Climate change mitigation potential of Japanese agricultural soils estimated by country-scale simulation of soil carbon stock change and CH_4 and N_2O emissions

Ayaka W. Kishimoto-Mo, Yasuhito Shirato, Tamon Fumoto, Nobuko Katayanagi, and Shin-Ichiro Mishima
Institute for Agro-Environmental Sciences, NARO
Kannondai 3-1-3, Tsukuba, Ibaraki 305-8604, Japan
mow@affrc.go.jp

Keywords: Climate change, cropland management, mitigation, modeling, soil carbon sequestration

1. Introduction

Mitigation of greenhouse gas (GHG) emissions in agricultural sector could be achieved through improved management practices. A large proportion of the mitigation potential in agricultural sector arises from soil carbon sequestration through improved organic amendments application. However, it may have trade-off with other greenhouse gases (CH_4 and N_2O). It is therefore important to evaluate the total GWP (Global Warming Potential) of each management option by taking above-mentioned trade-off into account. In order to estimate the country-scale climate change mitigation potential of Japanese agricultural soils, we have developed the country-scale simulation system of GHGs including soil carbon which link mechanistic models to simulate GHGs and country-scale datasets for model inputs such as weather, soil, land-use and agricultural activities. The purposes of this study were to estimate soil C stock change and CH_4 and N_2O emissions from agricultural soils from 1980 to 2013, and to simulate future climate change mitigation potential by comparing BAU (business as usual) and mitigation scenarios in 2020-2050.

2. Materials and Methods

1) Estimation of soil carbon sequestration in country scale

A country-scale soil carbon calculating system developed by Yagasaki & Shirato (2014a; b) was used to estimate soil carbon sequestration. The system was developed based on original and modified (Shirato et al., 2004, 2005) Rothamsted soil carbon turnover (Roth-C) model. The models were used for non-volcanic upland soils and for Andosols and paddy soils, respectively. The spatial resolution of the simulation unit of soil C stock change is 100 m over the whole country. Yagasaki & Shirato (2014a) provided details on the estimation of soil C stock change for four land-use categories (paddy, upland, orchard, and grassland).

2) Estimation of CH_4 and N_2O emission and fossil fuel consumption

Country-specific CH_4 emission factors were calculated using DNDC-Rice model (Katayanagi et al. 2016) for seven administrative regions, two water management regimes (continuous flooding and conventional mid-season drainage), and three soil drainage rates (slow, moderate, and fast). Katayanagi et al. (2017) provided details on the estimation of CH_4 emission from Japanese rice paddies using country-specific emission factors.

An empirical model for estimating annual or seasonal N_2O emission from upland soils using soil C/N ratio and decomposed CO_2 has been developed by Mu et al. (2009). We collected a range of dataset of N_2O and CO_2 emissions from different N application rates with different soil types and land-use categories in Japan. We used these field datasets to validate the empirical N_2O model of Mu et al. (2009) and improved the parameters for Japanese agricultural soils. We then combined the Roth-C model with this improved N_2O empirical model to calculate annual direct N_2O emissions over the national scale. Due to high N fertilizer application rates and high N_2O emissions from tea gardens, we separated tea gardens from the orchard land-use category.

Fossil fuel consumption by agricultural machineries, plastic films, fertilizers, pesticides and so on should be included in the total GWP, and was calculated using emission factors from a survey report of Ministry of Agriculture, Forestry and Fisheries in 2010.

3) Activity data and mitigation scenarios

The chemical fertilizer and manure application rates from 1970 to 2012 were calculated using data from a longitudinal questionnaire survey datasets (the Basic Soil Environment Monitoring Project, Stationary

Monitoring). Mishima et al. (2012) provided details on the workflow for producing activity data using those national questionnaire survey datasets.

We created future scenarios of agricultural activities, land-use changes and together with selected future climate projections by GCMs, and applied to run the simulation system to estimate future GHGs mitigation potential. Mitigation scenarios were designed for three levels: (1) increasing 10% C input to soils, (2) extend mid-season drainage for paddy fields, and (3) reduced 10% chemical fertilizer application to all land-use categories.

3. Results and Conclusions

Historical trends (1970-2013) in soil C stock changes and CH_4 emissions have been reported in previous studies (Yagasaki & Shirato, 2014a; Katayanagi et al. 2017). N_2O emissions from upland and paddy soils were the main contributors to the total N_2O emission, e.g. 49.3% from upland and 28.0% from paddy in 2012. Tea garden emitted 3% of total with 1% cropping area.

Among several agricultural management scenario analyses, 10%- increasing- carbon input to soils resulted in the increase of soil organic carbon (i.e. higher soil carbon sequestration) but also increased both of CH_4 emission from paddy soils and N_2O emission from all land-use categories. However, extending mid-season drainage and reducing N fertilizer application could further offset these increased GHGs by increasing C inputs to soils. We conclude that increasing C inputs to soil is effective for enhancing soil C sequestration, and accompanying increment of other GHGs (i.e. trade-off) can be offset by other options such as better paddy water or chemical fertilizer managements.

References

Katayanagi N., Fumoto T., Hayano M., Takata Y., Kuwagata T., Shirato Y., Sawano S., Kajiura M., Sudo S., Ishigooka Y. and Yagi K. 2016. Development of a method for estimating total CH_4 emission from rice paddies in Japan using the DNDC-Rice model. *Science of the Total Environment*, 547: 429-440.

Katayanagi N., Fumoto T., Hayano M., Shirato Y., Takata Y., Leon A. and Yagi K. 2017. Estimation of total CH_4 emission from Japanese rice paddies using a new estimation method based on the DNDC-Rice simulation model. *Science of the Total Environment*, 601-602: 346-355.

Mishima S.-I., Kimura S. D., Eguchi S. and Shirato Y. 2012. Estimation of the amounts of livestock manure, rice straw, and rice straw compost applied to crops in Japan: a bottom-up analysis based on national survey data and comparison with the results from a top-down approach. *Soil Science and Plant Nutrition*, 58: 83-90.

Mu Z., Huang A., Kimura S. D., Jin T., Wu S. and Hatano R. 2009. Linking N_2O emission to soil mineral N as estimated by CO_2 emission and Soil C/N ratio. *Soil Biology and Biochemistry*, 41: 2593-2597.

Shirato Y., Hakamata T. and Taniyama I. 2004. Modified Rothamsted carbon model for Andosols and its validation: Changing humus decomposition rate constant with pyrophosphate-extractable Al. *Soil Science and Plant Nutrition*, 50: 149-158.

Shirato Y. and Yokozawa M. 2005. Applying the Rothamsted Carbon Model for long-term experiments on Japanese paddy soils and modifying it by simple tuning of the decomposition rate. *Soil Science and Plant Nutrition*, 49: 921-925.

Yagasaki Y. and Shirato Y. 2014a. Assessment on the rates and potentials of soil organic carbon sequestration in agricultural lands in Japan using a process-based model and spatially explicit land-use change inventories – Part 1: Historical trend and validation based on nation-wide soil monitoring. *Biogeosciences*, 11: 4429-4442.

Yagasaki Y. and Shirato Y. 2014b. Assessment on the rates and potentials of soil organic carbon sequestration in agricultural lands in Japan using a process-based model and spatially explicit land-use change inventories – Part 2: Future potentials. *Biogeosciences*, 11: 4443-4457.