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Thesen der kumulativen Dissertation

A look into the past:
the formation of humus-rich soils in Northern Europe

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I Motivation and objectives of the dissertation

The pedogenic processes that formed locally restricted deep, dark and humus-rich (up to 120 cm) soils in Northern Europe are unknown.

Previous designation of these soils as Chernozems, based on similarities in soil organic matter (SOM) composition to typical Chernozems worldwide, is doubtful due to their patchy distribution and the absence of typical steppe conditions.

Reconstructing of the formation of these soils and other humus-rich soils requires disclosing the molecular signature of the SOM by a multi-methods approach along with ^{34}S measurements (to test for marine organic matter), P speciation and the determination of the SOM age in order to find out possible anthropogenic influences on soil formation.

II Major research findings

The complementary results of C *K*-edge XANES, Py-FIMS and BPCAs unequivocally showed relative enrichments of aromatic C and heterocyclic N compounds in the soils at the German island of Fehmarn and in the Jæren region of Norway which were assigned to combustion residues.

The stable isotope measurements demonstrated an enrichment of ^{34}S–values in the underlying Axh-horizons from Poel and Sjaelland and in the whole profiles of the Norwegian soils that is explained by the input of marine biomass as alternative soil amendment in ancient times.

The extraordinary high P concentrations in Norwegian soils compared to most soils of the world and the high Ca, Fe and Al concentrations compared to the surrounding soils suggested long-term inputs of P-rich amendments.

The corresponding enrichments of NaOH-P_i (from sequential P-fractionations) and Al-P, Fe-P (from P - XANES) as well as the extremely high concentrations of P, Al and Fe in the Norwegian soils pointed to applications of peat, animal manure, composts and human excreta.

The results of sequential P-fractionations, ^{31}P-NMR with improved spectra interpretation and P *K*-edge XANES revealed relative enrichments of Ca-P in the soils at the island of Fehmarn and at the peninsula of Wagrien. This provided compelling evidence for the input of biochar and animal manure, most likely with cattle excrements, as strongly supported by archaeological findings of cattle bones in this region.

The anthropogenic soil formation began between the Nordic Bronze Age (3,800 to 2,800 BP) and the Roman Iron Age (2,700 to 2,000 BP) for the soils in the Baltic Sea region and between the Roman

Iron Age (2,500 to 1,500 BP) and the Viking Age (about 1,200 to 1,000 BP) for the Norwegian soils. This was derived from AMS ^{14}C age of the humin fraction of these soils and the alignment to archaeological references.

III Conclusions

The outcomes obtained by a set of complementary methods (C and P *K*-edge XANES, Py-FIMS, BPCAs, stable isotope measurements and AMS ^{14}C–dating, elemental analyses, sequential P fractionations and ^{31}P-NMR) provided compelling evidence for the contribution of farming to the formation of soil profiles with deep, dark and humus-rich soils in Northern Europe.

The AMS ^{14}C dating provided evidence for different beginnings of soil formation depending on the geographical region from South (3,100 yr BP) to North (1,722 yr BP) which is in agreement with archaeological references that reported a gradual transition of farming practice from Central Europe (7,400 BP) towards Northern Europe (between 6,000 and 4,000 yr BP).

Combustion residues and marine biomass played a significant role in the anthropogenic formation of these soils, because 80% of the studied soils showed markers for these amendments.

Consequently, the compelling evidence for the decisive influence of human activities on the formation of these soils call for the classification as Hortic, Mollic and/or Umbric Anthrosols in the WRB system, although Mollic and Umbric horizons have been restricted to natural soils so far.

The ancient soil amendments by means of adding marine biomass, excrement and compost from almost all regionally available organic matter sources, have now been sustained for more than 2,000 years and have greatly improved the ecological soil functions. That could be a model for the responsible handling of the resource “soil”.

Therefore, we can learn from the ancient agricultural practice that recycling organic matter from humans, local area-adapted livestock husbandry, and biochar application improves soils and sustainably builds up soil fertility for many generations. Today, we have to reconsider our current agriculture practice. The adaptations of these old culture techniques are strongly recommended for the conservation and increase of soil health and fertility assuring the food production for the rapidly growing world population. This sustainable organic farming can counteract the global climate change using the potential of soils to take up and store greenhouse gases.