S-2 Development of Greenhouse-gas Sink/Source Control Technologies through Conservation and Efficient Management of Terrestrial Ecosystems
（Abstract of the Final Report）

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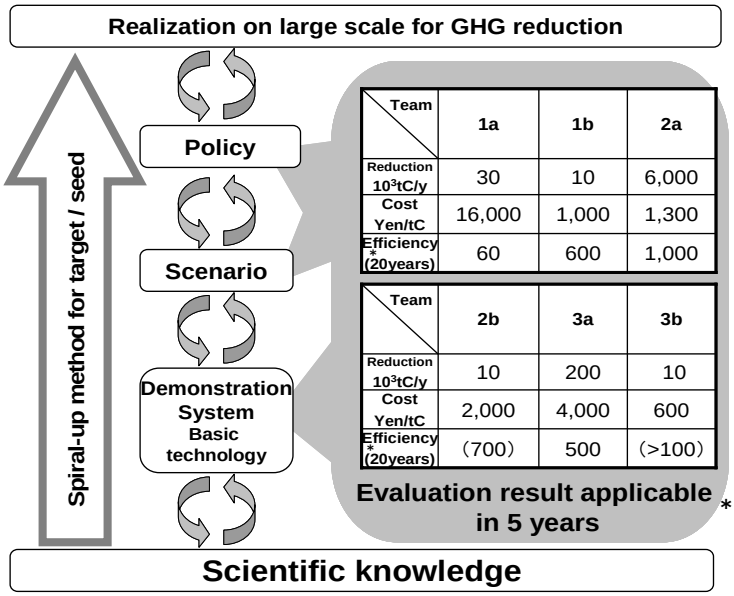
I. Overview

In this project, three typical ecosystems are studied: 1) forestry, 2) tropical wet land, and 3) agricultural (i.e., cultivated, slash-and-burn, agricultural, and cattle lands). These three ecosystems have been expected to have high potential of global warming mitigation in the terrestrial ecosystem. Two themes (a, b) are identified for each ecosystem for GHG sink/source control technology development.

Further, a common platform was constructed for sharing information among researchers in this area (research team 4), by gathering essential information about GHG sink/source control technologies of the three ecosystems from six research teams (1a-3b). On the platform, GHG reduction potential, effect of a developed technology implementation on environments, its cost and scenario are included.

The project have been operated effectively by a spiral-up method as shown following figures.



Team	1a	1b	2a
Reduction 10^3tC/y	30	10	6,000
Cost Yen/tC	16,000	1,000	1,300
Efficiency * (20years)	60	600	1,000

Team	2b	3a	3b
Reduction 10^3tC/y	10	200	10
Cost Yen/tC	2,000	4,000	600
Efficiency * (20years)	（700）	500	（>100）

II. Scientific outcome

The overviewed evaluation on GHG reduction potential , implementation cost and environmental impact in the objective and also global areas where the developed technology and knowledge obtained by this project was made in <Platform construction and information sharing for integrated promotion of the research project>

Scenarios were designed based on the project results to contribute to policy of global environmental issues.

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

Using the evaluation results obtained in <Platform construction and information sharing for integrated promotion of the research project>, the total GHG reduction potential by the technology developed in this project was calculated to be more than 10BtC in 20 years.

The highest potential in three ecosystems targeted by this project existed in South East Asia peat swamp and its value was 3.6BtC.

1. Introduction

Intermediate to long-term strategies for the stabilization of atmospheric greenhouse-gas (GHG) concentration are needed. New technologies to support the Japanese global environmental policy option should be developed, targeting the term after the Second Commitment Period of the Kyoto Protocol. Among the possible technologies, GHG sink/source control through conservation and efficient management of terrestrial ecosystem is promising because of its large potential impact on GHG concentrations, low cost and high reliability and applicability before the establishment of soft energy systems that rely only on renewable energy resources. However the technical background needed to make such systems, such as basic technologies and scientific knowledge, is still insufficient. The promotion of the development of these technologies and the accumulation of scientific knowledge are needed, including assessment of the environmental effects of the use of such new technologies, some of which can be effective measures for CDM (Clean Development Mechanism) and JI(Joint implementations) in the near future.

2.Research Objective

The research objective is to develop GHG sink/source control technology in forestry, tropical wetland and agricultural ecosystems which are expected to have high potential of global warming mitigation in the terrestrial ecosystem.

Further, other objective is to clarify GHG reduction potential, impact of developed technology implementation on environments and its cost to contribute to environmental policy issues.

3. Research Method, Results and Discussion

1. Development and evaluation of GHG absorption and fixation technology in forest ecosystems.

1a. Study of technological development for carbon fixation increase by systematic afforestation of arid lands.

Feature of this study was the active use of extensive arid and semi-arid land, where agricultural use for food production was quite difficult, as carbon sink. This study consisted of 4 categories which were effective use of water, plant ecology and physiology monitoring, carbon detection and modeling for construction of platform. Each categorized study was closely cooperated aiming for carbon sequestration efficiency maximization.

Consequently, following issues were achieved. Water balance was understood and modeled in arid and semi-arid research areas. *Eucalyptus camaldulensis*, especially Silverton ecotype, was revealed optimum and promising tree species for afforestation by ecological and physiological results. Five carbon pools (above-ground biomass, below-ground biomass, litter, dead wood, soil) accounted as carbon sink in arid area were grasped and modeled. Thus, potential carbon amount was estimated. All the achievements was gathered as afforestation simulation platform, which could be generalized in other arid and semi-arid area, and then carbon sequestration potential in Western Australia or in global scale.

1b. Enhancement of CO_2 sinks by improvement of afforestation technology in tropical forest

Paraserianthes falcataria (L.) Nielsen and *Gmelina arborea* ROXB. are one of leguminous and a fast growing tree species in tropical regions. This species can be planted in a widely tropical region because this species lives together with a nitrogen-fixing bacterium.

(1) Genetic improvement through provenance and individual selections

Evaluation and the establishment of seedling seed orchards with new provenances Provenance-spacing trials and seedling seed orchards of *Paraserianthes falcataria* were established in East Java, and then they were measured twice per year. Statistically significant variations among provenances and families were found in most of the growth and stem form with heritability of 0.1 to 0.2. Wood density was measure with Pilodyn as a non-distractive method and it proved applicable to this species by revealing significantly different provenance variation. Plus tree selection and within plot selection were done in the orchard. Statistically significant provenance variation was also found in provenance trials of *Gmelina arborea* established at three locations. These results suggest that CO_2 sink potential could be increased through genetic improvement. A model to predict a stand growth of *P. falcataria* was developed with Gadjah Mada University and the predictions were in good agreement with the observed basal area. This model shows that 10% improvement on height will result in 12% increase of stand volume, 18% increase of average stand stock at rotation age. Moreover, the extended model to estimate utilizable stem volume for sown timber showed that 10% genetic

improvement of height would bring about 22% increase in sown timber volume.

For establishing the evaluation method for superior tree, the inter-correlation of the growth increment and the wood quality parameters such as wood property (released strain of surface growth stress, density, microfibric angle and fiber length, wood processing performance), and the processability must be clarified: moreover, preferable technique for selecting superior tree should be developed. The parameters of wood properties and processability in *P. falcataria*, from Solomon and Java, and *Gmelina arborea*, from 3.5- to 7-y-old, were investigated. Consequently, there were no correlation between parameters of growth increment, wood quality and processability both species. It is thought that the quality of the material and processability do not fall both species even if it gathers growth speed.

(2) Upgrading of forest cultivation techniques with fast growing trees

The optimal nursing technique for shorter nursing period and for more growth in the initial stage, the clonal propagation technique by cutting with new rooting compound and tissue culture technique from mature tree will be developed. From all results, clonal propagation by shoot apex culture from mature trees was established. In the cuttage method, the efficacy of a newly-developed rooting compound, IBL, was reinvestigated. The results confirmed the efficacy of IBL and the concomitant effect of IBL and KODA and the patent was applied. In the nursery techniques, the infection of VA mycorrhiza and Rhizobium and the effect of the growth in seedlings were examined. VA myacorrhiza and Rhizobium were infected well in the soil which nourishment is poor and the growth of seedlings improved by increasing of the amount of VA myacorrhiza.

Nine primer sets of microsatellite locus for *P. falcataria* and 8 primer sets for *G. arborea* are designed by dual-suppression PCR method. These primer sets were issued patents. DNA extracted from the plywood of *P. falcataria* and *G. arborea* were successfully amplified by PCR, and the genotype could be identified. In the process of plywood production, veneers are heated for drying and during hot pressing. Genotyping was possible irrespective of heating. The results suggest that the source of wood can be traced by this technique. To clarify the genetic background of seedling seed orchards, *P. falcataria* and *G. arborea* are analyzed using microsatellite markers developed in this study. For *P. falcataria*, the introduced provenances have high genetic diversity and are genetically different from the artificial forests in Java Island. Therefore the breeding materials introduced into Java Island by our project are expected to have new genetic characters. But materials from Solomon showed linkage disequilibrium at 5 locus pairs and it is suggested to be originated from a few mother trees. For *G. arborea*, there are enough genetic differentiations among seed lots, but three seed lots showed high inbreeding coefficient. They are considered to be consisted of seeds produced by inbreeding. Therefore we need to check the inbreeding depression in the seedling seed orchard of *G. arborea*.

Studies were conducted in East Java, Indonesia. In 2004, *Paraserianthes falcataria* seedlings were applied for a fertilizing examination and a stand density trial. Same type of studies was started for *Gmelina arborea* in 2006. The results of density control trial suggested that the yield prediction model of *P. falcataria*[1)] would be improved its accuracy by following

data collections and those of fertilizing examination suggested that there was no fertilizing effects on height growths of *P. falcataria*. Based on the results and those of the other studies in 1b[1), 2)], economic balances and carbon fixations of various forest managements were simulated and an approach to the forest managements that maintain their profitability and improve carbon fixations was presented. *G. arborea* trees showed different growths among site. Significantly growth differences among strains were not detected. Frequency of fertilizing did not effect on growths but among amount of fertilizers did. The approach to optimal forest management would be applicable to all regions where *P. falcataria* could be planted. A series of studies in 1b might be applicable to other species and we had started corroborative studies for *G. arborea*.

2. Management and assessment of control systems for emission of GHG from ecosystem at tropical peat swamps.

2a. Development of technologies for GHG source control and sink increase at tropical peat swamps

Our final goal is: (1) to establish a system of water and soil management for source reduction, (2) to establish environmental reforestation techniques for sink enhancement, and (3) to make clear the missing sink in the global carbon cycle.

(1) Carbon sequestration of tropical primary peat swamp forest was estimated as 3.7 tC ha^{-1} y^{-1}. Of the assimilated carbon, 1.3 tC $ha^{-1}y^{-1}$ was estimated to accumulate as biomass and 2.4 tC ha^{-1} y^{-1} to accumulate as peat or flowout to the river.

(2) Horizontal distribution of the thickness of peat layer at Bacho swamp was investigated by means of GPS and GIS. Average thickness of peat layer was estimated to be 1.1 m. The thick peat stretched parallel to coastal line with striped pattern.

(3) Carbon emissions from the peat were calculated based on the measurement of peat subsidence. In developed, drained area, as much as 21 tC $ha^{-1}y^{-1}$ was emitted by bush-fire and 14 tC $ha^{-1}y^{-1}$ by decomposition. In conserved area, where water level was regulated to be high, 1.2 tC $ha^{-1}yr^{-1}$ was emitted by decomposition.

(4) Carbon emissions from the peat were estimated based on the measurements of soil respiration in the field and a diffusion model. The estimated value is 24 tC $ha^{-1}y^{-1}$ under dried condition and 0.9 tC $ha^{-1}y^{-1}$ under flooded condition.

(5) An incubation experiment of peat samples showed that carbon emission rate increased as peat layer thickness increased but reached a plateau of 21 tC $ha^{-1}y^{-1}$ with unsaturated layer thicker than 50 cm.

(6) CO_2, CH_4 and N_2O emissions from peat soil were calculated using Wetland-DNDC model with parameters based on the analysis of peat samples obtained from the experimental site. The total amount of GHG emission was estimated to be smaller under the flooding condition.

(7) Outflow from a primary peat swamp forest was estimated from gate control and water level. The water catchment areas was estimated based on elevation data on a topographic map with a GIS methodology.

(8) The concentration of total organic carbon of water flowed out from the peat swamp forest fluctuated more widely than those flowing into the forest. Compared to the influent water, effluent water was higher in the absorbance at 280 nm, electrical conductivity and chemical oxygen demand (COD) and lower in pH. It was suggested that aromatic compounds with high electrolyte content flow out from the swamp.

(9) Based on the dissolved organic content, outflow and water catchment area, the organic carbon flowed out from the peat swamp forest was estimated to be 1 tC $ha^{-1}y^{-1}$.

(10) Relative content of lignin in peat samples was 77 - 87%. The lignin in peat was highly modified and enriched in hydrophilic groups such as carboxyl residues.

(11) The major component of water-soluble organic matters in peat swamp water sampled in Bibai swamp, Hokkaido, was highly modified lignin, which had constitution of $C_9H_{10.8}O_{13.4}(Protein)_{0.68}$, which formed aggregates with aluminum at pH higher than 4.6. Water-soluble organic matters in outflow water from To Daeng peat swamp was isolated and the mineral element composition was analyzed.

(12) Reactions of plant cell wall in the supercritical condition gave furfural and aromatic monomers originated from cell wall polysaccharides and lignin, respectively. A variety of aliphatic hydrocarbons were also detected. A variety of oil compounds was produced by hydrothermal reactions of powdered wood of Pinus densiflora with potassium carbonate as catalyst. The isolated dissolved organic matter and lignin prepared from coniferous and non-coniferous woods were subjected to reaction under supercritical water condition. The major products were catechol and pyrogarol derivatives which were produced by demethylation reaction of lignin aromatics. Some of them are very close to the aromatic components in crude petroleum. Methyl function released from lignin aromatics may be stored as methane in deep sea sediments.

(13) Aboveground biomass of well developed secondary Melaleuca cajuputi forests was estimated to be 50 tC ha^{-1}. Annual increase of aboveground biomass of young M. cajuputi forests was estimated as 3 - 8 tC $ha^{-1}y^{-1}$.

(14) Aboveground biomass and belowground biomass, excluding fine roots, of 12-year-old Melaleuca cajuputi plantation forests were estimated to be 31 - 56 tC ha^{-1} and 9.1 - 16 tC ha^{-1}, respectively. Biomass increment was estimated to be 4.6 - 6 tC ha^{-1} y^{-1}.

(15) Fine root biomass of 10 to 12-year-old Melaleuca cajuputi plantation forests were estimated to be 0.6 tC ha^{-1}. The net production and turnover of fine roots were estimated to be 0.55 tC ha^{-1} y^{-1} and 1.1 y^{-1}, respectively.

(16) Fine root biomass of Hopea odorata plantation forests with height of about 5 m was estimated to be 0.34 - 1.06 tC ha^{-1}. The net production and turnover of fine roots were estimated to be 0.75 tC ha^{-1} y^{-1} and 0.85 y^{-1}, respectively.

(17) Respiration of stems, leaves and roots of 12 to 13-year-old Melaleuca cajuputi plantation forests were estimated to be 8.8 tC ha^{-1} y^{-1}, 12.6 tC ha^{-1} y^{-1} and 9.3 tC ha^{-1} y^{-1}, respectively.

(18) Respiration of stems, leaves and roots of 25-year-old oil palm plantation were estimated to be 2.5 tC ha^{-1} y^{-1}, 14.8 tC ha^{-1} y^{-1} and 7.0 tC ha^{-1} y^{-1}, respectively.

(19) Several indigenous and exogenous tree species were found as promising species to be planted on peat swamp area and acid sulfate soils.
(20) The promising species for reforestation mentioned above showed tolerance to hypoxia. Aerenchyma formation and enzyme activity for sucrose cleavage seems to be involved in flooding tolerance in some Myrtaceae species.
(21) An experimental plot consisting of two blocks with different water regime, flooded and drained, was set on a drained degraded peat swamp site. Several species including Melaleuca cajuputi seedlings were planted on the blocks to verify the possibility of managing peat swamp area as carbon sink. Measurements of soil respiration at the drained site revealed a diurnal fluctuation with higher respiration during nighttime compared to daytime.
(22) Temperature response of the respiration of peat soil measured at laboratory revealed that respiration rates increased proportionally as temperature increased at temperatures lower than 40 °C then once decreased and then increased again at 60 °C. Simulation of soil respiration based on this temperature response did not fit to the fluctuation observed at the field site.
(23) Planting experiments revealed that plantings using seedlings that are raised ordinarily do not success under continuous flooding condition even in the case of Melaleuca cajuputi, a highly promising species. Pretreatment of seedlings with flooding at nursery improved the survival of the seedlings.
(24) Based on a digital soil map and satellite images, the area of peat swamp in Southeast Asia was estimated to be 22.6 million ha. Within the area, 5.14 million ha was estimated to be bare land or area with scare vegetation caused by development.

Suppose a CDM project by means of peat conservation and reforestation, with controlling water level to reduce CO_2 emission and planting suitable tree species for carbon sequestration, will be carried out. Based on the outcomes above and literature search, we estimated the extent of carbon emission reduction by the project is 18 $tCO_2\ ha^{-1}y^{-1}$ in case of oil palm plantation as baseline, 30 $tCO_2\ ha^{-1}y^{-1}$ in case of bare land as baseline, and 51 $tCO_2\ ha^{-1}y^{-1}$ in case of bare land with frequent fire as baseline, respectively. Thus, emission reduction project with conservation of peat and reforestation brings about a considerably high reduction. In addition to such high reduction efficiency, because of the low productivity of the target site, peat conservation-reforestation project has low risk for the competition with food production, which often comes out in projects using terrestrial ecosystems. Assuming 5 million ha of tropical peat swamp area in Asia, the potential of emission reduction by peat conservation-reforestation is calculated as more than 1.8 GtC.

2b. Study on the option of land resources management and the empowerment for local community in the lowland swamp forest in Southeast Asia

1. Study Site and Methods

One of the study site is located Yasothon in Thailand. We carried out estimation of carbon

storage and accumulation rate at the fresh water swam forest. We got the alommetry related with individual size and weight. We also carried out to classify the structure of fresh water swamp forest. We have carried out the bowling for dating the peat and clarification of layers in Riau Province. Each core sample were analyzed their chemical properties and dating. We have also set the permanent plot of peat swamp forest (1 ha) at the center of peat swamp dome in Zamrud, Riau Province. This plot was analyzed its structure and DBH-H relation. Turuku Meranti and Tunbirahan were selected for estimation of peat decomposition. The study site is located at Zamrud, Tuluk Meranti and Tunbirahan, Riau Province and Parankararaya, Central Kalimantan Province, Indonesia. The peat swamp forest used to be converted into agriculture field such as paddy field, coconut plantation, lubber plantation, oil palm plantation and fast growing tree plantation etc. We have studied local community empowerment in Central Kalimantan. The changes of their agricultural methods were monitored. We also studied agricultural activities for local community empowerment in Jambi Province, Indonesia. We have monitored on farm agriculture project. The research was conducted, in the same way as last year, jointly with an Indonesian research group in August, 2006 and January/February, 2007 in the surroundings of Gunung Butung in Lampung Province, where a social-forestry project was implemented by the government. Since a kind of tension or conflict was observed last year between the provincial forest office and local farmers groups over the land-use management of the forest area, fieldworks were carried out in order to follow up the negotiation processes between two parties, and obtain relevant information related to empowerment of local societies by participating in the meetings among farmers groups. We have surveyed all of land use at coastal area of Jyambi, province, Indonesia. And we have monitored the examination of on farm paddy test caused by rehabilitation of salfic acidity damages.

2. Results

(1) Mangroves could accumulate carbon up to 282.2 tC/ha as the biomass in case of old growth while carbon fixation was highest in young stands as 5.5 tC/ha/yr. The carbon stock of riparian freshwater swamp forest differed by the period of water logged condition caused by annual flood so that nearly four times of difference was observed between very swampy low site and on drier terrace as 23 to 89 tC/ha even though the annual accumulation was equally small as ca. 1 tC/ha/yr in both site. Carbon stock of peat swamp forest was ca. 190 tC/ha at less nutrient-rich center site of peat dome. For belowground stored carbon in Iriomote, it was estimated to be about 200 tC/ha up to 1 m in depth. In Kosrae, it was estimated to be about 200 tC/ha up to 65 cm in depth and 2200 tC/ha up to 4 m in depth including mangrove peat overlain by freshwater swamp forest deposit. In the peat swamp on Sumatra, stored carbon up to 5 m in depth in the edge and up to 9.2 m in depth in the center were estimated to be about 2000 tC/ha and 2400 tC/ha, respectively. The belowground carbon accumulation rate was estimated to be 30 to 100 $g/m^2/yr$. Mangrove forests in Pohnpei were supported by mangrove peat and the belowground stored carbon were estimated to be 195 tC/ha for *Rhizophora stylosa* and *Sonneratia alba* forests, 585 tC/ha for *Rhizophora apiculata* - *Bruguiera gymnorrhiza* - *S. alba* forest and 1300 tC/ha for *R. apiculata* - *B. gymnorrhiza* - *Xylocarpus granatum* forest.

(2) We have also clarified that the secondary succession indicated its difficulties caused by loss of

seed source and severe environment at peat land. Peat swamp forest also indicated that annual organic matter accumulation was 1.25 Ct/ha/yr. We have also estimated the accumulation of peat and organic matter 5.7 t/ha/yr. As the 50% of peat and organic matter annual decomposition rate, We have gotten the less than 0.26 Ct/ha/yr at Tuluk Meranti and 0.15 Ct/ha/yr under the conversion of land utilization from forest to coconut plantation.

(3) Local government is still supporting remained immigrants with several community empowering projects, which are turned out being failed, without admitting intentions and views of remained immigrants. These projects could be economically sustainable, once remained immigrants are properly involved. For the reasonable project planning, this study can contribute largely, by mediating local government and immigrant community.

In Lampung Province, the provincial forest department tries to establish a collaboration committee involving local authorities to cope with various problems derived from conflicts related to the border of forest and agricultural lands. On the other hand, local people who established farm lands in the forest area also try to establish a collaboration forum by combining farmers groups. Such trials indicate that there are two different directions; top-down and bottom-up organizing vectors. As a result of the joint research, it was observed that the presence of facilitators or mediators is indispensable in order to solve tensions and conflicts between the local government and local communities, as well as to empower the local people's abilities to manage the problems. The research also revealed that mixed-farming consisting of various kinds of useful trees, which is practiced in the forest area, have provided a firm economic basis to the local people, and that they began to perceive that their farm lands may not be inferior to reforested lands with a single tree species in terms of environmental preservation. In order to confirm such perceptions of local people, more intensive surveys are planned to be conducted in collaboration with the Indonesian research group. Despite the dispute between the local government and local communities over the land management of "mixed gardens," rather stable balance was kept between them as the negotiation between them developed. However, in spite of this stable condition, Master Plan of National Forest Park prepared by the provincial forest office came to arouse a controversy. Immediately after the hearing, they began to strengthen their communication networks and to look for the occasions for publicizing their perceptions that the "mixed gardens" which were established by their agricultural activities play an important role not only in producing economic benefits but also in preserving the forest area and providing ecosystem services. It was expected that a model of collaboration with regard to the forest area management would be created between the local government and local communities, as was shown in the case of representation of Sumber Agung people as a participant to the National Assembly. As this indicates, it was concluded that the presence of facilitators or mediators is indispensable in order to reduce the tensions and conflicts, to empower the local community, and to create the collaboration between the local government and local communities.

(4) For renovation of wet rice cultivation: Our design for renovating the degraded wet rice cultivation produced remarkable increase of rice, that is, from 0 to 5.4 ton/ha in maximum case in abandoned fields, and from less than 1 ton/ha to 5.8 ton/ha in maximum case in rain-fed fields. The

key for the success lied in (1) flushing of acid before transplanting and continuous inundation of water on the fields during the growing season, (2) application of lime to carry soil pH to around 4.5, (3) application of micro-nutrients, particularly foliage spraying of Fe-containing solution, as well as macro-nutrients. For collaboration of pilot project with provincial government: Based on our remarkable success, provincial government joined to our project from 2005, and laid pilot project of 100 ha. However, once the project changed to theirs, various problems appeared, such as delayed starting of rice cultivation, and non-approval of micro-nutrient fertilizers. Therefore, rice yield retreated to 2.4 to 3.9 ton/ha. This result has been caused by artificial mistake of provincial government.

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

3a. Development and evaluation of mitigation technologies for CH4 and N2O emissions from agroecosystems.

Agriculture contributes to about 40% of respective global emissions of methane (CH_4) and nitrous oxide (N_2O). These greenhouse gases are emitted to the atmosphere during agricultural production processes from soils and animals. As it is described in the IPCC assessment reports, CH_4 and N_2O emissions from agricultural sources can be reduced significantly through improved technologies of agronomic practices, animal nutrition, and animal waste management (IPCC, 2007). The Theme 3a focuses on bridging the gaps in knowledge for CH_4 and N_2O mitigation in agricultural sector. The activities of the research project are based on field measurements of GHG exchange, laboratory experiments, GHG database compilation, and modeling, aiming at making a quantitative evaluation of the mitigation technologies for the emissions from cultivated land and animal industry in Asian countries.

Field experiments for mitigating CH_4 and N_2O emissions from paddy fields and N_2O emissions by nitrogen application to crop fields were conducted at various sites in Japan, China, Indonesia, and Thailand. Field experiments for the mitigating CH_4 emissions from Japanese paddy fields demonstrated promising options that can mitigate the emissions significantly (10% to >50%) ,compared with each corresponding control treatment, without trade-off for production or N_2O emissions. Those options include composting rice straw, improving mid-season drainage practices, rice transplanting without puddling, and installing underground draining pipes. The effects of water and organic management were confirmed at the paddy fields in China, Indonesia, and Thailand. N_2O emissions from a grass land were reduced by the addition of a nitrogen inhibitor to fertilizer or changing the split ratio of fertilizer application at different season. The mitigation of N_2O emissions was remarkable in Japanese summer cabbage, by significantly reducing the emissions from crop residue incorporation after the harvest. The experiment in a Chinese maize field also showed that applying slow release fertilizer reduced N_2O emissions by 23-67% compared with conventional urea application, similar as in Indonesia.

A statistical model analysis for the database of CH_4 emissions from rice fields in Asia

estimated a baseline emission of 130 mg m^{-2} day^{-1}, and scaling factors. The methods estimated global emission to be 25.4 Tg yr^{-1}, and that improving water and organic management can reduce the emission by respective 4 Tg yr^{-1}. Compilation of source data for N_2O emissions from Japanese agricultural lands determined country specific emission factors for N_2O, including that from synthetic fertilizer, organic manure, and leaching. A mixed ecosystem analysis for calculating carbon budget and GHG emission rates estimated net GWP in Ikushunbetsu catchment, Hokkaido. The results indicated that total GWP of the agricultural field increased from 18824 Mg CO_2eq yr^{-1} in 2002 to 26248 Mg CO_2eq yr^{-1} in 2007. An eco-balance analysis for a scenario to reduce GWP by 6% showed that it was possible by increase in bean area and decrease in paddy rice area. The mitigation effect of water management on CH_4 emissions from paddy fields in Hokkaido was quantitatively valuated by applying revised DNDC model and databases for soils and rice cultivation in the target area. The result estimated that average CH_4 emission with current water regime is estimated to be 4.2 Mg CO_2 ha^{-1} y^{-1}, and it could be reduced by 1.7 Mg CO_2 ha^{-1} y^{-1} by applying 2-week midseason drainage twice.

Incubation experiments of various paddy soils showed a simple CH_4 production model that was determined by available N and Fe contents. The revised DNDC model was also applied to simulate the effects of various mitigation options on CH_4 emission from rice fields in Thailand. The results suggested that rice straw management, field drainage, and ammonium sulphate application are recommended options.

Following issues are studied for mitigating CH_4 emissions from ruminant: 1) Analysis of a drifting factor of CH_4 production of ruminant, 2) Measurement of CH_4 production of ruminant in Asia, 3) Development of simple CH_4 estimation method, 4) Estimation of CH_4 production of ruminant at a local level. Analysis of a drifting factor of CH_4 production of ruminant showed that protein and non-structural carbohydrate sources varying in degradability in rumen gave to change CH_4 production of Holstein cattle. When the contents of Metabolic energy, Crude protein and Ether extract increase, and neutral detergent fiber and acid detergent fiber decrease CH_4 production decrease in high temperature. CH_4 production from cattle, Buffalo, and bulls in Southeast Asia were approximately 4.2-9.2% ($MJCH_4$/100MJ-Gross energy intake). It was demonstrated that additives, such as monensin and fumaric acid, high concentrate diets, various by products from soy bean, beer cake, and tofu cake, tannins suppressed CH_4 emission significantly. An *in vitro* gas production method (IVGPT) was suggested as a simple, low cost, and high capacity method that makes it ideal for estimating the CH_4 production in ruminant diets. The CH_4 production rates from grazing goat and camel in Inner Mongolian were evaluated by the SF_6 method.

Three research tasks were done for GHG control of the livestock manure management origin. The execution subject is as follows: (a) Mitigation of the source materials of GHG generating (C and N) by decrease discharge nitrogen and an organic matter per unit livestock, (b) Mitigation during the manure treatment process by control of oxidization / reduction conditions in a reactor, (c) Mitigation at the application to the cropland as organic fertilizer by the pelletizing of chicken manure compost. Breeding improvement in Vietnam showed that GHG reduced diet, which contains low crude protein and additional amino acids reducing nitrogen excretion of pigs, resulting

in reduced N_2O emission potentials. Sugarcane extract diet was considered to be the effective techniques on GHG reduction for chicks. Experiments for manure processing control showed that improving composition of nitrifying communities for complete nitrification promotion was useful to establish a composting method with low N_2O emission. A field experiment in a cabbage-harvested field applied with the chicken manure compost showed that N_2O emission was greater from the pellet of chicken manure compost, compare to that of its original powder form.

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.

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. The study area has been selected in the northern part of Lao PDR, which is one of the representative regions for the large shifting cultivation areas in MMSEA.

The major results and perspectives are summarized as follows.

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

Satellite images analyses using innovative methods[2)] 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. 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 (fallow period) 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 fallow period was less than 10 years for 60% of the area[3)]. A large volume of geo-information database created in this study is also valuable for a wide range of scientific and operational applications.

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

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. In a conventional procedure of slash-and-burn 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 CO2 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. We also 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[5)].

(4) Comprehensive examination of alternative crops and cropping systems

Our observations on farmers' fields showed that upland rice productivity rapidly decreased with decrease of fallow period. The grain yields of upland rice 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. The upland rice production in northern Laos, rice productivity is strictly limited by rainfall, fallow length, soil N availability and weed. Field experiments showed that the improved cultivars had higher productivity than traditional ones[4)]. 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 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 is not considered in this assessment, reality could be worse than the assessment[3)].

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 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[3)].

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. Socio-economic analysis also suggested the feasibility of the alternative cropping options and land-use scenarios[1)]. 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.

4. Construction of integrated platform and common information system for promoting the research project.

In this project, three typical ecosystems are studied: 1) forestry, 2) tropical wet -land, and 3) agricultural (i.e., cultivated, slash-and-burn, agricultural, and cattle lands). These three ecosystems have been expected to have high potential of global warming mitigation in the terrestrial ecosystem. GHG sink/source control technology development to mitigate the global warming is the project objective.

However, the research field expands to a wide range for attainment of the objective. Therefore, a common platform was constructed for sharing information among researchers by gathering essential information on GHG sink/source control technologies of the three ecosystems from six research teams. On the platform, GHG reduction potential, effect of a developed technology implementation on environments and its cost are evaluated on the same basis. A roadmap to implement developed technology is also included in the platform. This platform construction management was useful for the advance of the project. The total GHG reduction potential by the technology developed in this project is calculated to be more than 10BtC in 20 years.

The highest potential exists in peat swamps in South East Asia where development done has promoted CO2 emissions by the change from swamp to dry land, and the potential value is 3.6BtC in 20 years.

The measures applicable to policy of environmental issues in a short time were clarified for each research team based on the evaluation result of cost, technology level and environmental impact. Most of the C reduction costs of measures are below $100/tC of the project target value.

The selected measures from each research theme are as follows:

1a; Afforestation in Western Australia arid land by a blasting method.

1b; Improvement of reforestation system in tropical forest applied to timber industry.

2a; Rewetting of developed peat swamp by planting trees.

2b; Improvement of paddy field in developed peat swamp.

3a; CH4 reduction by water management of Indonesia paddy field

The following figure shows the result.

Table.1 Summary of overviewed evaluation of GHG reduction cost, efficiency and potential

GHG reduction cost, efficiency & amount

テーマ	Reduction rate (tC/ha･y)	Cost (Yen/tC)	*Efficiency (20 years)	Reduction in 2020 (10^3tC/y)
1a	3.7	16,000	60	30
1b	1.2	1,000	600	10
2a	30	1,300	1,000	6,000
2b	18	2,000	(700)	10
3a	0.8	4,000	500	200
3b	1.7	600	(>100)	10
				Total 6.5MtC/y

* Efficiency = $\frac{\text{CO2 reduced in 20 years}}{\text{CO2 emitted for system construction}}$

Major Publications

(1) K. Shiono, Y. Abe, H. Tanouchi, H. Utsugi, N. Takahashi, H. Hamano, T. Kojima and K. Yamada: Journal of Arid Land Studies, 17-1, 11-22 (2007) "Growth and Survival of Arid Land Forestation Species (*Acacia aneura*, *Eucalyptus camaldulensis* and *E. salubris*) with Hardpan Blasting"

(2) T. Kojima, H. Hamano, Y. Abe, H. Tanouchi, Y. Egashira, M. Saito, J. Law, N. Takahashi and K. Yamada: J. of Arid Land Studies, 16-3, 167-174 (2006) "Basic Data of Research Project on Large Scale Afforestation of Arid Land for Carbon Fixation near Leonora in Western Australia"

(3) H. Tanouchi, H. Utsugi, N. Takahashi, H. Hamano, S. Kawarasaki, T. Kojima and K. Yamada: J. of Arid Land Studies, 15-4, 267-270 (2006) "Water Use Efficiency of Trees in Arid Lands: Plasticity to Water Conditions"

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(Team 1a has 56 publications. Only five representative articles are listed. All publications are listed into detailed report (in Japanese).)

(Team 3a has 51 publications. Only ten representative articles are listed. All publications are listed into detailed report (in Japanese).)