Modelling of Boom and Bust of Cocoa Production Systems in Malaysia

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In the previous chapters in Part I, the concepts, methodology and techniques of system dynamics modelling and simulation in the areas of agricultural, biological, environmental and socio-economic systems are presented. This chapter presents applications of system dynamics modelling in ecological systems of boom and bust of cocoa production systems in Malaysia to demonstrate how to construct a system dynamics model and simulate it for policy planning and design. The model presented is an illustration of modelling and simulation of practical problems, and such an experience is essential to face the challenge of modelling and simulation of dynamic systems. To achieve this goal, the model of this case study is organised as follows: (1) introduction, (2) dynamic hypothesis, (3) causal loop diagram, (4) stock–flow diagram, (5) model validation, (6) simulation and policy analysis and (7) conclusion. The simulated results indicate that the collapse of cocoa production systems can be avoided through biodiversity conservation and insect control resulting from sustainable production systems and implementation of such policy demands adequate subsidy to retain high biodiversity, control pest and disease and attain acceptable yields through extension services through farmer field schools.

8.1 Introduction

The cocoa tree (*Theobroma cacao L.*) is an understorey forest species which evolved in the Amazon (Motamayor et al. 2008), and it is currently grown in many countries of the humid tropics. The largest cocoa-producing countries are Cote d'Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Malaysia, and these contribute 90 % of world production (Latiff 2007). Cocoa beans are primarily exported to Europe and North America to be processed to produce cocoa and chocolate.

Cocoa was introduced into Malaysia for commercial cultivation in 1950, became the third major commodity product in Malaysia after palm oil and rubber and was

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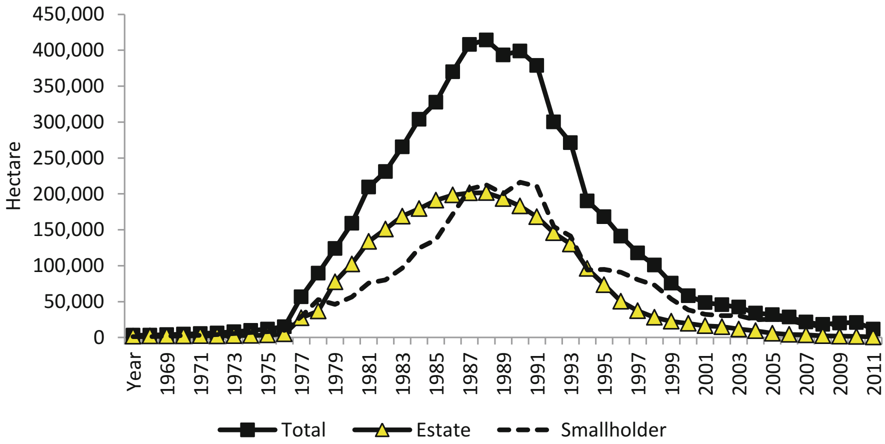

Fig. 8.1 Cocoa cultivation by type of holdings in Malaysia (Source: Department of Statistics, Malaysia 2014)

considered to be a crop for agricultural diversification in the Second Malaysia Plan, 1971–1975. The availability of superior planting materials and planting technology and the implementation of the government policy to encourage the growing of cocoa as an intercrop with coconuts coupled with the high favourable prices led to the rapid expansion of the cocoa planting industry in Malaysia (Fig. 8.1). The area planted increased to 123,855 ha in 1980 and 414, 236 ha in 1989. The high plantation rate is attributed to the unprecedented high cocoa bean prices in the 1970s and 1980s. (Lee 2013). But post-1980s marked a decrease in cocoa planting area with the decline of cocoa production due to poor world cocoa prices, labour constraints, competition for land use from oil palm cultivation and the severe spread and infestation of the cocoa pod borer (Lee 2013). The cultivated area decreased sharply from 393,465 ha in 1990 to 190,127 in 1995, and it continued till 2005 and the area was reduced to 33,398 ha due to severe pest infestation. By 2013, the cocoa planted area was reduced to only 13,728 ha. Fluctuations with small decline in cocoa areas were noted from 2005 (33,398 ha) to 2013 (13,728 ha), and during this period, strong government support was provided for cocoa planting especially in the rural and outlying areas to improve livelihood and elevate income with poverty reduction with targeted area of 40,000 ha by 2020 (MPIC 2011). However, there is an apparent uptrend of cocoa dried bean prices throughout the three regions of Malaysia as that of world cocoa prices. Malaysia has been dropped to the 12th position from 4th position in the world cocoa production (Lee 2013).

Questions remain to answer: What caused the boom and bust of cocoa plantation in Malaysia in particular? Why do cocoa plantations exhibit an extremely unstable pattern of development with ecological damages of biodiversity resulting from outbreak of severe pest infestation and diseases? What should be the policy for sustainable development of cocoa production systems in Malaysia?

Several studies have reported on the boom and bust of agricultural commodities like the shrimp aquaculture industry (Arquitt et al. 2005; Bala and Hossain 2010; Prusty et al. 2011). In these cases, from a systems perspective, we can conclude that when the industry is prone to exceed and consume its environmental carrying capacity, a boom and bust type of development results. Clough et al. (2009) reported a qualitative model of the boom and bust of the cocoa production systems. Franzen and Mulder (2007) highlighted the important ecological, economic and social considerations for sustainable cocoa production. This clearly indicates that there is a large research gap to understand the boom and bust and to search for policies for sustainable development of cocoa production and marketing in Malaysia.

Cocoa trees can be planted in the forest or under planted shade, but most cocoa plantations are planted into thinned forests. Shade removal increases the yield in the short run which damages ecosystems and reduces the biodiversity. As the boom busts, the plantation area falls sharply to a very low level due to extremely low productivity. Underlying production busts are failures of the industry participants particularly the policy makers to understand the problem and take effective measures. However, the boom and bust of cocoa production in Malaysia has been well documented (Lee 2013). Current cocoa production systems are not sustainable because of non-eco-friendly production of cocoa beans, although there is a demand of cocoa in chocolate industries. Sustainable development of cocoa production and marketing is a major concern for the policy makers and authorities who are searching for a sustainable planning to accomplish the targeted goals. Although boom and bust is the major concern, in addition, the sustainable development aims to achieve social, economic and ecological success in the cocoa production. However, sustainability cannot be achieved unless the ecological imbalance is rectified. The sustainable production should increase profit within the framework of ecological conservation of biodiversity. To cover this gap of understanding of boom and bust and designing sustainable production of cocoa beans and propose a realistic model which can add not only knowledge of boom and bust but also the implementation knowledge of sustainable production of cocoa in Malaysia, Fatimah et al. (2015) developed a system dynamics model to examine the underlying causes of the boom and bust of cocoa production systems in Malaysia and developed policies for sustainable development of production of cocoa in Malaysia. The modelling of the boom and bust of cocoa production systems presented here is adopted from Fatimah et al. (2015).

8.2 Dynamic Hypothesis

The dynamic hypothesis is a conceptual model typically consisting of a causal loop diagram, a stock–flow diagram or their combination. The dynamic hypothesis seeks to define the critical feedback loops that drive the system's behaviour. When the model based on the feedback concept is simulated, the endogenous structure of the model should generate the reference mode behaviour of the system, and thus, the endogenous structure causes the changes in dynamic behaviour of the system (Sterman 2000). The boom and bust of cocoa production systems can be represented by causal loop diagram and stock–flow diagram, and the simulation model based on the causal loop diagram and stock–flow diagram can generate dynamic behaviour of the cocoa production systems. The cocoa production systems in the form of causal loop diagram and stock–flow diagram are hypothesised to generate the observed boom and bust of cocoa production systems in the reference mode. In essence, the degradation of the biodiversity resulting from the reduction of shade level and subsequent large-scale insect infestation caused the boom and bust of cocoa production systems in Malaysia (Fig. 8.1), and this dynamics resulted from the endogenous consequences of the feedback structure (Sterman 2000).

8.3 Causal Loop Diagrams

The key factors influencing cocoa production are yield, thinning of shading trees and area under cultivation. The boom and bust of cocoa production in Malaysia is described by two reinforcing loops and six balancing loops. When production of cocoa and thinning generate profit for the producers, these motivate them to continue cultivation generating a feedback loop to work (R_1). Also when production of cocoa generates profit per ha, the producers are motivated to increase cultivated area (R_2). Area under cultivation and thinning of shading trees which creates ecological imbalance invites insect infestation. When insect infestation becomes intolerable and cocoa beans are damaged significantly, the cocoa production is affected negatively (B_1), and also cultivation is abandoned due to severe insect infestation (B_2). Profit per ha also is deciding factor for abandonment of cultivation area (B_3), and the cultivation cost affects the profit per ha (B_4). Thinning cost and cost incurred in insect infestation also affect profit per ha (B_5 and B_6). The dynamic interaction between cocoa production and ecology gives rise to the feedback loops. The causal loop diagrams of cocoa production systems are shown in Fig. 8.2 which shows the initial dynamic hypothesis of the boom and bust of cocoa plantation, and it is based on standard assumptions of how the cocoa production system typically works. If our hypothesis is correct, the model will be able to reproduce the general historical pattern of boom and bust followed by the simulated boom and bust of cocoa plantation.

8.4 Stock–Flow Model

Figure 8.3 shows the stock–flow diagram of the boom and bust of cocoa production systems in Malaysia. Fundamental equations that correspond to major state variables shown in Fig. 8.3 are as follows:

The cocoa plantation area is increased by the cocoa plantation rate based on the profitability of the cocoa plantation, and also the cocoa plantation area is abandoned based on yield and profit. This is expressed as:

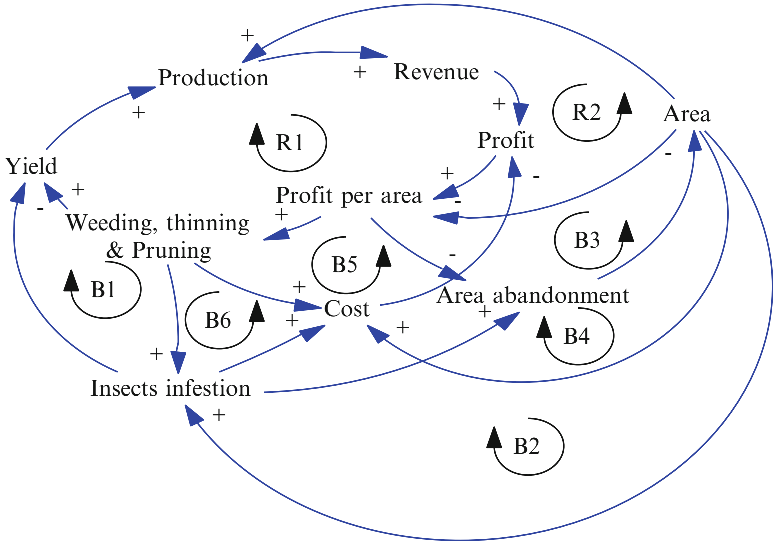

Fig. 8.2 Causal loop diagrams of cocoa production system

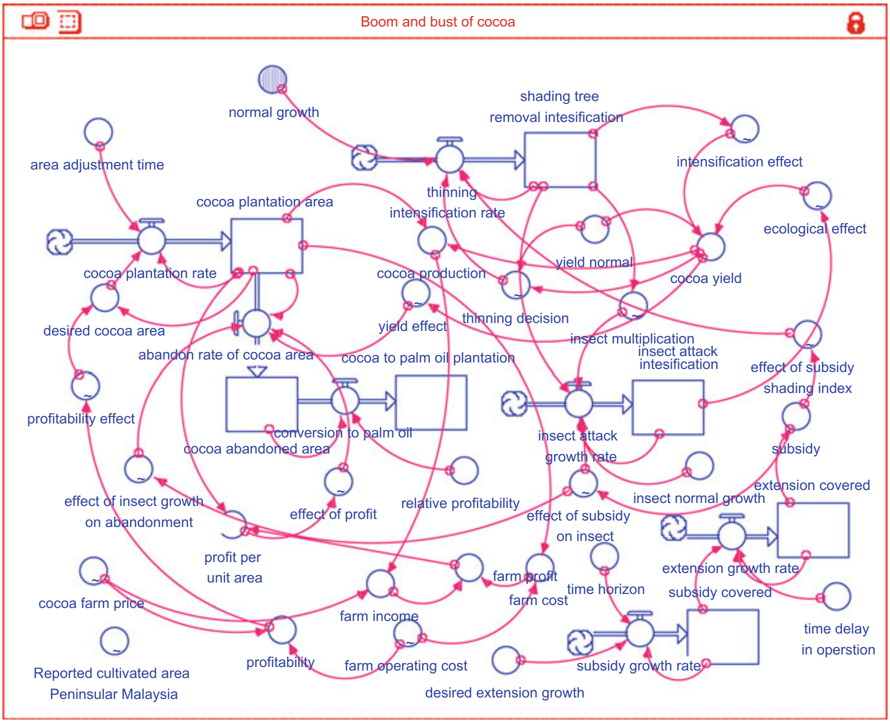

Fig. 8.3 Stock–flow diagram of boom and bust of cocoa production in Malaysia

$$\text{cocoa plantation area}\,(t) = \text{cocoa plantation area}\,(t - \Delta t) + \text{cocoa plantation rate} \times \Delta t - \text{abandon rate of cocoa} \times \Delta t \tag{8.1}$$

The cocoa plantation rate depends on the present level of the cocoa plantation area, the desired cocoa area and the time delay to reduce the gap between the desired cocoa area and level of cocoa plantation area, and it is expressed as:

$$\text{cocoa plantation rate} = \text{MAX}\big(0, (\text{desired cocoa area} - \text{cocoa plantation area}) / \text{area adjustment time}\big) \tag{8.2}$$

Desired area is computed from the level of the cocoa plantation area and profitability effect as:

$$\text{desired cocoa area} = \text{cocoa plantation area} \times \text{profitabilty effect} \tag{8.3}$$

The expansion of the cocoa area depends on the profitability of cocoa production and the non-linear relationship between profitability effect and profitability is expressed as:

profitability_effect = GRAPH(profitability)
(0.00, 0.02), (0.1, 0.738), (0.2, 1.16), (0.3, 1.50), (0.4, 1.76), (0.5, 2.00), (0.6, 2.14), (0.7, 2.21), (0.8, 2.24), (0.9, 2.24), (1, 2.27)

Abandon rate of the cocoa area depends on the level of the cocoa plantation area, yield effect and effect of profit, and it is expressed as:

$$\text{abandon rate of cocoa area} = \text{cocoa plantation area} \times \text{yield effect} \times \text{effect of profit} \tag{8.4}$$

The abandonment of cocoa area under cultivation depends on the yield of cocoa and the non-linear relationship between yield effect on the abandonment of cocoa cultivation area and yield of cocoa is expressed as:

yield_effect = GRAPH(cocoa_yield)
(0.00, 0.645), (1.00, 0.555), (2.00, 0.47), (3.00, 0.41), (4.00, 0.37), (5.00, 0.32), (6.00, 0.29), (7.00, 0.26), (8.00, 0.23), (9.00, 0.215), (10.0, 0.21)

Also the abandonment of cocoa area under cultivation depends on the profit per unit area and the non-linear relationship between effect of profit on the abandonment of cocoa cultivation area and profit per unit area is expressed as:

effect_of_profit = GRAPH(profit_per__unit_area)

(0.00, 1.11), (10.0, 1.09), (20.0, 1.08), (30.0, 1.07), (40.0, 1.06), (50.0, 1.05), (60.0, 1.04), (70.0, 1.03), (80.0, 1.03), (90.0, 1.03), (100, 1.02)

Cocoa yield is increased by the development of new hybrid varieties of cocoa through research and development, and also it depends on the ecological effect resulting from insect infestation due to limiting the shading index and intensity of shading index. This is described as:

$$\text{cocoa yield} = \text{yield normal} \times \text{ecological effect} \times \text{intensification effect} \tag{8.5}$$

The ecological effect resulting from the degradation of biodiversity and hence insect infestation affects the cocoa yield and the non-linear relationship between ecological effect and insect attack intensification, and it is expressed as:

ecological_effect = GRAPH(insect_attack__intesification)
(0.00, 1.00), (8.33, 0.87), (16.7, 0.725), (25.0, 0.535), (33.3, 0.41), (41.7, 0.335), (50.0, 0.24), (58.3, 0.2), (66.7, 0.11), (75.0, 0.075), (83.3, 0.045), (91.7, 0.02), (100.0, 0.005)

The shading tree removal enhances not only the cocoa yield, but it also invites insect infestation and the non-linear relationship between intensification effect and shading tree removal intensification is expressed as:

intensification_effect = GRAPH(shading_tree__removal_intesification)
(0.00, 1.04), (8.33, 1.18), (16.7, 1.24), (25.0, 1.29), (33.3, 1.34), (41.7, 1.37), (50.0, 1.41), (58.3, 1.45), (66.7, 1.46), (75.0, 1.48), (83.3, 1.48), (91.7, 1.48), (100.0, 1.48)

Yield normal is increased by development of new high-yielding/hybrid varieties through research and development.

Shading index reduction increases the yield in the short run, but large-scale reduction of shading index invites insect infestation which results in ecological degradation in the long run. Shading index is reduced by thinning the trees for higher yields in case of cocoa plantation under forest trees, and also shading index can be adjusted by changing the plant-to-plant distance of the coconut tree in case of cocoa plantation under coconut plantation, and the shading removal intensification is expressed as:

$$\begin{aligned}\text{shading tree removal intensification}\,(t) = {} & \text{shading tree removal intensification}\,(t - \Delta t) \\ & + \text{thinning intensification rate} \times \Delta t\end{aligned} \tag{8.6}$$

The thinning intensification rate depends on the present level of shading tree removal intensification, cocoa yield and subsidy for shading.

Shading tree and cocoa plants invite the insects, and the severity of insect damage depends on the intensity of insect attack, and the insect attack intensification is expressed as:

$$\begin{aligned}\text{insect attack intensification}\,(t) = {} & \text{insect attack intensification}\,(t-\Delta t) \\ & + \text{insect attack growth rate} \times \Delta t\end{aligned} \tag{8.7}$$

The insect attack growth rate depends on the present level of insect population, insect multiplication, shading tree removal intensification level and subsidy to control insects.

Cocoa production in Fig. 8.3 depends on cocoa yield (tons/ha) as well as on area under cocoa plantation, and it is computed as:

$$\text{cocoa production} = \text{cocoa yield} \times \text{cocoa area} \tag{8.8}$$

The coverage of the subsidy and extension through farmer field schools is expanded with a broad policy of high biodiversity and acceptable yields for sustainable development. These are described as:

$$\begin{aligned}\text{extension covered}\,(t) = {} & \text{extension covered}\,(t-\Delta t) \\ & + \text{extension growth rate} \times \Delta t\end{aligned} \tag{8.9}$$

and

$$\text{subsidy covered}\,(t) = \text{subsidy covered}\,(t-\Delta t) + \text{subsidy growth rate} \times \Delta t \tag{8.10}$$

The extension growth rate depends on the subsidy covered, present level of subsidy and time horizon in operation.

These systems of equation are solved by Runge–Kutta fourth-order method using STELLA software.

8.5 Model Validation

Initial values and the parameters were estimated from the primary and secondary data collected from different research reports, statistical year books of Malaysia and field visits. Tests were also conducted to build up confidence in the model. Tests for building confidence in system dynamics models essentially consist of validation, sensitivity analysis and policy analysis (Bala 1999). The two important notions of the building confidence in the system dynamics models are testing and validation of the system dynamics models. Testing means the comparison of a model to empirical reality for accepting or rejecting the model, and validation means the process of establishing confidence in the soundness and usefulness of the model. In the

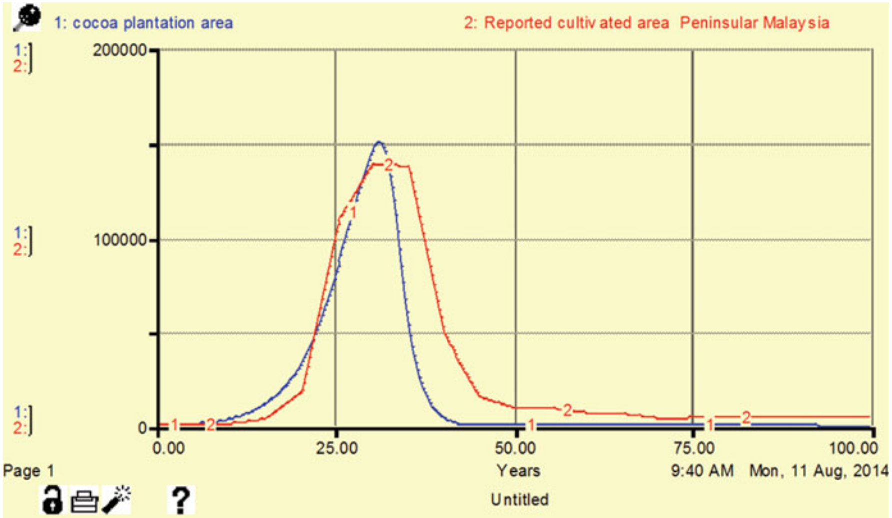

Fig. 8.4 Simulated and historical patterns of boom and bust of cocoa production systems in Peninsular Malaysia

behaviour validity tests, emphasis should be on the behavioural patterns rather than on point prediction (Barlas 1996).

To build up confidence in the predictions of the model, various ways of validating a model such as model structures, comparing the model predictions with historical data, checking whether the model generates plausible behaviour and checking the quality of the parameter values were considered.

Figures 8.4, 8.5 and 8.6 show the comparisons of simulated behaviours of plantation area of cocoa with the historical data. The historical data of cocoa plantation area in Peninsular Malaysia, Sabah and Sarawak show the boom and bust of cocoa production area in Malaysia. Simulated behaviours are numerically sensitive to parameters and shapes of the table functions. However, the basic patterns of the historical and simulated behaviours agree adequately, and model predictions represent reality.

8.6 Simulation and Policy Analysis

Figures 8.4, 8.5 and 8.6 show the collapse of cocoa production systems which may be attributed to mainly the reduction of the shade level which reduces the biodiversity and resulting large-scale insect infestation. The model was simulated to test how cocoa plantation changes with the changes in subsidy for maintaining high biodiversity attain acceptable yields and IPM-FFS (integrated pest management-farmer field schools) for pest management. The subsidy coverage (0–100 %) was gradually increased to cover the extension services (0–100 %) through farmer field schools for maintaining the recommended shading index and hence the biodiversity

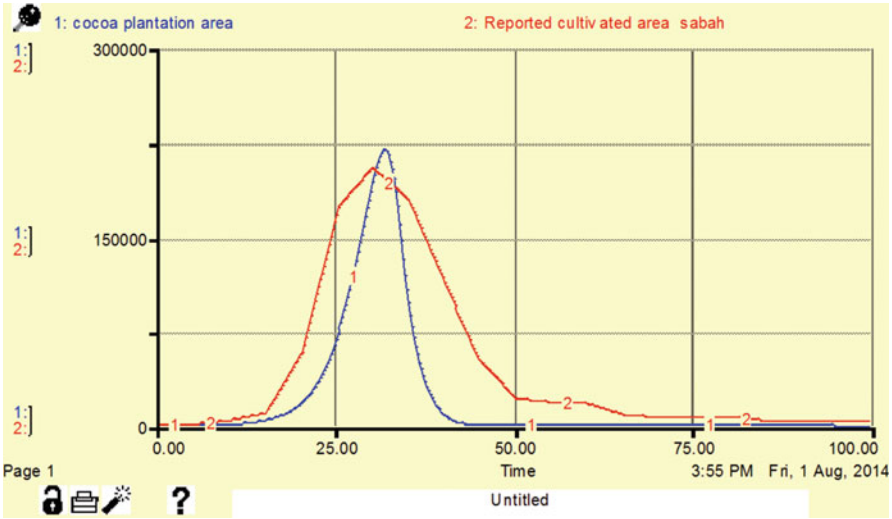

Fig. 8.5 Simulated and historical patterns of boom and bust of cocoa production systems in Sabah, Malaysia

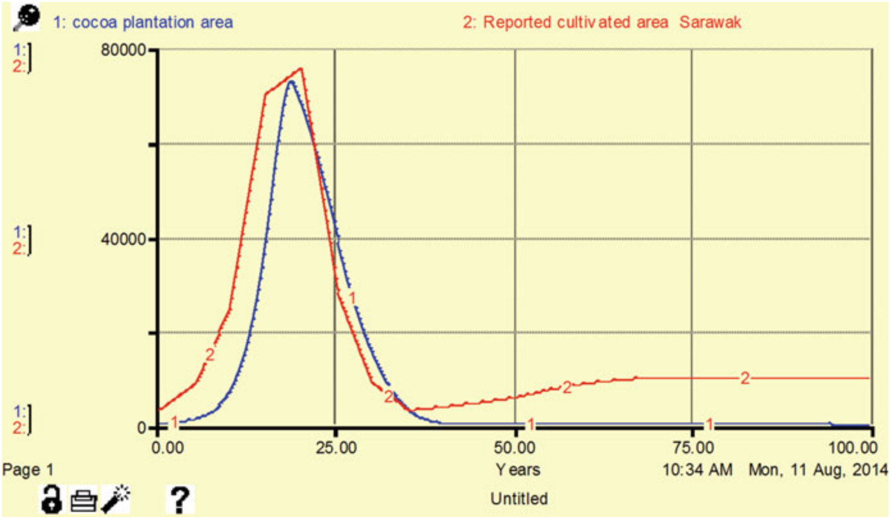

Fig. 8.6 Simulated and historical patterns of boom and bust of cocoa production systems in Sarawak, Malaysia

and providing pest control including IPM. Figure 8.7 shows the simulated cocoa plantation area for full subsidy (curve 3), 80 % subsidy (curve 2) and 60 % subsidy (curve 1) of the cost to cover conservation practices and insect control. The system is sustainable for full subsidy since financial support is provided for joint trade-off

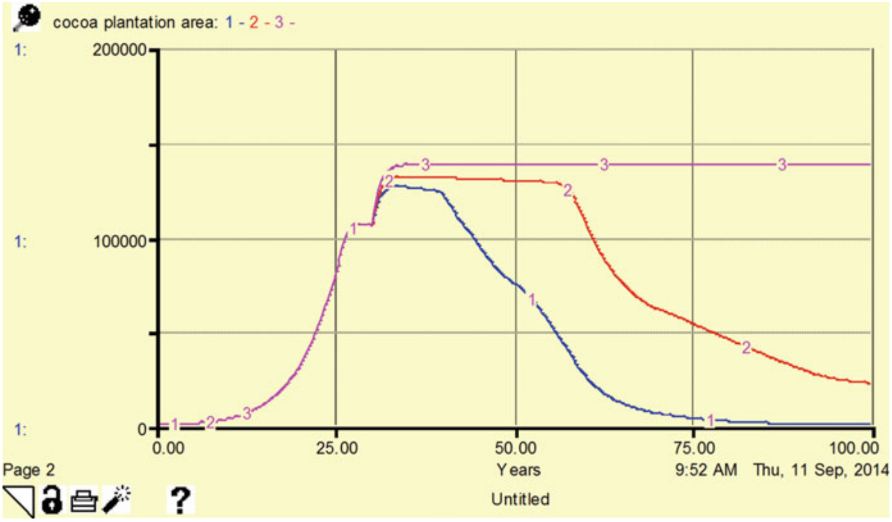

Fig. 8.7 Sensitivity analysis of subsidy for cocoa production systems in Malaysia

of biodiversity and yield along with IPM pest control through FFS, but the sustainability decreases with the degree of reduction of subsidy as there are lesser opportunities available to maintain biodiversity and insect control in terms of financial support. Waldron et al. (2012) also suggest that a simple development help specifically targeted at cocoa smallholders as the best short-term means to improve the long-term stability of the production in a sustainable environment, together with cocoa smallholders' economic status.

The model was also simulated for integration of subsidy with extension through farmer field schools to retain high biodiversity and attain acceptable yields along with proper integrated pest management for sustainable development of cocoa production systems in Malaysia. The model was simulated for two options: (1) First option is starting the joint programme of subsidy and extension at the peak of the boom. The subsidy coverage (100 %) at the peak of the boom covers the extension services (100 %) through farmer field schools for maintaining the recommended shading index and hence the biodiversity and providing pest control including IPM and (2) Second option is starting the joint programme of subsidy and extension at the beginning of the boom of cocoa. The subsidy coverage (0–100 %) was gradually increased from the beginning of the simulation period to cover the extension services (0–100 %) through farmer field schools for maintaining the recommended shading index and hence the biodiversity and providing pest control including IPM. Figure 8.8 shows reported results and simulated cocoa plantation area with subsidy and extension through farmer field schools at the peak of the boom, while Fig. 8.9 shows simulated cocoa plantation area with subsidy and extension through farmer field schools for coverage of the cocoa plantation with subsidy and extension through farmer field schools with 5 years of time horizon for

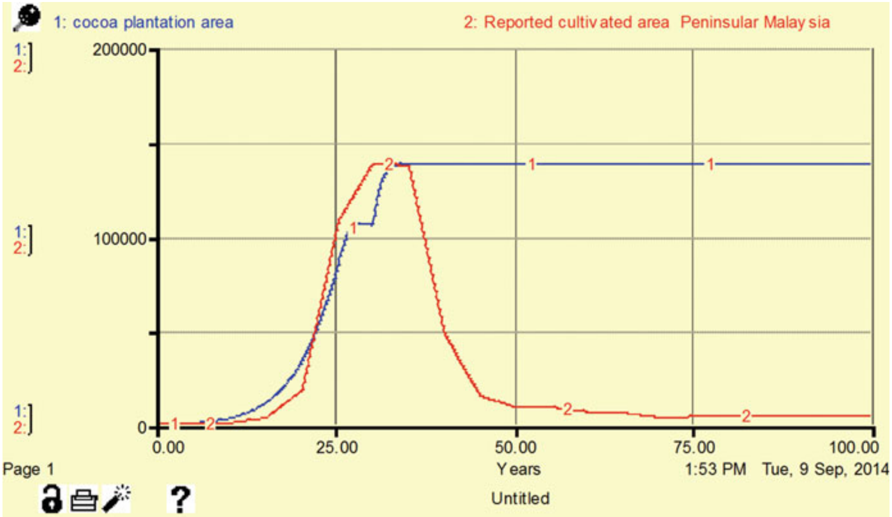

Fig. 8.8 Simulated results for subsidies for thinning and insect control

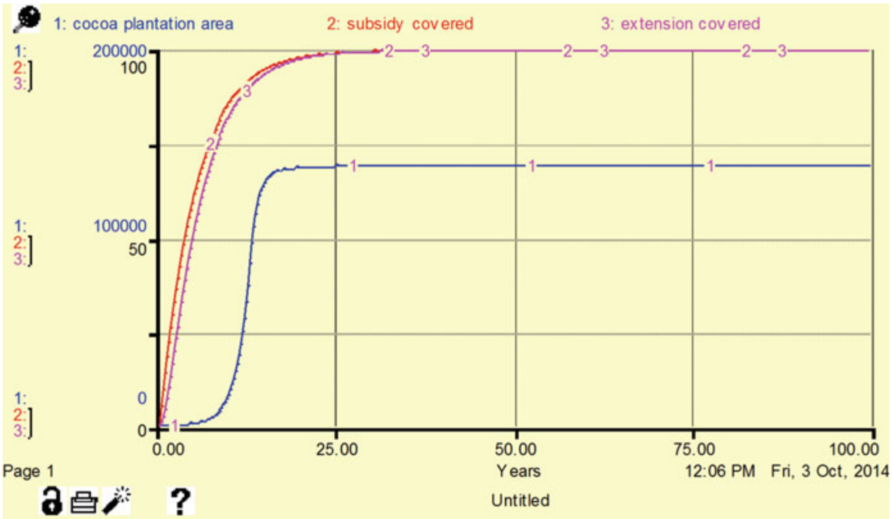

Fig. 8.9 Simulated cocoa plantation area, subsidy covered and extension covered for cocoa production systems in Malaysia

implementation of the subsidy and extension programme. In both the cases, the cocoa plantation area becomes stabilised. The cocoa production with subsidy and extension through farmer field schools at beginning of the production cycle not only stabilises the system but also returns to the stable condition much more quickly. The achievement of the stable cocoa production system largely depends on the success of integrated subsidy and extension programme to attain high biodiversity and acceptable yields through farmer field schools.

8.7 Conclusion

The boom and bust of cocoa production is one of the consequences of the short-term benefit of higher yield at the expense of reducing the biodiversity, thereby decreasing local habitat diversity and subsequently inviting pest and diseases. The subsidy policy proposed limits cocoa production to ecological carrying capacity which can be achieved by maintaining a joint trade-off between the shading index and proper actions for insect control of the cocoa production systems and acceptable yields. Simulated results support that suggested policy can lead to a sustainable production system. The Malaysian case study of the boom and bust of the cocoa production system gives an opportunity to develop a hypothesis of cocoa boom and bust and provided structure for policy simulation for sustainable development. Of course, adequate subsidy with effective extension of technologies from R&D for policy implementation is needed.

Exercises

Exercise 8.1 What do you mean by boom and bust? What caused the boom and bust of cocoa production systems in Malaysia?

Exercise 8.2 Draw the causal loop diagrams of cocoa production systems and then include insect infestation and finally shading of top covers.

Exercise 8.3 Draw a stock–flow diagram of cocoa production systems and explain how a causal loop diagram and stock–flow diagram represent the dynamic hypothesis of cocoa production systems. Also simulate the model.

Exercise 8.4 How can we make somebody to build up confidence in the system dynamics model of cocoa production systems? Also discuss the usefulness of the cocoa production system model.

Exercise 8.5 Discuss the policy issues to stabilise the boom and bust of cocoa production systems in Malaysia. How can the policy of stabilisation of cocoa production systems be implemented using the participatory systems approach?

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