Catena 162 (2018) 51–60

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Estimating carbon stocks in young moraine soils affected by erosion

D. Deumlich*, R.H. Ellerbrock, Mo. Frielinghaus

Leibniz Centre for Agricultural Landscape Research (ZALF), Soil Landscape Research, Eberswalder Straße 84, 15374 Müncheberg, Germany

ARTICLE INFO

Keywords:
Water erosion
Tillage erosion
Plot experiment
Carbon
Sequestration

ABSTRACT

In this paper the storage potential of soils within a heterogeneous structured hummocky young moraine region for organic carbon is discussed with respect to climate change and erosion. Erosion is discussed to be either a global terrestrial CO_2 sink or a source. In hummocky young moraine regions of North East Germany water and tillage erosion are steadily changing factors since the beginning of arable landuse in ancient times. For such topographically complex landscapes the knowledge on soil organic carbon (SOC) dynamics and the limits of carbon storage are still limited. Our objective is to combine data collected during former soil erosion studies with recent findings on (i) soil property and (ii) estimated "optimal" SOC data to predict the SOC storage related to tillage and crop rotation, among others. Classified catenae were analysed for texture, SOC, CO_3-C, nutrient contents, and depth of weathering. Optimal SOC contents were estimated on the fine sized particle content. Arable soil at convex slope positions of steep catenae show 4 time smaller SOC stocks as compared to respective forest soils and to arable soils at concave position. Our findings suggest changes in SOC stocks to be almost exclusively related to decomposable carbon pools. Comparison of estimated optimal with measured SOC contents in soils at such positions indicated that such soils could potentially store a surplus of 0.6 to 0.8 g kg^{-1}. SOC protection at convex positions is limited by soil texture, and frequent truncation of the respective soil profiles. Whereas truncation followed by downhill transfer may bury SOC at sedimentation/concave positions resulting in long-term SOC storage as far as decomposition is prevented by site conditions.

1. Introduction

Soil and climate are connected by complex interactions. The increase in carbon dioxide concentration of the atmosphere is discussed to affect the world's climate (IPCC, 2014). Climate-relevant gases (e.g., CO_2, N_2O and CH_4) were exchanged by complex processes between soils and atmosphere. In soils approximately $1500 \cdot 10^9$ Mg C is stored within the soil organic matter. This is about three times the amount of carbon stored in the entire biomass (Bodenatlas, 2015; MPG, 2016) in consequence soils offer the most important carbon sink. However, soils may act also as a source for carbon dioxide, and the quantities of carbon stored in soil differ significantly between various soils and climate zones: For terrestrial soils the storage capacities are smaller than that of semi-terrestrial soils (e.g., gley, marsh, alluvial soils). For groundwater influenced soils it is higher than for drained soils (Blume et al., 2010; Rinklebe, 2004) and it decreases in the sequence forest > grassland > arable land (e.g., Guo and Gifford, 2002; Freibauer et al., 2004; Smith, 2004; Leifeld and Kögel-Knabner, 2005). Determining SOC storage in soils as a climate protection effort is often difficult since geographic and temporal conditions are highly variable and changes in SOC mostly need decades to reach a new equilibrium (Hülsbergen and Rahmann, 2013; Körschens et al., 2014; Powlson et al., 1996). However, Körschens (1980) found by investigating soils with > 50 years of bare fallow the amount of inert organic carbon (i.e. the proportion of remaining SOC) generally to be related to the content of fine sized mineral soil particles (< 63 µm, cfs). Körschens et al. (2014) and Isermann and Isermann (2011) assume the cfs content to determine a lower and upper limit for the C storage potential in arable soils.

Since the Atlantic period (ca. 8000 BCE) the intensity of arable land use has globally increased and water erosion accelerates. Soil erosion is associated with carbon and nutrient fluxes (Quinton et al., 2010). For the past 4500 years Bork et al. (1998, p. 103) estimated for different time scales the following losses of soil masses and carbon based on the thickness of sediment layers (Table 1). These findings indicate that C loss caused by arable land use is about 20 times (270 kg C ha^{-1} y^{-1}) higher at the beginning of the 20th century as compared to that in the Bronze Age (14 kg C ha^{-1} y^{-1}). Consequently erosion is regarded as one of the most important threats to soils fertility (e.g., Montanarella et al., 2016; Pimental, 2006; Lal, 2005; Gregorich et al., 1998). The potential amount of sediment annually transferred by water erosion was estimated between 35,000 Tg y^{-1} (Quinton et al., 2010), 130,000 Tg y^{-1} (Reich et al., 2001) and 200,000 Tg y^{-1} (Lal, 2003).

---

* Corresponding author.
E-mail address: deumlich@zalf.de (D. Deumlich).

https://doi.org/10.1016/j.catena.2017.11.016
Received 7 June 2017; Received in revised form 13 September 2017; Accepted 16 November 2017

Table 1
Estimated soil and soil organic carbon (SOC) within time spans between 800 and 100 CE, 100 CE to 1910 and 1910 to 1988 (in brackets SOC contents assumed for translocated sediments).

Time scale	Soil loss Mg ha^{-1} y^{-1}	Carbon loss kg C ha^{-1} y^{-1}
800 BCE to 100 CE (Bronze Age and Iron Age)	6.1	14 (0.2%)
100 CE to 1910 (Middle Ages and Modern Age)	8.4	34 (0.4%)
1911 to 1988 (Modern Age)	33	270 (0.8%)

Such sediment transfer rates caused by water erosion will result in annual carbon (C) transfer rates of approximately 500 ± 150 Tg globally. However, the annual carbon transfer rates into river systems and oceans calculated by Quinton et al. (2010) are much lower (80 ± 20 Tg C).

Erosion may cause a burial of SOC at concave positions resulting colluvial soils to act as sinks for organic carbon. However, conditions of precipitation (intensity, duration), site (landuse, cover crop, soil conditions) as well as topography are known to affect kind and amount of eroded material (Richter, 1998). Such that colluvial soil will only act as a sink for SOC if the buried SOC remains stable, but may act as a source for CO_2 if SOC decomposition occurs (Kleber et al., 2015; Lorenz and Lal, 2012). Additionally at steep slopes a selective transport of particle size classes (Hjulström, 1935) may cause event specific textural rearrangements at the burial sites. Fine sized particles may -due to their small specific weight- potentially be translocated straight forward into drainage systems, while coarser sized particles will mostly remain at footslope positions (e.g., Doetterl et al., 2016). This is validated by Herzog (1990) who found by replacing Ap horizons by subsoil for the initial 7 year period a SOC sequestration, that increases until the 14th year after application (Herzog and Kunze, 1976), and then approached 90% of the site-specific SOC concentration determined by texture. However, Herzog and Kunze (1976) found the burying of SOC-rich soil to provide a possibility for permanent SOC storage which is confirmed by Müller (1980).

Assumptions whether erosion may act as a global terrestrial CO_2 sink or source remains still open (e.g., Lal, 2005) since different authors present contradictory estimations: Stallard (1998) and Ito (2007) estimates soil to be strong sinks (1000 to 2000 Tg y^{-1}), while van Oost et al. (2007) estimates them to be weak (by 400 Tg y^{-1}), and Lal (2003) assumed them to be strong sources (4000 to 6000 Tg y^{-1}). For understanding of landscape-scale SOC dynamics in cropland soils knowledge on effects of erosion on SOC dynamics becomes important (e.g., Quine and van Oost, 2007). The knowledge of SOC dynamics and the limits of carbon storage potential in erosion influenced arable soils in topographically complex landscapes are still limited (e.g., van Oost et al., 2007).

"*Long-term*" studies on soil erosion, starting originally in the 1980th for estimating soil erodibility in a hummocky young moraine region (Frielinghaus et al., 2002) offer a possibility for estimating erosion effects on the SOC storage potential of soils within time spans between 10 and 20 years related to site conditions, tillage, crop rotation among others.

Our objectives are to combine data collected during such "*long-term*" studies on erosion events together with actual soil property data to

(i) determine erosion driven effects on carbon storage potential of soils from a young moraine region with respect to
   a. land-use
   b. slope steepness and -position
(ii) differentiate the effect of tillage on SOC storage from the effect of water erosion
(iii) discuss the storage potential of arable soils for surplus carbon by comparing the erosion driven storage potential with the one estimated from the contents of fine sized mineral soil particles (< 63 μm, cfs), according to Körschens (1980).

2. Materials and methods

2.1. Study area

The studied sites located in Mecklenburg and Brandenburg are typical for a hummocky ground moraine landscape. The land forming processes during the glacial periods (i.e., Pommeranian stage; 15,200 years ago (Liedtke, 2003)) contributed to characteristic landscape properties of the soil formation: a relatively thick ground moraine and a strong differentiation of relief and typical thickness of Bt horizons. Eroded material is mostly deposited in lower parts of the catchment: concave positions, such as small depressions, kettle holes, or ponds. Processes of erosion and deposition caused a highly heterogeneous landscape (Schmidt, 1997) with Calcaric Regosols (truncated soil profiles), slightly eroded Luvisols - on convex and mid slope positions, respectively-, and Colluvic Regosols at concave positions. The concave positions often show deep colluvial deposits with Gley or Pseudogley characteristics (Schatz, 2000).

2.2. Studied sites

We compared erosion effect on SOC content for soils different in (A) land use (neighboured forest and grassland catenae), (B) slope steepness and catenae position, (C) tillage and site conditions – and (D) longer-term (10–20 years) tillage and crop rotation.

Slope and soil type were classified according to KA5 (AG Boden, 2005; IUSS, 2007). All investigated catenae were classified by considering inclination, morphology, horizon sequences, and soil types. Soil characteristics such as texture, SOC, CO_3-C, nutrient contents, depth of weathering were categorised according to Schmidt (1986) (Fig. 2).

2.2.1. A – Land use (neighboured forest and grassland catenae)

Near the city of Burg Stargard (Fig. 1, Table 2) neighboured catenae (type IV) under forest and under grassland with similar slope steepness were sampled (Frielinghaus and Ellerbrock, 2000). At the forest site well-developed Ael-horizon depleted in clay content and distinct illuviated Bt-horizons were formed above the C horizon with decalcification reaching down to 135 cm depth (Table 4). On today's grassland, a) Calcaric Regosols developed during the 250 years after deforestation caused by erosion at the concave positions and b) Colluvic Regosols due to continuous sedimentation processes at the convex positions.

2.2.2. B – Slope steepness and catenae position

According to Schmidt et al. (1986, Fig. 2) classified arable sites different in slope steepness were chosen that are located north and south of the terminal moraine of the Brandenburg stage in the hummocky young moraine (Table 2). Soils from flat catenae (Slope-steepness: 4 to 12%) were sampled at Müncheberg, Deven, Prötzel and Malchin site. While soils from steep catenae (Slope steepness: 8 to 18%) were sampled in Holzendorf and Brüel site (Fig. 1). The ANOVA single factor of "Excel's Analysis ToolPak add-in" was used for statistical analysis (Microsoft, 2014).

2.2.3. C – Tillage and site conditions

The effects of different tillage techniques (e.g., plough, cultivator and disc harrow) on erosion were studied at a field experimental site (Müncheberg; Kietzer, 2007) and at field sites located near Prenzlau (Augustenfelde, Basedow, and Holzendorf; Table 2). The soils ^{137}Cs-inventory was used as a tracer to distinguish effects of water erosion from that of tillage erosion throughout the past decades (Li et al., 1999; Lobb et al., 1995).