Model Simulation of the Impact of Soil Erosion and Deposition on Soil Carbon Dynamics in Terrestrial Ecosystems

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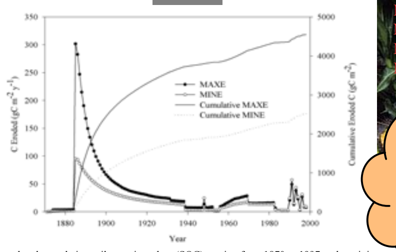
Soil erosion and deposition may play important roles in balancing the global atmospheric carbon budget through their impacts on the net exchange of carbon between terrestrial ecosystems and the atmosphere. Few models and studies have been designed to assess these impacts.

We developed a general ecosystem model Erosion-Deposition-Carbon-Model (EDCM) to dynamically simulate the influences of rainfall-induced soil erosion and deposition on soil organic carbon (SOC) dynamics in soil profiles. EDCM was applied to several landscape positions in the Nelson Farm watershed in Mississippi, including ridge top (without erosion or deposition), eroding hillslopes, and depositional sites that had been converted from native forests to croplands in 1870.

Overall, soil erosion and deposition reduced CO_2 emissions from the soil into the atmosphere by exposing low carbon-bearing soil at eroding sites and by burying SOC at depositional sites. The results suggest that failing to account for the impact of soil erosion and deposition may potentially contribute to an overestimation of both the total historical carbon released from soils owing to land use change and the contemporary carbon sequestration rates at the eroding sites.

Erosion



Annual and cumulative soil organic carbon (SOC) erosion from 1870 to 1997 under minimum (MINE) and maximum (MAXE) erosion scenarios.

About 60 cm and 21 cm of the soil have been eroded from the sites under the maximum and minimum erosion scenarios, respectively.

About 2500 to 4500 gC m^{-2} was eroded.

Table 1. Erosion Rates and Land Use History (adapted from Sharpe et al., 1998; Harden et al., 1999)

From	To	Min. Rates (kg Soil m^{-2} y^{-1})	Max. Rates	Land use and other characteristics
1870	1871	0.003	0.024	Forest
1872	1882	0.072	0.17	Pasture
1883	1929	3.8	12.3	Cotton; conventional tillage
1930	1936	3.8	10.67	Cotton; conventional tillage; fertilization began
1937	1945	1.11	4.4	Cotton; terrace
1946	1946	8.59	8.59	Cotton; terrace; very high rainfall
1947	1950	1.11	4.4	Cotton; terrace
1951	1953	0.85	0.85	Sorghum; terrace
1954	1967	1.95	4.4	Soybean; terraces ripped out; conventional tillage
1968	1980	1.51	2.15	Corn; conventional tillage
1981	1981	0.4	0.76	Winter wheat and soybean
1982	1983	0.24	0.24	Wheat
1984	1987	0.24	0.24	Grass (no crop)
1988	1988	1.74	1.74	Soybean; conventional tillage
1989	1989	4.4	4.4	Soybean; conventional tillage
1990	1990	1.02	1.02	Soybean; conventional tillage
1991	1991	3.26	3.26	Soybean; conventional tillage
1992	1992	1.9	1.9	Soybean; grass buffer strips installed
1993	1993	0.29	0.29	Soybean; conventional tillage
1994	1994	2.1	2.1	Soybean; high rainfall
1995	1997	0.64	0.64	Soybean; conventional tillage

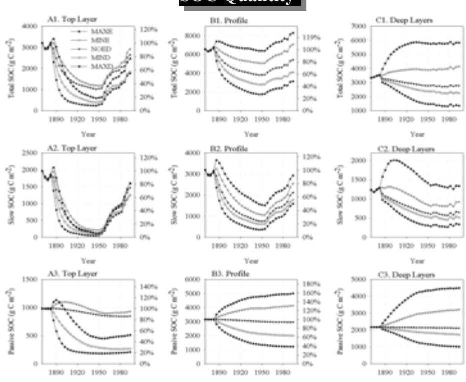
Table 2. Loss or gain of soil organic carbon (SOC) and the impact of soil erosion and deposition on SOC storage (Ψ_t) in the whole profile under various erosion and deposition scenarios compared with the presettlement conditions.

Scenario	Year	SOC (gC m^{-2})	SOC Change: Total[£] (gC m^{-2})	SOC Change: Annual (gC m^{-2}y^{-1})	SOC Change: % of Initial	Impact of Erosion or Deposition on SOC: Ψ_t Total (gC m^{-2})	Rate (gC m^{-2}y^{-1})	% of Initial
Initial	1870	6558						
MAXE	1950	1751	-4807	-60.1	-73.3	-2059	-25.7	-31.4
MINE	1950	2780	-3778	-47.2	-57.6	-1030	-12.9	-15.7
NOED	1950	3810	-2748	-34.4	-41.9	0	0.0	0.0
MIND	1950	5081	-1477	-18.5	-22.5	1271	15.9	19.4
MAXD	1950	6364	-194	-2.4	-3.0	2554	31.9	38.9
MAXE	1997	3178	-3380	-42.3	-51.5	-2292	-18.0	-34.9
MINE	1997	4176	-2382	-29.8	-36.3	-1294	-10.2	-19.7
NOED	1997	5470	-1088	-13.6	-16.6	0	0.0	0.0
MIND	1997	7023	465	5.8	7.1	1553	12.2	23.7
MAXD	1997	8222	1664	20.8	25.4	2752	21.7	42.0

[£]Equivalent to the integration of *dC/dt* over the period of simulation

Erosion reduced the SOC storage at the eroding sites and deposition increased the SOC storage at the depositional areas compared with the site without erosion or deposition.

SOC Quantity



Simulated historical trajectories of total soil organic carbon (SOC), slow, and passive SOC pools in the top 0.2 m soil layer (A1-A3), the whole profile (B1 – B3), and deep layers (20 to 200 cm) under various erosion and deposition scenarios. Two periods could be identified to characterize the SOC change in the top and entire profile: depletion (from start of cultivation to 1950) and recovery (from 1950 to 1997)

Soils were consistently carbon sources to the atmosphere at all landscape positions from 1870 to 1950, with lowest source strength at the eroding sites (13 to 24 gC m^{-2} y^{-1}), intermediate at the ridge top (34 gC m^{-2} y^{-1}), and highest at the depositional sites (42 to 49 gC m^{-2} y^{-1}). During this period, erosion reduced carbon emissions via dynamically replacing surface soil with subsurface soil that had lower SOC contents (quantity change) and higher passive SOC fractions (quality change).

Table 3. The exchange rates of C between the soil and atmosphere (Φ), and the impacts of soil erosion and deposition on sources/sinks (Ω) during two time periods (1870 to 1950 and 1870 to 1997).

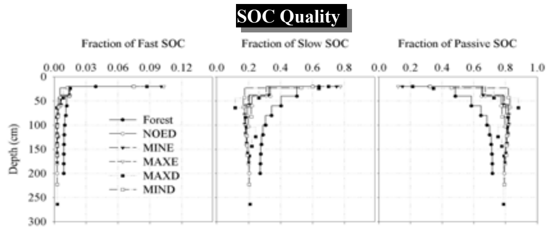
Scenario	Year	SOC (gC m^{-2})	Total SOC Eroded (-) or Deposited (+) (gC m^{-2})	Sink (+) or Source (-) Φ: Total (gCm^{-2})	Rate (gC m^{-2}y^{-1})	Impact of Erosion or Deposition on Source/Sink: Ω Total (gC m^{-2})	Rate (gC m^{-2}y^{-1})	% of Initial
Initial	1870	6558						
MAXE	1950	1751	-3752	-1055	-13.2	1693	21.2	25.8
MINE	1950	2780	-1887	-1891	-23.6	857	10.7	13.1
NOED	1950	3810	0	-2748	-34.4	0	0.0	0.0
MIND	1950	5081	1887	-3364	-42.1	-616	-7.7	-9.4
MAXD	1950	6364	3752	-3946	-49.3	-1198	-15.0	-18.3
MAXE	1997	3178	-4403	1023	8.1	2111	16.6	32.2
MINE	1997	4176	-2452	70	0.6	1158	9.1	17.7
NOED	1997	5470	0	-1088	-8.6	0	0.0	0.0
MIND	1997	7023	2452	-1987	-15.6	-899	-7.1	-13.7
MAXD	1997	8222	4403	-2739	-21.6	-1651	-13.0	-25.2

Soils at all landscape positions became carbon sinks from 1950 to 1997 due to changes in management practices (e.g., intensification of fertilization and crop genetic improvement). The sink strengths were highest at the eroding sites (42 to 44 gC m^{-2} y^{-1}), intermediate at the ridge top (35 gC m^{-2} y^{-1}), and lowest at the depositional sites (26 to 29 gC m^{-2} y^{-1}). During this period, erosion enhanced carbon uptake at the eroding sites by continuously taking away a fraction of SOC that can be replenished with enhanced plant residue input.

Table 4. Contemporary (1950-97) change of soil organic carbon in the whole soil profile and strength of soil carbon sequestration under the impact of soil erosion and deposition.

Scenario	SOC Change From 1950 to 1997: Total (gC m^{-2})	Rate (gC m^{-2} y^{-1})	SOC Eroded (-) or deposited (+) (gC m^{-2})	C Sink, Φ: Total (gC m^{-2})	Rate (gC m^{-2} y^{-1})
MAXE	1427	30.4	-651	2078	44.2
MINE	1396	29.7	-565	1961	41.7
NOED	1660	35.3	0	1660	35.3
MIND	1942	41.3	565	1377	29.3
MAXD	1858	39.5	651	1207	25.7

SOC Quality

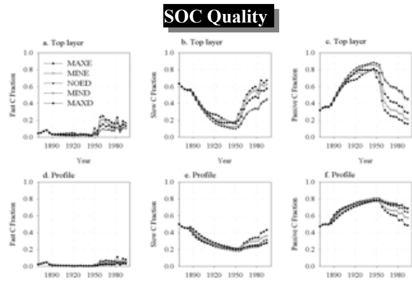


Simulated vertical distributions of fractions of active, slow, and passive soil organic carbon in soil profile for the forest (in 1870) and croplands under various erosion and deposition scenarios. No erosion or deposition was specified under forest and NOED during model simulation. MINE and MAXE represented minimum and maximum erosion scenarios, while MIND and MAXD corresponded to minimum and maximum deposition scenarios, respectively.

SOC quality in the top layer experienced dramatic temporal changes.

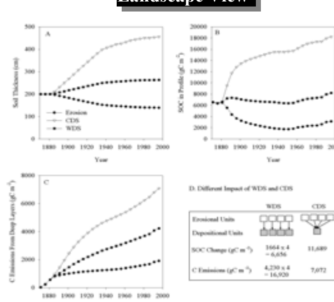
The quality of SOC in the deep layers changes significantly in all scenarios, although not as dramatically as in the top layer.

SOC Quality



Simulated temporal change of the soil organic carbon (SOC) quality (i.e., the composition of the fast, slow, and passive soil organic carbon pools) in the top 20-cm layer (top panels) and in the whole profile (lower panels) from 1870 to 1997.

Landscape View



Impact of the ratio of erosional to depositional area on SOC dynamics. Two ratios are presented. The first is the 1:1 ratio, representing a widespread deposition scenario (WDS). The other is the 4:1 ratio, representing concentrated deposition scenario (CDS).

Both SOC storage change and CO_2 emissions from deep layers indicated that concentrated deposition was more efficient in reducing CO_2 emissions from depositional sites. The results suggest that the redistribution patterns of eroded soil and SOC on the landscape has a significant impact on SOC dynamics.

Further Reading

Liu, S., N. Bliss, E. Sundquist and T. Huntington, 2003. Modeling Carbon Dynamics in Vegetation and Soil Under the Impact of Soil Erosion and Deposition. Global Biogeochemical Cycles (in press)

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