**3. Development and evaluation of new management options for improving GHG sink/source control in agricultural and forest ecosystems.**

**3b. New ecosystem management options for coping with enhanced GHG sink/source control and sustainable food production in the shifting-cultivation region of Southeast Asia.（Abstract of the Final Report）**

**Contact person** Yoshio INOUE
Senior Scientist, Ecosystem Informatics Division
National Institute for Agro-Environmental Sciences
1-3-1 Kan-non-dai, Tsukuba, Ibaraki, 305-8604, Japan
Tel:+81-298-838-8220 Fax:+81-298-838-8199
E-mail: yinoue@affrc.go.jp

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I. Overview

The objectives of our project are to provide a quantitative information on the dynamic change of the shifting cultivation ecosystems at a regional scale in terms of land-use, vegetation change and carbon budget, and to propose new land-use and ecosystem management options that improve rice productivity and farmer's income and enhance the $CO_2$ sink capacity of the ecosystem.

This project consists of four modules as shown in Fig.1. The wide-area assessment of land use and ecosystem carbon stock using remote sensing and GIS is one of the crucial parts of this study (Module 1). For assessment of ecosystem carbon

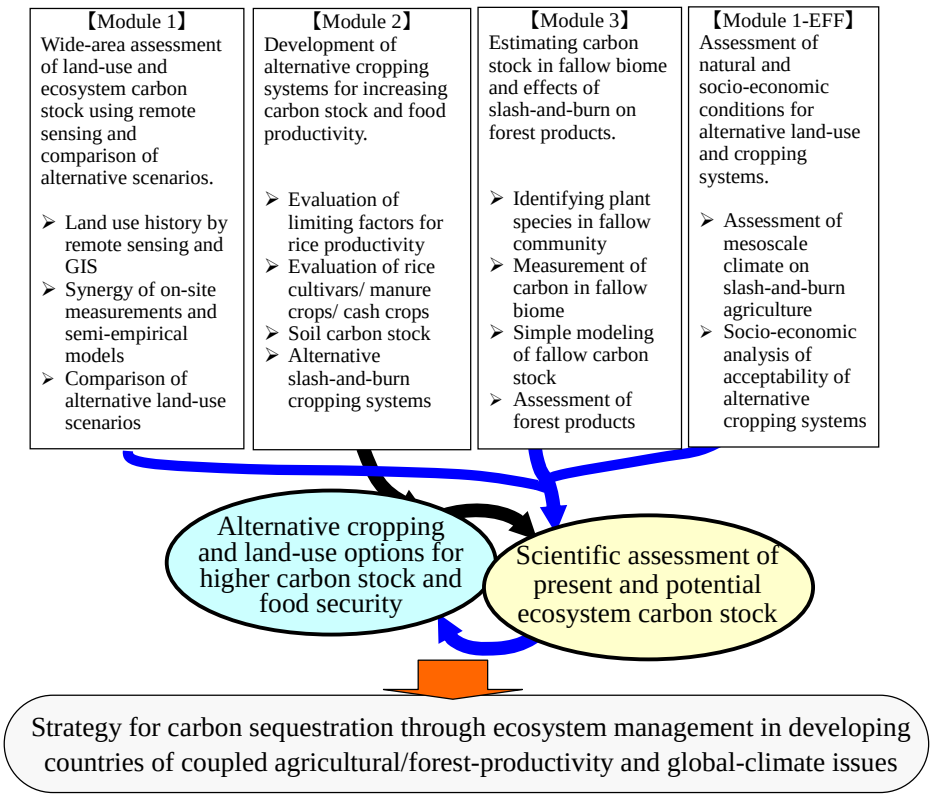


Fig.1. Framework of the project research

budget, we measured carbon in the soil and fallow vegetation, and derived semi-empirical models (Modules 2 and 3). Another important part was examination of alternative crops and cropping systems (Module 2). Most importantly, all of these data, information and models were synthesized for regional assessment of ecosystem carbon stock and comparison between alternative land-use and cropping scenarios (Modules 1). Supplementary studies were conducted by invited fellows (EFF) for assessing natural and socio-economic acceptability of alternative scenarios. This synergistic linkage of all Modules worked efficiently in this project research resulting in innovative outputs and useful outcomes.

II. Scientific outcome

(1) We obtained the first intensive and systematic data of carbon stock in the soil and fallow vegetation of slash-and-burn ecosystems. Semi-empirical models derived from the dataset play an important role in the assessment and prediction of ecosystems carbon stock in the region.

(2) The synergistic scheme was developed for liking land-use history and fallow age distribution from satellites imagery with semi-empirical carbon models. This may be the most robust and feasible approach for regional assessment of ecosystem carbon stock in such mountainous regions with poor accessibility. The first quantitative assessment of ecosystem carbon stock in the slash-and-burn regions is highly interested by international agencies.

(3) The IS database consisting time-series satellite imagery, topographic and climatic data may be one of the most powerful databases for the region so far. This could be useful for a wide range of scientific and operational works. Methodological innovations especially in the spectral remote sensing can be used widely not only in the studies of slash-and-burn ecosystems but in a range of terrestrial ecosystem studies such as fire monitoring using earth observation satellites.

(4) The high-yielding rice cultivars were found, which should be the major technological basis for alternative cropping systems and land-use with higher food security under poor soil conditions such as short fallow areas.

(5) We provided highly original data on bamboo biomass in tropics, which can be used as the unique default value for assessment of the similar species.

(6) We found that the responses of carbon in the slash-and-burn field and fallow productivity to fallow length were closely related each other, which provide useful insights on biodiversity and productivity of non-timber forest products in the slash-and-burn regions.

(7) Socio-economic analysis elucidated the complex structure among the poverty, population growth, food security, forest degradation, and carbon sequestration issues. This provides useful information for strategy and policy of carbon issues in developing countries.

(8) We derived the first results on the relationship of mesoscale climate events such as ENSO with local climate and regional rice yield, which would be useful for prediction of the effects of climatic change on agricultural production.

III. Contribution to policy of global environmental issues for decision makers

(1) This research work should commit to the carbon sequestration strategy through ecosystem management in developing countries where agricultural/forest resources and environmental issues are strongly coupled. This is a leading work for the REDD activities. Since food security and resource sustainability are strongly linked with ecosystem carbon stock, the alternative cropping and land-use scenarios would be one of feasible options for both people's welfare and global climate issues.

(2) The innovative and robust scheme for assessment of regional carbon stock is one of IPCC-Teie3 level approaches[4)], which should be applied to a wide range of operational monitoring of land-use and ecosystem carbon changes. International agents are highly interested in our publications.

(3) The agronomic results on the response of new rice cultivars to soil fertility are useful for improving yield performance of cultivars at farm scales. Some of them are already adopted by farmers in the region. The proposed cropping and land-use systems would be one of the promising options for CDM activities.

(4) Original data such as on bamboo biomass in the tropics can contribute as default values in LULUF-GPG, where no previous data are available. These data may be applied to carbon calculation in a wide range of bamboo-rich areas such as China and Indochina countries.

1. Introduction

Slash-and-burn agriculture is the major food production system in the mountainous mainland in Southeast Asia (MMSEA)[7)]. The rapid population growth during last few decades resulted in the expansion of shifting cultivation areas and shortening of fallow periods. The short fallow period is causing a vicious spiral of soil deterioration, weed problems, lowered crop yield, which further increase the land-use pressure. Such a drastic change in land-use may be associated with negative impact on global warming[2,3)] through decreasing ecosystem carbon as well as poor food security[10)]. That is, the global environmental issues are strongly linked with food security and sustainability of natural resources in developing countries such as Laos. Therefore, it is crucial to develop new ecosystem management options that can improve food productivity, resource sustainability, and carbon stock capacity of the ecosystem[1)]. Nevertheless, there are few scientific data on the carbon balance of slash-and-burn ecosystems and cropping options that could be used to improve food productivity, resource sustainability and carbon stock capacity[6,8,11)].

2. Research Objectives

The first objective of our research project was to obtain scientific data on the dynamic change of shifting cultivation ecosystems in terms of land-use, vegetation change and carbon budget. Another objective was to propose new land-use and ecosystem management options that would allow increased food productivity and ecosystem carbon stock.

3. Study Area and Methods

The study area is the northern part of Lao PDR, which is one of the representative regions for the large shifting cultivation areas in MMSEA (Fig.2). Agronomic field experiments are conducted to evaluate several cropping systems in terms of rice productivity, weed-controlling ability, and income. Dendrologic surveys are conducted to estimate and model the recovery process of vegetation during the fallow periods. Remote sensing, geophysical information, and modeling are synergistically liked with the above results to assess the long-term and regional change of land-use, vegetation change, and ecosystem carbon stock at the regional scale.

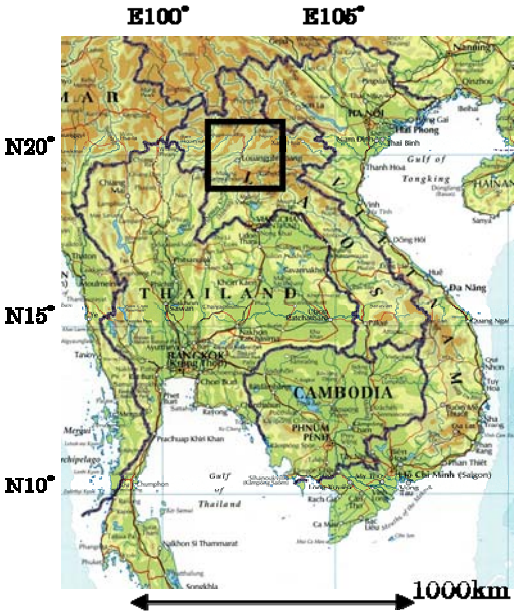


Fig.2 Study area; major regions for slash-and-burn ecosystems in northern Laos.

4. Results and Discussion

The major results and perspectives are summarized as follows.

(1) Geo-spatial and chrono-sequential change of slash-and-burn land use and community age

Satellite image analysis using innovative methods revealed that the slash-and-burn area increased rapidly during ‘90s to data, and now reached as high as 8-13%. The annual increasing rate was estimated to be 3-5% in the past decade (Fig.3). Some stabilizing trend in the slash-and-burn area was also found during recent years. In average, 77% of the area is abandoned after 1 year cropping, and 17% after 2 years cropping, i.e., less than 6 % is used for longer period for cropping. The community age, i.e., the fallow period after last cropping was derived from the chrono-sequential analysis of satellite images. This community age is the key variable for assessment of regional ecosystem carbon stock in this study. The area distribution of fallow period showed that fallow period was less than 10 years for 60% of the area. A large volume of geo-information database created in this study is also valuable for a wide range of scientific and operational applications.

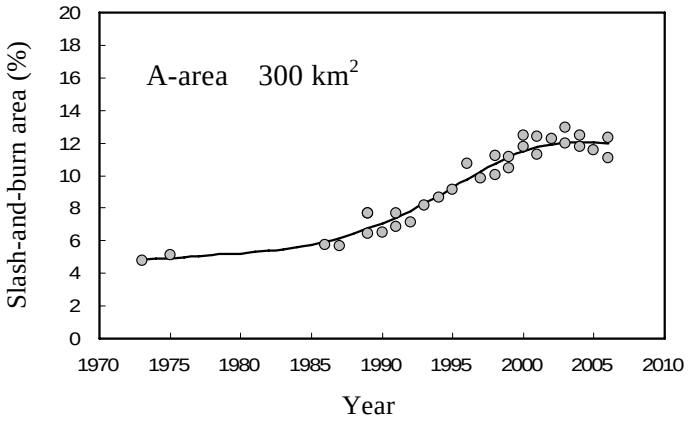


Fig.3. Chrono-sequential change of slash-and-burn area derived from time-series of Landsat images.

(2) Assessment of soil carbon stock in slash-and-burn land use

Change of the vegetation carbon stock associated with slash-and-burn procedure was measured at two fields, in which rice was cultivated after 3 yr and 10 yr fallow. The carbon stocks in vegetation before slash-and-burn were estimated to be 8.5 and 45.3 tC $ha^{-1}$, for the 3 yr and 10 yr fallow fields, respectively. After a conventional procedure of slash-and-burn, in which the slashed wood materials were piled and burned twice, the amounts of carbon stock were reduced to be 0.09 tC $ha^{-1}$ (1% of the stock before burning) and 5.5 tC $ha^{-1}$ (12%) in the respective fields. These values demonstrated that almost all the carbon stock in vegetation is lost by burning with the extent being more complete in short fallow field than in long fallow filed. Soil $CO_2$ efflux from forest floor ranged from 12.5 to 21.3 tC $ha^{-1}$ $yr^{-1}$ and was smallest at cropping period and increased with the fallow age. This chrono-sequential change was mainly due to change in root biomass. A simple model to predict chrono-sequence change in soil organic carbon (SOC) based on annual litter-fall input, fine root biomass etc, indicated that after a slash and burning and 1yr cropping, a 11 fallow year would be required to recover SOC to the original level.

(3) Assessment of chrono-sequential carbon stock changes during fallow period

We measured community biomass, deadwood and litter stocks in six plots of secondary plant communities established after slash-and-burn cropping (0-20 yr). The communities' biomass and deadwood significantly increased with time after the last cropping and the former reached about 100 tC $ha^{-1}$ after 15 years. Extending the fallow period from 2 to 5 years would increase fallow-period-average carbon stock from 14.2 to 25.1 tC $ha^{-1}$. This extending of the fallow period may also result in increasing potential for producing timber and non-timber forest products. To estimate the amount of carbon stocks extracted from fallowed land, we made preliminary surveys on firewood collection, charcoal production, and house construction practices by the local people in and nearby the Luang Prabang Province. We devised a model of carbon stocks in biomass, deadwood, and litter using parameters of years after the last cropping, altitude, and pasture use fallowed land. The growth rate of carbon stocks was faster in the montane than in the lowland.

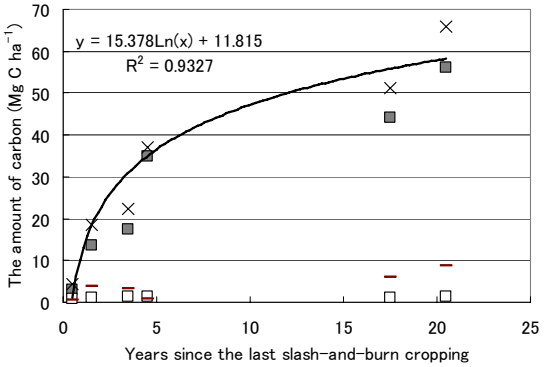


Fig.4. Relationship between the number of years since the last slash-and-burn cropping (x) and the sum of a community's carbon stocks in biomass, deadwood, and litter (y) in northern Laos. Filled square biomass carbon stocks, dash deadwood carbon stocks, open square litter carbon stocks, multiple symbol total carbon stocks.

(4) Comprehensive examination of alternative crops and cropping systems

In order to develop ecologically-sound slash-and-burn cropping systems with acceptability

to local farmers, we evaluated the applicability of various technological options for the improved production system. Field surveys and experiments were conducted in Luang Prabang province with close partnership with Northern Agriculture and Forestry Research Center (NAFReC), Laos, and International Rice Research Institute, Philippine.

Our observations on farmers' fields showed that upland rice productivity rapidly decreased with decrease of fallow period. The grain yields of upland rice at NAFReC positively correlated with the amount of precipitation during plant growth season. The addition of N fertilizer resulted in increased yields more evidently than did the application of other elements. Fields surveys suggested that the recent shortened fallow causes vigorous weed flourish and a labor demand for weeding as high as over 50% of the total labor spent for rice production. These facts indicated that in the upland rice production in northern Laos, rice productivity is strictly limited by rainfall, fallow length, soil N availability and weed[9)].

Our field experiments showed that the improved cultivars had higher productivity than traditional ones. Comprehensive evaluation of improved fallow systems from economical and agricultural viewpoints indicated that the introduction of paper mulberry and stylo into fallow period would be promising. Finally, we proposed an alternative cropping system for upland rice culture combining introduction of new cultivars, fertilizer application and fallow management.

(5) Assessment of regional ecosystem carbon stock and alternative land-use and scenarios

We assessed the chrono-sequential change of ecosystem carbon stock under various land-use patterns (Fig.5) by synthesizing the carbon stocks in the soil and fallow vegetation expressed as a function of community age. Results showed that average values of the chrono-sequential changes in ecosystems carbon stock over 35 years can vary up to 30 tC $ha^{-1}$ as affected by land use patterns. The relative decrease in short fallow land use such as 1c+2f or 1c+3f was serious. Since the negative effect of repeated short fallow was not included in this assessment, reality could be worse than the assessment in Fig.5.

The ecosystem carbon stock at regional scale was assessed by synthesizing the results of land-use and fallow period (community age) distribution with the carbon stock in the soil and fallow vegetation. Results showed that the regional carbon stock

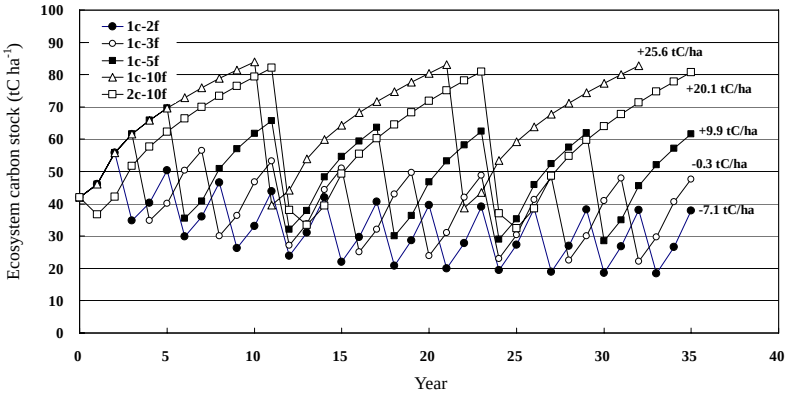


Fig.5. Simulated chrono-sequential change of ecosystem carbon stock in different land-use cycles. The ecosystem carbon stock is defined as the sum of carbon in all above-ground parts and in the soil down to 30 cm depth. The "1c-2f", for example, indicates the cycle of 1yr-cropping and 2yr-fallow. Values indicate the long-term average of carbon stock in each pattern.

would be only +5.6 tC $ha^{-1}$ compared to the initial level of soil carbon stock if the present land-use/cropping conditions are continued. It was also shown that the ecosystem carbon stock could be increased to +20.7 tC $ha^{-1}$ by extending the fallow periods to 10 years.

Results strongly suggest that crop productivity and resource sustainability in the region would be seriously degraded in the near future if sustainable and high-productive land-use/cropping systems are not available. Local and governmental agencies are highly interested in the alternative cropping options such as high-yielding cultivars from our results. Soci-economic analysis also suggested the feasibility of the alternative cropping options and land-use scenarios[5]. Since it is obvious that the slash-and-burn land use would continue in large percentage of the region even with partial introduction of cash plantation, and that the ecosystem carbon stock is closely linked with food security and resource sustainability, rice-based system would remain most important cropping systems.

Our results for alternative land-use and ecosystem management options would have a leading role in the REDD activities in the regions.

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