



## Impacts of land use change on soil aggregation and aggregate stabilizing compounds as dependent on time

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### ABSTRACT

Land use change is known to strongly affect soil aggregation and aggregate stabilizing compounds. In this study we wanted to gain insight into the temporal and spatial dimension of this process. Therefore, we studied water-stable aggregates, total organic carbon (TOC), carbohydrates and glomalin-related soil protein (GRSP) in a 110-year chronosequence of Stagnosols, which have been converted from pasture to cropland at different times in history. To describe the temporal dimension, the measured concentrations were approximated by an exponential decay function. The spatial dimension was assessed by analyzing the distribution of TOC, carbohydrates, GRSP, and  $^{14}\text{C}$  among the different aggregate-size fractions over the course of 110 years of cropland use. It was found that the TOC concentration decreased mono-exponentially ( $R^2 = 0.92$ ) from  $195.2 \text{ t ha}^{-1}$  to  $45.13 \text{ t ha}^{-1}$  in the first depth interval (0–20 cm) during the first 110 years after the conversion, and reached a new equilibrium  $23 (\pm 5)$  years after land use change. Carbohydrates and GRSP obtained a new equilibrium after  $14 (\pm 6)$  and  $56 (\pm 5)$  years in the same depth interval. The mean-weight diameter (MWD) of the water-stable aggregates reached a new equilibrium  $33 (\pm 2)$  years after the land use conversion. With respect to the spatial dimension we found that TOC, carbohydrates, and GRSP showed higher concentrations in the macroaggregates than in the microaggregates. The ratios of the distribution of TOC, carbohydrates and GRSP among macro- and microaggregates did not change significantly during the 110 years of arable use of the soils. The average age of the organic carbon in the different aggregate-size fractions analyzed by its  $^{14}\text{C}$  concentration showed of a wide range from  $65 (\pm 25)$  to  $251 (\pm 30)$  years, and did not change significantly during the cultivation of the sites. Thus, we conclude that water-stable aggregates and the concentrations of TOC, carbohydrates and GRSP reacted towards land use change at different speeds and reached a new equilibrium between  $14 (\pm 6)$  and  $56 (\pm 5)$  years after the conversion of land use. Secondly, we found, that the spatial distribution of aggregate stabilizing compounds was not significantly changed during the first 110 years of cultivation.

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### 1. Introduction

Soil aggregation is an important mechanism for stabilization of soil organic matter (SOM), especially in organic rich soils (Six et al., 2000; Lützwow et al., 2006). Furthermore, it supports soil fertility as it reduces erosion and mediates soil aeration, water infiltration, water retention, and nutrient cycling (Oades, 1984; Six et al., 2000). Soil aggregation is caused by a variety of aggregate stabilizing compounds, which work simultaneously at different spatial scales. Tisdall and Oades (1982) stated that mineral particles are bound together to microaggregates due to persistent binding agents. These microaggregates, in turn, build macroaggregates due to

transient and temporal organic binding agents like polysaccharides, roots, and fungal hyphae. This aggregate hierarchy theory, which states an uneven distribution of organic compounds among different aggregate-size fractions, has been used by many authors to explain correlations between a reduction of aggregation and a loss of SOM (Six et al., 2000, 2004).

Even though it is generally known that land use strongly affects soil aggregation (Haynes et al., 1991; Besnard et al., 1996; Jastrow, 1996; John et al., 2005; Ashagrie et al., 2007), the temporal dimension of this impact remains unknown. The major objective of our study was therefore to gain insight into the impact of land use change on soil aggregation and aggregate stabilizing compounds in time. For this purpose, we studied a 110-year chronosequence of Stagnosols, which have been converted from pasture to cropland at different points of history. Stagnosols were chosen, since mineral hydromorphic soils exhibit exceptionally high organic carbon

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concentrations (Grabe et al., 2003), and their conversion to cropland is accompanied by large losses of SOM (Neufeldt, 2005). As aggregate stabilizing compounds we choose to study carbohydrates and glomalin-related soil protein (GRSP). Carbohydrates in soils are derived from bacteria, fungi or root mucilage (Oades, 1984; Puget et al., 1999; Jolivet et al., 2006). Glomalin is a thermostable protein produced by arbuscular mycorrhizal fungi (Wright and Upadhyaya, 1996, 1998). As the glomalin fraction gained by high temperature extraction is not completely pure, it is addressed as glomalin-related soil protein (GRSP). Thus, GRSP is an operationally defined thermostable protein fraction, which has been shown to strongly contribute to soil aggregation (Rillig et al., 2003; Rosier et al., 2006).

In this study we hypothesize, firstly, that different organic compounds or fractions which assist soil aggregation react towards land use change at different speeds and, secondly, that land use change effects the spatial distribution of aggregate stabilizing compounds in the way that the uneven distribution of SOM among different aggregate-size classes is attenuated. To test the first hypothesis we measured aggregate stability, TOC, carbohydrates and GRSP in the chronosequence, and approximated the empirical data with a simple exponential decay model, which allows calculating the point of time when a new steady state is reached after the conversion of land use. To test the second hypothesis we measured TOC, carbohydrates, GRSP, and  $^{14}\text{C}$  in the different aggregate-size fractions and statistically tested if changes in the distribution occur over the course of cultivation.

## 2. Materials and methods

### 2.1. Study site

The study was conducted in the North German lowlands in the northwest of Bremen (53°14'N, 8°45'E). The region is characterized by an annual mean precipitation of 700 mm and an annual mean air temperature of 8.8 °C. The area was formed as ground-moraines during the Saalian ice age. Today, Stagnosols represent the main soil group in this region.

### 2.2. Geo-data sources and processing

Information about soil group distribution was taken from the 'Bodenübersichtskarte 50' (soil map on a scale 1:50,000). Topographical maps from 1900, 1937, 1968, 1976, 1982, 1995, 2002, 2008, (on a scale 1:25 000) as well as the 'Papen-Atlas' (1848) which contain precise information on land use, were used to attribute

former uses of cropland, pasture, and forest in order to establish a chronosequence. Sites, which have been converted from pasture to arable land at a defined point of time in history and have been used continuously ever since, were selected. As a zero point of the chronosequence, two permanent pastures were chosen. The remaining sites represented a sequence of arable land use durations with one one-year, one eight-year, two 30-year, and two 110-year sites (Table 1). The size of the sites ranged from 1.2 to 2.0 ha. The largest distance between two sites was 9 km.

### 2.3. Sampling and bulk density

On each site, samples were taken every 10 m along two diagonal transects to a depth of 40 cm, with at least 20 samples per site depending on the size of the sites. The cores were split into two parts (0–20 cm and 20–40 cm). All samples of each depth interval from one site were combined to gain one mixed sample. The mixed samples were homogenized, and oven dried at 70 °C for 96 h to prevent biodegradation during the drying process, which occurs at lower temperatures. Prior to chemical analysis, samples were crushed to pass through a screen (2 mm-opening). Additionally, four core samples per depth interval were taken in a randomly located soil pit at each site. These samples were oven dried (105 °C, 48 h) and used to calculate bulk densities.

### 2.4. Anorganic soil compounds

Particle size, pH and oxalate extractable Fe and Al ( $\text{Fe}_{\text{ox}}$ ,  $\text{Al}_{\text{ox}}$ ) were determined according to Schlichting et al. (1995). Fe and Al were measured using atom absorption spectrometry (SpectrAA300 and SpectrAA55, Varian).

### 2.5. TOC

Samples were analyzed for TOC and total N with a CHNS analyzer (Flash EA 112 series, Thermo Electron Cooperation) after being ground to fine powder with a ball mill for 5 min (MM301, Retsch) and dried at 105 °C.

### 2.6. Water-stable aggregates

The MWD of the water-stable aggregates was determined for the uppermost 20 cm as the subsoil horizons did not show aggregation. Water-stable aggregates were fractionated according to Kemper and Rosenau (1986). Briefly, 70 g of oven-dried soil was

**Table 1**  
Duration of cropland use of the chronosequence sites, bulk density, texture,  $\text{pH}_{\text{H}_2\text{O}}$ , and oxalate-soluble Al and Fe ( $\text{Al}_{\text{ox}}$ ,  $\text{Fe}_{\text{ox}}$ ) of the two analyzed depth intervals. Standard deviations are given in brackets.

Site	Duration [y]	Depth [cm]	Bulk density [ $\text{g cm}^{-3}$ ]	Sand [%]	Fine silt [%]	Rough silt [%]	Clay [%]	$\text{pH}_{\text{H}_2\text{O}}$	$\text{Fe}_{\text{ox}}$ [ $\text{g kg}^{-1}$ ]	$\text{Al}_{\text{ox}}$ [ $\text{g kg}^{-1}$ ]
0a	0	0–20	0.98 ( $\pm 0.08$ )	43.5	38.1	8.8	9.6	5.3	1.99 ( $\pm 0.17$ )	4.02 ( $\pm 0.15$ )
		20–40	1.51 ( $\pm 0.16$ )	36.5	39.6	10.2	13.7	5.3	0.82 ( $\pm 0.02$ )	1.12 ( $\pm 0.08$ )
0b	0	0–20	1.10 ( $\pm 0.06$ )	54.0	25.5	11.3	9.2	5.5	1.55 ( $\pm 0.03$ )	3.09 ( $\pm 0.22$ )
		20–40	1.47 ( $\pm 0.15$ )	46.7	30.1	11.9	11.3	5.6	0.95 ( $\pm 0.07$ )	1.69 ( $\pm 0.01$ )
1	1	0–20	1.37 ( $\pm 0.04$ )	52.2	25.5	10.3	12.1	5.7	1.21 ( $\pm 0.07$ )	1.36 ( $\pm 0.02$ )
		20–40	1.46 ( $\pm 0.06$ )	53.2	23.4	11.2	12.2	5.7	0.59 ( $\pm 0.01$ )	0.93 ( $\pm 0.14$ )
8	8	0–20	1.21 ( $\pm 0.08$ )	50.3	26.3	11.4	12.0	5.9	0.83 ( $\pm 0.03$ )	1.71 ( $\pm 0.03$ )
		20–40	1.41 ( $\pm 0.18$ )	51.2	23.4	11.2	12.2	5.8	0.76 ( $\pm 0.10$ )	1.77 ( $\pm 0.03$ )
30a	30	0–20	1.23 ( $\pm 0.05$ )	68.4	20.2	6.0	5.4	5.6	2.36 ( $\pm 0.02$ )	0.96 ( $\pm 0.12$ )
		20–40	1.28 ( $\pm 0.09$ )	67.1	17.2	8.5	7.1	5.5	1.96 ( $\pm 0.08$ )	0.96 ( $\pm 0.12$ )
30b	30	0–20	1.28 ( $\pm 0.11$ )	69.4	11.4	8.8	10.4	6.8	0.65 ( $\pm 0.03$ )	1.39 ( $\pm 0.04$ )
		20–40	1.58 ( $\pm 0.04$ )	66.8	10.9	13.3	9.1	6.8	0.57 ( $\pm 0.01$ )	1.12 ( $\pm 0.01$ )
110a	110	0–20	1.57 ( $\pm 0.06$ )	63.3	15.1	12.0	9.5	6.1	1.52 ( $\pm 0.03$ )	2.00 ( $\pm 0.30$ )
		20–40	1.55 ( $\pm 0.12$ )	61.7	13.9	12.6	11.8	5.7	1.13 ( $\pm 0.01$ )	2.04 ( $\pm 0.13$ )
110b	110	0–20	1.50 ( $\pm 0.16$ )	59.2	15.4	13.7	11.7	6.2	1.12 ( $\pm 0.01$ )	2.49 ( $\pm 0.00$ )
		20–40	1.70 ( $\pm 0.14$ )	64.3	15.1	10.9	9.7	6.0	1.00 ( $\pm 0.01$ )	1.83 ( $\pm 0.06$ )

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