Climate change mitigation potential of Japanese agricultural soils estimated by country-scale simulation of soil carbon stock change and CH₄ and N₂O emissions

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Outline

• Introduction – Research questions
• Methods – Modeling GHGs at country scale
  – CO₂ (Soil C): RothC (Shirato et al.)
  – CH₄: DNDC-rice (Fumoto et al.)
  – N₂O: Developing empirical model (this study)
  – Mitigation scenarios
• Results
  – Total emission of GHGs (1980-2013)
  – Mitigation potential and trade-off (2020-2050)
To assess the climate mitigation potential of Japanese agricultural soils through improved management practices, we have to answer two questions:

1. Historical trends in total GHG emissions (1980-2013)
2. Simulate future mitigation potential by comparing BAU and mitigation scenarios (2020-2050)

- at country scale
- all land-use categories (paddy, upland, orchard and grassland)

Evaluating total GHGs (GWP) considering “Trade-off”.
Country scale evaluation with models (IPCC tier 3) for each gas
Soil C (CO$_2$)

Led by Dr. Y. Shirato

- Shirato et al. 2004
- Shirato & Yokozawa 2005
- Yagasaki & Shirato 2014a, b

Soil C: Rothamsted Carbon (RothC) model

- Japanese version
- Modified RothC model for paddy soils and for Andosols (volcanic ash-derived soils)
Introduction

Results

Methods

Conclusions

Soil C: National-scale simulation using 3 versions

~50% of upland soils: Andosols

~50% of arable soils: Rice paddy

Volcanic ash derived \( \rightarrow \) Stable HUM + Al\(_{active}\)

Anaerobic condition \( \rightarrow \) Slow decomposition

Modified model

(Shirato et al., 2004)

Original RothC

(Shirato & Taniyama, 2003)

Modified model

(Shirato & Yokozawa, 2005)

Arable soils: ~500 million ha

Upland Andosols

Paddy

Upland (Other soils)

DNDC-rice model for simulating CH\(_4\) Emission from rice paddy

CH\(_4\)

Led by Dr. T. Fumoto and N. Katayanagi

- Katayanagi et al. 2016, 2017
**CH₄: DNDC-Rice model**

Modified version of DNDC for paddy rice field  
*(Fumoto et al., 2008, 2010, 2013)*

[Diagram showing the processes of decomposition, oxidation, methanogenesis, reduction, transport, diffusion, and assimilation of various elements and gasses.]

**New EFs generation by DNDC-rice for estimating CH₄ emission at national scale**

Temporal variability of the annual total CH₄ emission from Japanese paddy fields from 1990 to 2012 calculated by (upper) using EFs generated by DNDC-Rice model and (lower) the previous National Inventory Report  
*(Katayanagi et al., 2017)*
Empirical model for estimating Direct N$_2$O Emission from soils

N$_2$O

This study

✓ Andosols: ~50% of upland soils
✓ High SOC
✓ Stable humus with active Al
✓ Low N$_2$O emission

Difficulty on developing N$_2$O process model

Research mission: Estimate N$_2$O emission at national scale using model

Simple model that match the resolution of activity data (N application and managements)
✓ Simple model but could catch the effluence of climate and the difference of soil type

Soil types and distribution in Japan (Obara et al., 2016)
N₂O empirical model (Mu et al. 2009):
Linking N₂O emission to soil mineral N as estimated by CO₂ emission and soil C/N ratio

Cumulative N₂O emission = \( A \exp \left[ B \left( \frac{E_{CO2}}{SCN} + Fn \right) \right] \)

Mineralized N from OM
Decomposed CO₂: Changed with climate
C:N of organic matter
Chemical fertilizer N
RothC

Upland soils, N₂O&CO₂ datasets

Validation of Mu et al. (2009) at a plot scale
- Case in different N treatment-

Validation dataset: Sistani et al (2011) JEQ 40: 1797-1805
Upland Soil: Crider silt loam (Bowling Green, USA)
Crop/Treatment: No-till corn; Different N fertilizers (6 chemical fertilizers, 2 poultry litter, 1 control; 2009-2010)

Use data with author permission
Validation of Mu et al. (2009) using more datasets from different sites

Cumulative $\text{N}_2\text{O}$ emission = $A \exp [B(\frac{E_{\text{CO}_2}}{S_{\text{CN}}}+F)]$

Soil mineral N (kg N ha$^{-1}$) as $(\frac{E_{\text{CO}_2}}{S_{\text{CN}}}+F)$

RothC Activity data

Introduction Methods Results Conclusions

**N$_2$O: Contribution of land-use categories (2012)**

Upland contributed 49% > Paddy > Grassland ≒ (Orchard + Tea)

Tea emitted 3% of total with 1% planting area
Future projection

2 climate change scenarios: 1GCM × 2 emission scenarios
- MIROC5, rcp26
- MIROC5, rcp85

4 management scenarios:
- BAU
- Mitigation -1, 2, 3

Rcp: Representative Concentration Pathways

<table>
<thead>
<tr>
<th>Scenario</th>
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<th>Paddy water management</th>
<th>N fertilizer</th>
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<tbody>
<tr>
<td>BAU</td>
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</tr>
<tr>
<td>Mitigation1</td>
<td>+10%</td>
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</tr>
<tr>
<td>Mitigation2</td>
<td>+10%</td>
<td>Extend MSD</td>
<td>conventional</td>
</tr>
<tr>
<td>Mitigation3</td>
<td>+10%</td>
<td>Extend MSD -10%</td>
<td>-10%</td>
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MSD: Mid-season drainage

Summary: total mitigation potential

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Average of 2020-2050 (per year)
Average of two climate change scenarios

- +10% C input decrease CO2 but increase CH4 and N2O. Total GWP increase.
- Extending MSD decrease CH4 and its application in 50% paddy field can offset the above increase in GWP. Total GWP decrease.
- -10% N application decrease N2O. Total GWP decrease more (trade-off can be offset).
- “Mitigation scenario 3” can decrease 5% of total GWP including fossil fuel derived CO2.
Developing “Web tool” for calculating GHGs from Japanese agricultural soils

Web tool already established

http://soilco2.dc.affrc.go.jp/
Led by Dr. Y. Shirato

Calculator for Greenhouse gases from agricultural soils
- CO₂ (SoilC, fossil fuel)
- CH₄ (paddy rice)
- N₂O
- More mitigation options (coming soon)

Thank you for your attention.
Any question?

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