Historical Soil Organic Carbon Budget

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Abstract. SOC one of larges c sinks on earth (3 times larger biospehre pool). Agricultural management leads to a depletion of soil organic crabon. However this depletion of soil organic carbon (SOC) pools are so far not well represented in global assessments of historic carbon emissions. While SOC models often represent well the biochemical processes that lead to the accumulation and decay of SOC, the management decisions driving these biophysical processes are still little investigated. Here we create a spatial explicit data set for crop residue and manure management on cropland based on global historic production (FAOSTAT) and land-use (LUH2) data and combine it with the IPCC Tier 2 approach to create a half-degree resolution soil organic carbon budget on mineral soils. We estimate that due to arable farming soils have lost over (?) GtOC of which (??) GtOC have been released within the period 1990-2010. Tier 2 IPCC methodolgy estimates higher soil organic carbon losses than Tier 1 methods, which may origin from . . . . We also find that SOC is very sensity to management decision such as residue recycling indicating the nessessity to incorporated better management data in soil models.

1 Introduction

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2 Method (50)

2.1 Carbon Stocks following (new) Tier 2 method (50)

We calculate annual land use type specific soil organic carbon stocks for cropland, pastures and natural vegetation on half-degree resolution for the period of 1965 to 2010 based on the following three steps: (1) Calculating the land use (sub-)type specific steady-states and decay rates for SOC stocks given the current biophysical, climatic and agronomic conditions, (2) accounting for land conversation effects by transferring SOC between land use types and (3) updating SOC stocks based on the previous stock, the steady-state and the decay rate.

2.1.1 Steady-state SOC stocks and decay rates

In a simple first order kinetic approach the steady-state soil organic carbon stocks SOC^{eq} are given by

$$SOC^{eq} = \frac{C^{\text{in}}}{k} \tag{1}$$

with C^{in} being carbon inputs to the soil and k denoting the soil organic carbon decay rate. We use for our calculations the steady-state method of the refinement of the IPCC guidelines vol. 4 (IPCC (2019)) for mineral soils, which assume three soil carbon sub-pools (active, slow and passive) and entangled dynamics between them. Carbon inflow to each sub-pool (see 2.1.2) and decay rates (see 2.1.3) of each sub-pool are still the key components to determining steady-state SOC stocks.

2.1.2 Carbon Inputs to the Soil

We account for different carbon inputs sources depending on the land use type (see table 1). Following the IPCC methodology carbon inputs are disaggregated into different structural components depending on their lignin and nitrogen content (see @ref(ipcc_2019_2019)). For each structural components the sum over all carbon inputs sources is allocated to the respective SOC sub-pools. This implies that not only the amount of carbon, but also their structural composition is determining the effective inflow. Data sources for all considered carbon inputs as well as for lignin and nitrogen content can be found in table 1.

2.1.3 Soil Organic Carbon decay (300)

Decay rates are influenced by climatic conditions, biophysical and biochemical soil properties as well as management factors that vary over time (t) and space (i). Following the steady-state method of the refinement of the IPCC guidelines vol. 4 (IPCC (2019)) for mineral soils we consider temperature (temp), water (wat), sand fraction (sf) and tillage (till) effects to spatially

Table 1. Type and data sources for carbon inputs to different land use types

Land use types	source of carbon inputs	data source	nitrogen and lignin content
Cropland	residues	FAOSTAT, LPJmL4 [2, sec:residues]	default values given by [2]
	dead below ground biomass of crops	FAOSTAT, LPJmL4 [2, sec:residues]	default values given by [2]
	manure	FAOSTAT, Isabelle [2, sec:manure]	default values given by [2]
Pasture	annual litterfall	LPJmL4 [3]	default values given by [2]
	manure	FAOSTAT, Isabelle [2, sec:manure]	default values given by [2]
Natural vegetation	annual litterfall	LPJmL4 [4]	Nitrogen and lignin content of tree compartments used in CENTURY [4]

disaggregate default global decay rates. Since the three different SOC sub-pools represent different SOC characteristics, the global decay rates and the associated drivers differ. Thus k_{sub} is given by

$$k_{sub,t,i} = k_{sub} \cdot temp_{t,i} \cdot wat_{t,i} \underbrace{\cdot till_{t,i} \overbrace{\cdot sf_{t,i}}^{\text{only for sub = active}}}_{\text{for sub = (active,slow)}} . \tag{2}$$

For cropland we performed an assessment of tillage types and irrigation conditions, whereas on pastures and natural vegetation, we assume rainfed and non-tilled conditions. Data sources as well as considered effects for each land use types are shown in table 2. To account for variations of decay rates within grid cells based on different tillage and irrigation regimes, average rates based on area shares are calculated.

Table 2. Type and data sources for carbon inputs to different land use types

Land use types	type of decay driver	parameter use to represent driver	data source
all	Soil quality	Sand fraction of the first 0-30 cm	[SoilGrids]
	Mircobial activity	air temperature	[CRUp4.0]
	Water restriction	precipitation & potential evapotranspiration	[CRUp4.0]
Cropland (additionally)	Water restriction*	irrigation	[sec:irrigation]
	Soil disturbance	tillage	[sec:tillage]

2.1.4 SOC transfer between land use types

We calculate SOC stocks based on the area shares of land use types (lut) within the half-degree grid cells (i). If land is converted from one land use type into another, a respective share of the SOC stocks have to be reallocated as well. We account for land conversion at the beginning of each time step t by calculating a preliminary stock $SOC_{lut,t*}$ via

$$SOC_{lut,t*} = SOC_{lut,t-1} - \frac{SOC_{lut,t-1}}{A_{lut,t-1}} \cdot AR_{lut,t} + \frac{SOC_{!lut,t-1}}{A_{!lut,t-1}} \cdot AE_{lut,t} \qquad \forall sub, i \tag{3}$$

with A being the area, AR the area reduction and AE the area expansion for a given land use type lut. Note that $!lut$ denotes the sum over all other land use types, which decreases in the specific time step t. Data sources and methodology on land use states and changes are descripted in **??**.

2.1.5 Total SOC stocks

Carbon stocks SOC for each sub-pool (sub) converge towards the calculate steady-state stock SOC^{eq} for each land-use types (lut), each sub-pool (sub) and each annual time step (t) as represented in equation (4).

$$SOC_t = SOC_{t-1} + (SOC_t^{eq} - SOC_{t-1}) \cdot k_t \cdot \Delta t \qquad \forall lut, sub, i. \tag{4}$$

The global SOC stock for each time step can than be calculated via

$$SOC_t = \sum_i \underbrace{\sum_{lut} \overbrace{\sum_{sub} SOC_{lut,sub,t,i}}^{\text{land use type specific SOC stock within a grid cell}}}_{\text{total SOC stock within a grid cell}} . \tag{5}$$

3 Results

4 Discussion

Shortcommings:

- Carbon displacement via leaching and erosion is neglected in this study.
- Non-net/Gross land use transitions are not tracked in this study.

5 Conclusions

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Code and data availability. use this to add a statement when having data sets and software code available

Appendix A: Figures and tables in appendices

A1 Option 1

If you sorted all figures and tables into the sections of the text, please also sort the appendix figures and appendix tables into the respective appendix sections. They will be correctly named automatically.

A2 Option 2

If you put all figures after the reference list, please insert appendix tables and figures after the normal tables and figures.

`\appendixfigures` needs to be added in front of appendix figures `\appendixtables` needs to be added in front of appendix tables

Please add `\clearpage` between each table and/or figure. Further guidelines on figures and tables can be found below. Regarding figures and tables in appendices, the following two options are possible depending on your general handling of figures and tables in the manuscript environment: To rename them correctly to A1, A2, etc., please add the following commands in front of them:

Author contributions. Karstens wrote code and paper build on work of Bodirsky. Bodirsky and Popp revised paper.

Competing interests. The authors declare no competing interests.

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