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Calculating changes in soil organic carbon in Japanese agricultural land by IPCC-Tier 3 modeling approach: use of modified Rothamsted carbon model

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Abstract

Changes in total soil organic carbon (SOC) stock (at 0-30 cm depth) of entire Japanese agricultural land was calculated from 1970 to 2050 by using the Rothamsted carbon (RothC) model. At first, the RothC model was validated by using long-term field experiments and then modified respectively for Andosols and for paddy soils, by taking unique properties of these soils into account. Next, a calculation system of agricultural SOC in Japan was developed by linking these modified versions of the RothC model with spatial datasets such as weather, soil, land use, agricultural activities. This system is now used in the National Inventory Report (NIR) of Japan. CH_4 and N_2O emissions were also calculated at the country-scale for considering trade-off between SOC sequestration and other greenhouse gas (GHGs) emissions. Changes in SOC derived from monitoring project was compared with modelling results. Link between monitoring and modelling studies is needed to fill the gap between model and monitoring results.

Keywords: carbon sequestration, climate change, mitigation, modeling, soil organic matter

Introduction, scope and main objectives

Better agricultural soil management has huge potential to mitigate GHG emissions. Modelling approach is useful in estimating this potential at a country scale. Increasing carbon inputs to soils enhance soil C sequestration but it may increase other GHGs (CH_4 and N_2O) emissions. It is therefore important to evaluate total GWP (Global Warming Potential) for each management option by taking this trade-off into account. We have developed a country-scale simulation system of SOC and GHGs for reporting to NIR and to evaluate GWP of several future agricultural soil management scenarios as well as future climate change scenarios. Our objective was to evaluate how agricultural management options can affect SOC sequestration and other GHG emissions at a country scale.

Methodology

At the first step, the RothC model was tested against long-term experimental data sets in Japanese agricultural lands. The RothC model could adequately simulate changes in SOC contents with time in non-volcanic upland soils (Shirato and Taniyama, 2003) without any modification or calibration to the original RothC model (Coleman and Jenkinson, 1996). The original RothC model, however, underestimated SOC in Andosols (volcanic ash-derived soils) and in paddy soils. We then modified the model for Andosols (Shirato *et al.*, 2004) and for paddy soils (Shirato and Yokozawa, 2005) by taking unique mechanisms of soil C dynamics in these soils into account, and could have much improved fit between model and observation (Fig. 1).

Next, a calculation system of SOC at the country scale was developed (Yagasaki and Shirato, 2014a, b) by linking the RothC model with spatial data sets such as weather, soil properties, land use, and other activity data (the amount of C input to soils by crop residue and organic manure) including different agricultural management scenarios in future: BAU (Business as Usual) scenario and C sequestration scenarios in which 10% increase the amount of C input to soils. The initial soil C value was set at 1970 for each of spatial simulation unit (100 m grid). Changes in SOC was then calculated until 2050 by applying three different versions of the RothC model (the original RothC, the modified version for Andodols and that for paddy soils) depending on land use and soil type, and by adding different input data derived from weather, soil type, land use and agricultural management scenario in future. Two different climate change scenarios (MIROC-H and FGOALS) (Okada et al., 2009) were used in simulating future period to consider the effect of weather condition on SOC.

For evaluating trade-offs between SOC sequestration and other GHGs, N_2O was calculated from CO_2 emission calculated by the RothC, C/N ratio of soils and the amount of N fertilizer inputs by using empirical equation, which relates N_2O to mineral N in soils, proposed by Mu *et al.* (2008). CH_4 emissions from paddy soils were calculated by emission factors derived from the DNDC-Rice model (Katayanagi *et al.*, 2016). Fossil fuel consumption by agricultural machineries, plastic films, fertilizers, pesticides etc. were calculated, too.

Results

The total amount of topsoil (0-30cm) organic C in Japanese agricultural lands tended to decrease over time. As to agricultural management scenarios, 10%- increasing- C input to soils resulted in higher amount of SOC (i.e. lower CO_2 emission from SOC) but increased both of CH_4 and N_2O at the same time. Other mitigation options such as extending mid-season drainage for rice CH_4 and decreasing N inputs of chemical fertilizer for N_2O, however, could offset these increased GHGs by increasing C inputs to soils.

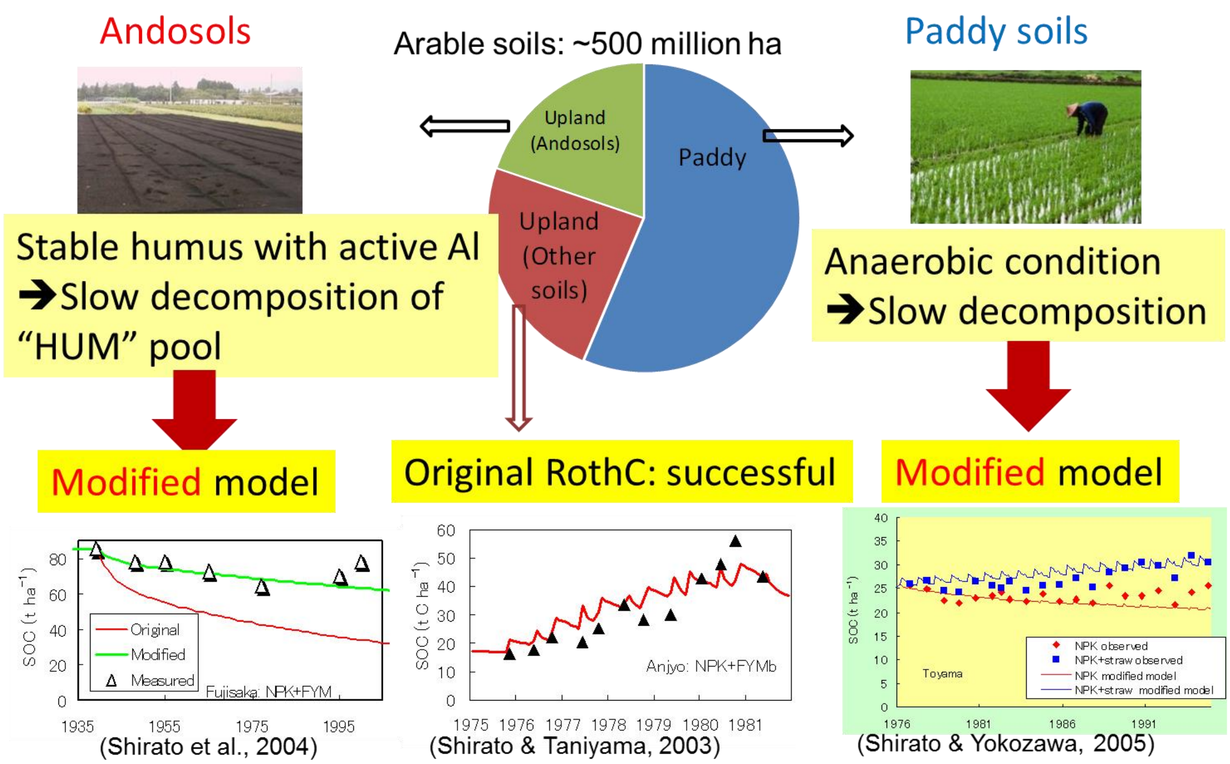

Fig. 1: Validation and modification of the RothC model in Japan. Country scale calculation system switches these three versions (The original RothC, Andosols version and paddy soil version) depending on soil type and land use.

Discussion

Trade-off between other GHGs emission

Our results show that increasing C inputs to soil is effective for enhancing SOC sequestration at country-scale, and accompanying increment of other GHGs (i.e. trade-off) can be offset by other options such as better paddy water management and effective N fertilizer managements. Modeling approach is effective to evaluate total GWP of management options at a country scale for future projection.

Comparison between modeling results and monitoring-based estimation of SOC

The IPCC Tier 3 modeling approach with the use of modified RothC model is currently used in Japanese NIR as explained above. This modeling approach has an advantage that model can be used for future projection as well as current inventory reporting. On the other hand, we have an agricultural soil monitoring system in Japan. It had ca. 20,000 stational monitoring points from 1979 until 1998 and each point was surveyed in every five years. After that, number of monitoring points has been decreased and it is ca. 4,000 points and every four years of soil survey at present. SOC data obtained from these monitoring points can be used for validating the results of SOC stock change estimated by the modeling approach. However, these monitoring points are not randomly distributed and it makes difficult the direct use of the results of this monitoring project into NIR or model validation. Because these monitoring sites might be biased to "progressive" farmer and have higher organic inputs to soils, SOC in monitoring sites were possibly higher than RothC-simulated one, which support our speculation. We have further analysis to fill this gap between monitoring sites and average farmers.

Conclusions

The calculation system by linking models with spatial datasets of mode inputs at a country scale is effective both for reporting for NIR and future projection of mitigation potential. Trade-off between soil C sequestration and other GHGs emissions can be evaluated at a country scale with this system. On the other hand, the importance of national-scale soil monitoring projects should be noted because a model has to be always validated by measured data. Linking modeling to monitoring studies is critically important.

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