Effects of surface drainage during fallow seasons on mitigating methane emissions from poorly-drained paddy fields in Japan

Yutaka Shiratori

Niigata Agricultural Research Institute, Nagaoka, Niigata, Japan
Methane (CH$_4$) is the second most important greenhouse gas after carbon dioxide (CO$_2$). Paddy fields are one of the sources of CH$_4$ in the atmosphere. Therefore, it is demanded to develop newly technologies to mitigate CH$_4$ emissions from paddy fields.
CH$_4$ is produced in paddy soil under reduced condition by methanogen, which is an obligate anaerobe. In contrast, CH$_4$ production is decreased under oxidized condition.
Mitigation options for CH$_4$ emission

- **Water management during rice growing season**
  Mid-summer drainage and intermittent irrigation
  Short flooding (*ex.* Alternate Wetting and Drying)

- **Soil amendments**
  Substitute compost for flesh rice straw or green manure
  Rice straw incorporate in previous autumn

- **Direct soil oxidation**
  and/or apply electron accepters to soils

- **Organic matter management**
  Substitute compost for flesh rice straw or green manure
  Rice straw incorporate in previous autumn

- **Deceasing substrate of CH$_4$**
  and/or decreasing electron donors in soils
The CH$_4$ emissions during rice growing seasons were correlated to the soil moistures just before first submergence.

CH$_4$ emission may decrease if dry the paddy soil during fallow seasons.

The purpose of this research is to clarify the influence of surface drainage during fallow seasons on CH$_4$ emissions following rice-growing seasons from poorly-drained paddy fields.
# Materials and Methods

1. One paddy field was divided in two parts by a levee.

2. Three treatments of organic matter applications were set up.

3. One part was drained rain and snow melt water during fallow season by open ditches which about 0.1 m depth. The other part was not drained in this period.

## Design of the experiment field

<table>
<thead>
<tr>
<th>Drainage part (D-part)</th>
<th>Rice straw + Rice husk</th>
<th>Rice straw</th>
<th>None</th>
<th>Rice straw + Rice husk</th>
<th>Rice straw</th>
<th>None</th>
<th>Rice straw + Rice husk</th>
<th>Rice straw</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(D-SH)</td>
<td>(D-S)</td>
<td>(D-N)</td>
<td>(D-SH)</td>
<td>(D-S)</td>
<td>(D-N)</td>
<td>(D-SH)</td>
<td>(D-S)</td>
<td>(D-N)</td>
</tr>
<tr>
<td>Levee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-drainage part (ND-part)</td>
<td>Rice straw + Rice husk</td>
<td>Rice straw</td>
<td>None</td>
<td>Rice straw + Rice husk</td>
<td>Rice straw</td>
<td>None</td>
<td>Rice straw + Rice husk</td>
<td>Rice straw</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(ND-SH)</td>
<td>(ND-S)</td>
<td>(ND-N)</td>
<td>(ND-SH)</td>
<td>(ND-S)</td>
<td>(ND-N)</td>
<td>(ND-SH)</td>
<td>(ND-S)</td>
<td>(ND-N)</td>
</tr>
</tbody>
</table>
Organic matter applications (19 October 2010)

Rice straw 7 t ha\(^{-1}\) in D-SH, ND-SH, D-S and ND-S plots.

Rice husk 4 t ha\(^{-1}\) in D-SH and ND-SH plots.
Incorporating (21 October 2010)

Plow depth 0.1 m

Drainage Part
Non-drainage part

Levee
Just snow thaw
3 April 2011
13 days after snow thaw
16 April 2011

Open ditches
Basal application
26 April 2011
Tillage (Plow depth 0.15m) and submergence
26 April 2011

D-part soils were brown

ND-part soils were blue gray
Start of mid-summer drainage
15 June 2011
End of mid-summer drainage
12 July 2011
Harvest time
7 September 2011
CH$_4$-C emission rate during rice growing season from each plot.

Bars indicate standard deviation ($n=3$). Arrows indicate the time of agricultural management operations; D, drainage; H, harvest; II, intermittent irrigation; MD, mid-summer drainage; S, submergence; TP, transplanting.
N$_2$O-N emission rate during rice growing season from each plot.

Bars indicate standard deviation ($n=3$). Arrows indicate the time of agricultural management operations; D, drainage; H, harvest; II, intermittent irrigation; MD, mid-summer drainage; S, submergence; TP, transplanting.
Mean amounts of cumulative CH$_4$ and N$_2$O emissions as global warming potentials (GWPs) in each plot.

Using global warming potential of 25 and 298 for CH$_4$ and N$_2$O, respectively. Bars indicate standard deviation ($n=3$). *Significant differences ($p<0.05$) between D and ND parts. Numbers indicate reduction rate.
Soil redox potential (Eh) of each rice straw application plots in drainage part and non-drainage part.

Arrows indicate the time of agricultural management operations; D, drainage; H, harvest; II, intermittent irrigation; MD, mid-summer drainage; S, submergence; TP, transplanting.
Changes in ferrous iron ($\text{Fe}^{2+}$) concentrations in flesh soils from just before first submergence to the start of mid-summer drainage.

Bars indicate standard deviation ($n = 3$). Arrows indicate the time of agricultural management operations; MD, mid-summer drainage; S, submergence; TP, transplanting.
Incubation experiment treated with amorphous oxidative iron (Asami et al. 1970)

In the control soil, not only CO\textsubscript{2} but also CH\textsubscript{4} is formed, while in the treated soil with amorphous oxidative iron, organic matter is decomposed as CO\textsubscript{2} under oxidative conditions.
Relationships between ferric-ferrous iron, soil organic carbon decomposition and CH$_4$ emission in different water managements.

Non-drainage during fallow season

Drainage during fallow season
Conclusion

Surface drainage during fallow seasons in poorly-drained paddy fields greatly reduced CH$_4$ emissions in the following rice growing season.

- Reduction rates of CH$_4$ emissions depend on the surface drainage during fallow seasons was approximately 45 %.
- Surface drainage during fallow seasons increased the amounts of ferric iron in soils at the time of first submergence. As a result, CH$_4$ production potentials and emissions were reduced in following rice growing season.
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Yutaka Shiratori
Niigata Agricultural Research Institute, Nagaoka, Niigata, Japan
sira@ari.pref.niigata.jp

Key words: fallow season, ferrous iron, methane emission, paddy, surface drainage

Introduction
To evaluate the effects of surface drainage during fallow seasons on methane (CH$_4$) emission following rice-growing seasons from poorly-drained paddy fields, intensive field experiments were conducted from Sep 2010 to Sep 2011.

Materials and Methods
The field experiments were conducted in rice paddy fields located in Nagaoka, Niigata Prefecture, Japan (37°36′N, 138°51′E). The experiment was designed to have 6 treatments (Table). On Sep 2010, one paddy field was divided in two parts by a levee. One part was drained rain and snow melt water during fallow season from 27 Oct 2010 to 25 April 2011 by making open ditches which about 0.1 m depth (D part). The other part was not drained in this period (ND part). Each part had 3 treatments of organic applications. Rice straws and/or rice husks were incorporated in 21 Oct 2010. After first submergence in 26 April 2011, rice cultivation and field management was similar on each part.

Results and Discussion
Methane fluxes were first observed only 5 days after transplanting (DAT) in ND-SH and ND-S, whereas those were not observed until 15 DAT in D-SH and D-S (Fig.1). CH$_4$ flux of ND-SH was more rapidly increased than that of ND-S. In contrast, CH$_4$ fluxes of D-SH and D-S were later increased than that of ND-S, and both were similarly increased. CH$_4$ fluxes of ND-N and D-N were much lower than that of other plots. All CH$_4$ fluxes were deceased after the start of mid-summer drainage in 15 June 2011.

Just before first submergence, ferrous iron (Fe$^{2+}$) concentrations in fresh soils were only a little in each plot of D part. However, Fe$^{2+}$ concentrations of ND-SH, ND-S and ND-N were 2 - 4 g kg$^{-1}$ in that period (Fig. 2). Those results indicated that the soils of ND part were already under reductive conditions before first submergence, whereas the soils of D part were under oxidative conditions. After submergence, Fe$^{2+}$ concentrations of all plot soils were increased with soil reduction. In particular, those of ND-SH were reached to about 7 g kg$^{-1}$ in 20 May 2011 and not increased until the start of mid-summer drainage. In contrast, Fe$^{2+}$ concentrations of other plot soils were continuously increased in that time. This indicated that, in ND-SH, the ferric iron which then acted as an electron acceptor and inhibited CH$_4$ production was likely to be used up earlier than other plots.

In the same organic application treatments, global warming potentials (GWP$s$) which combined cumulative CH$_4$ and nitrous oxide (N$_2$O) emissions during rice-growing season were significantly lower in D part than ND part (Fig. 3). Mean reduction rate depend on the surface drainage during fallow season was approximately 45 %.
### Table
Treatments of drainage and organic matter application in each plot

<table>
<thead>
<tr>
<th>Plot abbreviation of treatment</th>
<th>Drainage during fallow season</th>
<th>Organic matter application*</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-SH</td>
<td>Drained</td>
<td>Rice straw 7 t ha(^{-1})</td>
</tr>
<tr>
<td>ND-SH</td>
<td>Non Drained</td>
<td>Rice husk 4 t ha(^{-1})</td>
</tr>
<tr>
<td>D-S</td>
<td>Drained</td>
<td>None</td>
</tr>
<tr>
<td>ND-S</td>
<td>Non Drained</td>
<td>None</td>
</tr>
<tr>
<td>D-N</td>
<td>Drained</td>
<td>None</td>
</tr>
<tr>
<td>ND-N</td>
<td>Non Drained</td>
<td>None</td>
</tr>
</tbody>
</table>

*Rice straw and/or rice husk were incorporated in 21 Oct 2010.

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**Fig. 1** Rice-growing season \(\text{CH}_4\)-C emission rate from each plot. Bars indicate standard deviation (\(n =3\)). Arrows indicate the time of agricultural management operations; D, drainage; H, harvest; II, intermittent irrigation; MD, mid-summer drainage; S, submergence; TP, transplanting.

**Fig. 2** Changes in ferrous iron concentrations in flesh soils from just before first submergence to the start of mid-summer drainage. Bars indicate standard deviation (\(n =3\)).

**Fig. 3** Mean amounts of cumulative methane (\(\text{CH}_4\)) and nitrous oxide (\(\text{N}_2\text{O}\)) emissions as global warming potentials (GWPs) in each plot. Using global warming potential of 25 and 298 for \(\text{CH}_4\) and \(\text{N}_2\text{O}\), respectively. Bars indicate standard deviation (\(n =3\)). *Significant differences (\(p < 0.05\)) between D and ND parts. Numbers indicate reduction rate.

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**Conclusions**
Surface drainage during fallow seasons in poorly-drained paddy fields greatly reduced \(\text{CH}_4\) emissions in the following rice-growing season by improving aerobic conditions and reducing \(\text{CH}_4\) production potentials.

**References**