2. Management and assessment of control systems for emission of GHG from ecosystem at tropical peat swamps.（Abstract of the Final Report）

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

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I. Overview

The task was performed by the member of the team working together. The analysis of dissolved organic matters, establishment of sivicultural techniques and evaluation of carbon sequestration by reforestation were mainly executed by the member belonging to the University of Tokyo and the quantification of dissolved organic matters and analysis of respiration of soils and of biomass were executed mainly by the member belonging to Utsunomiya University.

II. Scientific outcome

No international standard for monitoring of the change in carbon stock in peat soils has been established, since the carbon stock in peat soils is too enormous to detect the difference between two sampling times, which is used to evaluate the stock change in the usual method. Through our research in this project, we clarified that the estimation of soil carbon change on the bases of the monitoring of soil respiration is in good agreement with the estimate based on the long-term peat subsidence monitoring, which will open a new way to the establishment of the monitoring methodology of soil carbon change in peat soils. Additionally, the outcomes from species selections and nursing experiments will contribute to the establishment of techniques for reforestation on degraded peat soils, which have been considered difficult. The finding that dissolved organic matters flowing out from peat swamp area is highly microbially-modified lignin that cannot be decomposed further suggests that the dissolved organic matters play a role as carbon sink in the carbon cycle.

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

The outcome contributes to the conservation of tropical peat swamp and the establishment of emission-reduction techniques using reforestation. The outcome will give scientific bases for AR-CDM in the post-Kyoto protocol and will support the activities under the Ramsar Convention on Wetlands. The finding of the stability of the dissolved organic matters that flow out from peat swamp area as carbon sink points out the importance of the terrestrial ecosystems in the global warming issue. Through the publication and presentation of the findings, we will contribute to the policy forming.

Based on the findings, we have submitted comments to United Nations Framework Convention on Climate Change: “Call for public inputs on simplified baseline methodologies for small-scale CDM afforestation or reforestation project activities applied on wetlands and settlements” (http://cdm.unfccc.int/public_inputs/SSCAR_PA_wetlands/index.html).

1. Introduction

In Southeast Asia, more than 20 million hectares of tropical peat swamps are distributed, which have been playing an important role as carbon sink in the global carbon cycle. Natural vegetation of the peat swamp is peat swamp forest, which has high net primary productivity. Recently, large area of the peat swamp has been dried up for agricultural development, and has turned into a large source of carbon dioxide. Based on the field study in southern Thailand and experiments in laboratory, we elucidate the carbon dynamics of tropical peat swamp with water-soluble organic carbon taken into account.

2. Research Objective

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.

3. Methods, Results and Discussion

(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.

Major Publications

1) H. Saito, K. Yoshino, T. Ishida, T. Nagano, W. Sirichuaychoo, A. Jagruskl, and N. Haraguchi : Geoderma, 125, 235-247 (2004)
"Geostatistical estimation of tropical peat soil volume at Bacho, Thailand"

2) M. Norisada and K. Kojima : For. Ecol. Manage. 216, 175-186 (2005)
"Nitrogen form preference of six dipterocarp species"

3) M. Norisada and K. Kojima : Photosynthetica 43, 491-499 (2005)
"Photosynthetic characteristics of dipterocarp species planted on degraded sandy soils in southern Thailand"

4) K. Tahara, M. Norisada, T. Hogetsu, and K. Kojima : J. For. Res. 10, 325-333 (2005)
"Aluminum tolerance and aluminum-induced deposition of callose and lignin in the root tips of *Melaleuca* and *Eucalyptus* species"

5) T. Yamanoshita, M. Masumori, H. Yagi, and K. Kojima : J. For. Res., 10, 199-204 (2005)
"Effects of flooding on downstream processes of glycolysis and fermentation in roots of *Melaleuca cajuputi* seedlings"

6) Z. Jin, K.S. Katsumata, T. B. T. Lam, and K. Iiyama : Biopolymers, 83, 103-110 (2006)
"Covalent linkages between cellulose and lignin in cell walls of coniferous and nonconiferous woods"

7) Z. Jin, Y. Matsumoto, S. Shao, T. Akiyama, K. Iiyama, and S. Watanabe : Bull. Tokyo Univ. For., 115, 37-51 (2006)
"Leaf litter decomposition of selected urban tree species during mulching"

8) S. Kogawara, T. Yamanoshita, M. Norisada, M. Masumori, and K. Kojima : Tree Physiol., 26, 1413-1423 (2006)
"Photosynthesis and photoassimilate transport during root hypoxia in *Melaleuca cajuputi*, a flood-tolerant species, and in *Eucalyptus camaldulensis*, a moderately flood-tolerant species"

9) Z. Jin, Y. Matsumoto, S. Shao, T. Akiyama, K. Iiyama and S. Watanabe : Bull. Tokyo Univ. For., 115, 51-64 (2006)
"Structural difference between leafblade and petiole of original and mulched leaf litter of *Ginkgo biloba*"

10) M. Norisada and K. Kojima : Photosynthetica, 45, 153-155 (2007)
"*Dipterocarpus obtusifolius* exhibits enhanced photosynthetic capacity at high temperatures"

11) Z. Jin, Y. Matsumoto, T. Tange and K. Iiyama : J. Wood Sci., 53, 412-418 (2007)
"Structural characteristics of lignin in primitive Pteridophytes: *Selaginella* species"

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"Spectrally segmented principal component analysis of hyperspectral imagery for mapping invasive plant species"

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"Role of aluminum-binding ligands in aluminum resistance of *Eucalyptus camaldulensis* and *Melaleuca cajuputi*."

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"Automated 3D forest surface structure extraction from balloon photographs" (in press)

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"Structual modification of lignin in peat during peat formation at tropical swamp"(in press)