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Interactions between crop, water, and dissolved organic and inorganic carbon in a hummocky landscape with erosion-affected pedogenesis

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ABSTRACT

Hummocky soil landscapes are characterized by 3D spatial patterns of soil types that result from erosion-affected pedogenesis. Due to tillage and water erosion, truncated profiles have been formed at steep and mid slopes and colluvial soils at hollows, while intact profiles remained at plateau positions. Pedogenetic variations in soil horizons lead to spatial differences in the soil water balance at hillslope positions. Here, possible interactions between erosion affected soil properties, the water balances, and the crop growth and feedback effects of erosion on the leaching rates were assumed. The hypothesis was tested by water balance simulations comparing uniform with hillslope position-specific crop and root growths for soils at plateau, flat mid slope, steep slope, and hollow using the Hydrus-1D program. The boundary condition data were monitored at the CarboZALF-D experimental field site, which was cropped with perennial lucerne (*Medicago sativa* L.) in 2013 and 2014. Crop and root growth at the four hillslope positions was assumed proportional to observed leaf area index (LAI). Fluxes of dissolved organic and inorganic carbon (DOC, DIC) were obtained from simulated water fluxes and measured DOC and DIC concentrations. For the colluvic soil at hollow, the crop growth was initially highest and later limited by an increasing water table; here the predominately upward flow led to a net input in DIC and DOC. For the truncated soils at steep slopes, simulations support the hypothesis that reduced crop growth caused an increase in percolation and DIC leaching from the subsoil horizons, which in turn led to accelerated soil development and more soil variations along eroding hillslopes in arable soil landscapes.

1. Introduction

The arable hummocky post glacial soil landscape is characterized by truncated soils at steep slopes and exposed hilltops (hummock) and by colluvial soils at the slope toe and in the topographic depressions (hollow) (Deumlich et al., 2010; Gerke et al., 2010). The hummock-hollow pedosequence is resulting from continuing soil erosion by tillage and water (Frielinghaus and Vahrson, 1998; Van Oost et al., 2000, 2006). Tillage erosion (i.e., soil movement during tillage) is often occurring in combination with water erosion during surface runoff; it depends on the landscape structure and is characterized by a soil loss from convexities and accumulation in concavities (Govers et al., 1999). The erosion-affected pedogenesis is creating spatially-distributed patterns of soil types that are closely related to landscape topography (e.g., Sommer et al., 2008; Bullock et al., 2008). Crop biomass reflects these soil landscape patterns by increased or reduced growth during dry or wet seasons. This has been reported for hollow positions (e.g., Manning et al., 2001; Malhi et al., 2004) and *vice versa* for eroded steep slopes where most pedogenetic horizons have been removed and the unweathered glacial till was partly incorporated in the topsoil (Gerke and Hierold, 2012).

Interactions between erosion-affected spatial patterns of soil types, soil structures, and the water balance in the hummocky soil landscape were reported in hillslope hydrology (e.g., Shah et al., 2007; Johnson et al., 2010). Additional interactions may be assumed when considering a spatially-distributed crop growth that depends on distributed soil properties and topography. In this case, more intensive root water uptake would reduce percolation and drainage while a reduced transpiration should have the opposite effect on the water balance and on solute leaching in yet unknown combinations for differently-eroded soils along the hillslope. The study of such intimate relationships between soil, crop, hydrology, and pedogenesis in the landscape was described as hydropedology (Lin et al., 2006); questions are not only how the

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spatially-distributed soil types control hydrologic and ecosystem functions but also how landscape or hillslope hydrology interacts with crop and soil moisture dynamics. Furthermore, the hydraulic properties of soil horizons that control water and solute movement are subject to soil structure and pedogenetic changes in space and time (e.g., Lin, 2011). Such changes could be observed, for instance, in soil horizons of erosion-affected profiles of the hummocky landscape; here the hydraulic properties of the same diagnostic horizons differed depending on horizon thickness and soil structure (Rieckh et al., 2012).

The erosion-affected pedogenesis has implications for the water and the carbon (C) balance of the hummocky soil landscape. Direct implications include the redistribution of C in the solid phase; and indirect implications can result from changes in the spatial patterns of soil hydraulic and transport properties. Leaching of dissolved C from the root zone was identified as a crucial component of the C balance of agricultural soils (Kindler et al., 2011; Lentz and Lehrsch, 2014). To quantify this component, attempts based on hydropedology tried to quantify the leaching of dissolved C from the root zone of forested and arable soil landscapes (e.g., Andrews et al., 2011; Mei et al., 2012; Rieckh et al., 2014). Mei et al. (2012) identified the water table depth as controlling factor for leaching of dissolved C. The spatially-distributed fluxes of dissolved organic and inorganic carbon (DOC, DIC) are also controlled by environmental conditions that affect decomposition of soil organic matter environmental conditions and management practices supporting enhanced mineralization (Kalbitz et al., 2000). Observations of DOC and DIC fluxes below the root zone are relatively difficult and thus any quantification of this component of the soil carbon balance remains a challenge (Lentz and Lehrsch, 2014); this is especially true for conditions of the hummocky ground moraine soil

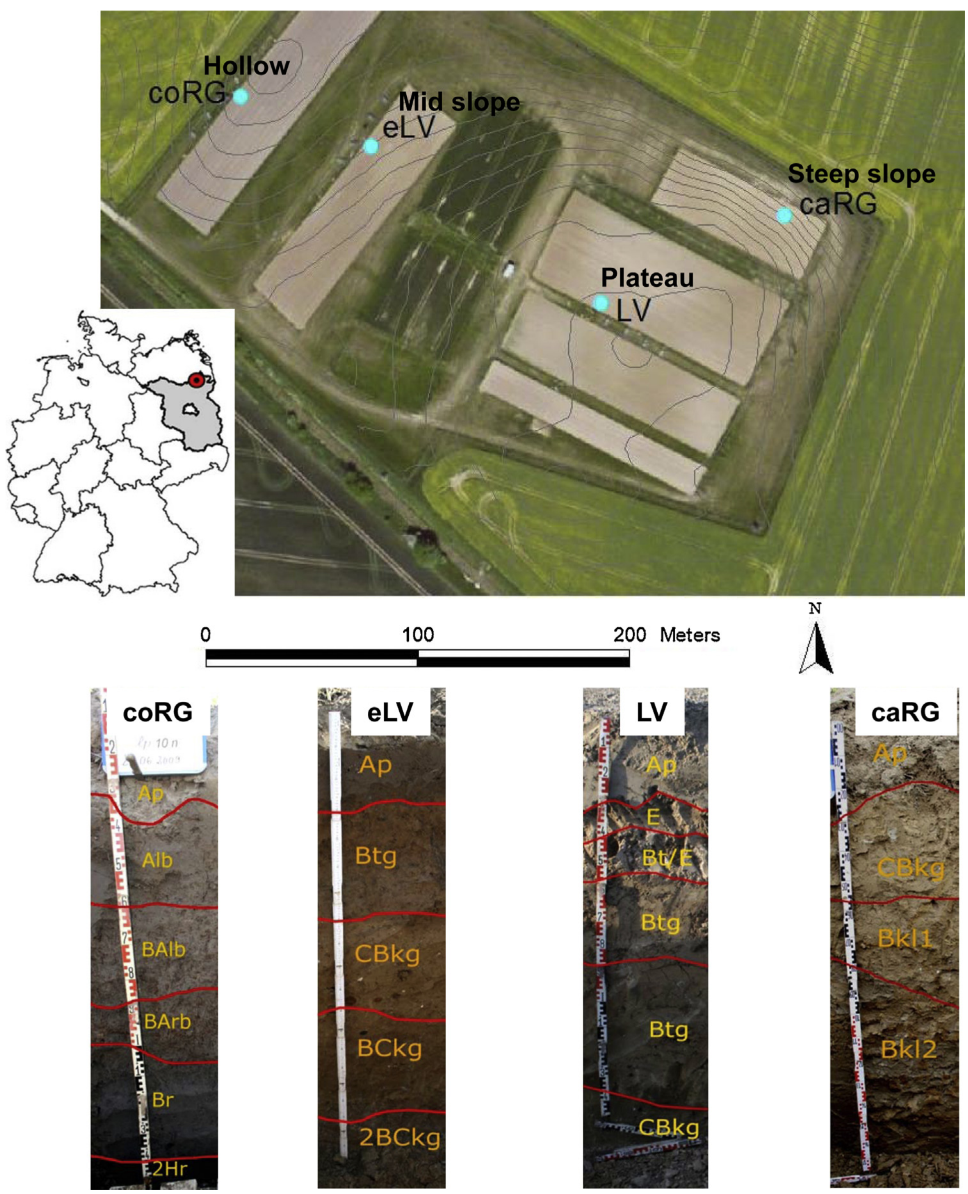

Fig. 1. Location of the experimental site in Germany (point on map) and aerial photo of the CarboZALF-D experimental field site in the hummocky soil landscape with 1-m contour lines; the location of soil profiles represented in the simulations is indicated by points; Plateau position: Albic Cutanic Luvisol (LV), Mid slope position: eroded Calcic Cutanic Luvisol (eLV), Steep slope position: Calcaric Regosol (caRG), Hollow position: Endogleyic Colluvic Regosol (coRG) (classification according to FAO).