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Short Communication

Rich soil carbon and nitrogen but low atmospheric greenhouse gas fluxes from North Sulawesi mangrove swamps in Indonesia

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HIGHLIGHTS

- North Sulawesi mangrove swamps are rich in soil organic carbon and nitrogen.
- N_2O, CH_4 and CO_2 fluxes from North Sulawesi mangrove soils are low.
- CO_2 flux is negatively correlated with soil water content and organic carbon.
- High porewater salinity decreases N_2O flux.

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ABSTRACT

The soil to atmosphere fluxes of greenhouse gases N_2O, CH_4 and CO_2 and their relationships with soil characteristics were investigated in three tropical oceanic mangrove swamps (Teremaal, Likupang and Kema) in North Sulawesi, Indonesia. Mangrove soils in North Sulawesi were rich in organic carbon and nitrogen, but the greenhouse gas fluxes were low in these mangroves. The fluxes ranged -6.05–13.14 μmol m^{-2} h^{-1}, -0.35–0.61 μmol m^{-2} h^{-1} and -1.34–3.88 mmol m^{-2} h^{-1} for N_2O, CH_4 and CO_2, respectively. The differences in both N_2O and CH_4 fluxes among different mangrove swamps and among tidal positions in each mangrove swamp were insignificant. CO_2 flux was influenced only by mangrove swamps and the value was higher in Kema mangrove. None of the measured soil parameters could explain the variation of CH_4 fluxes among the sampling plots. N_2O flux was negatively related to porewater salinity, while CO_2 flux was negatively correlated with water content and organic carbon. This study suggested that the low gas emissions due to slow metabolisms would lead to the accumulations of organic matters in North Sulawesi mangrove swamps.

1. Introduction

Mangrove swamps are regularly flooded, and their soils, which alter between oxic and anoxic, favor microbiological processes responsible for greenhouse gas productions and emissions (Rivera-Monroy and Twilley, 1996; Krithika et al., 2008), which would contribute to global warming problem. Some mangrove swamps have been recognized as contributors to atmospheric greenhouse gas emissions and the fluxes were found to be regulated by soil characteristics and positively related with carbon and nutrients contents (e.g. Allen et al., 2007, 2010; Chen et al., 2010).

The vast Indonesian archipelago represents the world hot spot for mangrove extent (FAO, 2005) and the mangrove swamps in this district have been characterized by rich carbon and nitrogen in their soils (e.g. Sukardjo, 1994; Hinrichs et al., 2009; Chen et al., unpublished), which show significant spatial variations with mangrove swamps and tidal positions. However, the emission characteristics of greenhouse gases from Indonesian mangrove swamps are poorly characterized. The present study therefore aimed to test the significance of greenhouse gas fluxes from the carbon- and nitrogen-rich mangrove soils in North Sulawesi, and examine whether the spatial variations in soil characteristics would lead to the changes in greenhouse gas fluxes. We hypothesized that the atmospheric greenhouse gases fluxes from

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mangrove soils rich in carbon and nitrogen would be high and their spatial variations would be related to soil properties.

2. Materials and methods

2.1. Study sites

The province of North Sulawesi is located at 0°30″ 4°3″ North Latitude and 121°127″ East Longitude. North Sulawesi has a typical equatorial climate, and the mean temperatures at sea level are uniform, varying by only a few degrees throughout the region and throughout the year, from 20 to 28 °C. Tides in this area are mixed and mainly semi-diurnal, and fluctuate slightly with an annual tidal range of 2.4 m. The present study was carried out in three oceanic mangrove swamps (Fig. 1), Teremaal (1°41′48.12″N, 124°58′19.56″E), Likupang (1°40′32.88″N, 125°2′3.84″E) and Kema (1°23′2.40″N, 125°5′46.32″E). In these mangrove swamps, *Rhizophora apiculata* and *Bruguiera gymnorrhiza* are the most dominant plant species. *Sonnertia alba* is also the comment species in Teremaal and Kema, while in Likupang, the co-dominant species is *Rhizophora lamarckii* (Ulumuddin et al., Unpublished). These study sites are subjected to strong influences of two monsoons, the wet northwest monsoon from November to March and the dry southeast monsoon from May to September (Aldrian and Susanto, 2003). The present study was carried out in April, the transition period. During our sampling dates, thunder shower occurred at the moon time. To avoid the effect of rainfall on our study, the investigations were done during non-rainfall and sunny period in the daytime.

2.2. Greenhouse gas samplings and flux measurements

Gas fluxes were quantified at low tides at three sampling stations, landward (LW), middle zone (MZ) and seaward (SW) in each mangrove swamp using static chamber method (Chen et al., 2010) and six replicate samples were collected at each sampling station. The tidal range, tidal flooding and exposure duration, as well as the meteorological condition, were comparable among sampling days and three mangrove swamps. The greenhouse gases concentrations were simultaneously analyzed by an Agilent 7890A GC system configured with a single channel using two detectors. N_2O concentration was determined with a 63Ni electron capture detector (μECD) and CH_4 was determined with a flame ionization detector (FID). CO_2 was analyzed by a FID after methanization. The temperature of the injector, column, μECD and FID were 100, 60, 350 and 250 °C, respectively. Gas concentrations were quantified by comparing peak areas of samples against Agilent Greenhouse Gas Checkout Sample (1 ppm N_2O, 5 ppm CH_4 and 600 ppm CO_2 in N_2).

2.3. Sampling and analyses of soil

Soil parameters were also measured (three replicates) at these sampling stations. After the gas sampling, the redox potential (E_h) of soil under the chamber was measured using a pH/E_h meter (IQ 150, Spectrum Technologies, Inc.) by inserting the platinum probe directly into the soil at a depth of 5 cm from the surface prior to soil collection. Soil cores (0–15 cm) under the chambers were then collected using hand-held PVC corers. The salinity of porewater was measured using a pocket refractometer (0–100 parts per thousand, Atago PAL-06S, Japan). Soil organic carbon (OC) concentration was analyzed using rapid dichromate oxidation procedure. Total Kjeldahl nitrogen (TKN) content after Kjeldahl digestion and NH_4^+-N and NO_3^--N contents in the KCl (2M) extracts were measured by the Continuous Flow Analyzer (CFA, Futura II, Alliance Instruments). All soil analyses were based on the standard methods for soil analyses described by Page et al. (1982), and data were expressed in terms of 105 °C oven-dried weight.

2.4. Statistical analysis

Two-way analysis of variance (ANOVA) was used to test any difference in greenhouse gas fluxes among the three mangrove swamps and the three sampling positions in each swamp. If the difference was significant at $p < 0.05$, a Post-hoc Student–Newman–Keul test was used to determine where difference lies. Pearson correlation coefficients were calculated to determine the relationships between soil properties and greenhouse gas fluxes. All statistical analyses were performed using SPSS 17.0 for Windows (SPSS Inc. USA).

3. Results and discussion

The mangrove soils in North Sulawesi were mainly consisted of plant detritus (by observation) and rich in organic carbon and nitrogen (Table 1). High soil carbon storage has been reported in Bunaken National Park mangrove swamp (Murdiyarso et al., 2010) in North Sulawesi; the high soil C and N measured in this study further indicated huge soil carbon and nitrogen storages in North Sulawesi mangrove swamps. Despite the high soil C and N as well as inorganic N concentrations in North

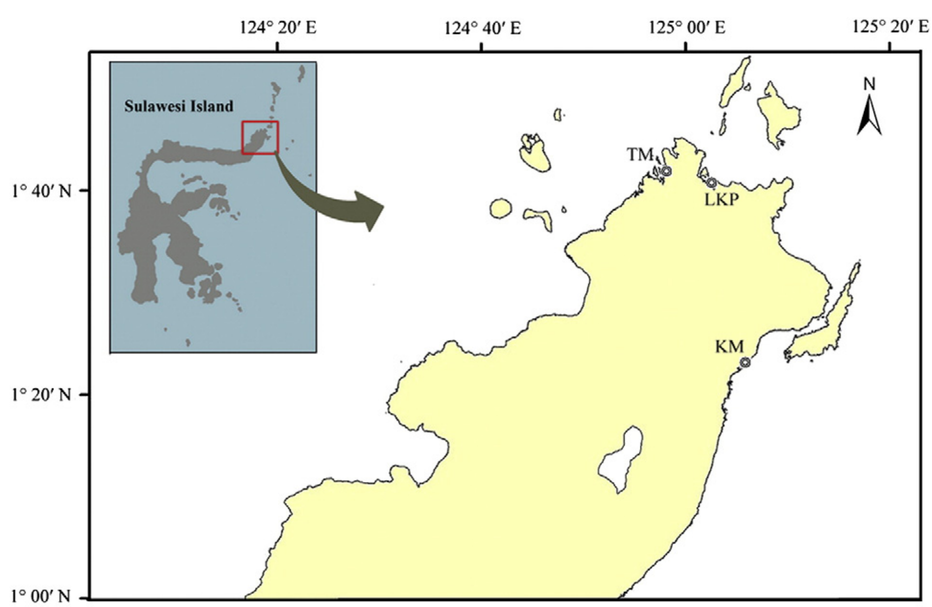

Fig. 1. Geographical location of the mangrove swamps in the present study. LKP: Likupand mangrove swamp; TM: Teremaal mangrove swamp; KM: Kema mangrove swamp.