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Anthropogenic Dark Earth in Northern Germany — The Nordic Analogue to *terra preta de Índio* in Amazonia

Katja Wiedner [a,*], Jens Schneeweiß [b], Michaela A. Dippold [c], Bruno Glaser [a]

[a] *Institute of Agronomy and Nutritional Sciences, Soil Biogeochemistry, Martin Luther University Halle-Wittenberg, von-Seckendorff-Platz 3, 06120 Halle, Germany*
[b] *Department of Prehistory and Early History, Georg August University Göttingen, Germany*
[c] *Department of Agricultural Soil Science, Georg August University Göttingen, Germany*

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ABSTRACT

During an archaeological excavation of a Slavic settlement (10th/11th C. A.D.) in Brünkendorf (Wendland region in Northern Germany), a thick black soil (Nordic Dark Earth) was discovered that resembled the famous *terra preta* phenomenon. For the humid tropics, *terra preta* could act as model for sustainable agricultural practices and for long-term CO_2-sequestration into terrestrial ecosystems. The question was whether this Nordic Dark Earth had similar properties and genesis as the famous Amazonian Dark Earth in order to find a model for sustainable agricultural practices and long term CO_2-sequestration in temperate zones. For this purpose, a multi-analytical approach was used to characterise the sandy-textured Nordic Dark Earth in comparison to less anthropogenically influenced soils in the adjacent area in respect of ecological conditions (pH, electric conductivity, cation exchange capacity, amino sugar) and input materials. Total element contents (C, N, P, Ca, Mg, K, Na, Fe, Cu, K, Zn, Mn and Ba) were highly enriched in the Nordic Dark Earth compared to the reference soil. Faecal biomarkers such as stanols and bile acids indicated animal manure from omnivores and herbivores but also human excrements. Amino sugar analyses showed that Nordic Dark Earth contained higher amounts of microbial residues being dominated by soil fungi. Black carbon content of about 30 Mg ha^{-1} in the Nordic Dark Earth was about four times higher compared to the adjacent soil and in the same order of magnitude compared to *terra preta*.

The input materials and resulting soil chemical characteristics of the Nordic Dark Earth were comparable to those of Amazonian Dark Earth suggesting that their genesis was also comparable. Amazonian Dark Earth and Nordic Dark Earth were created by surface deposition and/or shallow soil incorporation of waste materials including human and animal excrements together with charred organic matter. Over time, soil organisms degraded and metabolized these materials leaving behind deep black stable soil organic matter. The existence of the Nordic Dark Earth in the temperate zone of Europe demonstrates the capability of sandy-textured soils to maintain high soil organic matter contents and nutrient retention over hundreds of years. Deeper insights are needed urgently to understand soil organic matter stabilization mechanisms in this sandy soil to promote conceptual models for sustainable land use and long-term C sequestration.

It is argued that the knowledge of Nordic Dark Earth probably was an important part of the Viking–Slavic subsistence agriculture system, which could have had a great impact on the development of the Viking age emporia in the 9th/10th C. A.D.

1. Introduction

Ancient soils of anthropogenic origin are interesting research subjects for various reasons because these soils contain important information about e.g. agricultural practices, animal husbandry and livestock or handicraft activities. In view of important global topics such climate change and sustainable agriculture, more attention has been paid to anthrosols exhibiting high nutrient and soil organic matter (SOM) stocks. One of the best known examples is *terra preta de Índio* in Central Amazonia. In fact, tropical ecosystems are characterised by nutrient-poor and highly weathered soils with high turnover rates of SOM (Zech et al., 1990). Therefore, the occurrence of highly fertile soils with high SOM stocks in such ecosystems is remarkable. In the past years, *terra preta de Índio* served as a model for sustainable agricultural practices and long-term CO_2 sequestration in terrestrial ecosystems (Glaser and Birk, 2012; Glaser et al., 2001).

In Northern Europe, the *Plaggenesch* is an anthropogenic soil type of sods applied as an anthropogenic attempt to increase the fertility of fields; it was formed by many centuries of plaggen manure application consisting mainly of sods, i. e. flatly cut pieces of heath and grass, mixed with stable manure. Thus, the Ap horizon beyond the original soil was

* Corresponding author.
E-mail address: katja.wiedner@landw.uni-halle.de (K. Wiedner).

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increased up to a thickness of 50–100 cm, creating the anthrosol Plaggenesch (Behre, 1980; Lienemann, 1989; Mückenhausen et al., 1968). The Plaggenesch is well known from the southern and eastern coastal area of the North Sea, its geographical extension includes the Netherlands, Belgium, North-Western Germany and Denmark. There is a broad agreement about the chronological coincidence of the main distribution of the Plaggenesch economy with the beginning of permanent rye farming at the end of the 1st Millennium A.D. Nevertheless, there is strong evidence of sod cutting for fertilization in the pre-Roman Iron Age or even earlier (Kossack et al., 1987; Kroll, 1975).

In addition to the Plaggenesch cultivation further soils, developed through ancient manuring techniques in North Germany, are described but less investigated (e.g. Geschwendt, 1959; Reichmann, 1982; Schmidt, 1974). While the Plaggenesch is an intentional off-site feature, other anthrosols are settlement soils, from an archaeological point of view (so called “settlement horizon” or “cultural layer”). The study here aims to investigate whether the soil is man-made and, if so, what are the main inputs and whether there are parallels to the famous *terra preta de Ìndio* with respect to formation and ecological properties. In our opinion it is straightforward to compare these two soil types as both are of anthropogenic origin established at a similar time with probably similar natural resources (smoldering fire residues), household garbage, excrements and animal residues (bones) resulting in similar soil properties. For this purpose, a multi-analytical approach was undertaken using methods which has been applied in previous studies for terra preta investigations (e.g. Birk et al., 2010; Costa and Kern, 1999; Glaser, 2014; Glaser and Birk, 2012) such as multi-element soil analysis including phosphate and faecal biomarkers (stanols and bile acids). In addition, total organic C and N of bulk soil and its stable isotope signatures ($\delta^{15}N$, $\delta^{13}C$) were investigated and black carbon was used as molecular marker for charring residues. Amino sugars were analysed to identify the role of bacteria and fungi in soil organic matter formation.

This study allows deeper insights into the understanding of anthropogenic dark earth formation in the temperate climate zone of Europe. The identification of a terra preta-like soil in the temperate climate zone will provide a model for sustainable agricultural practices and long term CO_2-sequestration in soils beyond the tropics. From an archaeological point of view, the following study provides a completely new perspective on cultivation practices in the Viking–Slavic world which are currently to a big extent unknown.

2. Material and methods

2.1. Natural and historical background of the study area

The North German Plain was mainly formed during the late Quaternary, namely by glaciers during glaciation periods and by large scale erosion and sedimentation during the interglacial stages. As a result, the landscape is characterised by moraine areas, sand areas, river channels and floodplains as well as dunes and bogs. The depressions are filled with colluvium or loess. Podsolized and grey-brown podsolized soils, both relatively poor in nutrients and SOM are widespread.

A similar situation occurs in the lower middle part of the Elbe River (Lower Saxony, Germany; Fig. 1). This area was formed during the Saale glacial stage as an end moraine, and later by periglacial impacts during the Weichselian glaciation. The large bed of the present day Elbe River follows a former glacial channel. Alluvial sediments as well as aeolian sediments were accumulated near the river (Schneeweiss and Schatz, 2014).

During the 2nd half of the first Millennium A.D., the Elbe River roughly divided the German population in the West from the Slavic population in the East. The Slavic archaeological settlement sites are in some ways different from the contemporary German settlements in the West, and they are different from the earlier settlements of the Roman Iron Age. In general, the eastern sites cover a smaller area, reveal sunken buildings or ground level houses instead of post constructions and have no fences. The archaeologically so-called cultural layer (that is the anthrosol) of the Slavic settlements, if preserved, is often described as very dark and rich in SOM, even if the subsoil is nutrient-poor and sandy (Ansorge and Schindler, 2009).

During archaeological excavations of the site Brünkendorf 13 (Fig. 2), a deeply black coloured anthrosol (Fig. 3A) was found ~50 cm below soil surface covering an area of about 1.2 ha on a northern and north-western slope of a small sandy elevation near the Elbe river bed (Fig. 2). The anthrosol is clearly connected with relics of a Slavic settlement, which existed there from the late 9th to the 13th Century A.D. In an excavated area of 650 m^2 in total, several hundred features (relics of houses, pits, fire places etc.) were documented (Fig. 2) and thousands of artefacts were collected (Fig. 4), mainly deriving from the black anthrosol (*cultural layer*). The spectrum of the findings is quite usual for a Slavic settlement site and includes potsherds, animal bones, burnt clay, stone tools, bronze objects and silver coins, as well as coprolites and charcoal (Schneeweiß, 2013a). The bone preservation was mainly poor, but a general tendency can be observed: nearly half of the determinable animal bones were pig (49.7%), followed by cattle (32.9%) and goat/sheep (15%) (Morgenstern, 2013). Such reflects the generally assumed increasing importance of pig for the Early Medieval subsistence economy in Central Europe (Benecke, 1994; Morgenstern, 2013). Though the Slavic subsistence economy is known as complex, including fishing, gathering, animal husbandry and agriculture, its exact character remains mainly uncertain. For example, we do not yet know of any cultivated areas of the Slavs, especially for the older period. It is important to notice that the economy of the Northwestern Slavic area at that time (Viking Age, 8th–11th C.) is closely connected to the Baltic Sea region. Therefore, it would be possible to outline a (pagan) Viking–Slavic economy system, which was distinct from the (Christian) Carolingian/Ottonian economy system (e. g. Steuer, 2004; Schneeweiß, 2013b).

The site consists of yellowish-white sandy deposits. Taxonomic analyses of charcoal particles found in soil revealed mostly oak (76%) and, to a lesser extent, elm (7%), alder (5%), birch (4%), hornbeam (4%) and even less maple, salix, poplar, pine, ash, prunus and fagus (O. Nelle, Institute for Ecosystem Research, Palaeoecology Christian-Albrechts-University zu Kiel, Germany; personal communication). This spectrum reflects more or less the natural environment of the Slavic settlement, providing most of the wood resources for everyday life.

2.2. Chemical soil analysis

The positions of the soil profiles within (Dark Earth profile) and outside (reference profile) of the Brünkendorf settlement are shown in Fig. 2. Bulk soil samples were taken at 10 cm increments down to 80 cm soil depth from the Nordic Dark Earth (NDE) and the adjacent, not visibly anthropogenically influenced, reference soil (RFS; Fig. 3A and B). Soil samples were freeze-dried and sieved through stainless steel sieves to <2 mm prior to analysis.

2.2.1. pH and electric conductivity

Soil pH and electric conductivity (EC) was measured using suspensions with 0.01 M $CaCl_2$ and distilled H_2O (1:5). After shaking the suspensions for 1 h on a low speed shaker and sedimentation of solids for another hour at room temperature, pH and EC were determined in the supernatant.

2.2.2. Cation exchange capacity and exchangeable cations

Potential cation exchange capacity (CEC_{pot}) and exchangeable cations were determined according to the method of Lavkulich (1981) using ammonium-acetate (NH_4OAc) at pH 7. Ca, Mg, K and Na in the