TECHNICAL MEASURES TO MITIGATE GREENHOUSE GASES FROM AGRICULTURAL FIELDS

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ABSTRACT

Agriculture is a major anthropogenic source of greenhouse gases (GHGs), such as methane (CH_4) and nitrous oxide (N_2O). In contrast, agricultural soil has great potential to act as a sink of atmospheric carbon dioxide (CO_2). This study aimed to develop techniques for increasing soil C stocks and reducing GHGs from agricultural fields while adapting to climate change and meeting the increasing demand for agricultural products. Here, we summarize five major achievements of our study. (1) We conducted nine field experiments across Japan and demonstrated that prolonged mid-season drainage (MD) (1 week longer than local conventional drainage) reduced CH_4 emission from paddy fields by 30% compared with conventional drainage practice, while maintaining grain yields. The Ministry of Agriculture Forest and Fisheries has approved prolonged MD as a subsidized program. Prolonged MD has now been applied to approximately half of rice paddy fields in Shiga Prefecture and has been *approved in a total of five prefectures. (2) We assessed the effect of different biochar application rates (0, 10, 20, and 40 Mg ha^{-1}) on crop productivity and global warming potential by a 4-year field experiment in an Andosol field in Hokkaido. Wood residue-derived biochar application had no significant influence on the yield, quality of the harvested materials, or cumulative CO_2, N_2O, and CH_4 emissions. The net ecosystem C budget increased with the rate of biochar application; thus, biochar application has great potential for mitigating global warming through enhanced soil C sequestration. (3) We investigated the effect of organic matter application on soil C sequestration in orchards by long-term field experiments (>10 years) at three sites across Japan. Our results showed that organic matter application increased soil organic carbon concentration compared with that in bare soil control with no organic matter application. (4) We demonstrated that N_2O reductase (N_2OR) can mitigate N_2O emissions from soybean fields during nodule decomposition by inoculation with nosZ++ strains (mutants with increased N_2OR) of Bradyrhizobium diazoefficiens and by inoculation with a mixed culture of indigenous nosZ+ strains of B. diazoefficiens isolated from Japanese agricultural fields. (5) We conducted a meta-analysis of the effects of biochar and the inhibitors of nitrification and urease activities on N_2O emissions, nitrate leaching, and plant nitrogen uptake from urine patches of grazing animals on grasslands. Our results suggested that the application of dicyandiamide (DCD) (a nitrification inhibitor) or N-(n-butyl) thiophosphoric acid triamide (NBPT, a urease inhibitor) + DCD decreases N losses and increases N utilization from urine patches.*

Keywords: Methane, nitrous oxide, soil, mitigation, carbon sequestration

INTRODUCTION

Agriculture is a major anthropogenic source of greenhouse gases (GHGs), such as methane (CH_4) and nitrous oxide (N_2O). Rice paddy fields are a major source of CH_4, and the application of synthetic and organic fertilizers increases N_2O emissions from soil; however, agricultural soil has great potential to act as a sink for atmospheric carbon dioxide (CO_2). Changing farming practices can remove a substantial amount of CO_2 from the atmosphere via the storage of carbon (C) in the soil as organic matter, whereas increasing the input of organic matter and reducing tillage can increase soil C sinks.

This study aimed to develop techniques to increase soil C sinks and reduce GHGs emitted from agricultural fields while adapting to climate change and meeting the increasing demand for agricultural products. Our research also aimed to contribute to the National Greenhouse Gas Inventory Report and Refinement of IPCC Guidelines.

MAJOR ACHIEVEMENTS

Mitigation of CH_4 emissions from rice paddy fields by prolonged mid-season drainage (MD) and its application for farmers

According to the global statistical analysis, CH_4 emissions from MD of rice paddy fields accounts for 48% of CH_4 emissions from fields subjected to continuous flooding (Yan *et al*., 2005). In Japan, MD is already practiced in approximately 90% of paddy fields except those in Hokkaido; as a consequence, introducing MD to reduce CH_4 is only applicable in Hokkaido.

Prolonged MD (lasting 1 week longer than conventional MD) may reduce CH_4 emissions compared with conventional MD. To evaluate the effectiveness of prolonged MD on reducing CH_4 emissions, field experiments were conducted at nine sites across Japan for 2 years (Itoh *et al*., 2011).

Seasonal CH_4 emissions were significantly decreased at most sites as a result of prolonged MD compared with that as a result of conventional MD (Fig. 1), particularly at sites where organic matter was added to the soil before cultivation. The effect on N_2O emission was much smaller than that of CH_4 emission (considering CO_2 equivalents). Compared with conventional MD, seasonal CH_4 emissions and net 100-year global warming potentials (CH_4 + N_2O) can be reduced, as mean ± SE, by 69.5% ± 3.4% and 72.0% ± 3.1%, respectively, while maintaining grain yields at a high level of 96.2% ± 2.0% by prolonging MD.

The Ministry of Agriculture Forest and Fishery approved prolonged MD as a subsidized program to reduce GHG emissions from agriculture. Prolonged MD has now been applied to approximately 50% of rice paddy fields in Shiga Prefecture. Till date, prolonged MD has been approved in five prefectures (Shiga, Kyoto, Oita, Iwate, and Ishikawa), and its approval is expected to be extended to more prefectures.

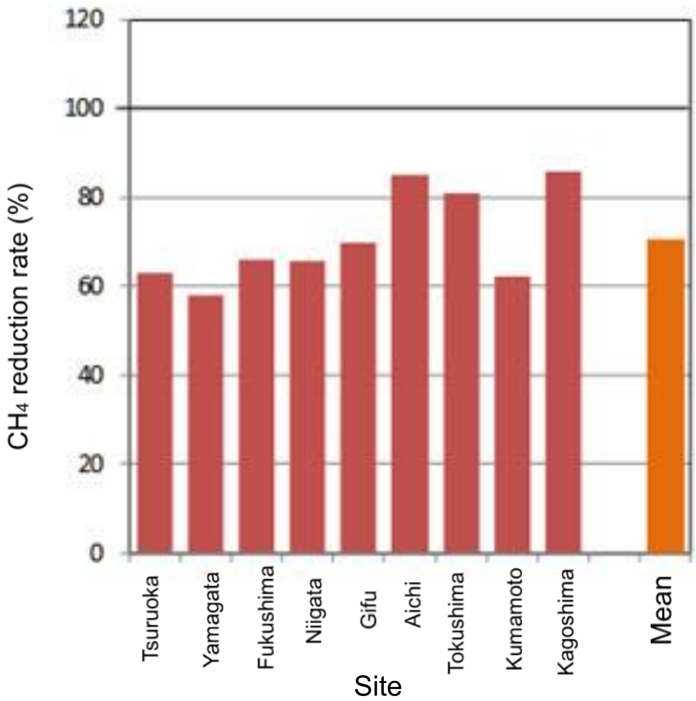

Fig. 1. CH_4 reduction rate (% of conventional mid-season drainage) by prolonged mid-season drainage at nine sites.

Biochar effects on crop productivity and greenhouse gas emissions from Andosol fields

To assess the effect of biochar application on crop productivity and global warming potential, a 4-year field experiment was conducted in a well-drained Andosol field in Hokkaido (Koga *et al.*, 2017). Wood residue-derived biochar (pyrolyzed at >800°C) was applied at the rates of 0, 10, 20, and 40 Mg ha^{-1} for potatoes, winter wheat, sugar beet, and soybeans cultivated in rotation, and CO_2, N_2O, and CH_4 emissions, yield, and the quality of harvested materials were assessed.

Biochar application, regardless of the rate, had no significant influence on yield and the quality of the harvested materials, except for soybean grain yield that increased at 40 Mg ha^{-1} of application rate. Moreover, it had no significant effect on cumulative CO_2, N_2O, and CH_4 emissions from the soil. The net ecosystem C budget during the study period increased with the rate of biochar application from −3.55 ± 0.19 Mg C ha^{-1} without biochar application to 4.89 ± 0.46, 13.4 ± 0.3, and 29.9 ± 0.4 Mg C ha^{-1} at the application rates of 10, 20, and 40 Mg ha^{-1}, respectively. As a consequence, the application of wood residue-derived biochar to Andosol has great potential for mitigating global warming through enhanced soil C sequestration without sacrificing crop productivity.

Another field experiment at an Andosol field in Tsukuba also confirmed that the application of biochar at a rate of 25 Mg ha^{-1} in four different feedstocks (rice husk, bamboo, hardwood, and wood briquettes of mixed hardwood and softwood) had no effect on N_2O and CH_4 emissions or crop productivity of spinach and *Brassica SP* (Yamamoto *et al.*, submitted).

Changes in soil organic carbon (SOC) after >10 years of continuous organic matter application to orchards in Japan

Orchards are typically managed with no-till, ground-cover vegetation (e.g., cover crops and weeds), manure application, and long-term cultivation. Therefore, orchards are considered to have a larger potential for soil C storage than other types of agricultural lands. To investigate the effect of organic matter application on soil C sequestration in orchards, long-term field experiments (>10 years) were conducted at three sites (Tsukuba, Yamanashi, and Omura), which were characterized by different fruit crop species, soil types, and climate (Sugiura *et al.*, 2017). Treatments were as follows: (i) bare ground control cultivation (CC), in which synthetic fertilizer was applied and the ground was kept bare; (ii) sod culture, in which synthetic fertilizer was applied and the ground was covered by grass or weed; and (iii) organic amendment (OA), in which synthetic fertilizer and cattle manure (OA_{cat}) or bark compost (OA_{brk}) were applied and the ground was kept bare. The application rates of organic matter in treatments (ii) and (iii) were 30 Mg ha^{-1} yr^{-1}, except at Yamanashi (20–40 Mg ha^{-1}).

Between the treatments, annual changes in SOC concentration were the highest in OA and the lowest in CC at all sites, with the organic amendment treatments indicating that the application of organic matter causes an increase in the SOC concentration.

Mitigation of soil N_2O emission by inoculation with a mixed culture of indigenous *Bradyrhizobium diazoefficiens* isolates in soybean fields

Soybean is an important leguminous crop worldwide. Soybean hosts symbiotic nitrogen-fixing soil bacteria (rhizobia) in root nodules. In soybean ecosystems, N_2O emissions often increase during decomposition of root nodules. Itakura *et al*. (2008) reported that inoculation of *nosZ*++ strains of *B. diazoefficiens* [mutants with increased N_2O reductase (N_2OR) activity] reduced N_2O in a laboratory study.

Our results showed that N_2OR can be used to mitigate N_2O emissions from soybean fields during nodule decomposition by inoculation with *nosZ*++ strains of *B. diazoefficiens* (Itakura *et al*., 2013). Moreover, Akiyama *et al*. (2016) showed that N_2O emissions during the harvest period could be reduced at the field scale by inoculation with a mixed culture of 125 indigenous *nosZ*+ strains of *B. diazoefficiens* USDA110 group (C110) isolated from 32 Japanese agricultural fields (Fig. 2). The results also suggested that nodule nitrogen (N) is the main source of N_2O production during nodule decomposition. Isolating *nosZ*+ strains from local soybean fields would be more applicable and feasible than generating mutants for many soybean-producing countries.

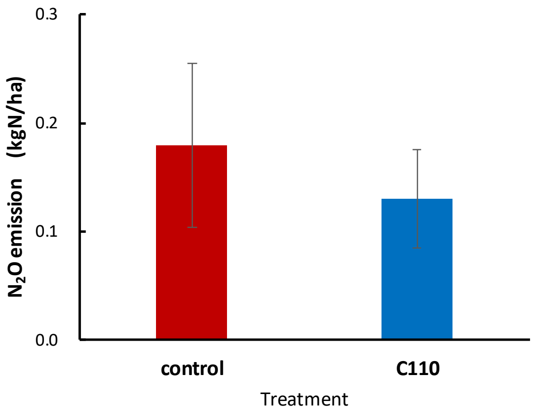

Fig. 2. N_2O emission during the harvest period from the control (without inoculation) and C110 (inoculation with indigenous *nosZ+* strains of *B. diazoefficiens* USDA110 group) in the field.

Effects of inhibitors and biochar on N_2O emissions, nitrate leaching, and plant nitrogen uptake from urine patches of grazing animals on grasslands: a meta-analysis

Excreta (urine and dung) patches on grazed grasslands are significant sources of N trace gas emissions and leaching. Nitrification inhibitors (NIs), urease inhibitors (UIs), and biochar have been shown to reduce N losses and increase N utilization in various agro-ecosystems. Although the effectiveness of NIs, UIs, or biochar on N losses or N utilization of chemical N fertilizers and manures have been evaluated in previous studies, there has been no comprehensive assessment on their effectiveness with respect to excreta patches of grazing animals on grassland. Thus, we analyzed the results of 44 studies (156, 65, 67, and 97 pair of comparison data of N_2O emissions, NO_3^- leaching, plant N uptake, and plant yields, respectively) to evaluate the effects of additives on N losses and uptake from excreta patches (Cai and Akiyama, 2016).

Our results showed that, compared with urine patches without additives, pyrazole derivatives (a NI), N-(n-butyl) thiophosphoric triamide (NBPT, a UI), and biochar did not affect N_2O emissions, whereas dicyandiamide (DCD, a NI) and a combination of NBPT and DCD (NBPT + DCD) significantly reduced N_2O emissions by 51% and 48%, respectively (Fig. 3). DCD and NBPT + DCD also significantly reduced NO_3^- leaching (46% and 42%, respectively), and increased plant N uptake (14% and 15%, respectively) and plant yields (7% and 12%, respectively). Our findings suggest that the application of DCD was effective in decreasing N losses and increasing N utilization from urine patches, whereas NBPT + DCD would be a better option in order to avoid potential increases in ammonia emissions following DCD application. However, the effect on environment and human health of inhibitor application should be evaluated.

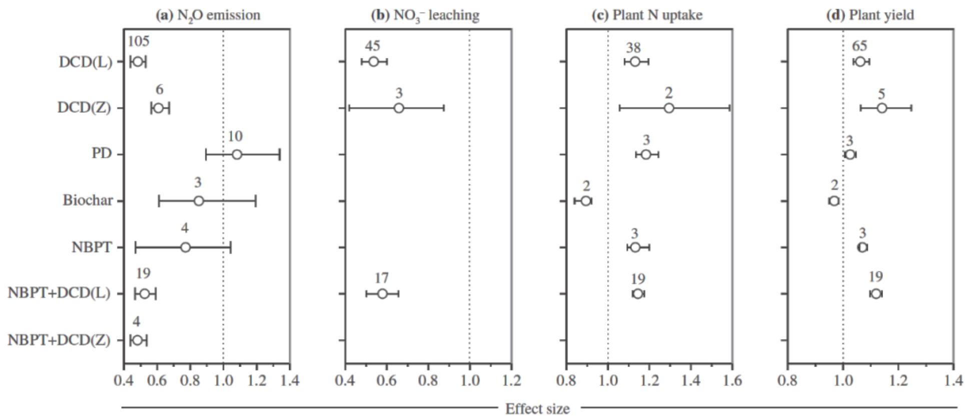

Fig. 3. Effects of inhibitors and biochar (relative to the control) on N_2O emissions (a), NO_3^- leaching amounts (b), above-ground plant N uptake rates (c), and above-ground plant yields (d) from urine patches. Mean effects and bias-corrected 95% confidence intervals are shown. Numerals indicate the number of data. DCD(L): dicyandiamide in liquid form; DCD(Z): dicyandiamide coated with zeolite; PD: pyrazole derivatives in liquid form; Biochar: biomass-derived charcoal; NBPT: N-(n-butyl) thiophosphoric triamide in liquid form; NBPT + DCD(L): both NBPT and DCD in liquid form; and NBPT + DCD(Z), both NBPT and DCD coated with zeolite.

CONCLUSION AND FURTHER RESEARCH

The mitigation technique of CH_4 emission from paddy rice fields by prolonged MD developed by Ito *et al.* (2011) became widely adopted by farmers after the Ministry of Agriculture, Forestry and Fisheries approved prolonged MD as a subsidized program to reduce GHG emissions from agriculture. Our research project continues to develop additional mitigation options to reduce GHG emissions from Japanese agricultural soil, such as the mitigation of CH_4 emissions from paddy fields by dry-seeding or carrying out MD in the Hokkaido region, the mitigation of N_2O emissions from upland fields by the use of NIs, and evaluating GHG emissions by life cycle assessment from animal waste treatment and the application of slurry or composted manure to grasslands.

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