Simulating soil organic carbon stock change in Japanese agricultural land with the RothC model

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Contents

• Why SOC models?
• Rothamsted carbon (RothC) model
• Validation and modification of the RothC (Plot scale)
• Country-scale simulation of SOC
Why SOC models?

Input:
- Quality of C input (Residue, manure)
- Temperature, Moisture
- Soil texture, pH
- Tillage

Output:
- Soil organic carbon (SOC)
- Dead root
- Crop residue

Factors Controlling Soil C Balance

SOC turnover models which cover these factors are useful tools.
Rothamsted Carbon model

Divide soil C and plant C into 5 conceptual compartments having different turnover rate = decomposability

↓

Calculate C movement among compartments

↓

Simulate soil C dynamics

5 compartments

DPM: Decomposable Plant Material
BIO: Microbial Biomass
RPM: Resistant Plant Material
HUM: Humus
IOM: Inert Organic Matter

Total C

Decomposition rate
Fast

Slow

Widely used, but not yet tested in Japan (or in Asia)
Validation of the RothC in Japan

- Data from 15 long-term experiments under a variety of weather, soil type

- Each site has several plots with different management (NPK, manure, straw, etc.)
Performance of RothC in non-volcanic upland soils

Good performance

Without any modification or calibration

- Increasing SOC
- Decreasing SOC

Brown lowland soil

Yellow soil

• 6 sites under various weather condition.
• Various soil types.
• Various management

(Shirato & Taniyama, 2003)
But in Andosols……

The model underestimated the SOC

Predicted SOC << Measured SOC

(Shirato et al., 2004)
Andosols have high C concentration

- Higher SOC than other soils caused by the presence of active Al or Fe derived from volcanic ash, which forms stable complex with humus.

- The model does not take this into account. (Only clay content as parameter of soil)

Need modification
How to modify the RothC for **Andosols**

Active Al or Fe derived from volcanic ash forms stable complex with humus ➔ Slow decomposition

1. **Changing HUM decomposition rate constant**
   - by dividing with a factor (F), which changes with the amount of active Al or Fe
   - $F = 2.50 \text{Alp} + 1.20$ (Alp: Pyrophosphate extractable)

   In soils with much Al-humus complex, SOC decompose slowly

2. **IOM=0**
Modified model for Andosols

Better performance than the original RothC

Alp=0.85%, F=3.33

(Shirato et al., 2004)
What happen in paddy soils?

The model underestimated SOC, as expected (slower decomposition because of anaerobic condition)

(Shirato & Yokozawa, 2005)
How to modify the RothC for paddy soils?

- Predicted SOC < observed (as expected)

- Rice growing period: anaerobic condition \( \Rightarrow \) slow decomposition

- How about non-rice growing period?
  
  Paddy soils have different microorganism composition (e.g. Smaller proportion of fungi, which play major role in decomposing lignin or cellulose, than bacteria)

  \( \Rightarrow \) decomposition may be slower than upland soils, too.

Decided to modify the model by...

1. Changing the decomposition rates of the RothC during the submergence period and the period without submergence, separately.
2. Find out the optimum combinations of the decomposition rate.
Modified model for paddy soils:
0.2 and 0.6 times slower decomposition rate, in rice growing season (submerged) and drained period, respectively

Good agreement (Shirato & Yokozawa, 2005)
Summary: Validation and modification of RothC in Japan

Half of upland soils: Andosols

Volcanic ash derived → Stable humus

Anaerobic condition → Slow decomposition

Proportion of area of soil types in Japanese arable land

Modified model

Original RothC is OK

Modified model

Next step: Country scale simulation
Country scale simulation of SOC 1970-2020

Spatial resolution: 100 m grid

- C inputs (t ha\(^{-1}\)) each year, resolution: prefecture
- Initial SOC in 1970: equilibrium assumed
- After 2008 with 2 scenarios (BAU, C sequestration)

Net-net accounting: Compare annual SOC stock change in 1990 with that of commitment period (e.g. 2013~???)
Selection of 3 versions of the RothC

Grids in which area of **paddy fields > upland crop fields**

- **Yes** → Paddy soils version
  - (Shirato & Yokozawa, 2005)

Grids in which **Dominant soil series was Andosols group**

- Andosols, Wet Andosols, Gleyed Andosols
- **Yes** → Andosols version
  - (Shirato et al., 2004)

- **No** → Original RothC-26.3
  - (Coleman & Jenkinson, 1996)

Soil map of “Fundamental Soil Survey for Soil Fertility Conservation” (1979)
Land use change

- Area of four agricultural land use (paddy, upland, orchard, grassland) has been changing.
- Different version of the RothC, different management (C inputs) should be applied for different land use.

- Land use change history data for each grid should be constructed.

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P: paddy
U: upland
O: orchard
G: grassland
Estimating C inputs 1) crop residue

1. Yield (t/yr)

2. Residue (t/yr)

3. C in residue entered soils (tC/yr)

- Water (%)
- Residue / yield ratio of each crop (%)
- Proportion of return into soil (%)
- C concentration (%)

- 4 land use (paddy field, upland crop, orchard, grassland)
- 47 prefecture
- 51 years: 1970〜2020
Estimating C inputs 2) FYM

Questionnaire

FYM application rate (t/ha/yr)

Usage

Area

FYM (tC/yr)

Paddy

Upland

Orchard

Grassland

Area

FYM (tC/ha/yr)

Production

Head

Livestock statistics

Excreta (t/head/yr)

Proportion used for FYM (%)

C (%)

Decomposition during composting (%)

FYM (tC/yr)
Accounting in Kyoto Protocol:
Different land area: base year $\Leftrightarrow$ commitment period

- **Base year**: 1990
- **Commitment period**: 1\textsuperscript{st}: 2008-2012
  - ??

EXCLUDED FROM c: Area under forest in base year and cropland management in reporting period (not included in cropland management reporting; reported under Article 3.3 as deforestation land)

Area under cropland management only in base year and in reporting year (could have been settlement, or grassland, or wetland, in the base year)

Area under cropland management only in base year
Summary

• The RothC was validated against long-term experiments in Japan.
• Good performance in non-volcanic upland soils, Modified for paddy soils and Andosols.

• Country-scale SOC simulation system was constructed.
• SOC in Japanese agricultural lands tended to decrease over time.
• Annual SOC stock change was affected by temperature and the amount of C input to soils.
• Net-net accounting method following Kyoto protocol resulted in net removal of CO$_2$.