ROTATION SYSTEM FOR CARDAMOM PLANTING AND FOREST REGENERATION IN THE TROPICAL RAINFOREST OF SOUTH-WEST CHINA

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GAO L & LIU HM. 2009. Rotation system for cardamom planting and forest regeneration in the tropical rainforest of south-west China. The cultivation of cardamom (*Amomum villosum*) in tropical rainforest led to biodiversity decrease and soil degradation. After removal of cardamom in the rainforest of Xishuangbanna of Yunnan, SW China, ecological restoration experiment was carried out from 1998 till 2001. The results showed that the number of plants increased, exceeding that of primary rainforest. The species richness, plant diversity and evenness had increased prominently, similar to the values of primary rainforest. The flora developed along that of tropical rainforest. In the rainy season, seedlings grew faster in areas where cardamom had been removed compared with that of primary rainforests, but there was no difference in the dry season. The biomass of seedlings was 636.1 ± 43.4 g m^{-2} after two years, exceeding that of the primary rainforest, due to the rapid growth of herbs and ferns. The water content of soil improved and was not different from that of primary rainforest. The organic matter content of deep soil increased remarkably but available phosphorus needed a long time to restore. The available surface calcium was lost through rain water. A new pattern of rotating cardamom planting in tropical forests was recommended.

Keywords: *Amomum villosum,* plant diversity, recovery, slash and burn, sustainable conservation

GAO L & LIU HM. 2009. Sistem giliran bagi penanaman kardamom dan pertumbuhan semula hutan di hutan hujan tropika di barat daya negara China. Penanaman kardamom (*Amomum villosum*) di hutan hujan tropika mengakibatkan kemerosotan biodiversiti dan pendegradan tanah. Ujian pemulihan ekologi dijalankan dari tahun 1998 hingga tahun 2001 selepas kardamom dituai daripada hutan hujan tropika di Xishuangbanna, Yunnan, barat daya China. Keputusan menunjukkan bahawa bilangan tumbuhan bertambah, melebihi bilangan di dalam hutan hujan primer. Kekayaan spesies, diversiti tumbuhan dan keseragaman tumbuhan bertambah dengan ketara dan nilainya serupa dengan nilai bagi hutan hujan primer. Floranya seakan-akan sama dengan flora hutan hujan tropika. Semasa musim hujan, anak benih tumbuh paling cepat di kawasan bekas penanaman kardamom berbanding dengan pertumbuhan di hutan hujan primer. Namun tiada perbezaan diperhatikan semasa musim kemarau di kedua-dua tapak. Biojisim anak benih ialah 636.1 ± 43.4 g m^{-2} selepas dua tahun. Nilai ini melebihi nilai hutan hujan primer disebabkan pertumbuhan pantas herba dan paku pakis. Kandungan air dalam tanah diperbaik dan tidak berbeza daripada nilai bagi hutan hujan primer. Kandungan bahan organik tanah dalam meningkat dengan banyak tetapi kandungan fosforus yang ada memerlukan masa yang lama untuk kembali kepada nilai asal. Kalsium permukaan tersedia hilang akibat air hujan. Sistem giliran kardamom yang baru disarankan untuk penanaman di hutan tropika.

INTRODUCTION

Tropical forests have richer biodiversity than any other terrestrial ecosystems. Despite increasing concern over the loss of tropical forests and significant local and international efforts in finding solutions to the problem, the current annual rate of deforestation in the tropics is around 0.9% (Burgess 1993), compared with 0.8% during the period 1980–1990 and 0.6% from 1976 till 1980 (FAO 1993). Xishuangbanna is located in southern Yunnan Province, in south-west China (24° 10' to 22° 40' N, 99° 55' to 101° 50' E; Figure 1) bordered by Laos in the south and south-east and Myanmar in the south-west. Xishuangbanna supports tropical rainforests due to its unique geographic location and climate. The rainforests occur mainly in valleys and on

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Figure 1 Shaded area shows Xishuangbanna, south-west China

lower hills with sufficient soil moisture, and have been termed seasonal rain forest (Wu 1980, Wu *et al.* 1987, Breckle 2002). The seasonal rainforest has almost the same forest profile, physiognomic characteristics and species richness per unit area as the equatorial lowland rain forests of South-East Asia (Zhu 1997). With increasing population growth and the expansion of agriculture, the area of primary rainforest has reduced from 60% in the 1950s to about 30% in the 1980s (Xu 1985). Managing conflicting interests between tropical rainforest conservation and economic development has attracted attention in recent years.

Cardamom (*Amomum villosum*) was introduced into south and south-west Yunnan in 1963 as a traditional Chinese medicine used for treating gastritis, stomachache and digestive troubles (Zhou 1993). Since this plant is a clonal plant, and can easily survive and reproduce by rhizome by the end of 2001, the area of cardamom cultivation reached 7252.7 ha in Xishuangbanna. The yield made up 60% that of China (Peng & Peng 2003). It is mainly planted in the understorey of seasonal rainforest. There are some studies investigating the effects of planting cardamon on the structure and composition of rainforest (Yin 1993, Liu 1996, Liu 1998), but there are few systemic studies on the cultivation model and its effect on the rainforest.

Planting cardamom under tropical forest has triggered many ecological questions (Feng *et al.* 2004, Zhang & Shi 2005). In nature reserves, biodiversity loss is very distinct because of cardamom cultivation (Zhu *et al.* 2002). Kumar *et al.* (1995) have studied the biodiversity changes after planting cardamom under the forest. Some researchers evaluated this planting model (Sharma *et al.* 1997a, b, Jain *et al.* 2000, Ashton *et al.* 2001, Sharma *et al.* 2002, Sharma *et al.* 2004, Sharma *et al.* 2008). However, no studies have been conducted on this cultivation model entirely. Moreover, the effects on biodiversity after planting cardamom have the attention of the government. Nature reserve is prohibited from planting cardamom continually in order to preserve the forest biodiversity. However, the local people consider planting cardamom in the forest as a source of income (Ducourtieux *et al.* 2006). It will not be practical to remove all the cardamom from the tropical rainforest. It is necessary to come up with a good management model for tropical rainforests, which gives attention to forest conservation and economic development (Aung 2007).

The objective of this study was to describe the ecological restoration of tropical rainforest in terms of plant diversity, seedling growth, soil water and nutrient content after removal of cardamom. We propose sustainable development model, which supports forest conservation and not limit economic development.

MATERIALS AND METHODS

The study was conducted at the Menglun Nature Reserve, which was established in 1958. Menglun Nature Reserve is part of the Xishuangbanna National Nature Reserve covering 1242 ha. The Xishuangbanna National Nature Reserve was first established in 1958 after being named a provincial reserve of Yunnan by the government. In 1986 Xishuangbanna was upgraded to national nature reserve status. In 1993, the nature reserve joined the UNESCO (United Nations Educational, Scientific and Cultural Organization) Man and Biosphere reserve network, with the primary objective of conserving the forest ecosystems including rare plant and animal species. Human disturbance is prohibited within the nature reserve. However, the local indigenous people occasionally enter the reserve for hunting and gathering or harvesting fruits, medicinal plants, and fuelwoods.

We sampled randomly three 50 × 50 m plots (21° 56' N to 21° 59' N, 101° 08' E to 101° 12' E, 650 m to 850 m elevation) in undisturbed seasonal rainforest within the nature reserve.

The forest soil of the plots was yellow latosol, developed from purple sandstone. Vegetation in the plots was dominated by *Pomentia tomentosa, Terminalia myriocarpa, Horsfieldia tetratepala, Horsfieldia kingii, Garruga floribunda, Baccaurea ramiflora* and *Pouteria grandiflora.* Six 50 × 50 m plots were established in the disturbed seasonal rainforest—three plots were in the nature reserve and the other three, outside. The disturbed site is adjacent to the nature reserve, and is a communal area where the villagers are allowed to lightly harvest some timber under a nature reserve station permit. In the 1980s local people cultivated cardamom in the communal forest and on the fringe of the nature reserve. Farmers maintained some overstorey trees to provide shade in the understorey for cardamom but cleared shrub and herb layer plants. For our research, we rented the disturbed forest plots from the villagers in order to exclude further human disturbance. From the six plots, we removed all the cardamom ramets and stolons of three plots while the other three plots were untouched. These three plots were used for ecological restoration study, in contrast with the other three plots with cardamom growing.

Plant diversity and biomass were measured in each 50 × 50 m plot in the disturbed and undisturbed sites. All trees with diameter at breast height (dbh) ≥ 5 cm and woody lianas with dbh ≥ 2 cm were identified and measured for height and diameter. Shrubs and herbs were surveyed in five 1 × 1 m subplots located at the four corners and centre of each large plot. Shrub and herb species were identified and individually counted. Following the survey, all shrubs and herbs in the subplots were harvested to determine the biomass. The height of seedling in the subplots of the three plots where cardamom were removed every three months from November 1998 till February 2001 were taken. After two years, five subplots of 1 × 1 m size in these three plots were chosen randomly and all the seedlings in them were removed. The seedlings were weighed for dry biomass. They were separated into shoots, leaves and roots, and the quantity was calculated for a 1 m^2 area (Tang *et al.* 1998, Zheng *et al.* 2000).

Diversity index (Shannon–Wiener, Simpson index), evenness and species richness were assessed for plant diversity, with p_i as the proportional abundance of the ith species and n_i the number of quotations for the ith species (Magurran 1988, Begossi 1996, Hanazaki *et al.* 2000). Statistical comparisons of Shannon–Wiener indices were made through a Student *t*-test as proposed by Magurran (1988). The similarity or dissimilarity of plant species used in both communities was analysed using the Sorenson index, $C_s = 2j/(a+b) \times 100$ (Whittaker 1972), where a and b are the number of species of plot, with cardamom or without cardamom, or original forest plot; j the number of species of co-occurrence in two communities a and b.

Soil nutrients and water content were measured by collecting soil samples at 0–10, 10–20 and 20–30 cm depths at five random locations in each plot. Soil samples were taken six times, i.e. during the dry (March, April and May) and wet seasons (July, August and September), but soil samples for nutrient analyses were only taken twice, i.e. in September 1998 and 1999. All samples were kept in plastic bags and transported to the laboratory for analyses. Samples for soil water content were weighed, dried at 105 °C for 24 hours and reweighed. Soils were analysed for organic matter (OM), total N, P and K, and extractable N, P and K.

RESULTS

Plant diversity

After removing cardamom, the total number of plants in the plots increased greatly (Table 1), higher than that of primary rainforest plots. The species number, diversity index and evenness index increased after removal of cardamom, higher than those of cardamom plots but lower than those of primary rainforest. After removal of cardamom, the composition of plants changed. There was an increase in the number of seedlings of the arbor layer, different from that of the cardamom plot. The coefficient of similarity was higher in the primary rainforest plot compared with the cardamom plot. Similar to the rainforest plot, the dominant species of the restoration plot was not distinct but had abundant plant species and higher heterogeneity of community. In the cardamom plots, the species are mainly *Myristica yunnanensis, P. grandifolia, P. tomentosa, Girronera subaequalis, T. myriocarpa, H. tetratepala, Drypetes cuminghii and Celtis cinnamomea.*

Table 1 Plant species diversity (mean ± SD) in the subplots

Plot	Total plant number	Species number	Shannon index	Evenness index	Coefficient of similarity
Restoration	33 ± 6	14 ± 5	0.944 ± 0.211	0.834 ± 0.121	–
Cardamom	156 ± 23	5 ± 2	0.38 ± 0.09	0.16 ± 0.04	25.1
Primary rainforest	18 ± 3	17 ± 4	1.128 ± 0.352	0.927 ± 0.213	32.8

Seedling growth

After removal of cardamom, the understorey seedlings grew slowly in the dry season, no difference from that of the primary rainforest. However, seedling growth was distinct in the wet season (May till August), higher than that of the primary rainforest (Figure 2). Compared with the primary rainforest, the seedling biomass of the plots where cardamom had been removed increased significantly ($p < 0.01$ $F=17.01 > F_{0.01}=10.04$), with a mean of 636.1 ± 43.4 g m^{-2}. The biomass of leaves was higher in cardamom plots after one year compared with that of the primary rainforest. However, in the rainforest plots, the biomass values of roots and shoots were higher than the biomass of leaves. After two years, the biomass values of roots and shoots of the cardamom plots were higher than the leaf biomass.

Soil water and nutrients

In the cardamom plots, the soil water content was lower than that of primary rainforest of the first year ($p < 0.05$) (Figure 4). After two years' restoration, the soil water content had increased partially but was not significantly different from that of primary rainforest ($p = 0.053 > 0.05$). The water contents in the restoration plots decreased with depth of soil ($p = 0.039 < 0.05$, $F_{0.05} = 3.26 < F = 3.55 < F_{0.01} = 5.25$). If we omit the annual rainfall changes (assuming the soil water content of primary rainforest would not change), then the soil water contents would be higher in restoration plots than before removing cardamom. The downward trend of soil water content from surface to deep layer would change horizontally.

The organic matter changed significantly after two years (Table 2). The change wasn't obvious on the surface layer, but the organic matter increased with depth of sampling. After removing cardamom, there was an increase in woody plants, so the soil organic matter of the deep layer had been ameliorated. However, changes in soil total nitrogen, total phosphorus and total potassium were not obvious after two years' restoration (Table 3).

The change in available nitrogen was not significant with time but significant with depth.

DISCUSSION

There has been a series of discussion on ecology since the cultivation of cardamom in the tropical rainforest of Xishuangbanna (Yin 1993, Gao *et al.* 2001, Feng *et al.* 2004). Searching for feasibility approach and ways of ecological restoration should be the key to realizing sustainable cultivation of cardamom. Unlike the slash and burn method practised by the people living in mountainous area, a model of cultivating cardamom in tropical rainforest has preserved trees of the arbor layer and the rain can provide water for vegetation restoration. When cardamom was planted in the forest, the potential threat was destruction of sapling–seedling bank of rainforest, which causes the forest to lose its regeneration capability (Zhu *et al.* 2002). However, from the list of saplings after removal of cardamom, we can see that they are mainly from the arbor layer and the community composition hasn't changed greatly so that the plant species and diversity can quickly restore to those of primary rainforest. The soil water and nutrients can be ameliorated due to litters of the arbor layer. Though the plant diversity of restoration plots was lower than that of primary rainforest, there was an increase in some herbs and the number of plants because of wider space available.

However, before planting cardamom in the forest, the local farmers lopped off only a part of the arbor trees and remove many small trees, herbs and shrubs (Zhu *et al.* 2002), rendering the crown density lower than that of the primary rainforest. After removing cardamom, the space is increased, seedlings on the forest floor are

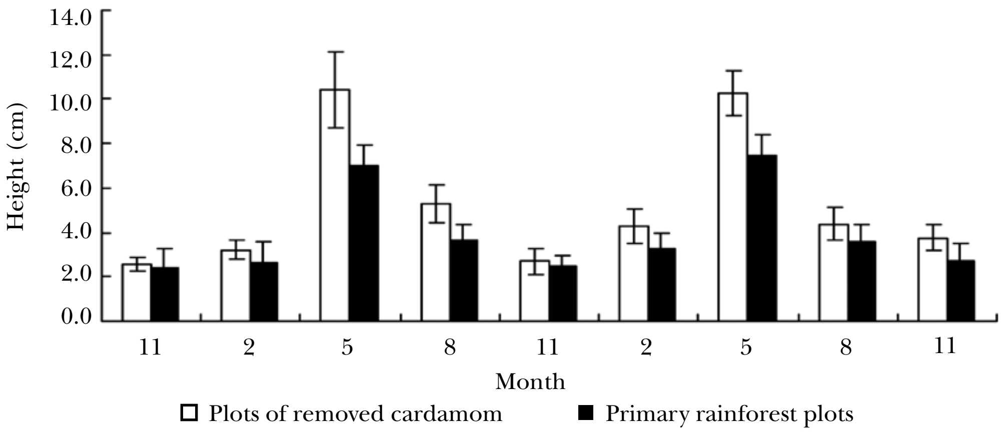

Figure 2 Total height of seedlings in plots after removal of cardamom, compared with primary rainforest. Values are means ± SD.

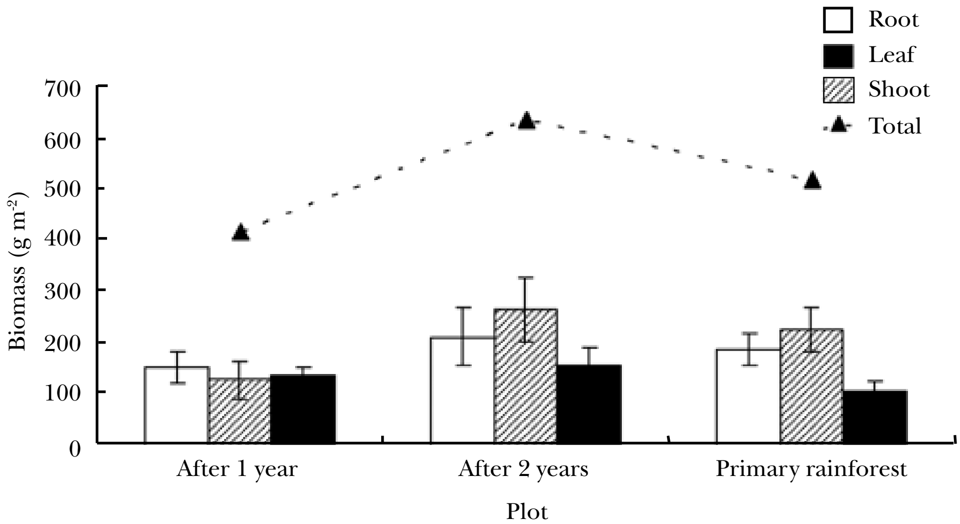

Figure 3 The biomass of plot after removal of cardamom, compared with primary rainforest. Values are means ± SD.

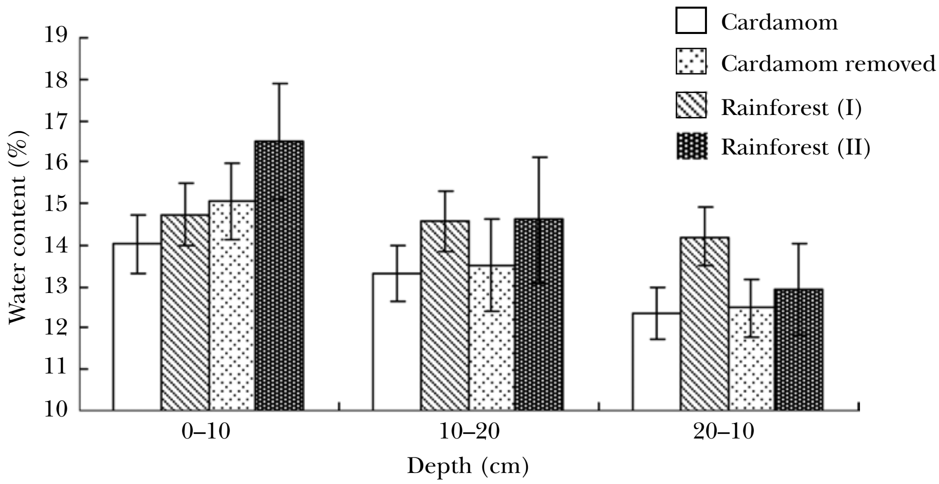

Figure 4 The water content of soil during the dry season, with and without cardamom, compared with the primary rainforest. Values are means ± SD.

Table 2 The soil nutrient contents after removal of cardamom

Parameter	Restoration at beginning			Restoration after two years		
	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm
OM(%)	2.96 ± 0.71	0.96 ± 0.22	0.78 ± 0.11	3.38 ± 0.48	1.38 ± 0.18	1.09 ± 0.18
TN(%)	0.18 ± 0.04	0.07 ± 0.07	0.05 ± 0.002	0.12 ± 0.03	0.06 ± 0.02	0.05 ± 0.01
TP(%)	0.03 ± 0.01	0.03 ± 0.003	0.025 ± 0.001	0.03 ± 0.004	0.022 ± 0.002	0.02 ± 0.003
TK(%)	0.56 ± 0.068	0.67 ± 0.09	0.72 ± 0.12	1.39 ± 0.33	1.35 ± 0.16	1.34 ± 0.24
AN (μg g^{-1})	150.96 ± 12.4	54.29 ± 6.70	47.00 ± 3.70	121.68 ± 10.19	66.12 ± 11.20	43.51 ± 6.45
AP (μg g^{-1})	3.02 ± 0.76	2.81 ± 0.98	2.74 ± 1.12	1.94 ± 0.72	1.37 ± 0.33	1.32 ± 0.67
AK (μg g^{-1})	184.57 ± 65.0	89.28 ± 49.62	73.17 ± 44.68	92.20 ± 30.31	57.54 ± 27.72	41.37 ± 13.34

OM = organic matter, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AN = available nitrogen, AP = available phosphorus, AK = available potassium

Table 3 ANOVA of the soil nutrient contents two years after removal of cardamom, compared with initial stage

Parameter	ANOVA	F	P-value	$F_{0.05}$	$F_{0.01}$
OM (%)	With initial stage	11.13	0.0059**	4.75	9.33
	Along depth	21.66	0.0001***	3.89	6.93
TN (%)	With initial stage	3.68	0.0791	4.75	9.33
	Along depth	33.25	1.28E-05***	3.89	6.93
TP (%)	With initial stage	2.69	0.1270	4.75	9.33
	Along depth	3.59	0.0601	3.89	6.93
TK (%)	With initial stage	59.69	5.36262E-06***	4.75	9.33
	Along depth	0.17	0.8452	3.89	6.93
AN (μg g^{-1})	With initial stage	2.05	0.1774	4.75	9.33
	Along depth	134.10	6.16926E-09***	3.89	6.93
AP (μg g^{-1})	With initial stage	8.68	0.0122*	4.75	9.33
	Along depth	3.87	0.0505	3.89	6.93
AK (μg g^{-1})	With initial stage	3.47	0.0871	4.75	9.33
	Along depth	3.16	0.0791	3.89	6.93

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

able to capture sunlight. During the wet season, understorey saplings flushing new leaves are positively correlated with photosynthetically active radiation (PAR) and negatively correlated with rainfall. However, during the dry season, rainfall is positively correlated with leafing and PAR but negatively correlated with flushing (Barone 1998). As such seedlings of removed cardamom plots grow significantly during the wet season but slowly during the dry season. Some herbs and ferns grow quickly, colonizing more space. They often become dominant species in the early stages of community restoration. Herbs and ferns can hold back soil and litters on slopes.

Since the dense roots of cardamom in the surface layer prevent rain water from penetrating down to the deep soil layer and the leaves of cardamom can transpire great amounts of water, the soil water content decreases and the structure of soil changes. The roots of cardamom are mainly distributed on the upper layer of soil and this causes soil elements to be easily washed away with rain water (Liu *et al.* 2006). After removing cardamom, the plants and diversity increased in a short while. These plants have relative deep roots, making it possible for the soil structure to be ameliorated and rain can penetrate deeply. Consequently, the water content of deep soil increases. In tropical wet areas, the supply of groundwater often is faster. In Xishuangbanna tropical rainforest, some arbor trees can be saved and the vegetation can recover quickly after removing cardamom. The groundwater amelioration of forest often needs a short process.

Xishuangbanna area is inhabited by many minorities. The mountainous peoples such as Hani, Jinuo and Bulang have abundant experience in the use of plant resources and managing the forests (Li & Lai 1994, Shi & Li 1999). However, this agroforestry model of cultivating cardamom in tropical rainforest has challenged nature reserve operators and ecologists.

The model of cultivating crops in natural forests is not in accordance with the principle of conserving biodiversity. The traditional swidden cultivation model needs to combine with agroforestry means. So integrating agroforestry with certain swidden models and conservation biology theory may be an effective and feasible approach towards sustainable development in tropical mountainous area (Gao *et al.* 2001).

The destruction of the eco-environment, induced by cardamom cultivation significantly affected the yield of cardamom fruit, thus stagnating their economic benefit (Gao *et al.* 2001). To achieve sustainable cultivation of cardamom, soil nutrient contents need to be enhanced and the structure of the soil ameliorated. In Xishuangbanna tropical rainforests, cardamom can flower and fruit in the second year after planting. After four to six years, it achieves the highest yield, and after seven or eight years, the yield decreases (Gao *et al.* 2002, Zheng *et al.* 2004). When the local people manage cardamom, they often remove the old ramets. New ramets which reproduced from old rhizomes have very low yields. In searching for a sustainable cultivation model, we should remove all the cardamom after a high yield phase. The vegetation could eventually achieve auto recovery. Due to leaving behind the arbor trees, plant diversity can increase in a short time, and the soil water and nutrients can increase with accumulation of litter. All saplings are mainly from arbor trees and they have deep shoots. Therefore, the deep soil structure will be ameliorated. In Xishuangbanna most lands are lowly populated (Gao *et al.* 2001). The labour force for cardamom is not sufficient. We can abandon a part of the cardamom land and allot more labour on areas with good management. After several years, when fruit yield decreases, all the cardamom can be harvested and the fallow land be used again. Using this model, there will be high fruit yield and reduces abuse on nature reserve. The numbers of flower and fruit of cardamom correlate with the number of bees such as *Apiscerana fabricius*, *Nomia chalybeata*, *Bombus trifasciatus* (Duan 1988). Therefore, patchy rotational land will be favoured in terms of pollination and people's management. On the contrary, a large area planted with cardamom will result in mugginess in the centre and bees only pollinating in the fringes, resulting in low fruit yield down (He & Hu 1988, He 1991). In the fallow stage, there are abundant plant resources around the wasteland. Biodiversity and some ecological factors can be recovered in a short time. From this point of view, it can contribute to the conservation of plant species. This model can generate income for the local people and also conserve the biodiversity of rainforest.

Converting shifting cultivation into cash crop-based agriculture is frequently presented as the solution to balancing forest protection and poverty alleviation (Ducourtieux *et al.* 2006). At Xishuangbann, cardamom is the main income of the mountainous people. Conservation biology cannot separate the social aspect from economic development.

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