Assessing Alternatives for Mitigating Net Greenhouse Gas Emissions and Increasing Yields from Rice Production in China Over the Next 20 Years

Changsheng Li¹, William Salas², Benjamin DeAngelo³, and Steven Rose³

¹Complex Systems Research Center, University of New Hampshire, Durham, NH, 03824
²Applied Geosolutions, LLC, Durham, NH 03824
³Climate Change Division, Office of Atmospheric Programs, U.S. Environmental Protection Agency
Paddy area ~ 300,000 km²
Rice sown area ~ 470,000 km²
Rice Paddies with mid-season drainage (estimated)

Qingmu Chen, Chinese Acad. Agric. Sci., pers. comm.

A former study indicated CH$_4$ emission from rice agriculture in China was reduced by 5 Tg CH$_4$ due to midseason drainage applied from 1980-2000.
Questions:

Can net GHG emissions from rice paddies in China be reduced even further?

CH$_4$ is typically sole focus for rice systems, but N$_2$O and SOC effects can be significant.

How do mitigation options ‘rank’ with further consideration of crop yield and water resources effects?
Methane production driven by anaerobic conditions and available C:

\[ H_2 + C \rightarrow CH_4 \]
The principles for CH$_4$ mitigation:

1. Increase soil Eh by introducing oxidents (e.g., O$_2$, nitrate, Mn$_4^+$, Fe$_3^+$, sulfate etc.) into the CH$_4$-production systems;

2. Decrease availability of DOC.

Note: Any change in the two factors will also affect SOC dynamics and N$_2$O emissions.
Observed and modeled CH$_4$ and N$_2$O fluxes from paddy with mid-season drainings, Jiangsu Province, China, 1997 (field data from Zheng et al. 1999)

kg C or N/ha/day

- field N$_2$O
- DNDC N$_2$O
- field CH$_4$
- DNDC CH$_4$
The DNDC Model

**Ecological Drivers**
- Climate
- Soil
- Vegetation
- Human activity

**Soil Climate**
- Soil temp profile
- Soil moist profile
- O₂ diffusion
- soil Eh profile
- O₂ use
- vertical water flow
- annual average temp.
- Potential evapotranspiration
- LAI-regulated albedo

**Temperature**
- Water demand
- Water uptake
- Water stress
- N-demand
- N-uptake
- Daily growth

**Moisture**
- Root respiration
- N-uptake
- Root growth
- Soil Eh
- Soil profile
- Vertical water flow

**pH**
- Nitrogen cycle
- DOC
- NH₄⁺
- NO₃⁻
- N₂O
denitrification

**Eh**
- Root respiration
- Oxygen use
- Vertical water flow

**Substrates: NH₄⁺, NO₃⁻, DOC**
- Labile
- Resistant
- Microbes
- Very labile
- Labile
- Resistant
- humads
- Passive humus

**Denitrification**
- Nitrate denitrifier
- Nitrite denitrifier
- N₂O denitrifier
- NO
- NO₂
- N₂
- N₂O
- NO₃⁻

**Nitrification**
- Nitrifiers
- DOC
- NH₄⁺
- NH₃
- clay-NH₄⁺
- N₂O
- NO
- NH₃

**Fermentation**
- CH₄ production
- CH₄ oxidation
- CH₄ transport
- Soil Eh
- aerenchyma
- DOC

**Effect of temperature and moisture on decomposition**

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**Soil Environmental Factors**
- Temperature
- Moisture
- pH
- Eh

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**Plant Growth**
- Root respiration
- N-uptake
- Root growth
- Soil Eh
- Soil profile
- Vertical water flow

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**Decomposition**
- Labile
- Resistant
- Microbes
- Very labile
- Labile
- Resistant
- humads
- Passive humus
A regional prediction for China from 2000-2020:

Baseline management scenario:

-Crop yield increases at rate of 1% per year  
  (matching IFPRI projections)

-Rice area remains fixed over time  
  (IFPRI projects decline, with regional variation)

-Crop residue incorporation increases from 15% to 50% in 2000-2010; rice straw is amended at rate 1000 kg C/ha at early season; no animal manure is applied

-Urea and ammonium bicarbonate are used at rate 140 kg N/ha per crop season

-80% rice paddies are under midseason drainage
Biogeochemical Implications:
- Improve soil aeration;
- Stimulate root/shoot development;
- Increase soil mineralization.

Consequences:
- Increase crop yield;
- Decrease water consumption;
- Alter GHG emissions.
A regional prediction for China from 2000-2020:

Alternative management scenario:
1. Marginal flooding
2. Upland rice
3. Off-season rice straw amendment
4. Ammonium sulfate
5. Fertilizer with slow-release rate
A regional prediction for China from 2000-2020:

- For each management scenario, DNDC simulated crop growth, soil water dynamics, and soil C and N biogeochemistry for each of 11 rice-rotated farming systems in 2,473 counties at daily time step for 21 years from 2000-2020;

- Crop yield, water consumption, and GHG fluxes from each farming system were summed up to get a county total. The county totals were further integrated to obtain watershed or national inventories.
DNDC-Predicted Total Emissions of CH₄ from Rice Yields in China in 2000-2020: Baseline v. Alternative Management Scenarios

Rice area remains constant in these runs
DNDC-Predicted Total Emissions of N$_2$O from Rice Yields in China in 2000-2020: Baseline v. Alternative Management Scenarios

Rice area remains constant in these runs.
DNDC-Predicted Total Emissions of CO$_2$ from Rice Yields in China in 2000-2020: Baseline v. Alternative Management Scenarios

Rice area remains constant in these runs

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**Graph Title:** DNDC-Predicted Total Emissions of CO$_2$ from Rice Yields in China in 2000-2020: Baseline v. Alternative Management Scenarios

**Graph Description:** The graph illustrates the predicted total CO$_2$ emissions from rice yields in China from 2000 to 2020 across different management scenarios. The x-axis represents the years from 2000 to 2020, while the y-axis indicates the CO$_2$ flux in Tg CO$_2$ equivalent per year. Various scenarios are color-coded: Base (black), Shallow (purple), Sulfate (green), Uplandrice (cyan), and OffStraw (red).

**Key Points:**
- The CO$_2$ flux, initially negative, shows a decreasing trend in the early years, with the Base scenario showing the least negative flux.
- As years progress, the CO$_2$ flux for all scenarios becomes increasingly positive, indicating an increase in emissions.
- Rice area remains constant in these runs.

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**Note:** The graph visually represents the emissions data and highlights the differences in CO$_2$ emission scenarios for rice cultivation in China over the specified period.

Rice area remains constant in these runs.
Predicted rice yield under different management scenarios

Rice yield, kg C/ha per season

Year

Continuous flooding
Midseason drainage
Marginal flooding
Upland rice
Sulfate fertilizer
Slow-release fertilizer
Off-season straw amendment
Census data
Rice field water demand under different management conditions

- Continuous flooding
- Midseason drainage
- Shallow flooding
- Upland rice
- 20% yield increase
- Sulfate fertilizer

Baseline

Water demand, mm water/yr

- Transpiration
- Evapotranspiration
DNDC Predicts 2000 Crop Yield and GHG Emissions under Different Climate/Soil/Management Conditions at County Scale

**Haidian, Beijing**

**Xishan, Yunnan**

- Continuous flooding
- Midseason drainage
- Shallow flooding
- Upland rice
- Sulfate
- Offseason straw
- Slow fertilizer

Yield in kg CO₂ equivalent or dry matter/ha

- CO₂
- CH₄
- N₂O
Discussion:

1. Results indicate 2000 net GHG level can be further reduced by 20-80%.

2. Based on net GWP calculations, effectiveness order of alternatives:
   - upland rice
   - shallow flooding
   - sulfate fertilizer
   - off-season straw amendment

3. Change in water management showed to be most effective in reducing both CH$_4$ and N$_2$O.

4. Shallow flooding decreased CH$_4$ by 1/2 and N$_2$O by 1/3. Upland rice eliminated CH$_4$ and reduced N$_2$O by 1/3. The two options slightly decreased soil C sequestration rates by <20 Tg CO$_2$ eq/yr.

5. Adopting ammonium sulfate slightly depressed CH$_4$ although significantly decreased N$_2$O.

6. Shifting straw amendment from in-season to off-season slightly decreased CH$_4$ but almost no effect on N$_2$O or SOC.
Discussion (continued):

7. Based yield predictions, alternatives can be divided into 3 groups:
   - Slow-release fertilizer & shallow flooding increased yield.
   - Sulfate & off-season straw incorporation almost no effects on yield.
   - Continuous flooding & upland rice significantly decreased crop yield.

8. Based on water use prediction:
   - Shallow flooding & upland rice significantly reduced water consumption.
   - Alternative water management practices mainly affected surface water and soil evaporation while plant physiological demand for water (i.e., transpiration) basically remained unchanged.
   - This study adopted 1990 climate data for all simulated 21 years -- no significant inter-annual variations in water consumption observed. Effect of inter-annual yield increase on field water consumption was relatively small.