The Impact of Land-Use/Cover Change on Greenhouse Gas Emissions in Terrestrial Ecosystems of Tropical Asia
(Collaborative study between Indonesia-Japan)

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1. Effects of land-use change on GHG emissions and major factors controlling GHG emissions and soil dynamics

1.1 Humid tropical forests in Jambi, central Sumatra

1.1.1. Long-term flux measurements of GHG from soils under 5 land-use patterns

1.1.2. Regional study on GHG fluxes from soils under different land-use patterns

1.2 GHG fluxes from Peatlands in Banjarmasin, south Kalimantan

2. Carbon budgets in a young secondary forest ecosystem suffered with the 1998 forest fires

2.1 CO₂ flux over the canopy in Samarinda

2.2 Long-term study on above-ground biomass in secondary forests

3. Monitoring of background CO₂ concentrations at a GAW station

4. Development of land-use database and of methodology of scaling up for regional estimate of GHG emissions

5. Trace gas and aerosol measurements emitted from biomass burning of forests and peatlands in tropical Asia
The influence of land-use/cover change on greenhouse gas emission/absorption in tropical Asia

Estimate of land-use/cover change by remote sensing and GIS data

Major factors controlling emission/absorption of GHG

Trace gas exchange in atmosphere-plant-soil system

Biomass burning

CO2 flux over the canopy

Emission rate of trace gases and aerosols

Flux measurements of GHG

Land-Use/Cover Change

Tropical forests
Peat wetlands

Change in organic matter; micro-organisms

Urbanization

Agriculture Plantation
Rubber jungle Grasslands

Development on methodology of scaling-up in regional estimate

Evaluation of emission/absorption rate of GHG in global scale
Location of field sites.
GHG emissions from Humid tropical forests:
Pasirmayang in Jambi
GHG emissions from Peatlands:
Muarasabak in Jambi, Banjarmasin in South Kalimantan
Biomass burning experiment:
Palembang, Sumatra; Parang karaya, central Kalimantan
Carbon budgets: Bukit Soeharto, Samalinda, ...
Atmospheric CO₂ measurement:
GAW station in Bukit Kototabang, Sumatra
Impacts of biomass burning on local/regional/global environment
Aerosol Measurements at Jambi Airport, Sumatra, during the last period of Forest Fires (November 7-16, 1997)

- Total Aerosols [525.2 μg/m³]
- Fine particles 83.6%
- Coarse particles 12.6%
- 3.8%

- Sampling dates at Jambi airport in 1997:
  - 7-8 Nov.
  - 8-9 Nov.
  - 9-10 Nov.
  - 11-12 Nov.
  - 13-14 Nov.
  - 15-16 Nov.

Graph showing aerosols (d <2 um) at Jambi Airport with T-mass, OC, and EC (μg m⁻³)
Methyl bromide (CH₃Br) and carbon monoxide (CO) concentrations by ground (and aircraft) measurements in the period of the forest fires (Oct.-Nov.1997) and of the non-forest fire period (Sep.1998)
Intensive field experiments on GHG emissions from soils in humid tropical forests
In Jambi, Sumatra

Sites: primary forests (P1, P2)
   - logged-over forest (L2)
   - logged-over forests → clear-cut and burned → rubber plantation (L1)
   - (clear-cut and burned →) Gmelina Arborea → rubber plantation (O)
   - (bush → rubber agro-forest) 4-year plantation (R)

Measurements:
   - Gas flux: CO2, CH4, and N2O fluxes from soils into the atmosphere
     (3 replicates, every month, closed chamber method)
   - Soil gas: CO2, CH4, N2O
   - Soil temperature, Soil moisture

Collection of soil samples:
   - analysis of physico-chemical properties of soils
   - incubation experiments:
     - Gas production potential of soils
     - Nitrification and denitrification rates
     - Microbial analysis
     - Isotopic analysis

2. Regional study on GHG fluxes from different ecosystems in Jambi, Sumatra
Land-use change in northern Jambi, including Pasirmayang Research Site by Landsat
The environmental conditions of 6 sites in Pasirmayang Research Site (PMRS) in Jambi, Sumatra

<table>
<thead>
<tr>
<th>Conditions</th>
<th>P1</th>
<th>P2</th>
<th>L2</th>
<th>L1</th>
<th>O*</th>
<th>R**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-use (1997)</td>
<td>primary forest</td>
<td>primary forest</td>
<td>logged-over forest</td>
<td>logged-over forest</td>
<td>rubber plantation</td>
<td>rubber plantation</td>
</tr>
<tr>
<td>Location</td>
<td>1°05.16’S 102°05.70’E</td>
<td>1°5.24’S 102°6.59’E</td>
<td>1°3.81’S 102°9.75’E</td>
<td>1°3.66’S 102°9.68’E</td>
<td>1°5.65’S 102°7.21’E</td>
<td></td>
</tr>
<tr>
<td>Deforestation period</td>
<td>(protected)</td>
<td>(protected)</td>
<td>clear-cut (Sep.97-Feb. 98) and burned (Mar.’98)</td>
<td>clear-cut and rubber (Aug.’96)</td>
<td>clear-cut rubber (Jul.’94)</td>
<td></td>
</tr>
<tr>
<td>Burning (Re-)plantation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>(note1)</td>
<td>(note2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>gentle middle slope</td>
<td>gentle middle slope</td>
<td>gentle flat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setting period</td>
<td>Jan.’97</td>
<td>Sep.’97</td>
<td>Sep.’97</td>
<td>Jan.’97</td>
<td>Jan.’97</td>
<td>Sep.’97</td>
</tr>
</tbody>
</table>

(note1): Vegetation of P1, P2 is a mixture of Shorea macrophylla, Dipterocarpus crimtus, etc.  
(note2): Vegetation of L2 is a mixture of Shorea macrophylla, Scaphium macropodum, etc.

*O*: A fast-growing tree species of Gmelina Arborea was planted but died soon.  
The young rubber was planted in 1998.

Undergrowth was Alng-alang(*Imperata cylindrica*).
Landsat TM
RGB=543
1999.4.9

P: Primary forest
L: Logged forest
R: Rubber plant
O: Open area

Scale

5 Kilometers
Just after clear-cut and burning, N$_2$O flux drastically increased, while CH$_4$ uptake gradually decreased.

Two years after cut and burning, N$_2$O and CH$_4$ fluxes were recovered to the same level as that before cut and burning.

This study showed the very quick recovery of GHG fluxes, compared to that in pasture in central America where N$_2$O enhancement lasted for ten years.
Long-term trends of CH4, CO2, and N2O fluxes at P2 (primary forest) and L2 (logged-over forest)

Note 1: CH4 flux was positive at P2
Note 2: Seasonal variation in CO2 and N2O fluxes
Nitrification is the major process of N$_2$O emission.

F(N$_2$O) = 0.176 + 9.55* N (F: µgN m$^{-2}$ h$^{-1}$, N: µgN g$^{-1}$ d$^{-1}$)

Global estimate of N$_2$O from tropical soils by IPCC were overestimated

Annual N$_2$O emission rate: 0.228, 0.380, 0.427 kgN ha$^{-1}$ y$^{-1}$ at P1, P2, L2 (this study)

Range of N$_2$O emission in tropical rain forests: 0.01-7.68 kgN ha$^{-1}$ y$^{-1}$ (Breuer et al., 2000)

Annual average N$_2$O emission from tropical rain forests: 1.364 kgN ha$^{-1}$ y$^{-1}$ (Potter et al., 1996)
1. Monthly mean negative CH₄ fluxes at PM (-22.1, -11.8, -26.1 µgC m⁻² h⁻¹ at P1, P2, L2) were lower than those (-32.8 ± 5.2 µgC m⁻² h⁻¹) in other tropical rain forests (Potter et al., 1996).
2. Positive CH₄ fluxes were frequently measured, and could be derived from termites.
3. Monthly mean CH₄ fluxes with only negative flux were still affected by termites.
4. It strongly suggests that the real CH₄ oxidation potential of soils could be larger than the observed CH₄ uptake rates.
1. Monthly mean CO₂ fluxes at PMRS (70.4, 92.1, 83.2 mgC m⁻² h⁻¹ at P1, P2, L2) were lower than the averaged value in tropical and subtropical lowland moist forests (143 mgC m⁻² h⁻¹) (Reich and Schlesinger, 1992) and comparable with relatively low CO₂ flux in tropical mountain areas (74-102 mgC m⁻² h⁻¹) (Reich, 1998).

2. This relatively low CO₂ flux is possibly attributed to low vegetation biomass (170 Mg ha⁻¹), compared to a reasonable average of 300 Mg ha⁻¹ for tropical rain forests (Laurance et al., 1998).

3. It makes the turnover rate of the carbon cycles of the ecosystems smaller in PMRS.

4. The CO₂ fluxes at PMRS were lower than those of other ecosystems.
Monthly mean GHG fluxes (Sep. 97 - Mar. 02)

Land-use change

Change in GHG fluxes through spatial site distribution could be equivalent to real land-use change from P1 → L1 → R.
Conclusions

I. Humid tropical forest soils

1. $\text{N}_2\text{O}$ emission was much lower than that in the other tropics.
   Annual $\text{N}_2\text{O}$ emission in the tropics by IPCC was overestimated.

2. Nitrification was the major process of $\text{N}_2\text{O}$ emission.

3. Heterotrophic nitrification is the main process of $\text{N}_2\text{O}$ production.

4. $\text{CH}_4$ uptake was much lower than in temperate forests, and could be influenced by $\text{CH}_4$ emission by termites.

5. $\text{CO}_2$ emission was lower than in the other tropics, possibly due to low vegetation biomass.
2. Regional study on GHG fluxes from different ecosystems and soil types in Jambi, Sumatra

Period: Sep. 2001
Sites: 27 sites in Jambi with 6 different land-use patterns
- Forests (primary and logged-over)
- Cinnamon plantation
- Rubber plantation (young and old-10 years)
- Oil-palm plantation (young and old-10 years)
- Alang-alang grasslands

with different soil types
(Udults, Ultisols and Entisols, Andisols)

Measurements:
- Gas flux: CO2, CH4, N2O (7 replicates)
- Soil gas: CO2, CH4, N2O (0~30cm)
- Soil temperature, soil moisture

Collection of soils:
- Analysis of physical and chemical properties of soils
- Gas production potential of soils
- Nitrification and denitrification rates
- Microbial analysis
- Isotopic analysis
Table 2. Number of plots in each soil type and land-use

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>F</th>
<th>C</th>
<th>oR</th>
<th>yR</th>
<th>oO</th>
<th>yO</th>
<th>A</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Udults</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Other Ultisols</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Andisols</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>27</td>
</tr>
</tbody>
</table>

*See Table 1 about the land-use code

Land-use type

- **F**: Forests (primary and logged-over)
- **C**: Cinnamon plantation
- **yR, oR**: Rubber plantation (young and old----10 years)
- **yO, oO**: Oil-palm plantation (young and old----10 years)
- **A**: Alang-alang grasslands

**with different soil types** (Udults, Ultisols and Entisols, Andisols)
$N_2O$ flux was affected by land-use pattern

$N_2O$ flux from Alang-alang grasslands was lowest

In Andisols, the nitrification rates were only 1/7 of that in other soil types

$N_2O$ flux was also affected by soil type.
STUDY ON LAND-USE/ LAND COVER CHANGE (LUCC) AND GREEN HOUSE GAS (GHG) EMISSION


* Bogor Agriculture University
** National Institute of Agro-Environmental Sciences
OBJECTIVES:

• DEVELOPMENT OF LAND-USE/COVER SPATIAL DATA FROM REMOTELY SENSED IMAGERY PHOTOGRAPHS AND DIGITAL DATA
  - 1986 – 1992 (JAMBI PROVINCE) : PHOTOGRAPHS, VISUAL INTERPRETATION
  - 1993 – 2000 (PASIR MAYANG) : DIGITAL INTERPRETATION

• QUANTIFYING LUCC:
  - 1986 – 1992 (JAMBI PROVINCE)
  - 1993 – 2000 (PASIR MAYANG)

• QUANTIFYING ABOVEGROUND BIOMASS LOSS

• ESTIMATION OF REGIONAL GHG EMISSION FROM SOIL UNDER DIFFERENT LAND-USE/COVER (PASIR MAYANG)

• ESTIMATION OF REGIONAL GHG EMISSION FROM BIOMASS BURNING (MUARA SABAK)
1. **Aboveground carbon stock data**

Information of aboveground carbon stock is derived from the result of field measurements of above ground biomass conducted by Center for Tropical Biology, Bogor-Indonesia, and Alternative Slash and Burn project conducted by International Center for Agroforestry Research (ICRAF).

2. **Soil Greenhouse gases flux measurement**

Soil GHG emission were conducted by Impact Center of South East Asia, National Institute of Agro-environmental Sciences, Japan; Forestry and Forest Product Institute, Japan; and National Institute for Resources and Environment, Japan.

3. **Emission Ratio of Biomass Burning**

Information of on-site burning emission ratio was derived from field measurement conducted in Sumatra-Indonesia, by National Institute for Resources and Environment, Japan and Fac. Forestry of IPB-Indonesia.
Land-use/land cover changes between 1986 and 1992

Legend:
- Provincial Boundary
- River
- Satanghad River
- Text: Sub-district name
- Sub-district Boundary
- Land-use/cover changes 1986-1992:
  - Cash crop plantation
  - Cultivated lands and secondary vegetation
  - Cultivated lands and settlement
  - Deforested areas
  - Degraded forest
  - Flood lands
  - Grasslands
  - Paddy field
  - Regenerated forest
  - Unchanged
  - Upland field
  - Urban areas
<table>
<thead>
<tr>
<th>Land-use/Land cover</th>
<th>Carbon Dioxide (ton/hour)</th>
<th>Nitrous Oxide (kg/hour)</th>
<th>Methane (kg/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logged forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>233.467</td>
<td>178.482</td>
<td>7.102</td>
</tr>
<tr>
<td>Bush/Shrubs (fallow lands)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>58.156</td>
<td>67.100</td>
<td>2.000</td>
</tr>
<tr>
<td>Rubber and Secondary vegetation (Rubber jungle)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.348</td>
<td>75.917</td>
<td>1.301</td>
</tr>
<tr>
<td>Grasslands</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.870</td>
<td>8.724</td>
<td>0.344</td>
</tr>
<tr>
<td>Bare lands</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.085</td>
<td>45.863</td>
<td>0.131</td>
</tr>
<tr>
<td>Total</td>
<td>346.927</td>
<td>376.085</td>
<td>10.878</td>
</tr>
</tbody>
</table>
To estimate carbon released directly from forest fire into the atmosphere, we make some assumption as follows:

50% of biomass of forest were removed from the site before forest fire. This is due the fact that commercial logs were already harvested.

Emission ratio per CO2 of secondary forest fire for CO, CH4, N2O, CH3Cl, CH3Br and CH3I are 0.265, 0.0392, 0.00582, 0, 0 and 0, respectively.

Gas conversion ratio from dry matter C to CO2 is 0.5

GHG EMISSION FROM BIOMASS BURNING

6 345 545 TON CO2
802.40 TON CH4
119.13 TON N20
840 784.71 TON CO
Thank you very much for your attention.

Thank so much to many researchers in Indonesia for productive collaboration for a long time.
Above ground carbon stock (ton/ha)

- Primary forest: 252.338
- Secondary forest: 58.053
- Logged forest: 155.178
- Fallow land/bush: 15
- Paddy and upland field: 7.5
- Cultivated and settlement: 3.75

Source: IC-SEA, BIOTROP
Adger and Brown
<table>
<thead>
<tr>
<th>Land-use/Land cover</th>
<th>Carbon stock per ha (ton C)</th>
<th>Area (ha)</th>
<th>Total above ground Carbon stock in (ton C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logged forest</td>
<td>155.2</td>
<td>66,273.25</td>
<td>50,664.75</td>
</tr>
<tr>
<td>Bush/Shrubs (fallow land)</td>
<td>15</td>
<td>10,014.50</td>
<td>11,554.75</td>
</tr>
<tr>
<td>Rubber and sec. vegetation</td>
<td>35.5</td>
<td>6,407.75</td>
<td>16,029.25</td>
</tr>
<tr>
<td>Grasslands</td>
<td>1.35</td>
<td>3,126.25</td>
<td>1,445.25</td>
</tr>
<tr>
<td>Barelands</td>
<td>0</td>
<td>973.75</td>
<td>7,339.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>86,795.50</strong></td>
<td><strong>87,033.00</strong></td>
</tr>
</tbody>
</table>


(c) Denitrifiers

![Bar chart showing MPN (log cells g⁻¹ SDW) for different sites and months: P1, P2, L1, L2, O, R. Oct. 1999 and Mar. 2000 data points are indicated.]

![Scatter plot showing N₂O flux (µg N h⁻¹ m⁻²) vs. denitrification activity (ngN h⁻¹ g⁻¹ SDW) for Mar. 2000 and Jun. 2000, with data points marked as filled circles and open squares, respectively.]
(b) Autotrophic nitrite oxidizers

(a) Autotrophic ammonia oxidizers
Table 2: Average of \(\text{N}_2\text{O}\) and NO production rate (\(\mu\text{g N}_2\text{O-N or NO-N d}^{-1} \text{ kg}^{-1} \text{ SDW}\))

<table>
<thead>
<tr>
<th></th>
<th>((\text{NH}_4)_2\text{SO}_4)</th>
<th>(\text{citric acid})</th>
<th>(\text{DCD})</th>
<th>((\text{NH}_4)_2\text{SO}_4)</th>
<th>(\text{citric acid})</th>
<th>(\text{DCD})</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.73</td>
<td>1.97</td>
<td>3.66</td>
<td>42.54</td>
<td>48.36</td>
<td>91.45</td>
</tr>
<tr>
<td>P2</td>
<td>0.81</td>
<td>1.91</td>
<td>3.02</td>
<td>57.50</td>
<td>28.57</td>
<td>47.54</td>
</tr>
<tr>
<td>L1</td>
<td>0.66</td>
<td>2.01</td>
<td>5.72</td>
<td>48.84</td>
<td>62.47</td>
<td>107.70</td>
</tr>
<tr>
<td>L2</td>
<td>0.49</td>
<td>1.35</td>
<td>3.34</td>
<td>3.01</td>
<td>32.88</td>
<td>70.55</td>
</tr>
<tr>
<td>O</td>
<td>0.29</td>
<td>0.90</td>
<td>0.86</td>
<td>16.23</td>
<td>25.22</td>
<td>40.24</td>
</tr>
</tbody>
</table>
| R     | 0.05                          | 0.16                     | 0.34           | 7.48                          | 6.67                     | 18.40          

\[y = 0.7656x + 1.0119\]
\[R^2 = 0.7471\]
Distribution of Tropical Peatlands

Venezuela, Brazil, etc.: 5.1 Mha
Zaire, Kenya/Uganda, etc.: 3.0 Mha
Malaysia: 2.4 Mha
Indonesia: 18.6 Mha
International Workshop
On
Land-Use Change and Greenhouse Gases, Soil C and Nutrient Cycling in the Tropics
19-21 Feb. 2002
Tsukuba, Japan

A special issue
of
Nutrient Cycling in Agroecosystems
On
Land-Use Change and Greenhouse Gases, Soil C and Nutrient Cycling in the Tropics
(Africa, America, and Asia)
To be published in 2004 (15 papers are included)


3. Intensive study on GHG fluxes at Pasirmayang Research sites

Period: Sep. 2001
Sites: 80 (grid---3m x 3m) including P1, P2

Measurements:
- Gas flux: CO2, CH4, N2O (no replication)
- soil temperature