International Meeting on Soil Fertility Land Management and Agroclimatology. Turkey, 2008. p367-378

Carbon Stock in Hydromorphic Soils of the North-Eastern Part of Germany

Jutta Zeitz[1], Albrecht Bauriegel[2], Joris Hering[2], and Michael Zauft[1]

[1)] Humboldt-Universität zu Berlin, Faculty of Agriculture and Horticulture, Division of Soil Science and Site Science, Invalidenstrasse 42, D-10115 Berlin, Germany, phone: 49(0)30 20932090, email: jutta.zeitz@agrar.hu-berlin.de;

[2)] State Office for Mining, Geology and Natural Resources Brandenburg, Stahnsdorfer Damm 77, D-14532 Kleinmachnow, Germany, phone: +49 (0)33203 36 691,

ABSTRACT

Changing climatic conditions in Germany mainly affect hydromorphic soils formed by groundwater. They offer comparatively high carbon contents and, as the only soil group, also accumulate C in the subsoil. The assessment of the storage capacity of these soils is essential to assign 'risk areas' according to national (German Federal Soil Protection Act, 1998) and international (EU Soil Protection Strategy, 2006) soil protection requirements. An appropriate water management enables preservation and protection of the soil organic matter in hydromorphic soils. Both aims, as a part of resource protection, require knowledge of the carbon stock of the soils and the transformation of area restricted results to a regional scale. Assessments comprise of two steps: in the first step, the carbon content of so-called horizon-substrate-combinations (HSC) for profiles of the dominant soil of a soil mapping unit is determined. This method is based on the hypothesis, that comparable soil properties are formed by equal soil substrates and pedogenetic processes. In the second step, the results are assigned to the profiles of the dominant soil of the soil mapping unit and extended to spatial polygons of functional maps. Carbon stock of hydromorphic soils is determined for the federal state Brandenburg, located in the northeast of Germany. Brandenburg is characterised by a percentage of 40 % hydromorphic soils of the country's territory and features a high vulnerability according to studies concerning climate change. The authors offer a proposal for the assignment of 'risk areas' and management principles for hydromorphic soils.

Key words: Gleysols, Histsols, estimation method, risk areas

INTRODUCTION

Organic and inorganic carbon compounds are stored as C pools in different reservoirs in various quantities. Flux between the C pool and the reservoir exists as continuous exchange in both directions (IPCC, 2001; Mannion, 2006). Among the natural carbon reservoirs of the earth the pedosphere has a significant status since it stores a C pool of 2500 Gt. of carbon, which amounts to about three times the magnitude stored by the atmosphere (Lal, 2004).

Hydromorphic soils, whose characteristics are based on the ground water and its dynamics, store the greatest amounts of carbon. Due to the specific site conditions, organic matter decomposition is limited and carbon is accumulated. As opposed to the terrestrial soils, hydromorphic soils also store carbon in the subsoil. Among the hydromorphic soils Histosols are of special significance. Although Histosols comprise only 3 % surface area of the pedosphere, and therefore are of secondary importance, they store 16 till 24 % of the total soil bound carbon (Bridgham et al. 2006; Joosten, 2008). Histosols in total store more carbon than is stored by all forests world wide and contain as much carbon as is stored in the total terrestrial biomass of the earth (Joosten and Clarke, 2002). Globally this amounts to a storage of as much as 350 till 535 Gt. of carbon (Gorham, 1995; Strack, 2008).

Soil moisture in the different soil horizons can vary, due to natural or anthropogenic fluctuations in ground water level, resulting in different redox potentials. Under aerobic conditions, readily decomposable carbon compounds can be oxidised. Through this an increase in release of climate-relevant gases, i.e. CO_2 and N_2O, as result of mineralisation can be recorded. Therewith the characteristic of the soils as carbon sink is altered to a carbon source (Drösler, 2005, Schulze and Freibauer, 2005). Especially peatland shows an increase in carbon loss, as was assessed in studies conducted between 1978 and 2003 by Bellamy et al. (2005) for various soils in England and Wales. In addition to requirements of lowering the ground water level, mainly due to the requirements in land cultivation, mineralisation processes in hydromorphic soils were further intensified in the previous years through climatic change.

Climatic change will lead to further limitations in water supply with a main problem resulting from summer drought (IPCC, 2007). Through summer drought soil warming is increased, resulting in an intensified mineralisation of the organic substance (Kuka, 2005). On the other hand extreme weather situations, i.e. torrential rainfall will increase, so that requirements for a greater retention capacity of the soils exist.

Due to alterations of moist soil conditions to dry and especially warmer soil conditions, soil carbon release is increased resulting in a decrease in soil organic matter (SOM) content. The cause effect relationship finally acts as driver, since dry and warm soil conditions lead to a release of climate-relevant gases (Byrne et al., 2004; Höper, 2007). In the final outcome soil carbon contents are reduced. In this respect hydromorphic soils show the greatest vulnerability of all soils (Eckelmann et al., 2006; Höper, 2007).

Decreases in SOM lead to an impairment in soil functions (Zeitz and Velty, 2002); this contradicts requirements of the German Federal Soil Protection Act (§1 and 2 general requirements and §17 with requirements regarding the good agricultural practice) as well as requirements of international law as postulated in the shortly to be implemented EU Soil Protection Strategy, which defines soil organic matter decline as one of the five main threats. According to the EU Soil Protection Strategy, every country will be asked to identify these vulnerable areas as „risk area“.

Maintenance and protection of SOM in hydromorphic soils can be achieved by adapted water management. To achieve the named goals of resource protection it is necessary to evaluate the soils in regard to their carbon stock.

Therefore the objective of this research was to provide a method to detect areas with very high carbon stock on the basis of available point and area databases using the federal state Brandenburg, situated in northeast Germany, as model region to assess and present first results. Emphasis was to be given to the relevance of C storage in the subsoil as is found in hydromorphic soils. The federal state Brandenburg was chosen, because it has a comparatively high vulnerability as compared to other federal states in Germany (Integriertes Klimaschutzmanagement, 2007) and because hydromorphic soils cover more than 40 % of the land area (soil map, scale 1:300 000).

MATERIALS and METHODS:

Test Area

The federal state Brandenburg is situated in northeast Germany and holds an area of approximately 30 000 km-2. As part of the North German Lowland it is the southern part of the North European Pleistocene glaciations so that the morphological form was shaped mainly by the Pleistocene ice age. Resulting from the quaternary development, two main morphological forms evolved: the glaciogene plateau and the (glazio-) fluviatile lowlands, to which the glacial valleys belong. The lowlands are structured by postglacial mire formations and dune drift. The mean altitude of vast areas in Brandenburg lies between 30 and 50 m above sea level. In the Pleistocene and Holocene valleys Gleyic Arenosols and Haplic Gleysols dominate and, with rising ground water levels, mainly Mollic or Histic Gleysols as well as Histosols are present.

Brandenburg is one of the federal states with the highest proportion of Histosols in Germany. A specific significance can be attributed to the Fluvisols in the floodplains. These soils, comprising of silty-clay deposits, are usually highly humous down into deep soil layers and mostly have high fluctuations in ground water level. Fluvisols are regarded the most fertile soils in Brandenburg.

Area Data

Soil geological maps with area polygons and linked subject contents exist for various requirements and target scales. These are generated by combining and describing approximately homogenous soil sections of a landscape to area polygons. Descriptions of the dominant soil type as well as important accompanying soil types, occurring with less area coverage, are the basis for the subject content of the area polygons i.e. area related data. Subject contents are based on established geological records (relatively stable parameters such as parent rock and soil textural class) as well as data from remote sensing and present survey data, which are appropriately blended.

Point Data and Horizon-Substrate-Combinations (HSC)

Area related data are based on the characteristics of dominant soil profiles representative for the area and are used to describe a section of a landscape by means of a this soil profile. This can be obtained in various ways: i) each area is assigned a typical soil profile on the basis of expert judgement; ii) a mean profile is assessed on the basis of statistical analysis, which does not truly exist but describes the given homogenous landscape section. The last-mentioned method was used in the present case. The method is based on the following hypotheses: soil material from the same parent rock and with the same soil texture as well as the same pedogenesis has comparable soil characteristics. By combining a large number of comparable data sets from the soil profiles ”mean and typical” combinations of horizons and substrates are derived by statistical averaging, resulting in the so-called horizon-substrate-combinations (HSC) for which soil parameters are then calculated (Bauriegel, 2004; Zeitz et al., 2008).

Classification

The German soil classification scheme differs from the WRB. Therefore, appropriate translations and assignments were made, so that results of the soil types given in the German classification could be assigned to the corresponding nomenclature of Reference Soil Groups in the WRB classification. The Nomenclature of the horizons in the HSC is only available in the German classification mode, so that the depth distribution of the bulk density and C_{org} are given in the German HSC nomenclature and are explained in the corresponding legends.

Calculation of Carbon Stock

The calculations of the carbon stock of various hydromorphic soils include four steps:

1.) Assessment of content homogenous area polygons for the hydromorphic soils
2.) Calculation of C amounts for the dominant soil profiles representative for the area using:
C amount per HSC = depth of HSC * bulk density * C_{org} content
3.) Calculation of C amount for the soil sections 0 – 0.3 m; 0 – 1 m, and 0 – 2 m soil depth
4.) Assignment of profile values to the area data and quantification on the basis of carbon content classes. For carbon content classes the German humus classification scheme, which comprises 7 classes for the mineral soils and an eighth class for all organic soils was expanded to ten classes with classes 8 till 10 differentiating organic soils.

C_{org} was analysed with a CNS Analyser (Variomax 2 Elemental, double analyses) and the bulk density using 100 cm-3 soil sampling cylinder (3 - 5 replicates).

RESULTS and DISCUSSION:

Bulk Density and C_{org} Content of Different HSCs in Hydromorphic Soils

Soils examined comprised three different mineral hydromorphic soils, belonging to the Gleysols, as well as Histosols. The selected soils differ in their ground water regime and therefore show great variations in the development of their horizons and soil characteristics.

Gleysols are wetland soils that, unless drained, are saturated with groundwater for long enough periods to develop a characteristic *“gleyic colour pattern”*. (WRB, 2006). According to the depth of organic matter and base saturation the three soils can be differentiated as presented in Fig. 1a – c.

If the ground water level is high during long periods of time and has only minor fluctuations a Mollic horizon develops (Fig. 1b). Even higher soil moisture content, resulting from a very high water level throughout the year and very small fluctuations of the ground water level, leads to the development of a Histic horizon in the Gleysol (Fig. 1c). This horizon comprises larger amount of organic material and the substrate can be classified as peat.

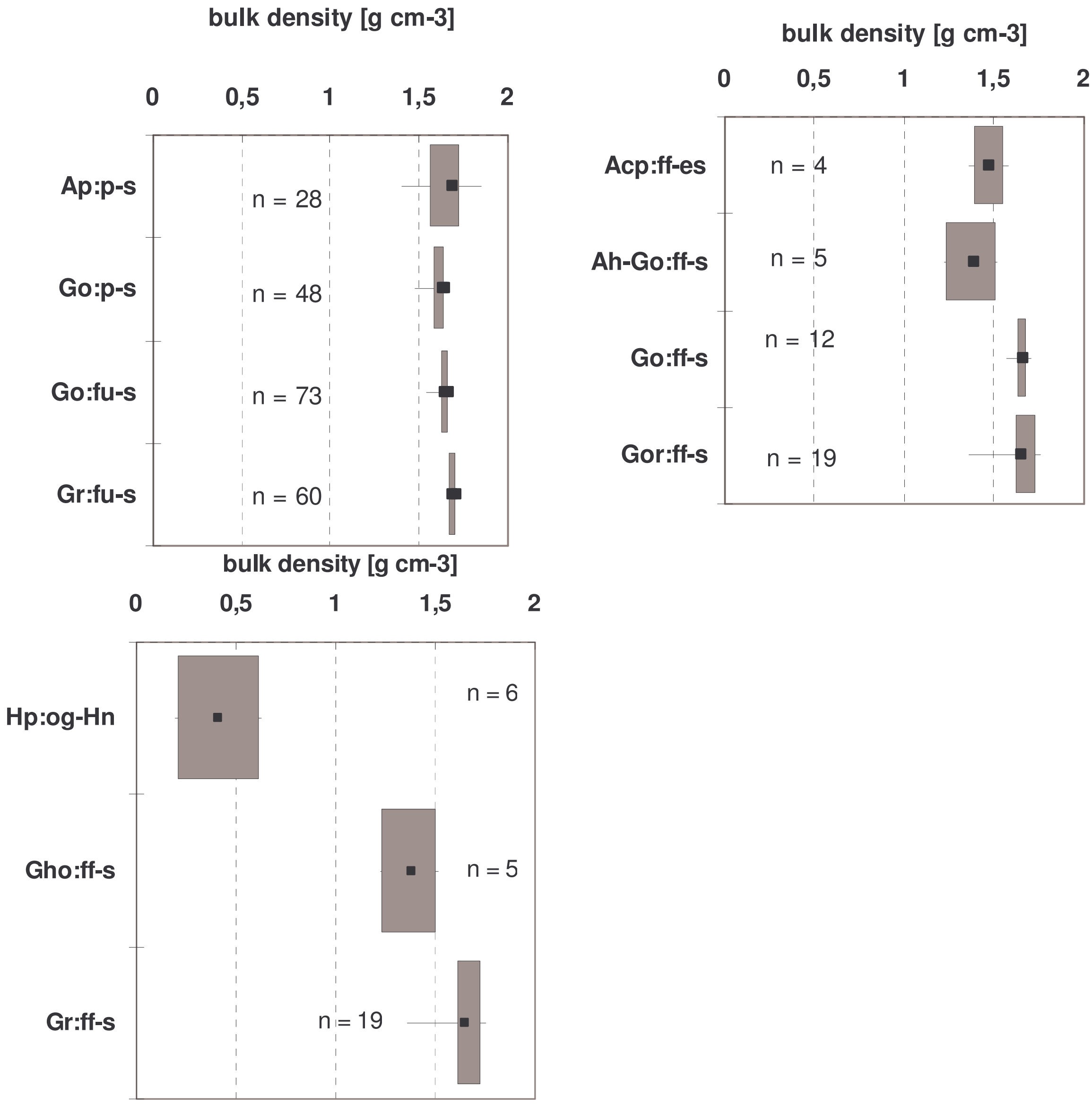

Figure 1(a-c): Bulk density values of the horizon-substrate-combinations (HSC) of representative soil profiles of hydromorphic soils in Brandenburg; a) Haplic Gleysol; b) Mollic Gleysol; c) Histic Gleysol (legends of HSC of all figures published on the end of the paper)

The lowest bulk density in the top soil (0 – 0.25 m depth) is found in the Histic Gleysol (Fig 1c). Bulk density in the subsoil (Gho horizon) of this soil is also comparably low, which can be attributed to a high soil organic matter content. The highest values in bulk density are found in the Haplic Gleysol in the top soil as well as in the in all other horizons throughout the profile (Fig. 1a). Mineral horizons show an increase in consolidation with increasing soil depth, which is especially

developed in the Haplic Gleysol. The Mollic Gleysol has lower values in bulk density in the topsoil than the Haplic Gleysol, but higher values than the Histic Gleysol (Fig. 1b).
Mineral horizons in the subsoil affected by ground water fluctuations have comparable values in bulk density, if identical substrates are given; i.e. Gr:ff-s horizons of the Mollic Gleysol and Histic Gleysol (median value 1.64 g/cm-3).

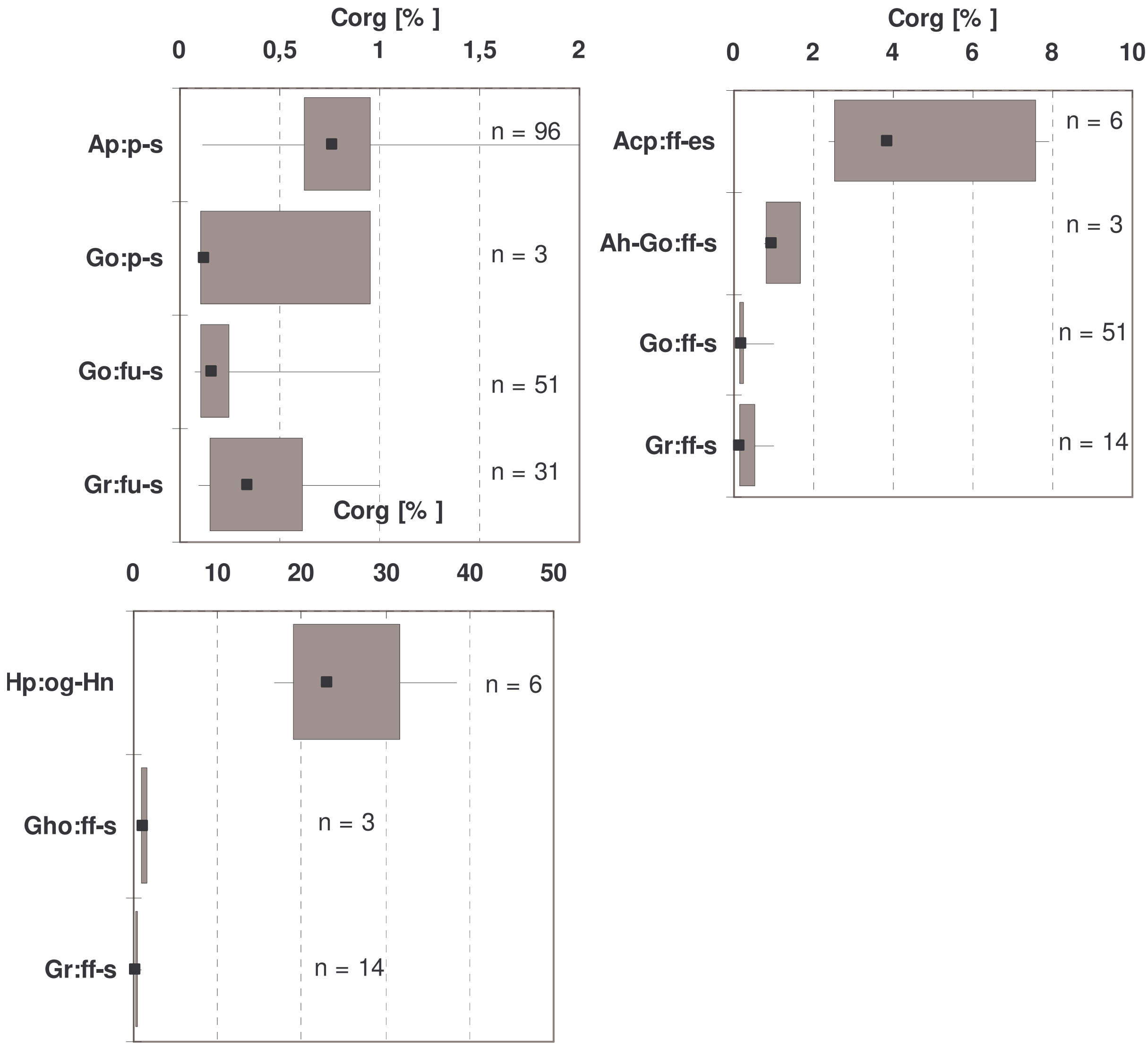

Figure 2 (a – c): C_{org} content of the horizon-substrate-combinations (HSC) of representative soil profiles of hydromorphic soils in Brandenburg; a) Haplic Gleysol; b) Mollic Gleysol; c) Histic Gleysol

The small range of the values for all results in bulk density is conspicuous. This was also found by Bauriegel (2004), who provided evidence that the bulk density is a soil parameter with very low statistical variation and is therefore highly suitable for modelling and quantification of e.g. soil functions.

Results for the Histosols (see Fig. 3) are based on data obtained from the federal state north of Brandenburg, Mecklenburg-Western Pomerania, which has a comparable geological development and considerably better data basis of Histosols than the federal state Brandenburg.

In the top soil of the Histosols bulk density values are similar to values assessed for the Histic Gleysol, but all HSCs of the Histosols have considerably lower bulk densities in the subsoil, due to the peat substrate in these layers. For Histosols, soil development as influenced by drainage and land use is of special importance: the anthropogenic affected top soils (nHv and nHa horizons) have clearly higher bulk densities than the only slightly degraded peat in the subsoil (nHt and nHr horizons).

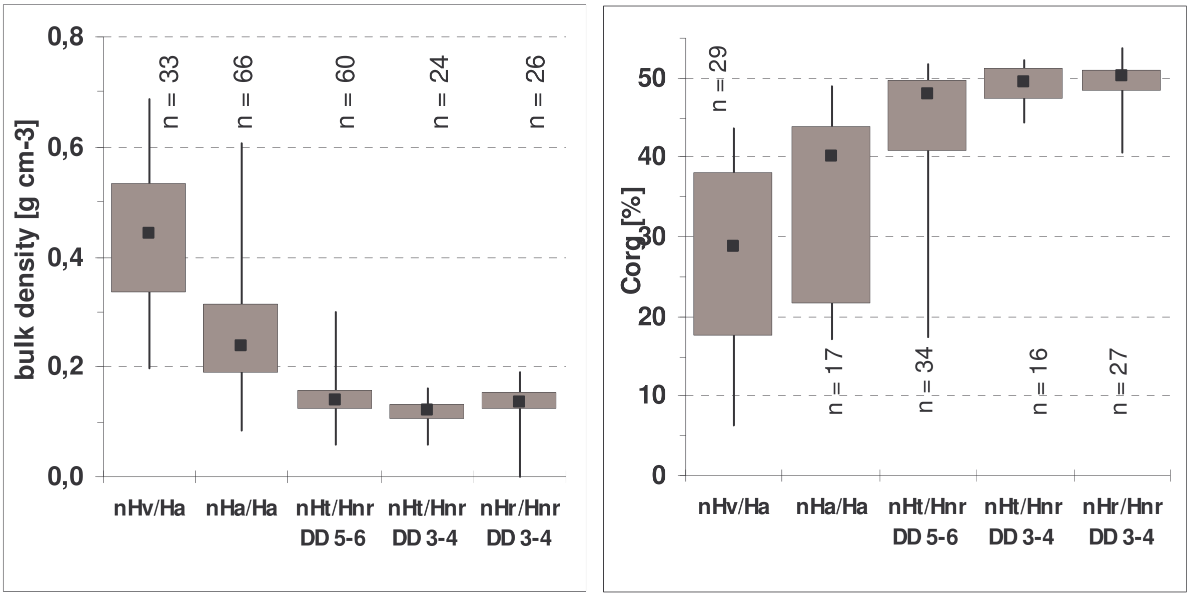

Figure 3 (a and b): Bulk density and C_{org} content of horizon-substrate-combinations (HSC) of Histsols

The contents in C_{org} are directly connected with the ground water conditions of the soils and affect bulk density. The higher the C_{org} content, the lower the bulk density. The highest C_{org} contents in the top soil, with mean values amounting to nearly 30 %, are found for the Histosols and with 25 % for the Histic Gleysols, respectively (Fig. 2c and 3b). All three soils with mineral substrate in the subsoil have lower contents in C_{org} in the subsoil than in the top soil, but it must be taken into account that in both cases, in the Mollic Gleysol as well as in the Histic Gleysol, an enrichment in organic substance of 0.9 % C_{org} (median value) in the subsoil till 0.5 m depth is given, due to water logging over long periods of time (Fig. 3b and 3c; Ah-Go:ff-s and Gho:ff-s). Despite the ground water influence present in the Haplic Gleysol, this soil has a very low value, with the C_{org} content amounting to 0.8 %. One reason could be the agricultural utilization (Ap horizon), since this involves intensive drainage and permanent aeration in effect of ploughing. The Histosol has very high C_{org} contents in the subsoil (Fig. 3b), which reaches a maximum value of 50 % C_{org} in the permanently ground water effected horizon nHr.

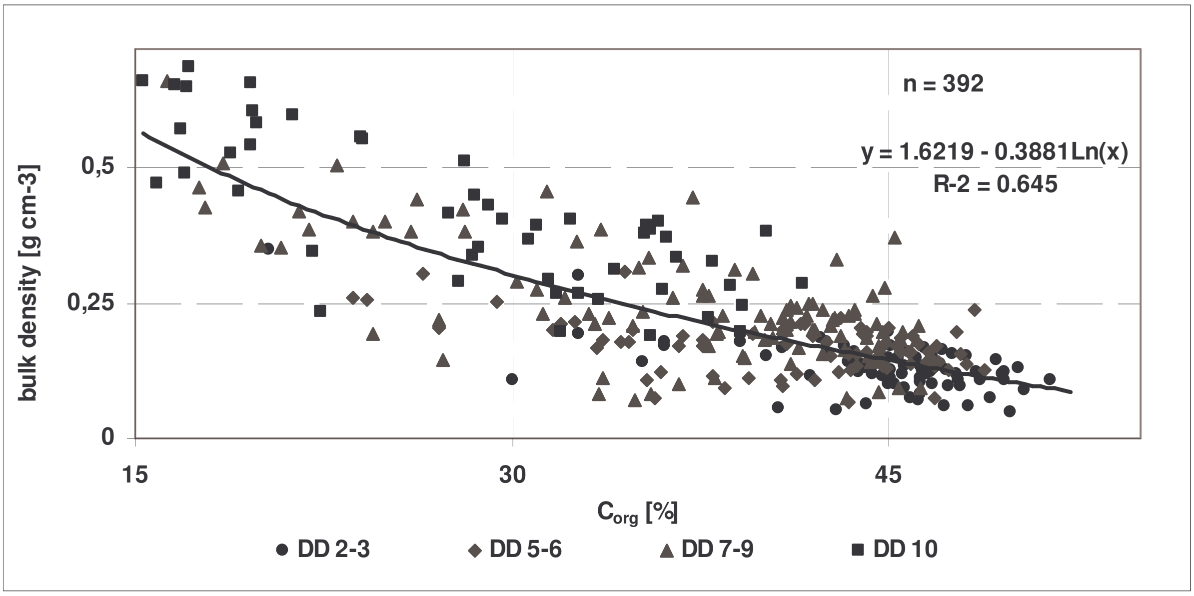

Figure 4: Correlation between C_{org} content and bulk density of various organic substrates (Data from Mecklenburg-Western Pomerania) (DD = degree of decomposition according to Von Post (1924)

Due to the laborious sampling method (undisturbed soil cores), results of bulk density in hydromorphic soils are often only available for the top soil. Within the scope of the EU-Project „CARBO-EUROPE" Bryne et al. (2004) identify detailed information on bulk density and depth of the organic layers in soils as crucial information gap for reporting of results to carbon occurrences in Histosols. For Scottland Chapmann (2008) also refers to gaps in the data basis of bulk density data due to the high labour intensity. On the basis of the comparably excellent data basis available for the federal state Mecklenburg-Western Pomerania, correlations between bulk density and soil organic matter of BD = 1.6219 – 0,3881 * Ln (% C_{org}) could be assessed for Histosols (Fig. 4).

Whilst marginally degraded peat has similar values in bulk density and C_{org} content, especially top soils with increased mineralization processes show variations with increasing bulk densities at decreasing C_{org} contents.

The results agree well with Chapmann (2008), who stated the pedotransfer function for Scottish Histosols as: BD = 1.772 – 0.4127 *Ln (%C_{org}). For two selected hydrological types of mires (percolation mire and water rise mire (with n = 242)) Zeitz et al. (2008) identified the correlation as BD = 1.68 – 0.40 * Ln (C_{org}) (R-2 = 0.70).

All profile related results indicate the significance of C storage in lower soil layers. Data published up to date all refer to the top soil only, as in the very interesting work of Bellamy et al. (2005) to carbon loss in soils of England and Wales between 1978 and 2003.

Area Related Data and Carbon Stock

Analysis of the area data for the federal state Brandenburg for all soils shows, that the land area comprises 51.4 % non-hydromorphic soils, 16 % Endogleyic soils, 5.3 % Haplic Gleysols, 5.0 % Mollic Gleysols, 5.2 % Fluvisols, 4.5 % Histic Gleysols, 8.1 % Histosols, and 4.5 % Anthrosols. For these soil units soil organic carbon content was calculated for the three given soil depths, 0 till 0.3 m, 0 till 1 m, and 0 till 2 m, and was ranked in a metric classification system. Distribution in area percentage shows the great importance of the hydromorphic soils and Histosols for C storage (Fig. 5). In all classes up till 90 t C_{org} ha-1, carbon stock in the top soil (till 0.3 m) is dominant. The high area percentage of terrestrial soils is documented in the classes with ≤ 90 t C_{org} ha-1. The area percentage in the classes with a very high carbon stock is generally high for hydromorphic soils and is highest for these soils for the class with > 240 t C_{org} ha-1 in the subsoil.

For the class with > 240 t C_{org} ha-1 the area percentage continually increases from 0.3 m to 1 m to 2 m soil depth. For all three soil depths maps were generated, which contain areal distribution. As an example Fig. 6 shows the distribution in area of carbon content classes for the soil depth of 0 till 2 m. Histosols and Fluvisols are clearly visible with their connection to the glacial lowlands in the landscape.

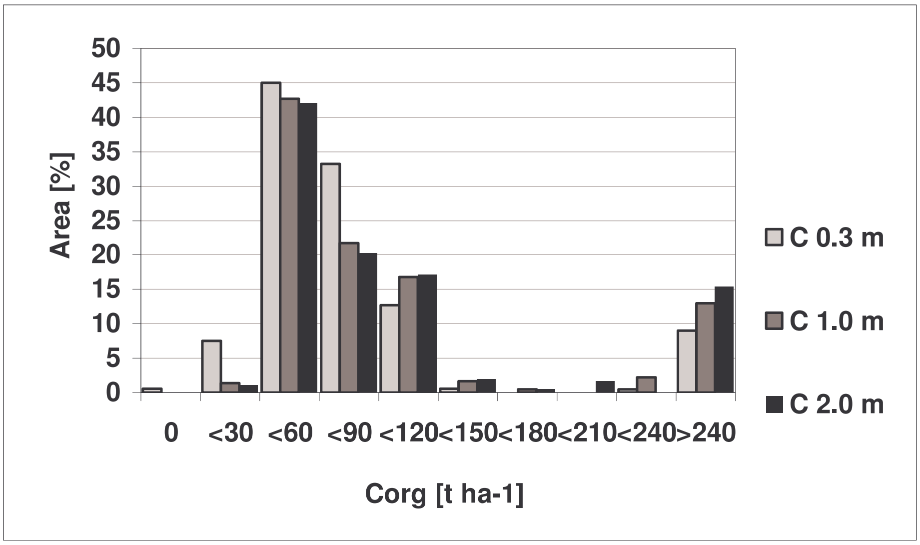

Figure 5: Classes of organic carbon stock and their area percentage in the landscape for 0 till 0.3 m, 0 till 1 m, and 0 till 2 m soil depth

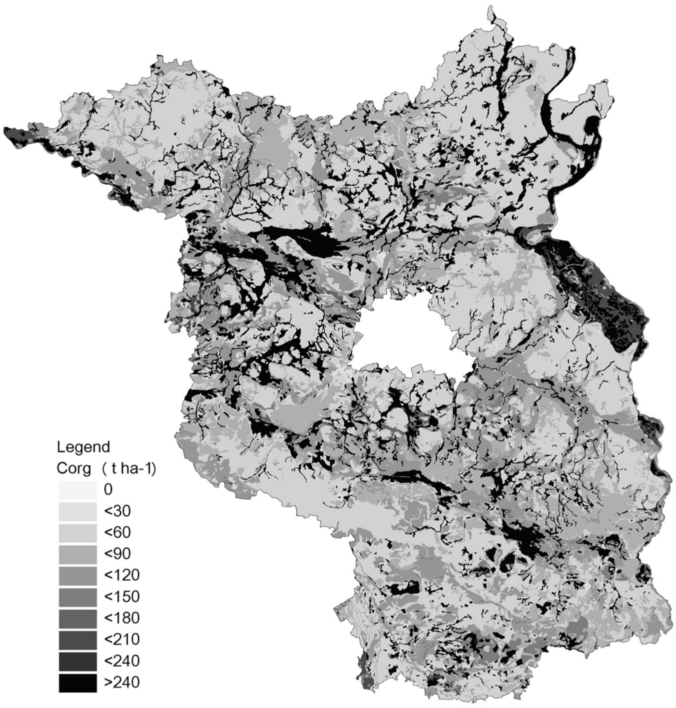

Figure 6: Organic carbon stock (C_{org} t ha-1) in soils of the federal state Brandenburg in 0 till 2 m soil depth

Presently available data and map materials for the federal states of Germany do not allow for a comprehensive calculation of soil characteristics and carbon stock, as presented in this article.

Also in the future in Germany the availability of funds for these very extensive field mappings and laboratory assessments can not be expected. Knowledge on the amount of carbon in soils is however of great importance for many international and national reporting requirements for climate protection.

The two-tier method described and using dominant soil profiles representative for the area, based either on pedotransfer functions or on carbon content values derived from HSCs, as presented for the federal state Brandenburg have proven to be successful. Uncertainty exists in area units (circumference : content) of hydromorphic soils, due to the utilized soil maps with a scale of 1:300 000. Furthermore, the data power could be enhanced by supplementary soil samples. The method allows for a depth dependable estimation of carbon content and for an areal allocation of areas with especially high contents. These areas, identified as „hotspots“ by the IPCC (2007), are to be regarded with special attention in land use. Water management schemes orientated on goals defined for resource management and incentives for farmers according to the conservation of soil carbon are conceivable. With the presented method land users can be recognised and a ranking depending on vulnerability can be established.

ACKNOWLEDGEMENTS:

The research is financially supported by the Federal Institute for Geosciences and Natural Resources (BGR) Hannover. We also wish to thank the Geological Survey team of Mecklenburg Western Pomerania for their support with special data sources.

REFERENCES:

Bauriegel, A. 2004. Methoden zur Ableitung und Parametrisierung von Flächenbezogenen Profil- und Horizontdaten – Am Beispiel der Bodenübersichtskarte des Landes Brandenburg im Maßstab 1:300 000. Dissertation, Humboldt-Universität zu Berlin, FG Bodenkunde und Standortlehre, p. 189.

Bellamy, P. H., Loveland, P.j., Bradley, R. I. Lark, M. R., Kirk, G. J. D. 2005: Carbon losses from all soils across England and Wales 1978 – 2003. Nature Vol 437/8, 245-248

Bridgham, S.D., Megonigal, J.P., Keller, J.K., Norman, B., Trettin, C. 2006. The Carbon Balance of North American Wetlands. Wetlands, Vol. 26, 4: 889-916.

Byrne, K.A., Chojnicki, B., Christensen, T.R., Drösler, M., Freibauer, A., Friborg, T., Frolking, S., Lindroth, A., Mailhammer, J., Malmer, N., Selin, P., Turunen, J., Valentini, R., Zetterberg, L. 2004. EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes. Christensen, R. T., Friborg, T. (Eds.) Carboeurope-GHG. Viterbo, Italy, University of Tuscia.

Eckelmann, W., Baritz, R., Bialousz, S., Bielek, P., Carre, F., Houskova, B., Jones, R., Kibblewhite, M., Kozak, J., Le Bas, C., Toth, G., Toth, T., Varallyay, G., Yli Halla, M. and M. Zupan 2006. Common Criteria for Risk Area Identification according to Soil Threats. European Soil Bureau, Res. Rep. No. 20, p. 94.

Gorham, E. 1995. The biogeochemistry of northern peatlands and its possible response to global warming. In: Woodwell, G. M., Mackenzie, F. T. (Eds.). Biotic Feedbacks in the Global Climatic System. pp. 169-187.

Integriertes Klimaschutzmanagement 2007. Integriertes Klimaschutzmanagement – Bericht an den Landtag Brandenburg; www.mluv.brandenburg.de/cms/media.php/2320/klima07.pdf

IPCC 2001. In: Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

IPCC 2007. Summary for Policymakers. In: Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M.L., Canziani, O.F., Palutikof, J. P., van der Linden P. J. and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

Joosten, H., Clarke, D. 2002: Wise use of mires and peatlands. IPS, Jyväskylä.

Joosten, H., Couwenberg, J. 2008. Peatlands and Carbon. In: Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., Stringer, L. (Eds.). Assessment on Peatlands, Biodiversity and Climate Change. Main Report. Global Environment Centre, Kuala Lumpur und Wetlands International, Wageningen, pp. 99-117.

Kuka, K. 2005. Modellierung des Kohlenstoffhaushaltes in Ackerböden auf der Grundlage boden-strukturabhängiger Umsatzprozesse. UFZ Leipzig-Halle GmbH, 18/2005, p. 109.

Lal, R. 2004. Soil Carbon sequestration to mitigate climate change. Geoderma, 123: 1- 22.

Mannion, A. M. 2006: Carbon and its Domestication. Dordrecht.

Schulze, E. D. and Freibauer, A. 2005: Environmental Science: Carbon unlocked from soils. Nature, 437: 205- 206

Strack, M. (Eds.) 2008: Peatlands and Climate Change. IPS, Jyväskylä.

Von Post, L. 1924: Das genetische System der organogenen Bildungen Schwedens. In :Commission pour la nomenclature et la classification des sols, commission pour l'europe, président: B. Frosterus (Eds), Mémoires sur la nomenclature et la classification des sols, Helsingfors, pp. 287-304.

Zeitz. J. and S. Velty 2002. Soil properties of drained and rewetted fen soils. J. Plant Nutr. Soil Sci., 165: 618- 626.

Zeitz, J., Zauft, H., Rosskopf, N. 2008: Use of stratigraphic and pedogenetic informations for the evaluation of carbon turnover in peatlands. In: Proceedings of 13th International Peat Congress (Eds. Catherine Farrell and John Feehan), Vol. 1, Tullamore, pp. 653- 655

Legend of HSC:

Example: Go:ff-s: subsurface horizon with gleyic properties and an accumulation of sesquioxides from holocene fluvic sands

Horizons: Ap - ploughing topsoil; Acp - ploughing topsoil horizon with accumulation of pedogenetic carbonates; Go - subsurface horizon with gleyic properties and an accumulation of sesquioxides; Gr - subsurface horizon with gleyic properties and reduction conditions; Gor - subsurface horizon with gleyic properties and mostly reduction conditions; Gho - subsurface horizon with gleyic properties and an accumulation sesquioxides and in parts of organic matter; Ah-Go - subsurface horizon with gleyic properties and an accumulation of organic matter and sesquioxides; nHv – earthified peat horizon, nHa – peat-crumb horizon, nHt – peat shrinkage horizon, nHr – peat horizon below groundwater table, reduced state,

Substrates: p-s: periglacial sands; ff-s: holocene fluvic sands; fu-s: periglacial fluvic sands; ff-es: river sands; Ha – amorph peat, Hnr – sedge peat