation (*Camellia sinensis var. assamica*) was spaced at 1.6×0.26 m (24,000 tea trees/ha). In the rubber-tea intercropping, the rubber trees were spaced by 2×12 m, and the intercropping space for tea plants was 1.6×0.3 m (405 rubber trees and 14,400 tea plants/ha). In addition, 1.5 m of space along each side of rubber trees was kept for the convenience of tending, fertilizing and rubber tapping. Those lanes of rubber trees are separated from another line by 9 m of tea plantations. Although this is the most common arrangement, some other arrangements, e.g., 2×14 m, 2×11 m, 3×11 m, do exist.

Establishment of the cultivation systems is the first and usually, the most costly step. It includes activities such as site clearance, terracing fields, soil preparation, spacing, hole making and planting. In mountainous regions, the establishment costs of the three production systems can be twice as expensive as those in the plain regions.

Maintenance involves a variety of tending activities to keep the rubber trees and tea plants healthy and to acquire normal annual outputs of tea and latex during the production cycle. Fertilizing, terrace maintenance, weeding, pest control and soil loosening are required throughout the production cycles. Besides the management activities listed above, rubber trees require pruning, wounded part protection, disease control, and covering with dries grass as part of the maintenance. More specifically, for maintaining mono-cultural rubber, it is required to plant trailing legume or green manure for soil improvement and protection. For the rubber-tea monoculture plantation, annual pruning is required to achieve 30–40% shade for tea bushes.

In contrast to forest plantations, thinning is not needed in both rubber monoculture and intercropping rubber-tea. However, the number of rubber trees decreases because of the damage by typhoons and low temperature. The damage rate of rubber trees in one production cycle is around 15%. Hence, the average number of the damaged rubber trees per ha in rubber monoculture is 75, while in intercropping plantation it is 60.

Tapping of latex in a mono-cultural plantation starts at the age of 8 years, while in an intercropping plantation the process normally starts 1 year earlier, i.e. at the age of 7 years. The standard time of starting tapping in the Hainan reclamation system is when the girth of the rubber tree is at least 50 cm at height of 1.5 m. The yield increases during the 6–7 years after tapping starts and lasts for around 13 years. Then the yield decreases considerably. Tea starts to be collected 2 years after planting, and its yield increases gradually until it reaches its peak at the age of 9 or 10 years. Then it becomes quite stable for a few years. The yield declines gradually from the age of 18. For more information about the temporal tea collection and rubber tapping, see Zheng and He (1991) and Hao (1986).

Both rubber monoculture and intercropping are regenerated when the yield of dried rubber decreases to below 750 kg/ha. The production cycle of selected rubber monoculture is 33 years, while the production cycle of intercropping is 34 years. Usually the farms start to regenerate tea plantations when the yield of dried tea decreases to below 750 kg/ha. The production cycle of the selected mono-cultural tea plantation is 31 years.

Harvesting and sales of rubber timber in state-run farms in Hainan are controlled by the Hainan General Reclamation Bureau (HGRB). The farms report the information about the rubber plantations to HGRB. The firm that purchases the plantation is responsible for harvesting, transportation and even the tax payment. Hence, the bidding price is the unit net revenue from timber which has already excluded the cost of harvesting, transportation and tax.

The general information about the farms, the establishment and management regimes, harvesting regime, budget situation, labor and input costs was collected directly from the Xinwei State Farm. Additional data were obtained from officials of the Hainan General Reclamation Bureau, the directors and managers of the farms, and other local farmers. The yield tables and cost structures of the three cultivation systems throughout the production cycles were directly collected from the Production and Technique Department of the Xinwei State Farm. The cost information is presented in Tables 1–3. We took the present long-term borrowing interest rate in China as the guiding rate of return, i_g = 5.76%, for each of the three land use systems.

The sales regulations and prices of rubber timber were collected from the Hainan General Reclamation Bureau, since all the sales of rubber timber in Hainan state farms are conducted through bidding by HGRB. The prices of tea and rubber products were directly collected from the Xinwei State Farm.

Table 1. Cost structure of mono-cultural tea plantation in Hainan, China.

Activities		Quantities	Prices	Costs (CNY/ha)
Planting				
	Land preparation			9075
Year 1	Seedlings	24,000	0.1	2400
	Planting (man-day)	180	6	1080
Year 2	Seedlings	3750	0.1	375
	Replanting (man-day)	27	6	162
Tending	(Incl. Fertilizer, pesticide, etc.)			
Year 1–2				4552.5
Year 3	Year 1×75%			3414
Year 4	Year 1×50%			2277
Year 5	Year 1×25%			1138.5
Administration				
Year 1–2				1365
Harvesting	(incl. tending fees)			
Year 3 – end	Unit plucking price (Y/Kg)		4.2	
Processing and sales	(Y/ton)		1.76	
Tax	Gross revenue × 8%			

Note: 1. Data from the Xinwei State Farm. 2. CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004.

Table 2. Cost structure of mono-cultural rubber plantation in Hainan, China.

Activities		Quantity	Prices	Costs(CNY/ha)
Planting				
	Land preparation			4830
Year 1	Seedlings	480	2	960
	Planting(/seedling)	480	0.3	144
Year 2	Seedlings	45	2	90
	Replanting	45	0.3	13.5
Tending	(Incl. fertilizer, etc.)			
Year 1–7				1680 + 849
Year 8				3000
Year 9	Year 0×50%			1264.5
Year 10	Year 0×25%			631.5
Administration				
Year 1–7				1215
Harvesting	(incl. tending fees)			
Year 3 – end	Unit tapping price(Y/kg)		1.9	
Processing and sales	(Y/ton)		3.49	
Tax	Gross revenue × 8%			

Note: 1. Data from Xinwei State Farm. 2. The cost of preventing diseases starts from Year 7 with 6.6 CNY, increasing till Year 15–11.6 yuan and stable till the end. 3. CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004.

Results and discussion

The optimal rotation age is calculated by maximizing NPV using Equations (2.1–2.3). The calculation is operated with an Excel worksheet, which facilitates repetitive calculations and tracks the operations. The graphs can also be easily created within in the Excel spreadsheet to give a visual comparison of economic benefit between different production systems under a certain market condition.

The results are presented in Figure 1. It indicates that rubber-tea intercropping generates the highest LEV, rubber monoculture second, and tea monoculture lowest under the current market conditions. It is interesting to note that such order does not depend on rotation age since there is no cross point of LEVs of the three land use systems.

Table 3. Cost structure of intercropping rubber-tea plantation in Hainan, China.

Activities		Quantity	Prices	Costs(CNY/ha)
Planting				
	Land preparation			8430
Year 1	Seedlings (tea)	14,400	0.1	1440
	Seedlings (rubber)	405	2	810
	Planting (man-day)	128.3	6	769.8
Year 2	Seedings (tea)	2250	2	90
	Seedlings (rubber)	45	0.1	225
	Replanting	21	6	126
Tending	(Incl. fertilizer, pesticide, etc.)			
Year 1–2(tea)				1995 + 915
Year 3 (tea)	Year0 × 75%			2182.5
Year 4 (tea)	Year0 × 50%			1455
Year 5 (tea)	Year0 × 25%			727.5
Year 1–7 (rubber)				1417.5 + 465
Year 8 (rubber)	Year2 × 75%			1412
Year 9 (rubber)	Year2 × 50%			941.25
Year 10 (rubber)	Year2 × 25%			470.7
Administration				
Year 1–2				1365
Year 3–7				682.5
Harvesting	(incl. tending fees)			
Year 2 – end (tea)	Unit plucking price (Y/kg)		4.2	
Year6-end(rubber)	Unit tapping price (Y/kg)		1.9	
Processing and sales	(Y/ton)			
Tea			1.76	
Rubber			3.49	
Tax	Gross revenue × 8%			

Note: 1. Data from the Xinwei State Farm. 2. CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004.

The results indicate that the optimal rotation age is 29 years (with NPV 39,286 CNY/ha) and 26 years (with LEV 50,717 CNY/ha) for rubber monoculture and rubber-tea intercropping plantation, respectively. There is no optimal rotation age with maximum NPV for tea monoculture.

Since prices, wages and interest rates do change over time, the possible effect of these changes should be evaluated. This is particularly important as all these factors are changing rapidly in China. Sensitivity analysis plays an important role by systematically testing how LEV would change. The results of the sensitivity analyses are presented in Figure 2a–d.

Figure 2a shows that rubber-tea intercropping is more sensitive to interest rate change, since it needs more investment at the beginning of the production cycle than the other two. With the low

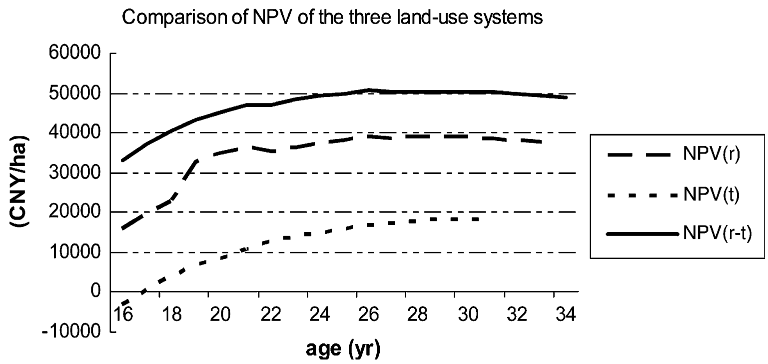

Figure 1. Comparison of NPV of the rubber monocropping, tea monocropping and rubber-tea intercropping in Hainan, China. Note: CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004.

level interest rate (2%), all the three land use systems generate more LEV than with the present interest rate: the optimal rotation age is 30 years with LEV 104,758 CNY for tea monoculture, 30 years with LEV 271,030 CNY for rubber-tea intercropping, and 29 years with LEV 230,829 CNY for rubber monoculture. With a high interest rate (10%), the profitability of all three land-use systems decreases dramatically, and the optimal rotation ages of rubber-tea intercropping and rubber monoculture decrease. Between the interest rates of 10 and 15%, there is a point where all three land use systems become unprofitable, i.e. the farms have to quit these three land use systems and will have to find an alternative land use scheme. Because the tea monoculture has only annual revenue, while forest has more capital accumulated in the standing trees than can be liquidated only by harvesting the trees, optimal rotation age of tree plantation is more sensitive to interest rates. However, the optimal rotation age of mono-cultural tea plantations, compared with that of tree plantations, is more difficult to determine.

Figure 2b shows that when the price of rubber decreases, the optimal rotation ages and the LEV of both rubber-tea intercropping and rubber mono-culture decrease as well. With the rubber price decreased by 30%, there is a cross point: with the rotation age shorter than 24 years, rubber-tea intercropping is more profitable than tea monoculture while with the rotation age longer than 24 years, tea monoculture is more profitable. Generally, the decrease of rubber price can cause the optimal land use change from rubber-tea intercropping to tea monoculture. When the rubber price increases, both rubber-tea intercropping and rubber monoculture become more profitable.

Figure 2c shows us that when tea price decreases, the LEV of rubber-tea intercropping and tea monoculture is less than that with the present price. With the tea price decreased by 15%, the LEV of rubber-tea intercropping approaches that of rubber monoculture, and tea monoculture becomes unprofitable. With the tea price decreased by 30%, rubber-tea intercropping is less profitable than rubber monoculture. It is clear that when tea price is decreased by more than 15%, the profit-maximizers would change the optimal land use from rubber-tea intercropping to rubber monoculture. If the tea price increases by over 15%, tea

(a)

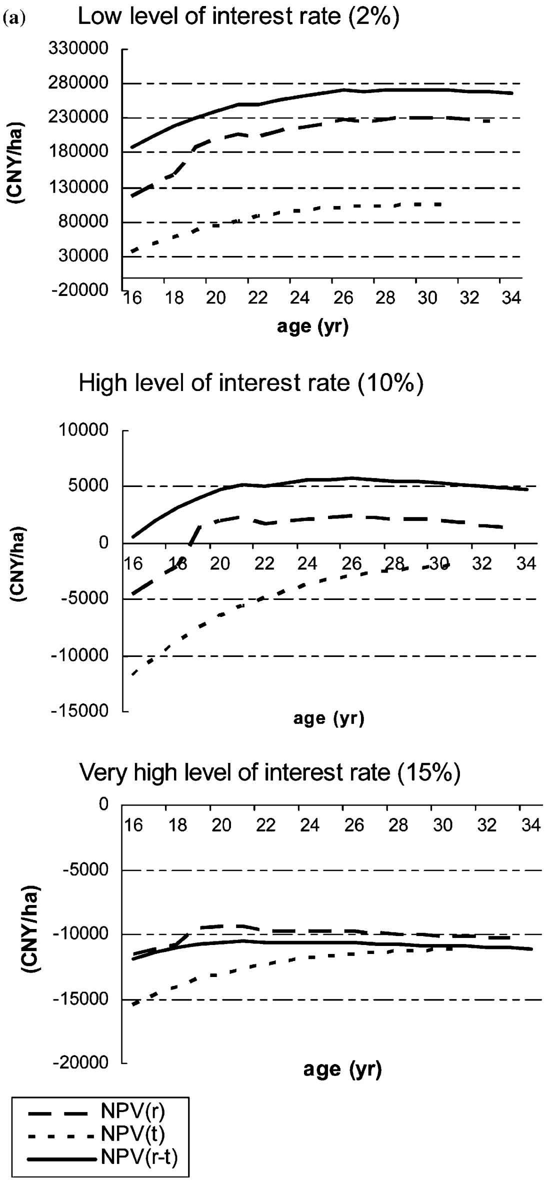

Figure 2. (a) Comparison of NPV of rubber monocropping, tea monocropping and rubber-tea intercropping in Hainan, China with different interest rates. Note: CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004. (b) Comparison of NPV of rubber monocropping, tea monocropping and rubber-tea intercropping in Hainan, China when rubber price changes. Note: CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004. (c) Comparison of NPV of rubber monocropping, tea monocropping and rubber-tea intercropping in Hainan, Chins when tea price changes. Note: CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004. (d) Comparison of NPV of rubber monocropping, tea monocropping and rubber-tea intercropping in Hainan, China when wages change. Note: CNY/ha = Chinese Yuan per ha, 1 US Dollar = 8.28 CNY, 2001–2004.

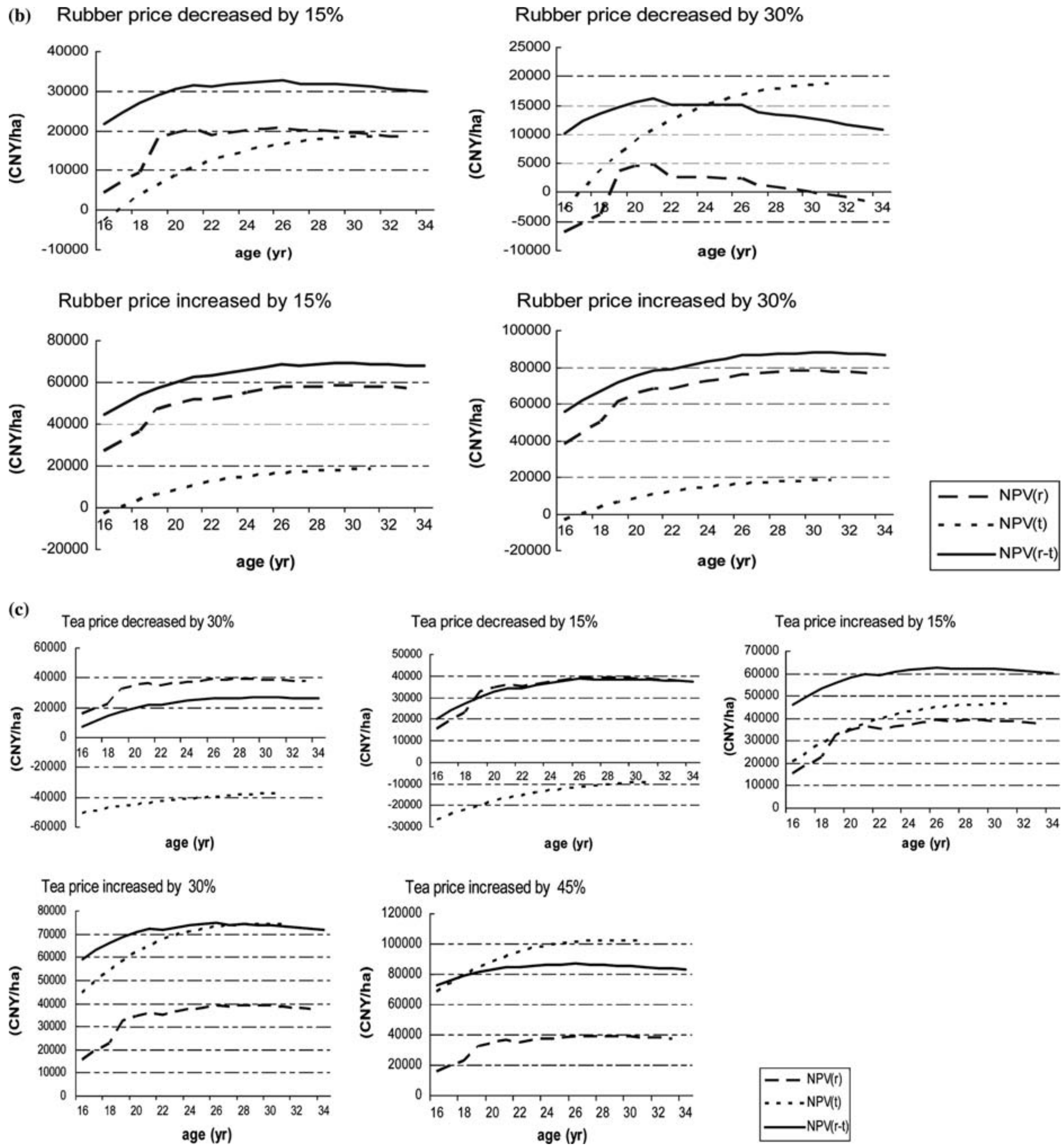

Figure 2. (Continued).

monoculture can generate larger LEV than rubber monoculture. When tea price increases by 30%, there is a cross point of the LEV of rubber-tea intercropping and tea monoculture. With rotation age shorter than 28 years, rubber-tea intercropping is more profitable than tea monoculture, while with rotation age longer than 28 years, tea monoculture is more profitable. The increase of tea price by over 30% will cause the optimal land use change from rubber-tea intercropping to tea monoculture.

Figure 2d shows that tea monoculture is most sensitive to the change of wages, followed by rubber-tea intercropping and rubber mono-culture,

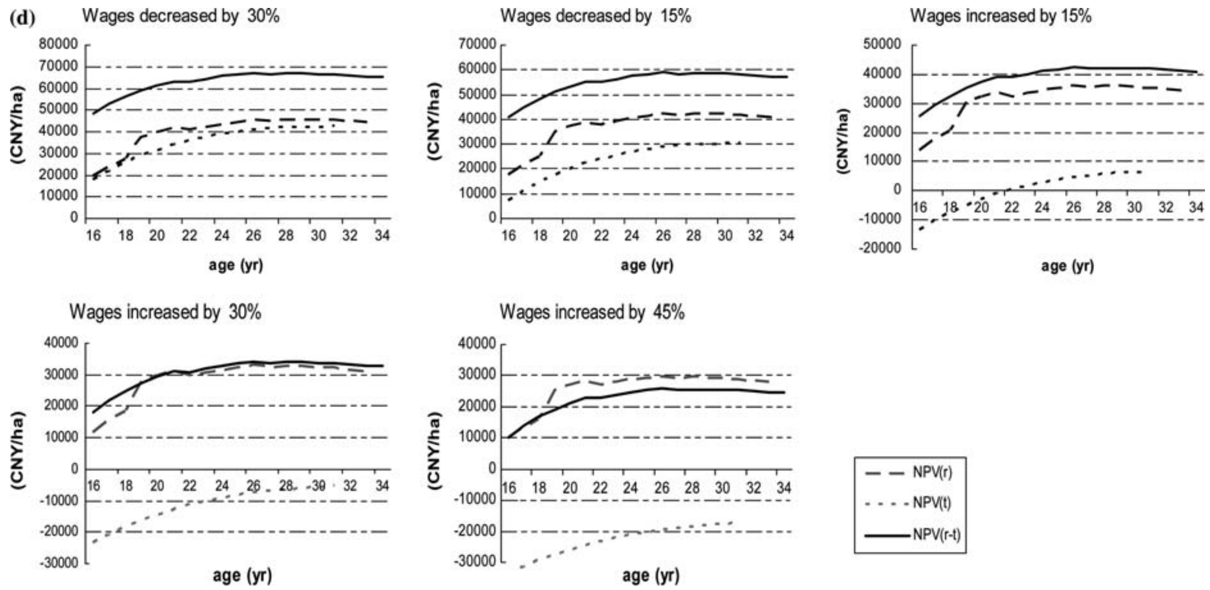

Figure 2. (Continued).

because the wage cost for plucking tea is 4.2 CNY/kg while latex tapping is only 1.9 CNY/kg. With the wages decreased by 45%, tea monoculture becomes more profitable than rubber monoculture. In contrast, with the increase of wages, the LEV of all the three land-use systems decreases. With the wages increased by 30%, the LEV for rubber-tea intercropping and rubber monoculture becomes similar, and tea monoculture is unprofitable.

Concluding Remarks

Even though rubber-tea intercropping can generate higher LEVs than the rubber monoculture and tea monoculture under current socio-economic circumstances, there are some barriers that need to be noted. First, rubber-tea intercropping is more labor intensive than the other two, so the development is more dependent on sources of labor and wages. Second, intercropping is more technically demanding (e.g., pruning, fertilizing, and disease control.) Without proper management, intercropping may generate lower LEV than the other two approaches. Third, intercropping is not suitable for high altitude land since rubber trees are susceptible to damage by cold temperature. Recently, rubber-tea intercropping has gradually been given up and replaced by rubber monoculture – largely because of the increasing labor costs and decreasing tea prices. This is consistent with the sensitivity analysis.

Tea plantations generate much lower LEVs, largely because of market conditions and policy changes, i.e. much weaker international market demand of black-powder-tea than originally expected and unexpected reform of Chinese foreign trade system. The selected tea species, *Camellia sinensis var. assamica*, which was widely planted in the past, was good for black-powder-tea product with higher export price and subsidies from government for earning foreign currency. At peak time, annual export had amounted up to 1 million US dollar. The low LEV was not expected when wide spread tea plantations were initiated. That is why, tea was still widely planted with current low LEV.

Due to the change in market, the black tea has been largely replaced by green tea in the past decade. Exports also significantly declined, followed by the dramatic decline in tea plantation area from 8000 ha in 1993 to 3000 ha in 2000. In order to meet the changing market, other species for green tea products with much higher prices have been introduced and planted in Hainan island. In this situation, tea monoculture might be even more profitable than rubber-tea intercropping and rubber monoculture.

After some years of fluctuation, it has been realized that some new tea species with much higher prices are viewed as more important strategies. Some new tea species, such as *Qilan*, *Fuding*, *Shuixian* (Chinese name), with prices over 10 times higher than the specie in our study have since been planted. Figure 2c shows that when tea price increases by 45%, tea monoculture generates the largest LEV among the three alternatives. Though the cost of seedlings and labor increase slightly and the yield of new species decreases by half, the monoculture of newly developed species can still generate much higher LEV than the other 2 alternatives. It is reported that new tea is widely planted, particularly replacing the traditional tea species across the Island.

The Faustmann rotation model had been widely used to determine harvest age, but it is still rare to combine annual revenue flow and final timber harvest in the model. Usually the optimal rotation age with the maximum NPV can be easily found, but it is different in this study – probably because of the annual revenue from the non-timber product: latex and tea. This study has adopted the Faustmann model to assess land use options. The methodology can be applied to other areas, particularly in tropical areas. More importantly, by using a spreadsheet together with the Faustmann Formula, we can easily simulate different scenarios by varying interest rate, input costs and output prices. This will be helpful for the decision makers to quickly change the land use options when socioeconomic circumstances change. It is also helpful for policy makers to assess the impacts on land use options from policy change such as taxes, subsidies, and price restrictions.

Some limitations must be pointed out. The data was collected only from one farm. In spite of the fact that we tried to choose a representative farm, we still need to be cautious to generalize our conclusions to other areas. The growth and yield of rubber plantation are strongly influenced by topographical, geological and climatic conditions. According to Chen (2000), more than half of the rubber plantations in Hainan have the similar production environmental condition to that of the selected studied plantation. However, in some plantations, the annual yield of latex, as well as the stumpage, may not be that high because of stronger typhoons, lower temperatures or poor topographical and soil conditions.

Future study needs to be done not only to include some other farms and locations, but also to cover different kinds of rubber and tea species and cultivation methods. Another important point that needs to be considered is the ecological benefit. In addition, we have not touched the social impacts from different cultivation systems. As in other developing countries, an agroforestry system in many cases may not be economically feasible, but it serves more socio-economic and community development oriented purposes. How to include the comparison of the different social impacts is another aspect that needs to be considered in the future study. We also need to consider policy and institutional variables, which are often important in developing countries. Zhang et al. (2000) found that both market and institutions contribute to the forest plantation in Hainan.

Acknowledgements

We are greatly indebted to the Xinwei Farm and Hainan General Reclamation Bureau for providing the available data for this study. Zhimei Guo sincerely express her deep gratitude to the German Academic Exchange Service (DAAD) for the financial support. The comments from two reviewers of this journal are also greatly appreciated. Ms. Elizabeth P. Bowersock of Auburn University checked the language. The authors are responsible for all errors.

References

Chen H. 2000. The Cultivation Technique of Rubber Trees. Hainan Publishing House, Haikou (in Chinese).

Dyack B.J., Rollins K. and Gordon A.M. 1999. A model to calculate ex ante the threshold value of interaction effects necessary for proposed intercropping projects to be feasible to the landowner and desirable to society. Agroforest. Syst. 44: 197–214.

Faustmann M. 1849. On the determination of the value which forest land and immature stands possess for forestry. J. Forest Econ. (Reprinted) 1(1): 7–44.

Feng Y. 1986. Ecological studies on an artificial rubber-tea community. Intecol Bull. 13: 93–95.

Follis M.B. 1993. Economic considerations. Chapter 22 in Nair PKR. In introduction to Agroforestry. Kluwer Academic Publishers, Dordrecht, pp. 385–411, 449.

Hao Y. 1986. Rubber cultivation in China's tropical regions. Intecol Bull. 13: 89–91.

Huang X. 1990. On the compounding multiple-stored structure of tree-rubber-tea in tropical agricultural system in Hainan island. J. Sci. Technol. Tropical Crops 3: 15–18. (in Chinese).

Long Y. 1991. Evaluation on ecological and economical benefits of the man-made rubber-tea community. Chinese J. Ecol. 10(3): 37–40. (In Chinese).

Mehta N.G. and Leuschner W.A. 1997. Financial and economic analyses of agroforestry systems and a commercial timber plantation in the La Amistad Biosphere Reserve, Costa Rica. Agroforest. Syst. 37: 175–185.

Ramírez1 O.A., Somarriba E., Ludewigs T. and Ferreira P. 2001. Financial returns, stability and risk of cacao-plantain-timber agroforestry systems in Central America. Agroforest. Syst. 51: 141–154.

Rodrigo V.H.L., Stirling C.M., Naranpanawa R.M.A.K.B. and Herath P.H.M.U. 2001. Intercropping of immature rubber in Sri Lanka: present status and financial analysis of intercrops planted at three densities of banana. Agroforest. Syst. 51: 35–48.

Sullian G.M., Huke S.M. and Fox J.M. (eds), 1992. Financial and Economic Analysis of Agroforestry Systems. Proceedings of a workshop held in Honolulu, Hawaii, USA, July 1991.

Zhan X. 1990. Economic and social benefits of man-made rubber-tea community. Hainan Reclam. Sci. Tech. 2: 16–18. (in Chinese).

Zhang Y., Uuivuori J. and Kulluvaianne J. 2000. Econometric analysis of the causes of forest land use changes in Hainan, China. Can. J. Forest Res. 30: 1913–1921.

Zhang Y., Uusivuori J., Kuuluvainen J. and Kant S. 2003. Deforestation and reforestation in Hainan: roles of market and institution. In: Hyde W.F., Belcher B. and Xu J. (eds), China's Forest Policy. Resource for the Future. Washington DC, pp. 135–149.

Zheng H. and He K. 1991. Intercropping in rubber plantation and its economic benefit. In: Zhu Z., Cai M., Wang S. and Jiang Y. (eds), Agroforestry Systems in China. Chinese Academy of Science, and the International Development Research Centre, Canada, pp. 204–206.