Pathways of N₂O emission from rice paddy soil
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Abstract

The pathways of nitrous oxide (N₂O) emission from a paddy soil were investigated in a pot experiment. The results indicate that the main pathway of N₂O emission from rice–soil system depends on the soil water status. When the soil was flooded, the emission was predominantly (87.3% on average) through the rice plants, while in the absence of floodwater, N₂O was emitted mainly through the soil surface, with only 17.5% on the average released through the plants. Cutting the rice stems below water surface immediately decreased the N₂O flux to 55.8% of that before cutting, while the N₂O flux from the pots with intact plants did not change. Two days after the cutting, the average N₂O flux from the cut pots was 51.1% of that from the intact pots. During the absence of floodwater, cutting the rice stems did not significantly affect the N₂O flux compared with that from the pots with intact plants. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Nitrous oxide; Rice plant; Paddy soil

Nitrous oxide emissions from paddy fields, although small compared with those from upland systems, represent a substantial source of atmospheric N₂O (Hasegawa et al., 1998; Xing, 1998). The pathway of the release of N₂O from paddy soils is less well documented than that of CH₄, which is transported from the soil to the atmosphere, predominantly through the rice plants (Cicerone and Shetter, 1981; Seiler et al., 1984; Holzapfel-Pschorn et al., 1986). By comparing N₂O fluxes in chambers with and without rice plants, Mosier et al. (1990) demonstrated that young rice plants facilitated the efflux of N₂O from paddy soil to the atmosphere. By distinguishing between N₂O emission from rice plants and the soil/water interface, Yu et al. (1997) showed that, similar to CH₄ emission, more than 80% of the N₂O emission from paddy soil was through the rice plants. However, they conducted their experiments when the soils were flooded, but N₂O emission from paddy fields occurs primarily during the drier periods of the rice growth season (Cai et al., 1997; Xing, 1998). We therefore carried out pot experiments to investigate the pathways of N₂O emission from paddy soil in the presence and absence of floodwater.

Paddy soil was collected from Wuxi, Jiangsu province (31° 37’ N, 120° 29’ E). It was air-dried and passed through a 1 cm mesh sieve. It contained 1.39 g kg⁻¹ N and 14.6 g kg⁻¹ C and had a pH value of 6.9. Samples of 14 kg of soil (dry weight basis) were mixed thoroughly with 2.8 g urea, 2.5 g KH₂PO₄ and 0.7 g KCl and packed in specially designed PVC pots (30 cm high × 25 cm diameter). As shown in Fig. 1, the top of each pot was surrounded by a water-filled trough, which allowed a chamber to stand on the pot and prevent gas exchange during sampling periods. A PVC plate with a hole in the center and four downward pipes (1.5 cm diameter) were placed on the pot. The rim of the plate was submerged in the water trough and the pipes were inserted into the soil. The hole in the center of the plate allowed both the exchange of air and the addition of floodwater.
between sampling occasions and was sealed by a rubber stopper during sampling periods to allow the withdrawal of headspace gas.

After the soil was flooded, three rice seedlings were transplanted into each pipe. Thirty days later, when the pipes were filled with rice stems, silicone sealant was applied to prevent gas leakage from inside the pipes. After 24 h the sealant had dried and measurement of the N\textsubscript{2}O fluxes from the rice plants and the soil/water surface commenced. On each sampling occasion, 20 ml of gas was withdrawn from the head-space under the plate into an evacuated vial and then a chamber was immediately placed on the pot and 20 ml of gas in the chamber was sampled. Thirty minutes later, the headspace gases in the chamber and under the plate, were sampled again. The exact time that elapsed between the two sampling occasions was recorded. The first flux measurement was made about two hours after the floodwater was drained and the second measurement was made two days later. The soil was then flooded again and the gas fluxes were measured on five consecutive days. The floodwater was then drained again and the gas flux measurement was repeated. The N\textsubscript{2}O concentrations in the gas samples were determined by gas chromatography (HP 5890 GC) equipped with an electron capture detector.

The experiment was conducted using three pots to obtain data in triplicate and the mean values and standard deviation were calculated.

Table 1 shows the N\textsubscript{2}O fluxes from rice plants and the soil/water interface. In the presence of floodwater, N\textsubscript{2}O emission from the soil–rice system was predominantly (87.3% on average) through the rice plants, while in the absence of floodwater, N\textsubscript{2}O was emitted mainly through the soil surface, with only 17.5% on average released through the plants.

<table>
<thead>
<tr>
<th>No. in sampling sequence</th>
<th>Water status</th>
<th>N\textsubscript{2}O flux from soil/water surface (g N pot\textsuperscript{-1} h\textsuperscript{-1})</th>
<th>N\textsubscript{2}O flux from rice plant (g N pot\textsuperscript{-1} h\textsuperscript{-1})</th>
<th>% of emission from rice plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>unsaturated</td>
<td>4.6 ± 2.6</td>
<td>1.8 ± 1.3</td>
<td>24.4 ± 9.5</td>
</tr>
<tr>
<td>2</td>
<td>unsaturated</td>
<td>93 ± 41</td>
<td>6.7 ± 1.7</td>
<td>7.3 ± 2.1</td>
</tr>
<tr>
<td>3</td>
<td>unsaturated</td>
<td>5.5 ± 2.2</td>
<td>1.3 ± 0.2</td>
<td>20.7 ± 8.5</td>
</tr>
<tr>
<td>4</td>
<td>flooded</td>
<td>0.64 ± 0.26</td>
<td>7.92 ± 6.02</td>
<td>87.5 ± 10.5</td>
</tr>
<tr>
<td>5</td>
<td>flooded</td>
<td>0.42 ± 0.32</td>
<td>4.82 ± 3.65</td>
<td>86.4 ± 12.0</td>
</tr>
<tr>
<td>6</td>
<td>flooded</td>
<td>0.44 ± 0.50</td>
<td>5.89 ± 5.03</td>
<td>81.9 ± 20.8</td>
</tr>
<tr>
<td>7</td>
<td>flooded</td>
<td>0.26 ± 0.10</td>
<td>9.71 ± 0.20</td>
<td>88.3 ± 16.8</td>
</tr>
</tbody>
</table>

Table 1: N\textsubscript{2}O emission fluxes from rice paddy soil in the first pot experiment. Results are presented as mean ± standard deviation.
the soil surface in nine pots to give three sets in triplicate. The pots were of the same design as those used in the earlier experiment as described above, but without the PVC plates. Thirty-five days after the rice seedlings were transplanted, the rice stems were cut below the water surface in one set of three pots. N$_2$O fluxes were measured from this set of pots and also from one set of three pots in which the plants remained uncut. The N$_2$O flux measurements were made on three occasions: before the rice plants were cut, immediately after cutting and two days after cutting. The water in the two sets of pots in which the plants were still uncut was drained. The rice stems in one set of pots were then cut under drained conditions. The N$_2$O fluxes were again measured in all six pots (three with cut rice and three with uncut rice plants) at three times: before rice cutting, immediately after cutting and two days after cutting.

When the soil was flooded with 2 cm water, removal of the above-ground parts of the rice plants immediately decreased the N$_2$O flux to 55.8% of that before cutting, while the N$_2$O fluxes from the pots with intact plants did not change. Two days after cutting, the average N$_2$O flux from the pots containing cut plants was 61.2% of that before cutting and 51.1% of that from the pots with intact plants (Fig. 2a). This result supports the conclusion that rice plants are an important pathway of N$_2$O emission in the presence of floodwater. However, cutting the above-ground parts of plants did not reduce the N$_2$O flux by as much as 87% (the percentage of N$_2$O emission through the rice plants in the previous experiment) and this may be explained as follows. Firstly, Seiler et al. (1986) demonstrated that cutting rice shoots above the water surface did not significantly affect the CH$_4$ emission rate, showing that the conductance of the plants was unaffacted. If this is also the case for N$_2$O, cutting the rice stems below the water surface in the present experiment may have led to an increase in dissolved N$_2$O in the floodwater, resulting in an increase in N$_2$O emission through the water surface. Secondly, cutting rice stems below the water surface would have restricted the transport of O$_2$ to the rhizosphere, resulting in a more anaerobic environment favorable to the generation of N$_2$O via denitrification. In addition, the physical damage to the plants by cutting would have increased the exudation of organic C from the roots and this may have stimulated the production of N$_2$O, as reported by Beck and Christensen (1987) in grassland.

In non-flooded conditions, soil moisture decreased rapidly because of the high temperature, resulting in decreased N$_2$O emission fluxes from both cut and uncut pots. Compared with the uncut pots, cutting the rice stems did not significantly affect the N$_2$O emission (Fig. 2b). This result supports the conclusion that N$_2$O is emitted primarily through soil the surface in the absence of floodwater.

Rice and other hydrophytes develop ventilation systems to facilitate the transport of O$_2$ from the atmosphere to the rhizosphere. Nouchi et al. (1990) suggested a mechanism for CH$_4$ transport through rice plants, i.e. CH$_4$ dissolved in the soil water surrounding the roots diffuses into the cell-wall water of the root cells, gasifies in the root cortex and is then transported to the shoots via the ventilation system and released mostly through the micropores in the leaf sheaths. They indicated that this mechanism might also be applicable to other gases dissolved in paddy soil water. However, upland crops (which, in contrast to hydrophytes, do not develop ventilation systems) were also found to be able to transport N$_2$O from the soil to the atmosphere when the soil was saturated (Chang et al., 1998). This observation is consistent with the results of our experiment. The mechanism of N$_2$O transport through the rice plant is thus poorly characterized and deserves further investigation.

Acknowledgements

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transport from the rhizosphere to the atmosphere through rice plants. Plant Physiology 94, 59–66.

