



*Impacts of Soil Redistribution on the Transport and Fate of Organic Carbon in  
Loess Soils*

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# **Impacts of soil redistribution on the transport and fate of organic carbon in loess soils**

## **Summary**

Soil erosion is an important environmental process leading to loss of topsoil including carbon and nutrients, to reduction of soil quality and to loss of biomass production. The erosion-induced redistribution of soil organic carbon (SOC) is an important component of the global C cycle. So far, the fate of SOC in eroding landscapes is not yet fully understood, which remains an important uncertainty in quantifying the global C cycle. The main objective of this dissertation is (i) to get an insight into the possible mechanisms regulating stabilization and destabilization of SOC in coupled eroding and depositional environments (Chapter 2 and 3) and (ii) to improve our process understanding of the behavior and fate of different SOC pools under the impact of soil erosion, transport, and subsequent deposition processes (Chapter 4 and 5). In all the presented work loess soils from Western Europe were studied by combining field scale measurements, laboratory scale rainfall simulation and incubation experiments.

Chapter 1 provides an introduction to the topic studied and an overview of the ongoing debate on the sources or sinks of atmospheric CO<sub>2</sub> in the context of soil erosion. The importance of the transport and fate of erosion-induced SOC for estimating the global C cycle is emphasized. Furthermore possible mechanisms controlling stabilization of SOC in eroding and depositional environments are explained.

In chapter 2 possible mechanisms controlling stabilization of eroded SOC against microbial decay are investigated. Loess soils were sampled from coupled eroding and depositional sites in the Belgian Loess Belt for incubation experiments in the laboratory. Deposition of eroded soil material resulted in significantly increased SOC contents throughout the entire soil profile (2 m) and microbial biomass C in the topsoil. This SOC accumulation at depositional sites was accompanied by low mineralization rates and small contents of water-extractable organic C. Glucose addition enhanced soil respiration particularly in the subsoil of the depositional site indicating that the low availability of C in colluvial subsoil horizons limits mineralization of deposited C. The availability of O<sub>2</sub> showed the expected positive relationship with C mineralization in topsoils only. Small O<sub>2</sub> concentrations did not result in decreased C mineralization in subsoils indicating that controls of C dynamics were different in top- and subsoils. Furthermore, limited availability of O<sub>2</sub> in subsoils can be excluded as an important control of soil C accumulation. I concluded that stabilization of deposited SOC in subsoil horizons of the depositional site is more important for C accumulation than its

translocation. It seems that the composition of the microbial community after burial of the organic-rich material might play a decisive role.

In Chapter 3 it is determined how aggregation affects stabilization of eroded SOC in comparison to interactions of SOC with minerals. I determined and compared aggregate size distributions, SOC distribution in density fractions, and lignin-derived phenols from aggregated soil samples at both eroding and depositional sites. The stabilization effect of aggregation was quantified by comparing mineralization from intact and crushed macro-aggregates. Soil erosion and deposition changed the aggregate size distribution and C associated in these aggregate fractions. Both macro-aggregate associated SOC and C associated with minerals increased in their importance from the eroding to the depositional site. In the uppermost topsoil (0–5 cm), SOC mineralization from intact aggregates was larger at the depositional site than at the eroding site, reflecting the large input of labile organic matter promoting aggregation. Contrastingly, in the subsoil, mineralization rates were lower at the depositional site because of effective stabilization by interactions with soil minerals. Aggregate crushing increased SOC mineralization by 10 to 80% at the eroding site, but not at the depositional site indicating that SOC is better protected in aggregates at the eroding than at the depositional site. The content of lignin-derived phenols did not differ between eroding and depositional sites in the topsoil but was larger in the subsoil of the eroding site, which was accompanied by higher lignin oxidation. Lignin data indicated minor effects of soil erosion and deposition on the chemical composition of SOC. I could show that the interplay between aggregation and the formation of mineral-associated SOC is one of the key issues to understand the stability of eroded SOC. During transport disaggregation and consequently SOC mineralization took place, while at the depositional site re-aggregation occurred mainly in the form of macro-aggregates. However, this macro-aggregation did not result in a direct stabilization of SOC. Optimal conditions for macro-aggregation as the deposition of organic C rich soil with a high proportion of plant residues are the pre-condition for the formation of mineral-associated SOC. I propose that the occlusion of C inside aggregates serves as a pathway for the eroded C to be later stabilized by organo-mineral interaction. This stabilization is underpinned by decreased C mineralization in subsoils of the depositional sites in comparison to that of the eroding site.

In Chapter 4 effects of soil erosion, transport and subsequent deposition on the movement and fate of SOC pools are investigated and a complete C budget determined using a pseudo-replicated rainfall-simulation experiment. The experimental setup allowed me to determine CO<sub>2</sub> efflux directly at different slope positions. Erosion, transport and deposition processes resulted in significantly higher carbon enrichment ratios (CER) of the sediments exported, ranging between 1.3 and 4.0. The C enrichment showed an inverse and non-linear relationship with the concentration of suspended solids. In the exported sediments, C contents (mg per g soil) of particulate organic C (POC, C not bound to soil minerals) and mineral-associated organic C (MOC) were both significantly higher than those of non-eroded soils

indicating that water erosion resulted in losses of C-enriched material both in forms of POC and MOC. The averaged SOC fluxes as particles ( $4.7 \text{ g C m}^{-2} \text{ yr}^{-1}$ ) were 18 times larger than DOC fluxes. Cumulative emission of soil  $\text{CO}_2$  slightly decreased at the erosion zone while it increased by 56% and 27% at the transport and depositional zones, respectively, in comparison to non-eroded soil. Overall,  $\text{CO}_2$  emission is the predominant form of C loss contributing about 90.5% of total erosion-induced C losses in our 4-month experiment, which were equal to  $18 \text{ g C m}^{-2}$ . Nevertheless, only 1.5% of the total redistributed C was mineralized to  $\text{CO}_2$  indicating a large stabilization after deposition. Our study also underlines the importance of C losses by particles and as DOC for understanding the effects of water erosion on the C balance at the interface of terrestrial and aquatic ecosystems.

In Chapter 5 the mineralization of eroded SOC in solid and dissolved forms, transported from soils into the aquatic environment is evaluated. Incubation experiments using total runoff C and dissolved organic C (DOC) showed that a significant portion (3.9 to 4.8%) of eroded C was mineralized to  $\text{CO}_2$  indicating a preferential translocation of labile forms of C from soils to waters. However, the majority of SOC delivered by overland flow will remain in aquatic ecosystems, potentially contributing to an erosion related aquatic C sink. Solid SOC was less degradable than DOC but accounted for 69 – 80% of total C mineralization from runoff because of its large contribution to the total C export into aquatic environments. Dissolved organic C contributed relatively little (2 – 21%) to total C export but the variability of  $\text{CO}_2$  emissions from runoff depended to a large extent on DOC. Different amounts and mineralization rates of solid SOC and DOC and their potentially different effects on aquatic communities emphasize the need to determine both fractions separately for getting an overall picture of soil erosion impacts on aquatic environments.

Chapter 6 provides a synthesis of the results of this dissertation to reveal the relationship between soil erosion and SOC redistribution. Erosion, transport, and deposition led to breakdown of aggregates, which not only altered lateral redistribution of SOC in quantity and quality (i.e. fPOC, oPOC and MOC) but also C mineralization at different slope positions, resulting in C depletion at upslope positions and C accumulation at downslope positions. Differences in C mineralization at different positions on the slope did not just result from a general lateral redistribution of SOC, but also from changes in different SOC pools. Most of the eroded C will be deposited downslope. Soil redistribution led to accumulation and stabilization of SOC in the depositional area due to the burial of C rich topsoil (decreased C mineralization). However, a significant portion of eroded soil material with labile C in solid and dissolved phases will be transported by overland flow into aquatic environments, where it can be potentially mineralized.

In general, this thesis has answered a number of questions related to the impacts of soil erosion processes on redistribution and fate of SOC. The C fluxes as determined in laboratory rainfall simulation experiments showed good correspondence with published values obtained

in real landscapes. This confirms that a laboratory approach, despite its shortcomings e.g. with respect to scale, is valuable and gives additional information on processes affecting the soil C budget in erosion-depositional systems in comparison to using modelling approaches.

As heavy rainfall events are predicted to increase in Western Europe in the future, more sediment could potentially be redistributed. However, this does not mean that more C will be lost because C stabilization will be affected as well. Carbon enrichment of exported sediments is one of the pivotal factors governing erosion-induced C loss. Additional research combining modelling approaches and field scale measurements is needed to further explore the role soil redistribution plays in regional and global C budgets. The used scale is decisive to finally answer the question whether soil erosion results in an overall fixation or release of atmospheric CO<sub>2</sub>. Future research should particularly focus on C replacement at eroding positions, transport processes, the role of micro-aggregation and microorganisms, and the fate and effects of eroded C in aquatic environments.