「森林総合研究所研究報告」(Bulletin of FFPRI) Vol.13 No.3 (No.432) 79 - 88 September 2014

論 文（Original article）

Can converting slash-and-burn agricultural fields into rubber tree (*Hevea brasiliensis*) plantations provide climate change mitigation?：A case study in northern Laos

Yoshiyuki KIYONO[1)*], Naoyuki FURUYA[2)], Naoko FUJITA[3)], Tamotsu SATO[4)], Mitsuo MATSUMOTO[5)], Soukanh BOUNTHABANDID[6)] and Somchay SANONTY[6)]

Abstract

The area of rubber tree (*Hevea brasiliensis*) plantations markedly increased in the 2000s in northern Laos. We estimated the carbon sequestration rates of the rubber trees using a dataset from 15 rubber tree plantations and compared the rates with those in natural vegetation growing in fallowed slash-and-burn land. The stand age-averaged carbon stock in the biomass of the rubber trees was 50.0 Mg-C ha^{-1}, after accounting for emissions from the soil while preparing the site for planting rubber trees, based on an assumed economic life of 30 years for the rubber trees. This value was much greater than fallow period averaged carbon stock for the slash-and-burn agricultural system with a 5-year fallow period (18.6 Mg-C ha^{-1}). However, this benefit is lost when rubber tree plantations replace slash-and-burn agricultural activity that must be replaced by the conversion of natural forest reserved. Consequently, conversion of the land-use system from slash-and-burn agriculture with a short fallow period into rubber tree plantations can mitigate climate change if it does not require consequent conversion of natural forest into slash-and-burn agricultural land. Without that conversion, the rubber tree plantations can help mitigate climate change, although it will be necessary to minimize the environmental and economic risks to residents of this region that are associated with this land use.

Key words : biomass, carbon sequestration, land use change, REDD+, rubber tree plantation, slash-and-burn agriculture

1. Introduction

Most rubber tree (*Hevea brasiliensis*) plantations are located in South and Southeast Asia, particularly in Indonesia, Thailand, Malaysia, and China (FAO 2010). The area of rubber tree plantations increased markedly in the 2000s in northern Laos (Mahanty et al. 2006) owing to growing global demand for rubber, especially from China, Vietnam, and Thailand, and to the Lao government's policy of promoting development of this upland region (Manivong and Cramb 2007). Rubber tree planting in Oudomxay Province in northern Laos started in 2003 and has experienced a rapid expansion (851 ha in 2003-2004 and 2,941 ha in 2005-2006) and for entire northern Laos, the planted area was 16,547 ha in 2007 and the Ministry of Agriculture and Forestry planned to expand this to 121,000 ha in 2010 (Vangkhamor et al. 2008). In northern Laos, companies and local residents own the rubber tree plantations, and rich residents of rural small towns and villages have also established plantations by leasing (they pay an annual fee for use if the land is from the local people). Both local people and the rich residents are unlikely to retain the land when conversion into other land uses is expected to be more profitable.

Most plantations were established on land previously used for slash-and-burn agriculture, which has long been widespread in northern Laos (Spencer 1966). Slash-and-burn agriculture is the repeated use of a patch of forested land for the cultivation of crops, and its traditional one is characterized by long fallow periods between short periods of crop production. The floristic composition of the forests in slash-and-burn agricultural land is typically characterized by a lack of the original tree species or a low density of these species, and by succession that favors pyrophytic tree species that are less vulnerable to felling and fire and that have high sprouting capacity (Kiyono and Hastaniah 2005). The mean fallow period used for slash-and-burn agriculture in the region was about 20 years in the 1970s and decreased to about 5 years in the 1990s (Roder 1997). More recently, three years fallow length became common in 2003-2004 (Inoue et al. 2010).

Rubber tree plantations are usually established as a monoculture system in the open sites. Rubber trees grow

Received 27 January 2014, Accepted 23 June 2014
1) Principal Research Coordinator, Forestry and Forest Products Research Institute (FFPRI)
2) Hokkaido Research Center, FFPRI
3) Faculty of Design, Kyushu University
4) Department of Forest Vegetation, FFPRI
5) Principal Research Coordinator, FFPRI
6) Department of Forestry, Ministry of Agriculture and Forestry, Lao People's Democratic Republic (Vientiane, Lao People's Democratic Republic)
* Principal Research Coordinator, FFPRI, Matsunosato 1, Tsukuba, Ibaraki 305-8687, Japan; e-mail: kiono@ffpri.affrc.go.jp

rapidly in the humid lowland tropics (Cannell 1982). The economic life of rubber trees is around 30 years including the first several years when the tree is not tapped for latex according to the reports in rubber producing countries of the world: 29 to 30 years (Sajen 2006) and 30 to 35 years (Gnanaharan and Mathew 1982) in India, 32 years in Malaysia (Etherington 1977), and 35 years in Nigeria (Mesike et al. 2010).

Rapid changes in land use have raised concerns over the decreasing area of arable land available for food production and for the production of natural resources such as non-timber forest products. Although no official statistics are available, we have observed the conversion of natural forest into slash-and-burn fields in regions where rubber tree planting has increased in northern Laos.

However, the economic life of rubber trees exceeds the recent fallow period of slash-and-burn agriculture. The increased carbon stock in rubber tree plantations could generate carbon credits for use in the mechanisms that have been implemented or discussed to mitigate climate change, such as afforestation and reforestation (A/R) clean development mechanism (CDM) projects (hereafter, A/R CDM projects; UNFCCC 2002, 2012), reducing emissions from deforestation in developing countries (REDD) (UNFCCC 2008), REDD+, reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (https://unfccc.int/methods/redd/methodological_guidance/items/4123.php). These mechanisms offer incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development (UN-REDD Programme, http://www.un-redd.org/AboutREDD/tabid/102614/Default.aspx). However, no study has examined the potential carbon sequestration function of rubber tree plantations that have been established in slash-and-burn agricultural fields. Although there have been a few reports on the biomass of rubber tree plantations (Cannell 1982; Chaudhuri et al. 1995; Yahya 2007), only stem volume data (Khun et al. 2008) are available for Indochina, including Laos.

In the present study, we predicted that carbon stocks would increase as a result of land use change from fallowed slash-and-burn agricultural fields to rubber tree plantations. We then tested this prediction using data from plantations in northern Laos. On the basis of our results, we discuss issues related to evaluating the potential enhancement of the ecosystem's carbon sequestration function in terms of the mechanisms of A/R CDM and REDD+ projects designed to earn carbon credits.

2. Materials and methods

2.1 Study sites and plot establishment

The study sites were located in Luang Namtha Province (Fig. 1), which has a subtropical monsoon climate; there is a pronounced rainy season from April to October and a dry season from November to March (Fig. 2). Between 2003 and 2009, the mean annual rainfall was 1493 ± 316 mm (mean ± SD) and the mean annual temperature was 23.9 ± 0.3 ºC (mean ± SD) at the Luang Namtha Weather Station, at an elevation of 644 m a.s.l. (http://www.tutiempo.net/en/Climate/LUANG_NAMTHA_M_SIN/489240.htm). The elevation of the study sites ranged from 598 to 800 m a.s.l., which is the upper zone of the region's lowland semi-

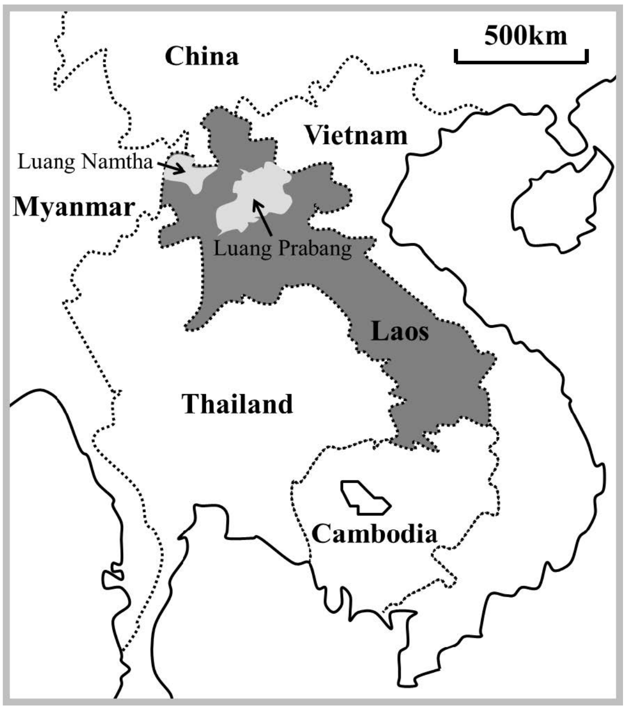

Fig. 1. Location of the study area.

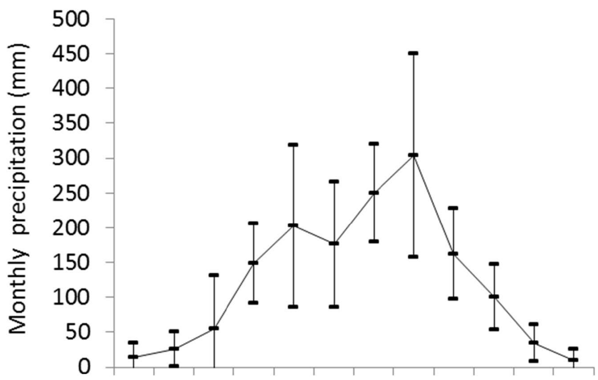

Fig. 2. Monthly precipitation at the Luang Namtha Weather Station (2003–2009). Values are means ± SD.

Table 1. Details of the studied rubber tree plantations.

Plot	Location: longitude	Location: latitude	Altitude	Slope	Year planted	Age	Rubber cultivar	Tree density	Mean DBH	Basal area	Tree: Biomass	Tree: Biomass carbon	Land use before rubber tree plantation [a]	Plot area
	dddmm.mm E	dddmm.mm N	m a.s.l.	degree		years		no. ha^{-1}	cm	m^2 ha^{-1}	Mg ha^{-1}	Mg-C ha^{-1}		m^2
1	101 24.55	21 01.49	615	9	1995	14	001	250	20.4	8.5	138.8	69.4	F, G	544
2	101 24.53	21 01.55	602	16	1995	14	001	258	18.0	7.2	130.5	65.2	F, G	472
3	101 24.54	21 01.34	604	1	1994	15	001	258	19.9	8.2	142.0	71.0	P, G	501
4	101 24.57	21 01.32	598	1	1994	15	001	275	19.6	8.6	131.2	65.6	P, G	573
5	101 25.95	21 02.48	757	25	2006	3	001	258	4.3	0.38	3.5	1.7	U	456
6	101 25.94	21 02.47	763	27	2006	3	001	250	4.5	0.40	3.7	1.9	U	449
7	101 25.92	21 02.46	786	23	2005–2006	3.5	001	275	6.3	0.90	9.9	5.0	U	455
8	101 25.90	21 02.47	800	24	2005	4	001	225	6.8	0.84	12.8	6.4	U	340
9	101 25.77	21 02.21	754	24	2005	4	001	242	6.5	0.82	9.2	4.6	F	446
10	101 25.67	21 02.20	767	30	1998	11	001	233	15.6	4.6	111.6	55.8	D, G	316
11	101 25.67	21 02.21	769	25	1998	11	001	292	13.9	4.7	117.6	58.8	D, G	291
12	101 25.66	21 02.23	771	25	2003	6	001	242	10.3	2.0	46.7	23.4	F	269
13	101 25.64	21 02.21	738	28	2003	6	001	242	10.0	1.9	51.3	25.7	F	235
14	101 24.89	21 02.06	646	34	2004	5	600	242	7.9	1.2	19.6	9.8	F, G	339
15	101 24.90	21 02.05	640	31	2004	5	600	258	8.7	1.6	31.7	15.8	F, G	297

[a] F, fallowed land after slash-and-burn agriculture; P, pineapple field; U, upland rice field; D, forest degraded by logging; G, grazing by cattle or water buffalo.

evergreen forest. The topography is generally steep. Soils were classified as Alisols and Acrisols (Soil Survey and Land Classification Center, National Agriculture & Forestry Research Institute, Ministry of Agriculture and Forestry, Laos PDR). Rubber tree plantations in this province date back to 1994 (Schipani 2007). The land uses in this region can be broadly grouped into three types: (1) conservation forest; (2) agricultural land, including slash-and-burn fields and fallowed fields; and (3) other land, including settlements, the rubber tree plantations, and land reserved for future use.

We established 15 rectangular research plots (Table 1) with areas ranging from 235 to 573 m^2, each containing 27 to 35 rubber trees aged 3 to 15 years old (in February 2009), in rubber tree plantations at Ban Hat Nyao, in Luang Namtha Province. The slope angles in the 15 plots ranged from 1° to 34° and averaged 22 ± 10° (mean ± SD). Most of these rubber tree plantations (13 out of 15) were on land that had been used for agriculture. The owners used almost no fertilizer in the plantations that we studied. Rubber tapping started when the trees were 5 to 7 years old. Grazing by cattle or water buffalo had been practiced at around half of the 15plots (Table 1).

2.2 Estimating carbon stocks

We measured stem diameter at breast height (DBH) using a steel measuring tape for all trees ≥5 cm DBH in the plot, and estimated tree biomass using the parameters of DBH and basic density in a generic equation for tropical and subtropical trees (Kiyono et al. 2006):

$$\text{Tree biomass} = 5.29 \times BA^{1.24} \times D^{1.28} \ (n = 515,\ R^2 = 0.978,\ P < 0.001) \quad (1)$$

where tree biomass is the sum of aboveground and belowground biomass (kg), *BA* is the basal area of a stem at 1.3-m height (m^2), and *D* is the basic density; for *Hevea brasiliensis*, D = 530 kg m^{-3} (IPCC 2006). The default carbon fraction (i.e., the proportion of the biomass accounted for by carbon) of 0.5 (IPCC 2003) was used. This generic equation (Kiyono et al. 2006) was developed using data from 62 species, including *Hevea brasiliensis*, and 515 trees, mostly in planted forests.

The relationship between *Stand age* (years) and the carbon stock in the rubber trees ($Biomass\ carbon_{RT}$, Mg-C ha^{-1}) was approximated using the following Gompertz equation because the Logistic equation (R^2 = 0.9354) and others provided inferior results, where the stand age ranged from 3 to15 years:

$$Biomass\ carbon_{RT} = 78.1 \times 0.000515^{0.755^{\text{Stand age}}} \ (n = 15,\ R^2 = 0.9794,\ P < 0.0001) \quad (2)$$

Rubber tree plantations on slopes are usually terraced (Fig. 3). The terracing may increase soil carbon emissions because the surface soil temperature increases in the ground denuded by the terracing and accelerates the soil carbon releasing into the air. The amount of soil disturbed during site preparation was estimated by a topography model of the plantation. We measured the slope shape at 16 randomly located sites in 3 plantations (each 2 to 3 years old) located along highways in Luang Prabang Province (Fig. 1), where the establishment of rubber tree plantations increased during the late 2000s and the province has a similar climate to that of Luang Namtha Province. Between 1998 and 2005, the mean annual rainfall was 1312.7 mm and the mean annual temperature was 25.2 °C at the Station of Northern Agriculture and Forestry Research Center, National Agriculture and Forestry Research Institute, in Houaykhot Village, Luang Prabang Province. The distance between the planting rows (D_{PR}) was 4.45 ± 0.73 m (mean ± SD) and the terrace width (W_T) was 1.23 ± 0.18 m (mean ± SD). Since both D_{PR} and W_T were not significantly related to the slope angle (data not shown), we estimated the height of the cut slope (h_{CS}) as 0.44 m at a slope angle of 22° (the mean value for the plots in Table 1). We roughly and conservatively estimated the maximum possible carbon stock loss (C_{loss}) from the topsoil during the site preparation for rubber tree plantations from the volume ratio of soil lost: $(h_{CS}/2) \times (W_T/D_{PR})$ (Fig. 3). Since its organic carbon in the displaced soil is more prone to be released into the air, we assumed that all of the soil carbon was released to provide a conservative estimate. On the assumptions that h_{CS} = 0.44 m, D_{PR} = 4.45 m, and W_T = 1.23 m, we estimated the soil volume to a depth of 0.22 m ($h_{CS}/2$) that 28% (W_T/D_{PR}) of the volume was lost during site preparation. Since the soil carbon fraction was generally high in this shallow layer, we used the default value for the soil organic carbon stock to a depth of 0.3 m obtained for moist tropical soils with low-activity clay (47 Mg-C ha^{-1}; IPCC 2003) itself to represent the soil organic carbon stock to a depth of 0.22 m. On this basis, we assumed that 12.9 Mg-C ha^{-1} was lost at every site during site preparation for the rubber tree plantations. Recovery of soil carbon levels as the rubber tree plantation aged was assumed to be negligible, because previous research found no clear trend in the soil carbon stock with increasing stand age in rubber tree plantations established in a forest with a seasonal climate in Cambodia (Toriyama et al. 2011).

We predicted the carbon stock in natural vegetation in the fallowed slash-and-burn land using an equation (Kiyono et al. 2008, 2011) developed on the basis of data from three provinces (Luang Prabang, Udomxai, and Houaphan) in northern Laos. The equation provides the sum of the carbon stock in the aboveground biomass, belowground biomass, dead wood, and litter:

Carbon stock = 4.50 + 11.9 ln (Y) + 0.00903 *Alt* − 4.43 G (R^2 = 0.822, P < 0.0001) *(3)*

where *Carbon stock* is the sum of the carbon stock in the aboveground biomass, belowground biomass, dead wood, and litter (Mg-C ha^{-1}), Y is the number of years since the last crops. *Alt* is the elevation (m a.s.l.), and G is 1 when grazing has occurred and 0 without grazing. This equation is considered to be applicable to the stand with stand age ranged from one to 35 years (Kiyono et al. 2011).

In the present study, the carbon stock at an elevation of 707 m a.s.l. (the mean value for the plots in Table 1) and without grazing activity was selected for our predictions as the equation *(4)*.

Carbon stock = 10.88 + 11.9 ln (Y) *(4)*

Time-averaged carbon stock was estimated for rubber tree plantations by replacing *Stand age* in Equation *(2)* with various years after establishment of the rubber tree plantations from 0 to 30 years on the assumption of a 30-year economic life of the rubber trees: Time (period after rubber tree planting)-averaged carbon stock. For slash-and-burn agriculture, the time-averaged carbon stock was estimated by replacing Y in Equation *(4)* with various number of years after the last crop under slash-and-burn agriculture from 0 to 20 years, the mean fallow period used for slash-and-burn agriculture in the region in the 1970s: Time (fallow period)-averaged carbon stock.

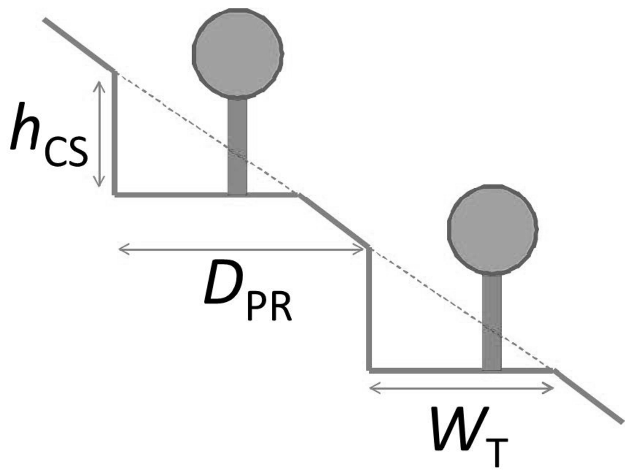

Fig. 3. Schematic profile of the geometry of the slopes in a terraced rubber tree plantation.
D_{PR}, distance between the planting rows; W_T, width of the terrace; h_{CS}, height of the cut slope.

3. Results and discussion

3.1 Carbon sequestration rates of rubber tree plantations and of fallowed slash-and-burn agriculture

The carbon stock of the rubber trees (Fig. 4) was small during the initial stages of plantation growth; the current annual increment (CAI; obtained as slope of regression line) for the 3- to 4-year-old stands (n = 5) was averaged at 3.7 Mg-C ha^{-1} $year^{-1}$. However, it increased rapidly at around 5 years once the rubber trees were established; CAI for the 5- to 6-year-old stands (n = 4) was 11.7 Mg-C ha^{-1} $year^{-1}$. The growth then looked slow; CAI for the 11- to 15-year-old stands (n = 6) was 2.9 Mg-C ha^{-1} $year^{-1}$. Rubber tapping, which started around 5 to 7 years after planting, might have slowed the biomass accumulation rate.

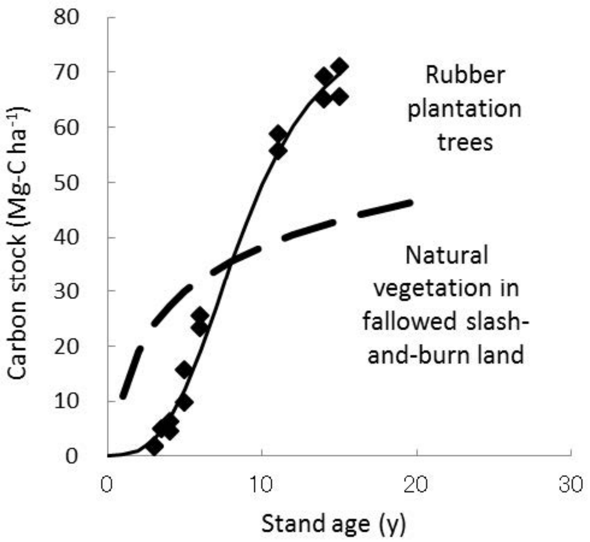

Fig. 4. Relationship between stand age and the carbon stock of rubber tree plantation and natural vegetation in the fallowed slash-and-burn land.
Rubber tree plantation: the carbon stock equals the sum of the carbon stock in aboveground and belowground biomass of rubber trees.
Natural vegetation in fallowed slash-and-burn land: the carbon stock equals the sum of the carbon stock in aboveground biomass, belowground biomass, dead wood, and litter.

The carbon stock in the fallowed slash-and-burn land by Equation *(4)* increased markedly during the first few years, and exceeded that in the rubber tree plantation during the initial stages of the fallow period (Fig. 4). However, the rate of increase slowed over time, and after around 8 years, fell below the rate for the rubber tree plantation. The dominant species of natural vegetation in the fallowed slash-and-burn land were usually bamboo and pyrophytic trees that sprouted from stumps after the land was fallowed; these included *Bambusa* sp., *Cephalostachyum* sp., and *Cratoxylum formosum* ssp. *pruniflorum* (Kiyono et al. 2007). Young sprouts from the bamboo rhizomes and tree stumps of the pyrophytic species may grow rapidly during the initial stages of recolonization of the fallowed site. However, they grow more slowly than rubber trees during later stages.

3.2 Comparison of the climate change mitigation benefits of rubber tree plantations and fallowed slash-and-burn agriculture

The time (fallow period)-averaged sum of the carbon stock in the aboveground biomass, belowground biomass, dead wood, and litter was estimated at 18.6 Mg-C ha^{-1} for a slash-and-burn agricultural system after 1 year of cultivation and a 5-year fallow period (Table 2), which was the mean fallow period during the 1990s (Roder 1997). For the rubber tree plantation (Table 2), the time (period after rubber tree planting)-averaged carbon stock in the tree biomass was estimated using Equation *(2)* at 50.0 Mg-C ha^{-1} on the assumption of a 30-year economic life of the rubber trees. Although the rubber tree plantation's values did not include the dead wood and litter carbon stocks, they nonetheless far exceeded those in the slash-and-burn agricultural system after 15 years. This result suggests that the conversion from slash-and-burn agriculture with a short fallow period into rubber tree plantations increases carbon sequestration and mitigates climate change.

3.3 A comparison of carbon sequestration rates when planting rubber trees causes additional land use change from natural forest to slash-and-burn fields

Since rubber tapping starts between 5 and 7 years after plantation establishment, slash-and-burn farmers must obtain their food and meet their other basic needs from outside the land that has been converted to rubber tree plantations. We estimated the carbon loss when “forest in the land reserved for future use", land that will be used for agriculture or other purposes in future, is converted to slash-and-burn agricultural land on the assumption that *(i)* the area of forest converted to new slash-and-burn agricultural land equaled *(ii)* the area of land converted from slash-and-burn fields to rubber tree plantations. However, since carbon stock data for the “forest in the land reserved for future use” was unavailable, we used a carbon stock of 173.0 Mg-C ha^{-1} as the averaged biomass carbon stock of natural forest in our study area. This value represents the mean biomass carbon stock of forests in Luang Prabang Province, which we calculated from data from the Asia Air Survey Co. (2011): the mean overstory tree height (*OTH* , 19.2 m) of forests in Luang Prabang Province was related to tree biomass carbon stock (*BCS*) using the following empirical equation: $BCS = 0.0959\ OTH^{2.5373}$, $R^2 = 0.9227$.

The time (stand age)-averaged sum of the carbon stock becomes positive after 5 years when no additional forest is converted to slash-and-burn agriculture, but remains negative throughout the economic life of the rubber trees when the conversion of natural forest for agriculture is considered (Table 2).

Table 2. A comparison of the time-averaged sum of the carbon stock for three main land-use scenarios in the study area.

Year[a]	Time-averaged sum of the first-rotation carbon stock		
	Slash-and-burn agriculture[b]	Rubber plantations converted from fallowed slash-and-burn agricultural land after 5 years[c]	
		No additional forest converted to slash-and-burn agriculture	Conversion of natural forest to replace lost areas of slash-and-burn agriculture[d]
	Mg-C ha^{-1}	Mg-C ha^{-1}	Mg-C ha^{-1}
0	0.0	−12.9	−185.9
5	**18.6**	−0.4	−173.4
10	25.4	16.2	−156.8
15	30.2	29.6	−143.4
20	33.7	38.9	−134.1
25	—	45.3	−127.7
30	—	**50.0**	**−123.0**

[a] Years after the last crop under slash-and-burn agriculture or after establishment of the rubber tree plantation.
[b] Time (fallow period)-averaged carbon stock estimated using *Carbon stock* = 10.88 + 11.9 ln (*Y*) (after Kiyono et al. 2008, 2011) where *Carbon stock* is the sum of the carbon stock in aboveground biomass, belowground biomass, dead wood, and litter (Mg-C ha^{-1}); *Y* is the number of years since the last crop. The boldfaced value of 18.6 is for the recent mean fallow period.
[c] Time (period after rubber tree planting)-averaged carbon stock estimated using $Biomass\ carbon_{RT} = 78.1 \times 0.000515^{0.755^{Stand\ age}}$ (n = 15, R^2 = 0.9794, P < 0.0001), where the stand age ranged from 3 to 15 years. The values for 20-30 years are outside the applicable range of the equation. However, the values appear reasonable in comparison with those obtained from Malaysian rubber tree plantations (calculated from the biomass in Cannell (1982) with the default carbon fraction of 0.5 (IPCC 2003)): 67.7 Mg-C ha^{-1} in a 24-year-old stand and 141.5 Mg-C ha^{-1} in a 33-year-old stand. The boldfaced values of 50.0 and –123.0 are for rubber trees at the assumed end of their economic life.

3.4 Probable requirements to achieve climate change benefits by introducing rubber tree plantations in northern Laos

Our results show that converting the land-use system from fallowed slash-and-burn fields to rubber tree plantations may help mitigate climate change by increasing the carbon stock (Table 2), while also generating a new income source by selling latex of rubber tree or wage labor in plantations for local people. However, when natural forest reserves must be converted into slash-and-burn agriculture to feed local residents, this benefit is lost, and there is a large negative effect resulting from the net decrease in the local carbon stock (Table 2). The benefit from introducing rubber trees depends on the assumption that *(i)* the rubber tree plantations are successful and that *(ii)* the incomes from rubber production and the enhancement of carbon sequestration rates will not jeopardize the other ecosystem services provided for local residents, such as a food supply and the other goods and services that people received before introducing rubber tree plantations.

It's also important to note that rubber trees are an exotic plant in Laos, and that northern Laos has only a short history of planting these trees. Since rubber tree plantations have so far been established mostly in the lowland humid tropics, cultivars must be identified that are capable of thriving in the monsoon tropics in regions such as the study area, which has a relatively long dry period (Fig. 2), to ensure that they provide an acceptable economic yield. Table 1 lists 2 different cultivars. According to a preliminary comparison of cultivar 001, the mean values between 4 and 6 years of age (plots 8, 9, 12, and 13), to cultivar 600 at 5 years (plots 14 and 15), no significant difference was found at present. The market value of rubber products from Laos is not secure (Vangkhamor et al. 2008), so the economic viability criterion may not be obtainable. Since the ecological and economic suitability of the plantation sites in northern Laos remains uncertain, the rubber tree plantations that have been established must be monitored to confirm the benefits of introducing rubber trees into the region. In addition, it will be necessary to confirm that there are no unexpected consequences from establishing the plantations, such as increased soil erosion or a loss of native species that results from the conversion of forest reserves to new agricultural land.

In terms of the carbon credits provided by increasing carbon stocks, A/R CDM projects accept land-use changes only from non-forest to forest vegetation (UNFCCC and CCNUCC 2007). Land-use change from slash-and-burn fields with low levels of woody vegetation to rubber tree plantations meets this criterion. However, fallowed slash-and-burn agricultural land with sufficient woody vegetation to meet the criteria for forested land in the national greenhouse gas inventory is also defined as forest (IPCC 2006). Land-use change from such "forest" to rubber tree plantations does not meet the A/R CDM criteria. Although the applicability of the REDD+ rules is uncertain in this situation, if the rubber tree plantations can be defined as forest, the change in land use from slash-and-burn agricultural land to rubber tree plantations could be considered to represent an enhancement of the forest carbon stocks. However, our results show that if additional forest reserves must be converted into agricultural land to feed local residents, the large net loss of carbon sequestration means that this change should not qualify for a carbon credit.

In terms of biodiversity, conversion of natural forest to slash-and-burn agricultural fields and from slash-and-burn fields to rubber tree plantations can result in a decline in species richness or can bias the species composition compared with the natural conditions of the region's forests. To mitigate such changes and changes in the production of non-timber forest products and other ecosystem services, it will be necessary to establish more balanced land uses through the development of effective land-use plans based on statistics to address food security and environmental impacts. This will include the need for regulations to control the establishment of rubber tree plantations based on an understanding of the differences between natural forest ecosystems and rubber tree plantations.

In conclusion, the conversion of the land-use system from short-fallow (e.g., 5-year) slash-and-burn agriculture to rubber tree plantations could mitigate climate change if it can minimize the environmental and economic risks to residents of the region. Our results therefore support more informed international discussion about climate change mitigation in the study area.

Acknowledgments

This study was conducted as part of programs B-072 and A-0802 of the Global Environment Research Fund of the Ministry of the Environment, Japan, and under "The emergency project to develop the structure of promoting REDD action" of the Forestry Agency, Japan. Special thanks are due to

Mr. Si Amphone Siboune of the Department of Forestry, Ministry of Agriculture and Forestry and the chief of Silalek Village and the head of the Xiang Ngeun District Office of Luang Prabang Province, the Lao People's Democratic Republic for helping with our field measurements in October 2009.

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焼畑農地のパラゴムノキ林転換には気候変化を緩和する機能があるか？ 北部ラオスにおける事例研究

清野 嘉之[1)*]、古家 直行[2)]、藤田 直子[3)]、佐藤 保[4)]、松本 光朗[5)]、
Soukanh BOUNTHABANDID[6)]、Somchay SANONTY[6)]

要 旨

北部ラオスでは 2000 年代にパラゴムノキ（*Hevea brasiliensis*）林の面積が急増した。15 林分の調査データでパラゴムノキの炭素貯留速度を推定し、焼畑休閑地に成立する天然植生の炭素貯留速度と比較した。パラゴムノキ林の経済的寿命を 30 年とし、地拵え時の土壌からの排出を考慮したときのパラゴムノキ林経営による平均炭素貯留量は 50.0 Mg-C ha^{-1} と推定された。この値は休閑期間 5 年の焼畑農業経営による平均炭素貯留量の 18.6 Mg-C ha^{-1} に比べ明らかに大きい。しかし、パラゴムノキ林造成により農地が失われ、天然林の農地転換が引き起こされると、パラゴムノキ林造成による平均炭素貯留量増加のメリットはなくなる。結論として、短期休閑の焼畑農地のパラゴムノキ林転換は、それが新たな天然林の焼畑転換をともなわず、パラゴムノキ林転換で発生する地域住民への環境や経済的リスクを最少化するのであれば、気候変化の緩和に役立てることができる。

キーワード：バイオマス , 炭素貯留 , 土地利用変化 , REDD+, パラゴムノキ , 焼畑農業

原稿受付：平成 26 年 1 月 27 日　原稿受理：平成 26 年 6 月 23 日
1) 森林総合研究所研究コーディネータ
2) 北海道支所
3) 九州大学
4) 森林総合研究所森林植生研究領域
5) 森林総合研究所研究コーディネータ
6) Soukanh BOUNTHABANDID, Somchay SANONTY（ラオス森林局）
＊森林総合研究所研究コーディネータ　〒 305-8687　茨城県つくば市松の里 1