Evaluation and Future Prediction of the Effect of Climate Change on Asian Forest Soil Carbon Dynamics Based on a Comprehensive Field Study

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[Abstract]

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Methane (CH_4) is the second most important greenhouse gas after carbon dioxide (CO_2), contributing to human-induced global warming. CH_4 has a Global Warming Potential 86 and 28 times larger than CO_2 for time horizons of 20 and 100 years. The atmospheric concentration of CH_4 is about two and half times higher than pre-industrial levels and is responsible for 11-30% of the rise in global temperature. On Earth, water-unsaturated soils are the only sinks of atmospheric CH_4 due to the presence of methanotrophic bacteria, and the CH_4 sink strengths are high in soils with high porosity but low in soils with high water content. In Japan, about 70% of forest soils are volcanic ash-derived soils characterized by a high porosity and mean annual precipitation (1740 mm) is more than double of that in global land (740 mm). Accordingly, we hypothesized that Japanese forest soils would have high CH_4 uptake potential, but the high potential might be offset by their high-water content, and consequently, their CH_4 uptake rate would be comparable to or even weaker than that of mean of global temperate forest soils. To support this hypothesis, as well as to compare soil CH_4 sink of the Japanese forests with that of other monsoon Asian countries, we have been performing continuous measurement of CO_2 and CH_4 flux, periodically sampling of soil for laboratory analyses of soil physical and chemical properties, methanotrophic bacteria, methanogenic archaea, and soil radiocarbon (^{14}C) at thirteen typical forests distributed from northern Hokkaido to Honshu, Kyushu, Taiwan, Mainland China, Hong Kong, and Peninsular Malaysia.

We found that monsoon Asian forest soil CH_4 uptake rate was significantly higher than that of dataset used for estimation of global methane budget, with 6.4, 2.2 and 1.9 times of that in boreal, temperate, and tropical forests. Soil CH_4 uptake rate of Japanese forests was systematically higher than that of other monsoon Asian countries, probably due to both of high soil organic carbon (SOC) content and volcanic ash-derived soils. Compared to the previous reports for American and European forests, global warming is expect having positive and high effect on both soil CO_2 emission and CH_4 uptake, because the warming effect showed positive correlation with SOC stock as well as soil drought induced by warming treatment. In fact, the increase in the amount of aerobic methanotroph and the decrease in that of anaerobic methanogen in response to soil drought were detected by genetic analyses. We also found that ^{14}C signature of SOC, as an index of soil carbon turnover, can be a key parameter to explain the regional difference and temperature sensitivity of soil CO_2 emission. In addition, soil CH_4 uptake rate is found to be higher in soils with higher contents of acid oxalate extractable aluminum and iron, which supports the high CH_4 absorption capability of volcanic ash-derived soils in Japan.

Based on our database, by using machine learning and process models, we have successfully upscaled our field network observations to the monsoon Asian region. Our high-resolution map with 1km spatial resolution predicts that more CO_2 will be released from the soil to the atmosphere under global warming than we previously expected, however, the increasing CH_4 sink induced by global warming will offset much portion of the increasing soil CO_2 emission. Our results are expected to contribute to establishing efficient environmental policies for both Paris Agreement and 2050 Carbon Neutral Strategy.