Agricultural recultivation of brown coal mining areas – initial soil physical properties after site construction

Julia Krümmelbein[A], Oliver Thomas Raab[A], Alexander Zink[B], Oliver Bens[C], Reinhard F. Hüttl[C]

[A]Chair of Soil Protection and Recultivation, Brandenburg University of Technology, Konrad-Wachsmann-Allee 6, 03046 Cottbus, Germany, Email kruemmel@tu-cottbus.de
[B]Institute for Plant Nutrition and Soil Science, Kiel University, Hermann-Rodewald-Str. 2, 24118 Kiel, Germany
[C]GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

Abstract
We investigated the agricultural recultivation of open cast brown coal mining areas in Lusatia, Eastern Germany. Lignite mining activities lead to large-scale disturbance of soils. Recultivation efforts attempt to regenerate mining areas for new agricultural land use options. The mainly sandy substrate used for recultivation is excavated from depths of several meters and is therefore devoid of recent soil organic matter. However, some lignite fragments are present. The substrate itself has poor soil structure. During the excavation, deposition and management process the substrate is subjected to strong mechanical stresses. This practice leads to more or less compacted soils/substrates, which may result in reduced yields of agricultural crops. In this context, we investigate the effect of different organic soil additives in combination with different recultivation crop rotations to improve soil structure for enhanced agricultural productivity and land use. Our experimental site was heaped up and levelled off in 2006/2007. On each of the experimental sub plots undisturbed soil samples have been taken to characterise the substrates according to their mechanical and hydraulic parameters before the application of any recultivation measures. We present results of the initial soil physical properties of the site.

Key Words
Precompression stress, dynamic loading, static loading, air conductivity, Technosols, anthropogenic site

Introduction
Open cast lignite mining activities result in the deposition of substrates, which have covered the brown coal. These overburden sediments of Quaternary and Tertiary origin are subsequently used to recultivate the post mining landscape (Pflug *et al.* 1998). The Quaternary substrates utilized for agricultural recultivation in our study originates from depths of several meters below the former soil surface. These substrates have not undergone pedogenetic processes, are unstructured, more or less devoid of organic carbon and have calcium carbonate contents of up to 4%. During dry periods the substrate is susceptible to intense hardening processes (i.e. hard setting) and during wet periods the mechanical stability is low (Stock *et al.* 2007). During wetting, the effective stress between soil particles decreases and becomes neutralised with increasing water saturation of the substrate. During drying increasing pore water suctions propagated by water menisci induce the movement of soil particles towards each other and consequently lead to a compressive deformation of the soil (Krümmelbein *et al.* 2007). Because of the lack of contemporary organic matter and poor soil structure the substrate is very susceptible to compaction (Stock *et al.* 2007), especially at high water contents. This natural process is intensified by the technical process of excavating, depositing and levelling off of the substrate on the recultivation sites using heavy machinery. The substrates are deposited on dams of several meters in height. Afterwards a heavy crawler, which induces strong mechanical stresses is used to level off these dams. Compacted areas often show poor soil functionality, which induces low agricultural productivity as well as negative environmental impacts such as water erosion (Krümmelbein *et al.* 2006; Hakansson 2005). High bulk density and a small interaggregate (macro-) pore volume cause productivity problems due to decreased aeration and modified hydraulic properties and nutrient fluxes. Soil water storage capacity and groundwater recharge are decreased due to soil compaction (Horn & Smucker 2005), which is especially problematic in typical dry summer periods in Lusatia. The recultivation sites are constructed as anthropogenic soil landscapes and are supposed to be constructed homogeneously according the utilised substrates. The technical processes are also applied uniformly on all recultivation sites of one open cast mining pit. In this investigation results of the status-quo-sampling before the application of any recultivation measures are shown.

Material and methods

Experimental area:

The experimental area is situated in Lusatia, Brandenburg, Germany (E14°35', N51°47') and belongs to the largest lignite mining area in Germany. The site of a total size of about 6 ha is supposed to be prepared homogenously according the utilised substrate and technical processes. It was constructed in winter 2006/2007, therefore the moisture content of the utilised substrate presumably was relatively high. The mean annual precipitation in the experimental area is about 570 mm with comparably dry summers and wet winters. Before the first sampling, the site had only experienced slight fertilization to supply the subsequent seeded clover-grass-mixture with nutrients. No recultivation treatment has been applied at this time. After the first sampling the experimental area was divided into 25 subplots, which were treated with various recultivation strategies (different organic soil additives, partly deep loosening, different crop rotations). The recultivation strategies will be investigates in terms of accumulating soil organic matter, developing improved soil structure stability as well as soil water balance. The mean content of calcium carbonate in the experimental area is 2.3% and the mean pH value ($CaCl_2$) is 8.4. The classification of texture according to the German system (2000 > sand> 63 µm; 63 µm > silt > 2 µm; clay < 2 µm) (Ad-Hoc-Arbeitsgruppe Boden 2005) is overall sandy and ranges from pure sand to loamy and silty sand.

Soil sampling:

Two sampling campaigns were planned, one directly after establishing the site (S1) and a second one after two years of recultivation (S2). For S1 on each subplot undisturbed samples were collected from a soil profile in three depths (15-19 cm, 45-49 cm, 75-79 cm). For purposes of clarity, only the results of one depth (45-49 cm) and eight (I - VIII) of the 25 subplots are shown (S1).

For the determination of static and dynamic precompression stress (n = 5) and air permeability (n = 15), undisturbed soil samples of a volume of 235 cm³ and for the determination of saturated hydraulic conductivity undisturbed samples of a volume of 100 cm³ were used.

For S2 eight soil profiles will be chosen to take samples in spring 2010. The same parameters as for S1 will be determined.

Measurements:

Bulk density (n = 15) was determined by drying the soil samples at 105°C for 24 h (Hartge & Horn 2009). For the determination of precompression stress and air permeability the samples have been equilibrated to a standard matric potential of -6 kPa prior to the laboratory measurements. Static and dynamic precompression stress was measured using a drained multistep-oedometer (n = 5). The loading steps were 20, 40, 50, 60, 80, 100, 120, 150, 300 and 400 kPa. For the determination under dynamic loading stepwise increasing loads were applied in loading cycles. One loading cycle consists of 30 s loading and 30 s unloading, 20 cycles were applied per load step. The method is described in detail by Krümmelbein *et al*. (2007). Precompression stress values have been determined graphically according to Casagrande, 1936 (Kezdi 1980).

Results

The soil bulk density of the soil profiles I-VIII varies between 1,35 g/cm³ and 1,90 g/cm³ (Figure 1).

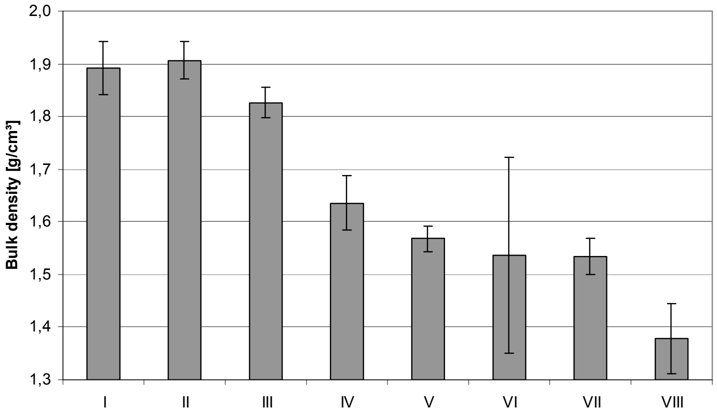

Figure 1. Soil bulk density of the profiles I-VIII (40-45 cm depth). Error bars show standard deviation, n=15.

The values of static precompression stress vary between 30 kPa and 70 kPa (Figure 2). The values of dynamic precompression stress show the same trend as the static ones but in generally about 10-20 kPa higher.

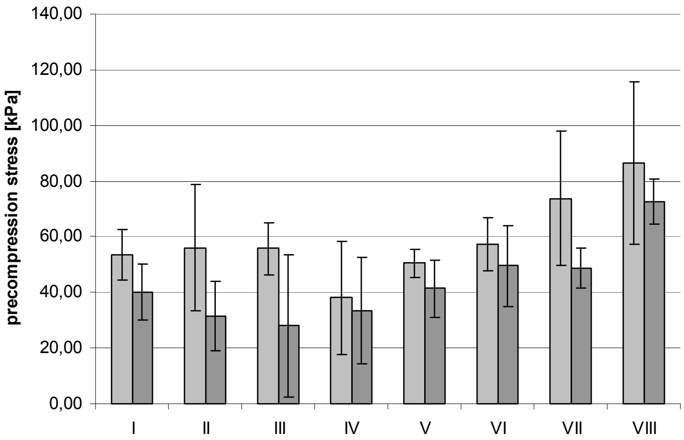

Figure 2. Precompression stress [kPa] of the profiles I-VIII (45-49 cm depth). Light grey: dynamic determination; dark grey: static determination. Error bars show standard deviation, n=5.

Discussion

The results presented in Figures 1 and 2 illustrate that the spatial heterogeneity of all the measured parameters is high, even though the preparation of the site is "assumed to be homogenous". These differences are mainly due to the technological processes of piling up and levelling off substrate dams of several meters height using heavy crawlers. The differences in bulk density not only result from the shape of the dams (higher bulk densities in former dam-areas, lower bulk densities in the former gaps between the dams) but also from the number of wheelings of the caterpillar. Furthermore, varying water contents of the substrate during levelling off influenced the substrate's effective soil strength, thus the amount of compaction (Fazekas and Horn 2005). Unfortunately, no water content of the substrate during site construction is available. To characterize soil physical properties, some authors determine bulk density and draw conclusions concerning soil functions, e.g. from hydraulic or air permeability and soil stability properties (Assouline 2006). It is assumed that the mechanical stability of soils and substrates increases with increasing bulk density (e.g. Rücknagel *et al.* 2007; Krümmelbein *et al.* 2006). Our results show that this is not necessarily the case for substrates, which have poor structure and additionally are homogenized during transport, deposition and levelling. We even found a negative correlation between bulk density and precompression stress. Our results prove that especially on strongly disturbed sites like our experimental area, that it is not possible to derive definitive soil characteristics such as air permeability or precompression stress from other parameters, (e.g. bulk density). In our study, soil functions such as air permeability are neither correlated with soil texture nor to bulk density (not shown). The dynamically determined values of precompression stress show the same trend as the static ones but are generally about 10-20 kPa higher, which is due to the time-dependency of the settlement. Precompression stress increases with decreasing loading time (Fazekas and Horn 2005). The concept of precompression stress assumes that mechanical loading of a soil below the precompression stress will completely be converted into elastic deformation (Horn 1989). Our results show that during the 20 loading cycles of each loading step and even if the applied load is kept below the precompression stress there was a slight additive settlement effect, which defines the deformation as partly plastic (not shown). Therefore cyclic loading can lead to compaction even though the load is kept below the precompression stress of the soil (Krümmelbein *et al.* 2007; Peth & Horn 2006).
In summary, it can be stated that a site, which has been anthropogenically constructed to be "technically homogeneous" is not necessarily the case because it may simply illustrate a "visual" homogenous distribution of soil physical parameters. Even if the texture of the substrate is similar across the total area, considerable differences in soil hydraulic and soil mechanical parameters can be expected to occur because of the technical compaction processes on the substrate, which is structureless and mechanically instable before site construction.

Outlook

The second soil sampling and measuring campaign in spring 2010 will allow to draw conclusions concerning the development of soil physical properties in dependence of the applied recultivation practice.

References

Ad-hoc-Arbeitsgruppe Boden (2005) Bodenkundliche Kartieranleitung. (Ed Bundesanstalten für Geowissenschaften und Rohstoffe, Niedersächsisches Landesamt für Bodenforschung) pp 140-142 (Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany).

Assouline S (2006) Modelling the relationship between soil bulk density and the hydraulic conductivity function. *Vadose Zone Journal* **5**, 697-705.

Fazekas O, Horn R (2005) Zusammenhang zwischen hadraulischer und mechanischer Bodenstabilität in Abhängigkeit von der Belastungsdauer. *J. Plant Nutr. Soil Sci.* **169**, 60-67.

Hakansson I (2005) Machinery-induced compaction of arable soils -incidence-consequences-counter-measures. (Ed Swedish University of Agricultural Sciences Department of Soil Science) (Reports from the Division of soil management 109).

Hartge KH, Horn R (2009) Die physikalische Untersuchung von Böden: Praxis Messmethoden Auswertung. Schweizerbart'sche Verlagsbuchhandlung,Stuttgart.

Horn R and Smucker A. (2005) Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. *Soil and Tillage Research* **82**(1), 5-14.

Kezdi A (1974) Handbook of soil mechanics, 1. Soil physics (Ed Kezdi A) 367pp (Elsevier, Amsterdam).

Krümmelbein J, Wang Z, Zhao Y, Peth S and Horn R (2006) Influence of various grazing intensities on soil stability, soil structure and water balance of grassland soils in Inner Mongolia, P.R. China. In: Advances in Geoecology 38: Soil Management for Sustainability (Eds. Horn, Fleige H, Peth S, Peng X), pp. 93-102. (Catena Verlag Reiskirchen, Germany).

Krümmelbein J, Peth S, Horn R (2007) Determination of pre-compression stress on a variously grazed steppe soil under static and cyclic loading. *Soil and Tillage Research* **99**(2), 139-148.

Peth S and Horn R (2006) The mechanical behaviour of structured and homogenized soil under repeated loading. *J. Plant Nutr. Soil Sci*. **169**, 401-410.

Pflug W (1998) Braunkohlentagebau und Rekultivierung (Ed W. Pflug). 1068 pp (Springer Verlag Berlin, Heidelberg, Germany).

Rücknagel J, Hofmann B, Paul R, Christen O and Hülsbergen K-J (2007). Estimating precompression stress of structured soils on the basis of aggregate density and dry bulk density. *Soil and Tillage Research* **92**(1-2), 213-220.

Stock O, Lesturgez G, Bens O and Hüttl RF (2007) MechanicaL properties of metastable glacial till before and after water-induced compaction. *Journal of Plant Nutrition and Soil Science* **170**(4), 560-565.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.