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Chernozem—Soil of the Year 2005

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Summary—Zusammenfassung

The proclamation of the “Soil of the Year” was made for the first time in Germany in 2005 on occasion of the World Soil Day. Chernozems were selected for this purpose. In this paper an overview of these groups of soils is given. Chernozems are concentrated in the drought region of Central Germany. A standard profile from the core area of Chernozems developed from loess is presented with comprehensive laboratory analysis. Chernozems developed primarily upon carbonatic loess substrates under summer-dry climatic conditions in an open park-like landscape with isolated forest stands. The development of Chernozems began as early as the late glacial period, and they were fully developed by the Atlantikum age. The far-reaching, uniformly thick humus horizons indicate substrate differences in the loess cover, which are partly the result of bioturbation. Within Germany, Chernozems and Chernozem-like soils make up approx. 3% of the surface area and 5% (approx. 11,000 km^2) of the arable land. The results of the Static Fertilization Experiment in Bad Lauchstädt, founded in 1902, clarify the high value of Chernozem for biomass production and the environment. Each loss due to erosion or decrease in surface area reduces the fulfillment of soil ecological functions of the soils and is comparable to a loss of animal and plant species. Therefore, soil scientists and the results of soil research must be more comprehensively implemented for soil preservation, protection, and politics. For acceptance of these goals among the general public and the political-decision makers, the campaign “Soil of the Year” should give some thought-provoking impulses.

Key words: Chernozem / Soil of the Year 2005 / soil classification / soil genesis / soil characteristics / Static Fertilization Experiment Bad Lauchstädt

Schwarzerde – Boden des Jahres 2005

Anlässlich des Weltbodentages wurde in Deutschland für 2005 mit der Schwarzerde erstmalig ein „Boden des Jahres“ proklamiert. Damit soll in der Bevölkerung und bei politischen Entscheidungsträgern ein stärkeres Bewusstsein für den Boden und ein höheres Engagement für den Bodenschutz angeregt werden. Im Beitrag wird ein Überblick über diese Bodengruppe gegeben und ein Standardprofil aus dem Kerngebiet der Schwarzerden aus Löss (Mitteldeutsches Trockengebiet) mit umfassenden Laboranalysen exemplarisch präsentiert. Schwarzerden entwickelten sich vorwiegend auf kalkreichen Lössen unter sommertrockenen Klimabedingungen in einer offenen parkähnlichen Landschaft mit Waldinseln. Die Entstehung der Schwarzerden setzte bereits im Spätglazial ein, und im Atlantikum waren sie voll entwickelt. Die weiträumig gleiche Mächtigkeit der Humushorizonte zeichnet primäre Substratunterschiede in der Lössdecke nach; sie sind nicht nur das Ergebnis einer Bioturbation. In Deutschland nehmen die Schwarzerden und schwarzerdeähnlichen Böden etwa 3 % der Bodenfläche bzw. 5 % (ca. 11.000 km^2) der landwirtschaftlichen Nutzfläche ein. Die Ergebnisse des seit 1902 bestehenden Statischen Düngungsversuchs Bad Lauchstädt verdeutlichen den hohen Wert der Schwarzerden für Biomasseproduktion und Umwelt. Jeder Verlust durch Erosion oder Flächenentzug mindert die Erfüllung ökologischer Funktionen der Böden und ist dem Artenverlust von Tieren und Pflanzen gleichzustellen. In der Bodenpolitik müssen deshalb die Ergebnisse der Bodenforschung zum Erhalt und Schutz unserer Böden umfassender als bisher umgesetzt und Bodenwissenschaftler stärker in politische Entscheidungen eingebunden werden. Für die Akzeptanz und Umsetzung dieser Ziele in der Öffentlichkeit soll der „Boden des Jahres“ Impulse geben.

1 Introduction

Soils control significantly processes in nature and assume a central role within ecosystems. Nevertheless, the importance of soils has been traditionally underestimated by society. The proclamation of the “Soil of the Year” was made for the first time in Germany in 2005 on occasion of the World Soil Day. A more pronounced awareness of soil among the population and more engagement by the political-decision makers regarding soil protection should be initiated within this context.

In contrast to other objects from nature (*e.g.,* plants and animals), which are chosen annually for proclamations, the multiplicity and natural beauty of soil are not immediately discernible. In order to generate an increase in appreciation for soils, such soils have to be selected as “Soil of the Year” that would be impressive for the general public due to their constitution, dissemination, and functional significance. Therefore, the

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most essential soil types or groups of soils are primarily taken into consideration for this selection process.

A curatorship of the German Soil Science Society and the National Association of Soil (speaker: Prof. Dr. M. Frielinghaus) chose, from numerous candidates, Chernozem as "Soil of the Year 2005". In the following contribution, we give an overview of these soils from the authors' point of view, which refer to a standard soil profile from the core region of Chernozems in Germany. Thereby we do not raise a claim of a complete characterization and specification for these Chernozems.

2 Classification of Chernozems

Even prior to the foundation of a genetic soil classification by *Dokutschajew* (1883), Chernozem (*Tschernosjom* in Russian and Germanized as *Tschernosem*) was common as a designation for soil in the Russian steppes (Akonin, 1771, quoted by *Kubiena*, 1953). Apparently Salmon Gubert (1645) described first a "black earth", and Lomonossow (1747) (both quoted by *Reintam,* 2001) introduced the term into the scientific world. It is quite possible, that the terms *Tschernosjom* or *Tschernosem* or Chernozem comprise the oldest derivations for a soil type.

In the German Soil Classification System of today (*AK Bodensystematik der DBG*, 1998; *Ad-hoc AG Boden,* 2005), the multiplicity of Chernozems is taken into consideration due to its differentiation into several soil classes and soil types. Consequently, it would not be appropriate to highlight only one Chernozem type or subtype for the general public, rather the different appearance of Chernozems must represent the "Soil of the Year". For this purpose, Chernozems are characterized as follows:

Chernozems and chernozemic soils are soils which are dark brown to black in color, due to their enrichment of high-quality humus (high base saturation, stabile aggregate structure, and definitive bioturbation) down to a depth of more than 40 cm, mostly 60 to 80 cm.

The soil types *Tschernosem* (Chernozem) and *Kalktschernosem* (Calcic Chernozem) have been subordinated according to the German Soil Classification System into the soil class of Chernozems (*AK Bodensystematik der DBG*, 1998; *Ad-hoc AG Boden,* 2005) (*WRB*, 1998, mainly: Chernozem, Phaeozem, Kastanozem, or Greyzem). The *Kalktschernosems* are differentiated from the *Tschernosems* in their secondary carbonate content (mostly pseudomycelia), which is detectable up to the surface. This phenomenon does not involve "residual carbonate" from a topsoil decalcification process (*Lieberoth,* 1982). However, this cannot be completely ruled out, as *Altermann* and *Schröder* (1992) were able to substantiate the highest carbonate content in loess of the *Kalktschernosems* of Central Germany (Tab. 1). Soil animals are able to calcify the soil secondarily through relic and recent substrate transfer from lower to upper soil layers and *vice versa.* Furthermore, underground materials which contain carbonate can also be transported into humus horizons by deep plowing. This is especially where small-scale changes between *Tschernosems* and *Pararendzinas* (*WRB*, 1998: Regosol) occur. Gradual transitions between *Tschernosems* and *Kalktschernosems* are common.

For the differentiation between *Tschernosem* and *Kalktschernosem*, only pseudomycelia, but no minimum of carbonate content is demanded for *Kalktschernosem* up to the present (*Ad-hoc AG Boden,* 2005). In contrast, a minimum carbonate content of 2% is required for the differentiation between *Regosol/Ranker* and *Pararendzina/Rendzina* (*WRB*, 1998, mainly: Regosol, Rendzic Leptosol) (*Ad-hoc AG Boden,* 2005). Analogue is supposed to determine between *Tschernosem* and *Kalktschernosem.* However, a safe field-pedological differentiation between both soil types is sometimes impossible, due to the difficulties in discrimination between secondary and anthropogenic carbonate enrichment in Chernozems. Therefore, the carbonate content should be characterized with the aid of substrate identification, what allows renouncing on the differentiation between both soil types.

The soil subtypes *Braunerde-Kalktschernosem* (Calcic Chernozem with cambic properties) and *Parabraunerde-Kalktschernosem* (Calcic Chernozem with luvic properties) are not known to exist in the Chernozem regions of Central Germany up to now. Contrarily, Chernozems with stagnic and calcic properties in this region often contain Ca up to the surface level, so that in future the *Pseudogley-Kalktschernosem* has to be included into the German Soil Classification System.

Within the soil classes *Lessivés* (*WRB*, 1998, mainly: Luvisols, Albeluvisols, Alisols), *Stauwasserböden* (soils with stagnic properties) (*WRB*, 1998, mainly: Planosols), *Auenböden* (floodplain soils) (*WRB*, 1998, mainly: Fluvisols, Gleysols), and *Gleye* (*WRB*, 1998: Gleysols), transitional subtypes are recorded among the *Tschernosems*, such as *Tschernosem-Parabraunerde* (*WRB*, 1998, mainly: Luvic Chernozem, Luvic or Greyic Phaeozem, Haplic Greyzem) (formerly known as *"Grieserde"*), *Tschernosem-Pseudogley* (*WRB*, 1998, mainly: Stagnic Phaeozem, Mollic Planosol), and *Tschernosem-Gley* (*WRB*, 1998, mainly: Mollic Gleysol, Gleyic Chernozem). These are Chernozemic soils, whereas the *Tschernitzas* are floodplain soils similar to Chernozem. The latter often shows both, autochthonous humus as well as allochthonous Chernozem humus from the neighboring river catchment areas.

Tschernosems with a brown horizon (Bv) under the humus horizon were defined by Kubiena (1953) as "degraded Chernozem", which were more decalcified than the "typical" Chernozem. *Altermann* and *Schröder* (1992) described degraded Chernozems with Bv horizons of up to 15 cm. If this thickness limit is surpassed, it is known as *Braunerde-Tschernosem* (Chernozem with cambic properties) (*WRB*, 1998, mainly: Haplic Phaeozem) (*Altermann* and *Schröder*, 1992), or *Braunschwarzerde* (brown-Chernozem) (*TGL 24300/08*, 1986). According to the German Soil Classification System, the degraded Chernozems are assigned to the *Braunerde-Tschernosems.* Brown horizons of Chernozems with >20 cm thickness often indicate clay coatings. The transitions from *Braunerde-Tschernosem* to *Parabraunerde-Tschernosem* (*WRB*, 1998, mainly: Luvic Phaeozem, Luvic Chernozem, Haplic Phaeozem) are gradual. The formerly mentioned subtypes were described by *Rau* (1965) as *"durchschlämmte Schwarzerden"* (lessivated Chernozems) and by *Rohdenburg* and *Meyer* (1968) as *Grieserden.* These are today assigned to the *Parabraunerde-Tschernosem* or *Tschernosem-Parabraunerde.*

Gehrt (1994) characterized *Grauerden* (grey earths), which are similar to Chernozems but differentiated from them in their lighter color and lower humus content. They have been investigated east of the Hildesheimer Börde, but not taken into consideration in the recent German Soil Classification System.

Lieberoth (1982) described *"Feuchtschwarzerden"* (hydromorphic Chernozems), which were built up beneath moist grassland. The humus horizons of these soils are considerably black in color, which is also the case for Chernozems with stagnic and/or with gleyic properties.

In the Chernozem regions of Central Germany, varied transitions to *Pararendzina* (*WRB,* 1998, mainly: Regosol, Arenosol) and to *Kolluvisol* (*WRB*, 1998: Terric, Regic, or Cumulic Anthrosol) appear even in lightly contoured terrains, due to erosion and accumulation of the humus of the Chernozems. The *Pararendzina* can sometimes contain remnants of the Axh horizon, or a mixture of humus from agricultural land use with loess substrate can build up the eAp horizon. Contrastingly, the thickness of colluvial layers can vary from a few decimeters to over 3 m in relief depressions. Locally appearing *"Braunerden aus Löss"* (brown-earth made-up of loess) within the loess-Chernozem regions (*Rau*, 1965) are identified by *Altermann* and *Kühn* (1995) as erosion locations for the *Braunerde-Tschernoseme* (Chernozems with cambic properties) in the foreland of the Harz Mountains.

Chernozems can occur in different substrates and substrate sequences so that a multitude of soil and substrate types becomes characteristic of these soil landscapes. Most Chernozems develop from loess of varying thickness. For the identification of soil substrate and for the evaluation of the soils, the geological layers underlying loess (consisting of till marly-fluviglacial sands, gravel, as well as Triassic or Tertiary clays, and solid rock) are also included.

Chernozems also developed from sandy-loess covers, which border the belt of loess with a thickness of <1 m, but can appear in small areas within the loess landscapes. *Parabraunerde-Tschernosems* and *Tschernosem-Parabraunerden* are dominating on sandy loess (*Altermann* and *Fiedler*, 1975). Loamy air-borne sands occur locally within the loess landscape on river terraces, upon which *Braunerde-Tschernosems* have usually developed. The Chernozems distributed outside of the loess belt (*e.g.,* Altmark, Uckermark, Island of Poel) are predominantly linked to glacial till, local moraines rich in clay and basin silt. These carbonate-rich sediments are usually covered by a 4 to 6 dm thick loamy cover layer (cover loam, cover clay, loamy-till cover sand).

3 Genesis of Chernozems

The genesis of Chernozems has been discussed controversially for a long time. According to the predominant explanation of soil scientists, Chernozems developed in the post–ice age warming period under steppe vegetation. Summer-dry conditions and intensive biological mixing (bioturbation) build up a thick, base-rich humus horizon from the unconsolidated, carbonate-rich loess (*Scheffer*, 2002). Thereafter, the development of Chernozems was determined by an array of factors, which are represented by the essential elements of steppe vegetation, climatic conditions, carbonate-rich loess substrate, and bioturbation. *Rohdenburg* and *Meyer* (1968) disputed that European Chernozems could have developed solely under conditions of steppe vegetation. After having completed a summary of the state of scientific awareness regarding this question, *Ehwald* et al. (1999) consider the build-up of Chernozem beneath dense and closed mixed-deciduous woodland (almost devoid, therefore, of grass and herbs) as unlikely. There has been, since today, no definite clarification of whether the Chernozems were able to develop beneath sparsely stocked woodlands (*Ehwald,* 1980) or steppe vegetation (*Laatsch*, 1957; *Rau,* 1965; *Scheffer*, 2002). An open landscape with spread of woodland seems to be probable for the main period of development of Chernozems (*Mania*, 1995). Today's wooded *Fahlerde* (*WRB*, 1998, mainly: Albeluvisol) distinctly bordered by Chernozem supports this assumption.

Undisputed are the climatic preconditions for the development of Chernozems. On the other hand, the Normtschernoseme (and the Kalktschernoseme) are not limited to the driest core region of the Central German dry area, since as long as some amount of low-carbonate loess substrate appears, *Braunerde-Tschernoseme* (*WRB*, 1998, mainly: Haplic Phaeozem) and *Parabraunerde-Tschernoseme* (*WRB*, 1998, mainly: Luvic Phaeozem, Luvic Chernozem, Haplic Phaeozem) also developed on these sites. The primary carbonate content of the loess could have been more decisive for the distinctiveness of various subtypes of Chernozem than the existing local climatic circumstances. *Altermann* and *Schröder* (1992) recorded for the loess of various Chernozems in Sachsen-Anhalt different carbonate contents (Tab. 1).

The carbonate content of the loess was considerably influenced by the pre–Weichsel time subsurface. The carbonate

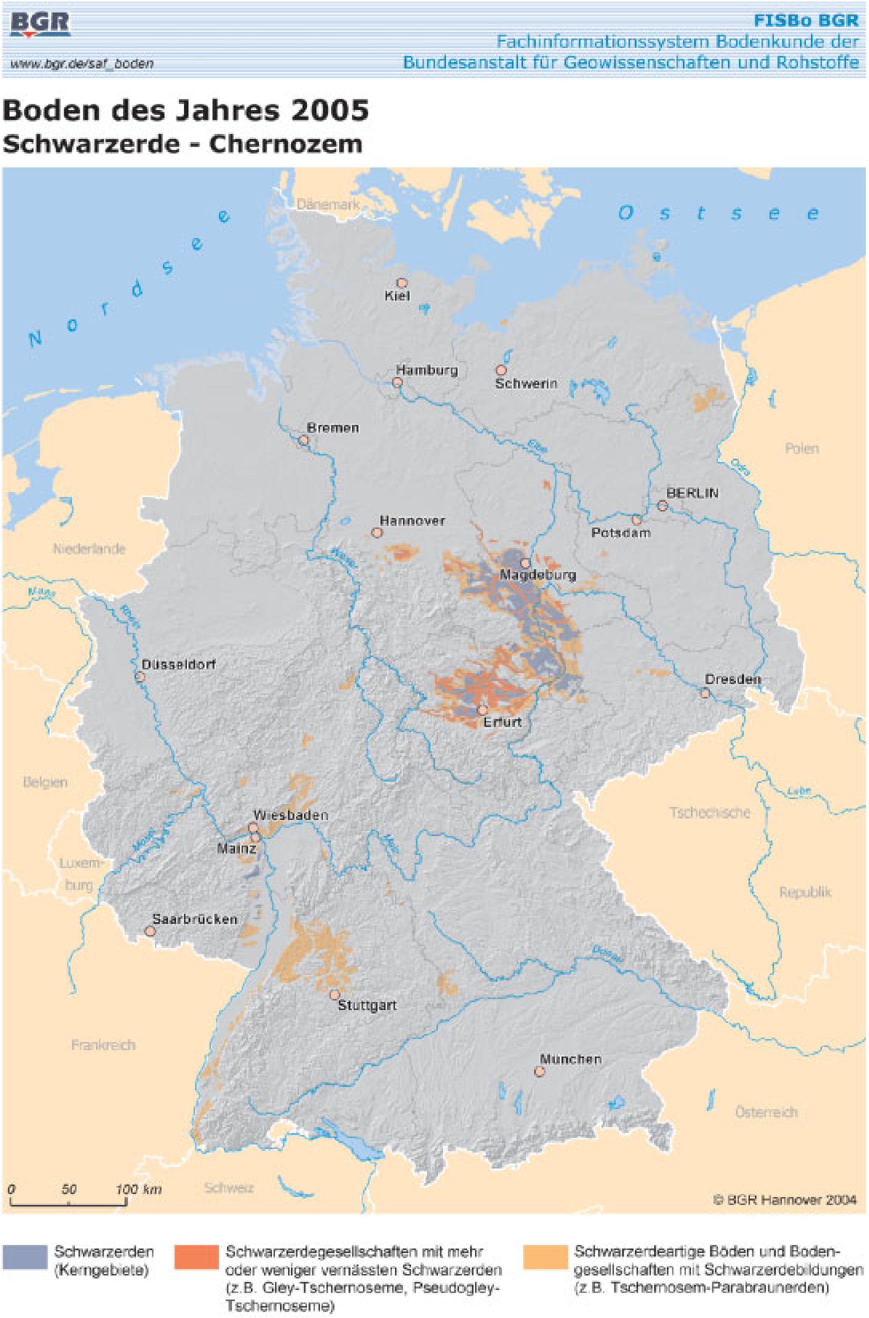
Table 1: Carbonate contents (mean values and standard deviation) of loess of different subtypes of Chernozemic soils and Lessivés in Sachsen-Anhalt (according to *Altermann* and *Schröder*, 1992, modified).

Tabelle 1: Carbonatgehalte (Mittelwerte und Standardabweichung) von Löss unterschiedlicher Subtypen des Tschernosems und der Fahlerde in Sachsen-Anhalt (nach *Altermann* and *Schröder*, 1992, verändert).

Soil subtype	**n**	**$CaCO_3$ [%]**	
		mean values	**standard deviation**
Normkalktschernosem	61	18.1	4.7
Normtschernosem	60	16.3	3.7
Braunerde-Tschernosem (degradierter Tschernosem)	39	15.2	3.0
*Braunerde-Tschernosem (incl. Parabra*unerde-Tschernosem)	41	13.9	3.0
Normfahlerde	14	12.2	3.8

content in loess above sea-shell limestone is for instance higher than the content above porphyry. High primary carbonate content in the loess is a crucial precondition for the formation of Chernozem. The *Fahlerden* (*WRB*, 1998, mainly: Albeluvisols) examined by *Altermann* and *Schröder* (1992) achieve the lowest levels of carbonate content in loess as compared to the Chernozems (Tab. 1). No Chernozems are evidenced above the carbonate-free/low-carbonate loess of northern Saxony. Therefore, the hypothesis can be postulated for Central Germany that the soil border *Tschernoseme/Fahlerden* is essentially affected by the substrate (especially primary carbonate content and probably the mineralogical composition of the loess) (*Altermann* and *Fiedler,* 1975).

The even thickness of the Chernozem is primarily explained as the result of bioturbation. Soil animals such as earthworms, hamsters, and European ground squirrels have reworked and mixed the litter into the soil. Recognizable even today are the constructions and paths of the small mammals



Quelle: Digitales Archiv FISBo BGR: BÜK 1000, Vers. 2.0 (Stand 2000)

Figure 1: Distribution of Chernozems and Chernozemic soils in Germany (origin: www.bgr.de, Chernozems on the island of Fehmarn are not included).

Abbildung 1: Verbreitung von Schwarzerden und schwarzerdeartigen Böden in Deutschland (Quelle: www.bgr.de, Schwarzerden der Insel Fehmarn sind nicht ausgegrenzt).

(crotovinas) as dark lines in loess or light patches in the humus horizons of Chernozem. The far-ranging, uniform thickness of Chernozem over a broad area cannot be simply the consequence of biogenic activities, as *Gehrt* et al. (2002) mentioned. The upper layer of the loess (0.4 to 0.8 m) was supposedly formed by periglacial activity, which was the basis for soil formation. The humus accumulation traces probably this prepared zone. In a few soil profiles, it was observed that the lower border of the humus horizon is marked by an accumulation of fine gravel and gritty material. Conclusively, the humus cover represents mostly the main layer (*"Hauptlage"* according to *Ad-hoc AG Boden,* 2005). Differences in the substrate in the vertical profile of the aeolian covers consisting of loess and sand loess were proved for the Central German Chernozem area by *Altermann* and *Fiedler* (1975), *Altermann* and *Schröder* (1992) as well as by *Gehrt* (1994) for Niedersachsen. The soil horizons mirrored these primary substrate differences evidently.

The development of Chernozem started probably during the late glacial period (*Altermann* and *Mania,* 1968; *Rohdenburg* and *Meyer,* 1968; *Scharpenseel* and *Pietig*, 1969). *Altermann* and *Mania* (1968), *e.g.,* found a *Pararendzina* with a Chernozem-like humus composition under the *Alleröd*-age tuff as an initial phase of Chernozem. Contrastingly, Chernozem was completely developed already in the *Atlantikum* age (*Czerney*, 1965; *Altermann* and *Mania*, 1968). Due to the early human settlement and cultivation of Chernozem areas in the Neolithic age, the invasion of woodlands during the moist Holocene was hindered, which preserved Chernozems. Since the beginning of agriculture, the transformation of a "natural steppe" into a "cultivated steppe" ensued (*Laatsch,* 1957).

Conceptions have emerged in recent times that, at least for part of the organic matter of Chernozem, the source is burned-C organic material (*e.g., Schmidt* et al., 1999). This hypothesis was critically evaluated by *Saile* and *Lorz* (2003). Nevertheless, remnants of fires are surly incorporated in Central German Chernozems, which was interpreted as interference between human activities and Chernozem genesis (*Kleber* et al., 2003). However, doubtless this phenomenon has not impacted the build-up of Chernozems significantly.

The brightness of color in surface horizons of Chernozems (usually Axp horizon up to 0.3 to 0.4 m depth) is referred to as a consequence of agricultural management (*Laatsch,* 1957). This alone cannot be the cause, since this occurrence was also diagnosed in a previously never-used fossilized Chernozem covered with lake-marl (*Altermann* and *Kühn*, 1995). The lighter color of the agriculturally tilled soil above an obviously darker Axh horizon can also often be observed in Chernozems developed from sandy loess (*Altermann* and *Fiedler*, 1975). The separation of the humus complex of Chernozems and grey earths from the Hildesheimer Börde was described by *Roeschmann* (1968) and *Gehrt* (1994). It remains to be evaluated whether the above mentioned phenomena possibly involve two different humic horizons, which developed consecutively.

4 Distribution of Chernozems in Germany

Chernozems, including Chernozem-like soils and their transitions, comprise a surface area in Germany of approx. 11,000 km^2. This corresponds to roughly 3% of the total surface or approx. 5% of the arable land. Chernozems are concentrated in dry loess areas, such as Magdeburger Börde, Harzvorland, Querfurter Platte, Hallesche and Köthener Ackerland, Thüringer Becken, Hildesheimer Börde, Wetterau, Kraichgau, Oberrheintal as well as Pfälzer Tiefland. Also worth mentioning are Chernozem-like soils which appear outside the loess region in the Zerbster Ackerland, in Altmark, and the Uckermark as well as on the islands of Poel and Fehmarn (Fig. 1).

In Sachsen-Anhalt, Chernozems reach the highest proportion of the surface area (nearly 20%) and of the agriculturally arable land (nearly 33%) as compared to all other German states. In Thüringen, the Chernozem proportion comes to a slightly lower value of the agricultural land (nearly 20%). In Baden-Württemberg and Hessen, the proportions of agriculturally arable land achieve more than 5%. In all other federal states, the proportion is considerably lower—usually <5%.

In Germany, the *Parabraunerde-Tschernosem* and the *Tschernosem-Parabraunerde* represent the largest distribution with almost 60% of the total Chernozem surface, so that Haplic Chernozems as well as Haplic and Luvic Phaeozems dominate. The situation is different in Sachsen-Anhalt, the "Chernozem state": here the *Normtschernosem* and the *Braunerde-Tschernosem* reach levels of almost 80% of the Chernozem surface of this federal state.

Gunreben (1992) presented a regional comparison of Chernozems from chosen distribution areas of Germany. An areawide, comprehensive characterization and evaluation of various Chernozems under consideration of the respective special history of development is still missing today. Furthermore, there is an absence of site-related soil-protection concepts which have yet to be constitutive from these results.

Chernozems are distributed world wide, especially in loess regions of Ukrainia, Russia, Czech Republic, Slovakia, Romania, Bulgaria, Hungary, Austria as well as in N China, S Canada, N and S America, and Australia.

5 *Locus typicus* of the Haplic Chernozem developed from loess—soil profile at the experimental station of the UFZ at Bad Lauchstädt

The standard profile for the Central German Chernozem region is accessible for the public on the experimental station of the UFZ Centre for Environmental Research Leipzig-Halle at Bad Lauchstädt (15 y without fertilization and tillage, under lawn; Fig. 2).

Soil samples were collected according to soil horizons. Soil properties were determined according to standard methods (Tab. 2). The location and description of the Haplic Chernozem developed from loess are given in Tab. 3. Analytical results for chemical, physical, and microbiological soil proper-

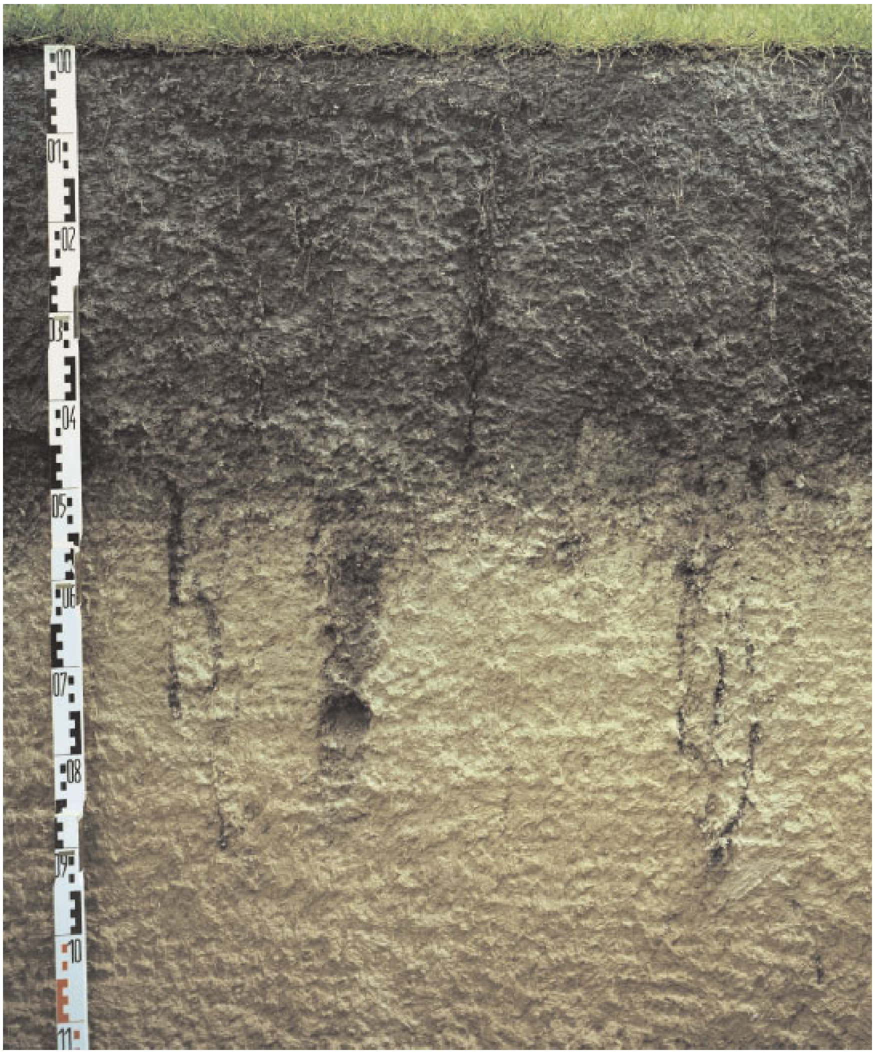


Figure 2: Chernozem (Normtschernosem) developed from loess in Bad Lauchstädt, south of Halle, Germany; photo: UFZ.
Abbildung 2: Normtschernosem aus Löss; Ort: Bad Lauchstädt, südlich von Halle, Deutschland; Foto: UFZ.

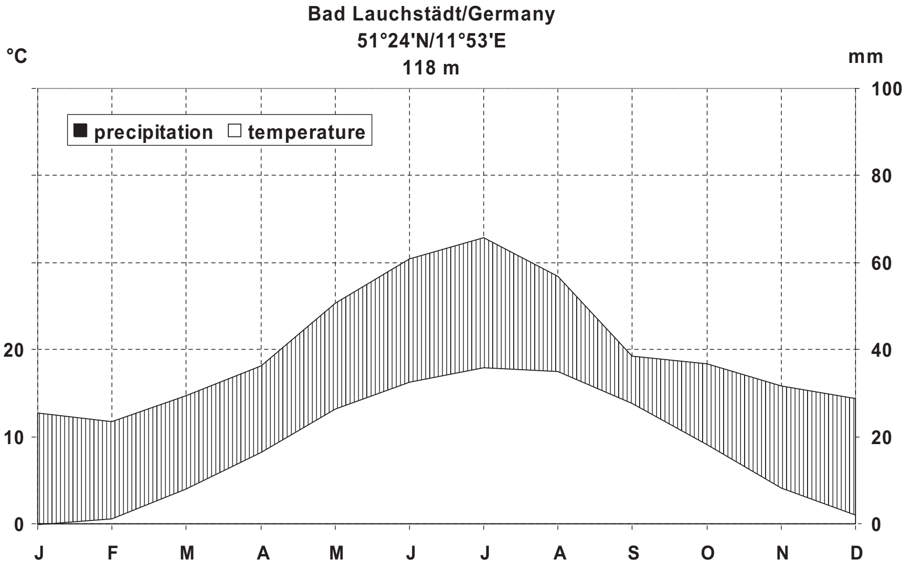


Figure 3: Yearly dynamics of precipitation and air temperature in Bad Lauchstädt, mean temperature 8.8°C, mean precipitation 484 mm (1896–2003).
Abbildung 3: Jahresdynamik der Niederschläge und Lufttemperaturen in Bad Lauchstädt, langjähriges Temperaturmittel 8,8 °C, langjähriges Niederschlagsmittel 484 mm (1896–2003).

Table 2: Used methods.
Tabelle 2: Verwendete Methoden.

Parameter	Abbreviation	Reference
Soil description	AK SYS	*Arbeitskreis für Bodensystematik der Deutschen Bodenkundlichen Gesellschaft* (1998)
Soil classification	AK SYS KA 5	*Arbeitskreis für Bodensystematik der Deutschen Bodenkundlichen Gesellschaft* (1998) *Ad-hoc AG Boden* (2005)
Soil classification	WRB	*WRB* (1998)
Color (moist)		*Munsell* (1994)
Soil reaction	pH	DIN ISO 10390 (*HBU*, 2000)
Double lactate-soluble P and K	P_{DL}, K_{DL}	*Egner* et al. (1960) (*Schlichting* et al., 1995)
Cation-exchange capacity	CEC	DIN ISO 11 260 (*HBU*, 2000)
Exchangeable cations		DIN ISO 14 254 (*HBU*, 2000)
Total element contents (oxides)	As, Cd, Cr, Ni, Cu, Zn, Pb, Hg, V, Mg, Mn, Mo, S, Si, P, K, Fe, Al, Ca, Na, Zr, Ti, Ba	X-ray fluorescence spectrometry (XRF) (*Alloway,* 1995)
Dithionite-extractable Fe and Mn	Fe_d; Mn_d	*Mehra* and *Jackson* (1960)
Oxalate-extractable Fe and Mn	Fe_o; Mn_o	*Schwertmann* (1964)
Organic-C content	C_{org}	Wet combustion; DIN 19684 oxidation with $K_2Cr_2O_7$
Total N content	N_t	VD LUFA III 4.1.1
Carbonate content	CO_3	*Schlichting* et al., 1995 (Ströhlein)
Particle-size distribution		DIN ISO 11 277 (*HBU*, 2000)
Dry bulk density	d_B	DIN ISO 11272 (core size 250 cm^3)
Particle density	d_P	helium-pycnometer (Fa. Micromeretics) (*Blake* and *Hartge*, 1986)
Pore space	PS	calculated from d_b and d_p
Field capacity (6.3 kPa)	FC	sandbox, DIN ISO 11274 (core size 250 cm^3)
Water content (31.6 kPa)	WC	pressure-membran apparatus, DIN ISO 11274 (core size 250 cm^3)
Field air capacity	FAC	calculated from PS and FC
Macropore volume (>10 μm)	MP	calculated from PS and WC (31.6 kPa)
Available water content	AWC	calculated from FC and PWP
Permanent wilting point (1.500 kPa)	PWP	Pressure-membran apparatus with porous ceramic plate DIN ISO 11274
Saturated hydraulic conductivity	K_s	DIN 19683-9 (core size 250 cm^3)
Hygroscopicity	Hy (K)	according Kuron at steam pressure equilibration with 50% H_2SO_4
Maximum water capacity	WC_{max}	24 h capillary saturation and 8 h absolutely saturation of 100 cm^3 soil cores, reaching of water capacity after 2 h on a 6 cm thick sandbed
Soil microbial biomass	C_{mic}	*Anderson* and *Domsch* (1978) *Heinemeyer* et al. (1989)
β-glucosidase activity		*Hoffmann* and *Dedeken* (1965)
Protease activity		*Ladd* and *Butler* (1972)
Alkaline phosphatase activity		*Tabatabai* and *Bremner* (1969)

Table 3: Site characteristics and description of the Haplic Chernozem developed from loess.
Tabelle 3: Lage und Beschreibung des Normtschernosem aus Löss.

General information	**Location**	Experimental station of the UFZ Centre for Environmental Research Leipzig-Halle (Bad Lauchstädt) near by the weather station
	Landscape category	Querfurter Platte
	Elevation above sea level	118 m
	Relief	even plateau; gradient: 0°
	Coordinates	Ordnance map Merseburg/West (4637): R: 4491575; H: 5695320
	Geology/ Geological parent material (Nomenclature of layers according to *Ad-hoc AG Boden*, 2005)	I Weichselian loess—main periglacial layer (LH) II Weichselian loess—middle periglacial layer (LM) III Ground moraine (sandy till marl) of the Saale (Drenthe)–cold age —periglacial reshaped to basis position (LB)
Soil systematics	**According to *Ad-hoc AG Boden* (2005)**	
	Soil class:	Schwarzerden (T)
	Soil type:	Tschernosem (TT)
	Soil subtype:	Normtschernosem (TTn)
	Substrate type:	Schluff über Carbonatschluff (Löss)/Silt over calcareous-silt (loess)
	Symbol:	*p-u (Lo)/a-eu (Lo)*
	Substrate subtype:	Kalkführender Kryoturbattonschluff über Kalklehmschluff (Löss) über sehr tiefem stark reinkiesführendem Fließkalklehmsand (Geschiebemergel)/calcareous cryo-turbat-clay-silt over calcareous-loam-silt (loess) over very deep strong gravel-containing flow-lime-loam-sand (till marl)
	Symbol:	*pky-(c)tu (Lo)/a-cu (Lo)///pfl-(kk4)ckls (Mg)*
	Bodenform (form of soil):	Normtschernosem aus Schluff über Carbonatschluff (Löss)/Normtschernosem developed from silt over calcareous-silt (loess)
	Symbol:	*TTn:p-u (Lo)/a-eu (Lo)*
	WRB (1998):	Haplic Chernozem Notes: There are small-scale interferences and smooth transitions between Haplic and Calcic Chernozem on the experimental field in Bad Lauchstädt.

Features of horizons

No.	**Depth** [cm]	**Symbol of horizon**	**Symbol of substrata**	**Pedogenic features and characteristics of substrata**
1	0–30	rAxp	pky-ctu (Lo)	Medium humous (h3); brownish black, 7.5YR2/2; poor in carbonate content (c2); heavy clayey silt (Ut4), very sparse fragments of medium gravel (mG1) of anthropogenic origin; medium granular and partly medium platy structure; strongly rooted
2	30–45	Axh	pky-ctu (Lo)	Medium humous (h3); black to brownish black, 7.5YR2/1-2; poor in carbonate content (c2); heavy clayey silt (Ut4); aggregate structure; crotovinas; strongly rooted, root channels; needles of secondary gypsum
3	45–55	elC+Axh	pky-ctu (Lo)	Weak humous (h2); greyish brown, 7.5YR4/2; strong in carbonate content (c3.4); heavy clayey silt (Ut4); subprismatic structure; crotovinas; medium rooted, root channels
4	55–125	II elCc	a-clu (Lo)	Very weak humous (h1); yellowish brown, 10YR5/6; rich in carbonate content (c4); discontinuous concentrations of carbonate as pseudomycelia, cutans, soft and hard nodules, loess-kindl; medium clayey silt (Ut3); subprismatic structure; weakly rooted, root channels; accumulations of stones on the basis
5	125–170	III elCkc	pfl-(kk4)cls (Mg)	Nearly free of humus (h0); yellowish brown, 10YR5/8; weak in carbonate content (c3.2); weak loamy sand (Sl2), strong coarse gravel (gG3), concentration of gravel in tapes and shirns; subprismatic structure; very weakly rooted; veins of rust; cryoturbations; veins of lime, discontinuous concentrations of carbonate as pseudomycelia, cutans, soft and hard nodules, and loess-kindl
6	170–190	elCc	pfl-(kk2)cus (Mg)	Nearly free of humus (h0); brown, 10YR4/6; weak in carbonate content (c3.2); medium silty sand (Su3), sparse fragments of coarse gravel (gG2); veins of lime

Table 4: Particle-size distribution of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 4: Korngrößenverteilung des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	Particle-size distribution									
	G	gS	mS	fS	Σ **S**	gU	mU	fU	Σ **U**	Σ **T**
	>2	0.63–2	0.2–0.63	0.063–0.2	2–0.063	0.02–0.063	0.0063–0.02	0.002–0.0063	0.063–0.002	<0.002
	[mm]									
[cm]	[% total]	[% fine earth]								
0–30	**2**	2	4	5	**11**	43	19	6	**68**	**21**
30–45	**0**	1	2	6	**9**	43	22	5	**70**	**21**
45–55	**0**	<1	2	8	**10**	45	21	5	**71**	**19**
55–125	**0**	1	2	8	**11**	55	18	4	**77**	**12**
125–170	**28**	15	30	32	**77**	10	5	2	**17**	**6**
170–190	**10**	2	26	32	**60**	9	8	16	**33**	**7**

Table 5: Ratios of particle sizes, total contents of Ba, Ti, Zr, and Ti : Zr ratios as well as potential cation-exchange capacity (CEC_{pot}) and exchangeable cations of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 5: Kornquotienten, Ba-, Ti-, Zr-Konzentrationen und Ti:Zr-Verhältnisse sowie potenzielle Kationenaustauschkapazität (CEC_{pot}) und austauschbare Kationen des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	**gU : fS**	**gU : mS**	**mU : fU**	**U : S**	**Ba**	**Ti**	**Zr**	**Ti : Zr**	**CEC_{pot}**	**exchangeable cations**			
										Ca	Mg	Na	K
[cm]					[g kg^{-1}]				[cmol^{+} kg^{-1}]				
0–30	8.6	2.3	3.2	6.2	0.43	4	0.50	8.0	24.4	26.2	1.5	<0.1	0.2
30–45	7.2	1.9	4.4	7.8	0.42	4	0.49	8.2	19.4	23.6	1.4	0.1	0.2
45–55	5.6	2.1	4.2	7.1	0.39	4	0.49	8.2	13.6	21.8	1.2	0.2	0.2
55–125	6.9	3.1	4.5	7.0	0.36	4	0.49	8.2	7.3	16.5	1.0	<0.1	0.2
125–170	0.3	2.0	2.5	0.2	0.18	2	0.26	7.7	3.4	10.1	1.6	<0.1	0.1
170–190	0.3	1.1	0.5	0.6	0.24	2	0.21	9.5	6.2	12.1	3.4	<0.1	0.3

Table 6: pH values, contents of C_{org}, N_t, $CaCO_3$, total and double-lactate-soluble P and K as well as the C : N ratio of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 6: pH-Werte, Gehalte an C_{org}, N_t, $CaCO_3$, Gesamt- und doppellaktatlöslichem P und K sowie C:N-Verhältnisse des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth		**pH**		**C_{org}**	**N_t**	**C : N**	**$CaCO_3$**	**P_{total}**	**K_{total}**	**P_{DL}**	**K_{DL}**
[cm]	[KCl]	[$CaCl_2$]	[H_2O]	[%]	[%]		[%]	[g kg^{-1}]	[g kg^{-1}]	[mg kg^{-1}]	[mg kg^{-1}]
0–30	7.3	7.5	7.9	2.06	0.18	11.3	0.6	1	20	64.5	101.8
30–45	7.5	7.7	8.2	1.12	0.11	9.9	1.4	1	19	15.2	56.7
45–55	7.8	7.9	8.3	0.60	0.07	8.6	8.0	1	18	3.4	34.8
55–125	8.0	8.0	8.4	0.11	0.03	4.2	12.8	<1	18	2.6	34.8
125–170	8.3	8.1	8.3	0.01	0.02	0.6	3.6	<1	13	3.4	25.8
170–190	8.0	8.1	8.3	0.04	0.02	2.5	3.8	<1	15	2.7	67.0

Table 7: Total contents of Ca, Na, Al, Fe, Mn, oxalate- and dithionite-extractable Fe and Mn as well as the $Fe_o : Fe_d$ and $Fe_d : Fe_t$ ratios of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 7: Gesamtgehalte von Ca, Na, Al, Fe, Mn, oxalat- und dithionit-extrahierbarem Fe und Mn sowie Fe_o:Fe_d- und Fe_d:Fe_t-Verhältnisse des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	Ca	Na	Al	Fe	Mn	Fe	Mn	Fe	Mn	$Fe_o : Fe_d$	$Fe_d : Fe_t$
	total					oxalate-extractable		dithionite-extractable			
[cm]	$[\text{g kg}^{-1}]$					[%]					
0–30	11	8	42	22	<1	0.122	0.040	0.631	0.037	0.19	0.29
30–45	11	11	42	21	<1	0.107	0.035	0.626	0.031	0.17	0.30
45–55	39	<4	39	20	<1	0.075	0.021	0.543	0.021	0.14	0.27
55–125	59	5	32	17	<1	0.054	0.013	0.429	0.013	0.13	0.25
125–170	30	4	21	13	<1	0.016	0.006	0.317	0.006	0.05	0.24
170–190	34	8	31	19	<1	0.025	0.009	0.493	0.010	0.05	0.26

Table 8: Total contents of As, Cd, Cr, Ni, Cu, Zn, Pb, Hg, V, Mg, Mo, S, and Si of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 8: Gesamtgehalte von As, Cd, Cr, Ni, Cu, Zn, Pb, Hg, V, Mg, Mo, S und Si des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	As	Cd	Cr	Ni	Cu	Zn	Pb	Hg	V	Mo	Mg	S	Si
[cm]	$[\text{mg kg}^{-1}]$										$[\text{g kg}^{-1}]$		
0–30	8.0	0.2	59.2	15.3	17.9	61.9	31.9	<0.8	19.3	<1.4	5	<1	340
30–45	5.8	0.4	58.8	18.6	12.8	43.8	20.2	<0.8	18.4	<1.4	3	<1	347
45–55	5.6	<0.2	54.0	15.0	10.2	36.2	16.3	<0.8	15.5	<1.4	8	<1	329
55–125	4.7	<0.2	48.9	13.2	9.0	31.5	14.5	<0.9	<10.0	<1.4	8	<1	316
125–170	2.4	<0.3	26.1	9.2	7.2	22.3	13.6	<0.8	<10.0	1.4	4	<1	379
170–190	6.9	<0.2	44.5	17.0	11.5	37.5	14.9	<0.8	28.1	<1.4	7	<1	348

Table 9: Soil physical characteristics of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 9: Bodenphysikalische Kennwerte des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	d_B	d_P	PS	FC 6.3 kPa	WC 31.6 kPa	PWP 1500 kPa	FAC 6.3 kPa	MP 31.6 kPa	AWC	K_S
[cm]	$[\text{g cm}^{-3}]$		$[\text{m}^3\ \text{m}^{-3}]$							$[\text{cm d}^{-1}]$
0–30	1.40	2.60	0.462	0.384	0.328	0.155	0.078	0.134	0.229	60.4
30–45	1.38	2.63	0.475	0.385	0.330	0.151	0.090	0.145	0.234	28.0
45–55	1.31	2.66	0.508	0.377	0.319	0.150	0.131	0.189	0.227	27.7
55–125	1.42	2.67	0.468	0.382	0.294	0.095	0.086	0.174	0.287	10.8
125–170	1.81	2.66	0.320	0.156	0.113	0.070	0.164	0.207	0.086	124.3
170–190	1.70	2.63	0.354	0.202	0.142	0.084	0.152	0.212	0.118	62.5

ties are documented in Tabs. 4–10 and the mean annual distribution of precipitation and air temperatures in Bad Lauchstädt in Fig. 3.

5.1 Soil chemical properties

The Haplic Chernozem developed from loess is characterized in the rAxp horizon by C_{org} content of 2.06% (Tab. 6). The C_{org} contents decrease with increasing soil depth, and correspondingly the CEC (Tab. 5); P_{DL} and K_{DL} indicate a similar depth function (Tab. 6). In contrast, carbonate content and pH levels increase as they get closer to the loess (Tab. 6). Similar results have been documented by *Diez* and *Weigelt* (1991), *A*ltermann and *Schröder* (1992) as well as *Scheffer* (2002).

The carbonate content in the rAxp horizon of the profile and in the Axp horizon of the neighboring experimental field evidenced significantly variations (range on the field between 0% and 4.9% in extreme; data not shown), but usually carbonate content is <2%. Pseudomycelia are not occurring in the upper horizons. Therefore, the soil was classified as *Normtschernosem.* However, there are small-scale interferences and smooth transitions between *Normtschernosem* and *Kalktschernosem* on the experimental field. Significant amounts of carbonate in the upper horizons might be of biogenic and anthropogenic origin. In case of dryness, white-grey needles of secondary gypsum occur in the upper horizons, due to high SO_4^{2-} depositions in former time and the low infiltration rate in the Central German dry area (*Dultz,* 1997).

The contents (or oxides) of Ca, Fe, K, Mg, Mn, Mo, P, S, and V in the Chernozem (Tabs. 7 and 8) are within a common range for Central European soils containing carbonate, which were formerly under agricultural use (*Scheffer*, 2002). Oxalat-extractable Fe is considered mainly as of short-range order and dithionite-extractable as crystalline Fe oxide fractions (*Schwertmann,* 1964; *Schlichting* et al., 1995). The Fe_d : Fe_t ratios of the Haplic Chernozem range between 0.30 in the upper soil and 0.24 in the subsoil, while those of Fe_o : Fe_d range between 0.19 and 0.05 (Tab. 7). Both ratios do not indicate pedogenic formation of Fe oxides.

Chernozems in Central Germany are dominated by illite contents of approximately 80% (*Dreibrodt* et al., 2002; *Kahle* et al., 2002a). Organic matter accumulates in the fractions of smallest size and highest surface area, apparently intimately associated with the mineral phase (*Kahle* et al., 2002a). The specific surface area, the CEC, and the content of dithionite-extractable Fe enable a prediction of the content of organic C in illitic clay fractions of topsoils of Chernozems developed from loess (*Kahle* et al., 2002b).

The Haplic Chernozem is not contaminated by heavy metals or As (Tab. 8) (*cf., Blume*, 1990; *Alloway,* 1995). On neighboring arable fields, amended with heavy metal–contaminated sewage sludge, heavy metals were retained over 11 y within to 50 cm depth (*Schaecke* et al., 2002).

Functional boundaries in soil profiles may be identified by the distribution of "immobile" elements in the profile. Both Ti and Zr are commonly considered immobile in weathering environments owing to the relatively insoluble nature of the detrital minerals in which they are concentrated, such as zircon ($ZrSiO_4$) and rutile/anatase (TiO_2) (*Fitzpatrick* and *Chittleborough,* 2002; *Stiles* et al., 2003). If they are both immobile, the ratio Ti : Zr should remain constant throughout the profile depth and is therefore a proxy for parent-material uniformity or heterogeneity. In the investigated Haplic Chernozem, the Ti : Zr ratios are uniform at around 8, and their changes with soil depth are relatively low, only in the underlying glacial drift the Ti : Zr ratio is 9.5 (Tab. 5).

5.2 Soil physical properties

The Haplic Chernozem, with the dominance of coarse silt, is characterized by total silt content of around 70% and a clay content of 20% (Tab. 4). The quotient of particle sizes (Tab. 5) lies within the range given by *A*ltermann and *Schröder* (1992). Furthermore, they are able to assign the borders of different parent material within the profile. The bulk density (d_B) amounts 1.40 g cm^{-3} in the rAxp horizon (Tab. 9). The adjacent arable fields are showing bulk densities between 1.25 and 1.35 g cm^{-3} after upturning soil tillage outside track-impacted grounds. After long-term conservational soil tillage, bulk densities are around 0.05 to 0.10 g cm^{-3} higher with air capacities of 6 to 8 vol.% and saturated water conductivities of 30 to 50 cm d^{-1}.

Top soils of Chernozems are characterized by medium to high saturated water conductivities and air capacities. Damaging soil compaction occurs seldom in central parts of the field. Especially endangered are the surface areas heavily impacted by tracks. Recent studies have shown that Chernozems, considered as relatively stable in structure, are endangered as a consequence of increasing wheel weights as well as considerable shear and kneading actions (wheel slip) due to increasing technological structural damage to the surface soil and surface soil base (*Gieska* et al., 2003).

The medium effective root depth (*Ad-hoc AG Boden,* 2005) of the Haplic Chernozem is about 12 dm. The soil may store 460 mm water in this zone, nearly the same as the mean annual precipitation. Correspondingly, low to medium permanent wilting points in the effective root space lead to a very high available water capacity of approx. 300 mm, which is typical for these silt-rich Chernozem soils. The high soil water-retention capacity and the sum of the advantageous physical soil properties provide an essential basis for the relatively low yield losses on these Chernozems in case of drought stress.

5.3 Soil microbial properties

Nutrient cycling in soils involves biochemical, chemical, and physicochemical reactions, with biochemical processes being mediated by microorganisms, plant roots, and soil animals. This study focused on soil microbial biomass and activities at different depths according to the soil horizons (Tab. 10).

Table 10: Soil microbial biomass (C_{mic}), $C_{mic} : C_{org}$ ratio, and selected soil enzyme activities of the Haplic Chernozem developed from loess (under lawn, 15 y without fertilization and soil tillage).
Tabelle 10: Mikrobielle Biomasse im Boden (C_{mic}), C_{mic}:C_{org}-Verhältnis und ausgewählte Bodenenzymaktivitäten des Normtschernosem aus Löss (unter Rasen, 15 a ohne Düngung und Bodenbearbeitung).

Depth	**Biomass (C_{mic})**	**$C_{mic} : C_{org}$ ratio**	**β-Glucosidase**	**Protease**	**Alkaline phosphatase**
[cm]	[μg C_{mic} (g dw)$^{-1}$]	[μg mg^{-1}]	[μg Saligenin (g dw)$^{-1}$ (3 h)$^{-1}$]	[μg Tyrosin (g dw)$^{-1}$ (2 h)$^{-1}$]	[μg p-NP (g dw)$^{-1}$ h^{-1}]
0–30	174.6	8.5	64.3	130.1	1802.4
30–45	66.1	5.9	32.8	60.4	1752.4
45–55	36.5	2.5	25.3	29.0	1429.2
55–125	18.5	1.4	9.9	9.9	477.5
125–170	20.1	1.2	4.2	4.8	44.7
170–190	18.9	2.1	3.6	2.5	22.6

According to *Dick* (1994), *Kandeler* et al. (1996), and *Wick* et al. (1998), soil microbial biomass, enzyme activities of β-glucosidases, proteases, and alkaline phosphatases were identified as attractive indicators for soil quality of agricultural and heavy metal–contaminated soils; generally they are closely related to SOM.

The general decline of C_{mic} content for subsoil layers is in agreement with several studies (*Jörgensen* et al., 2002; *Fierer* et al., 2003; *Agnelli* et al., 2004; *Machulla* et al., 2004). The C_{mic} values of the topsoil (rAxp) of the Haplic Chernozem (Tab. 10) are in the same dimension as reported by *Klimanek* (2000) and *Langer* et al. (2001). However, even the highest soil microbial biomass of the rAxp horizon was 35% lower than the average C_{mic} content of 270 μg g^{-1} for 27 agricultural soils in Germany obtained by *Jörgensen* (1995). According to the estimation procedure of soil microbial biomass presented by *Machulla* et al. (2001), the topsoil horizon contained 733.1 kg ha^{-1} C_{mic}. Consequently, the C_{mic} amount of this soil can be classified as moderate, which is clearly below the average content of different ecosystem types.

A close relationship between C_{mic} and C_{org} is generally well documented (*Insam* et al., 1989). The $C_{mic} : C_{org}$ ratio can be regarded as an indicator of the relative availability of substrate for soil microorganisms in arable soils (*Anderson* and *Domsch*, 1989; *Schinner* et al., 1993). According to *Haider* (1996), a $C_{mic} : C_{org}$ ratio between 20 and 40 can be considered as nearly constant for topsoil. The low ratios (between 8.5 and 1.2) of the Haplic Chernozem indicate the fairly low amount of C_{mic} as well as the fact that the soil microbial community seems to be less efficient in using C_{org}.

Extracellular enzymes, like β-glucosidases, proteases, and alkaline phosphatases, are the primary means by which soil microbes degrade complex organic compounds into small molecules that can be assimilated (*Allison* and *Vitousek*, 2005). Their activities are strongly influenced by soil management systems (*Kandeler* et al., 1999) as well as by physicochemical and pedo-climatic conditions (*Khaziyey,* 1977; *Nannipieri* et al., 2002).

The soil enzymes also decreased with increasing soil depth in the Haplic Chernozem due to the abiotic conditions such as declining C_{org} concentrations (Tab. 6) and diminishing pore volume (Tab. 9). Similar results are documented in a sandy and clayey soil (*Taylor* et al., 2002), in a range of floodplain soils (*Rinklebe* et al., 1999; *Rinklebe*, 2004) as well as in urban soils (*Lorenz* and *Kandeler*, 2005). The β-glucosidases and proteases activities in the rAxp horizon of Chernozems are in the size obtained by *Klimanek* (1999, 2000), *Langer* et al. (2001), *Böhme* et al. (2004), and reviewed by *Emmerling* et al. (2002). The alkaline-phosphatases activity ranged in the magnitude for grassland soils given by *Dormaar* et al. (1984) and *Langer* (2000) as well as for wetland soils by *Wright* and *Reddy* (2001).

6 Characterization of the yields and ecological importance of Chernozem by the example of the more than 100 years long-term Experiment at Bad Lauchstädt

The "Static Fertilization Experiment Bad Lauchstädt" initiated in 1902 by Schneidewind and Gröbler is one of the most significant long-term experiments in the world (*Körschens* et al., 1994). The results of the experiment allow a comprehensive understanding concerning the characteristics and potential of Chernozems developed from loess and cause thereby the need for sustainable protection of these soils.

The **yield capacities** of the Chernozems are different due to the formation of their soil substrate. The valuation audited by the *"Reichsbodenschätzung"* assigned the Chernozem developed from loess as the soil with the highest agricultural value in Germany. The Chernozems of the arable farm at Eickendorf (Magdeburger Börde) achieved the highest soil ratings (*Bodenzahlen: 97....100*) (*Altermann* and *Jäger*, 1992). The development of yields and soil fertility of Chernozem developed from loess can be observed by the data of the "Static Fertilization Experiment Bad Lauchstädt" (*Körschens* et al., 1998).

The greatest increases in yield were achieved for winter wheat with 135% with the 2 y application of farmyard manure (20 t ha^{-1}) and NPK fertilization (Tab. 11). Under consideration of the utilization of nutrients and environmental impacts, this fertilization is optimal (*Körschens*, 2004). The increasing yields achieved during the total time period, also in case of

Table 11: Development of yields in the Static Fertilization Experiment Bad Lauchstädt depending on fertilization (t ha^{-1}).
Tabelle 11: Entwicklung der Erträge im Statischen Düngungsversuch Bad Lauchstädt in Abhängigkeit von der Düngung (t ha^{-1}).

Fertilization	Period	Winter wheat corn, 86% dry matter	Spring barley corn, 86% dry matter	Sugar beets sugar	Potatoes dry matter
without	1905–1914	2.98	1.99	5.12	2.88
	1995–2004	5.46	2.77	4.70	3.47
NPK[a]	1905–1914	3.79	2.99	7.33	4.95
	1995–2004	9.09	6.41	11.19	9.62
20 t ha^{-1} (2y)$^{-1}$ farmyard manure	1905–1914	3.81	2.61	7.22	5.27
	1995–2004	7.12	5.38	8.31	8.72
20 t ha^{-1} (2y)$^{-1}$ farmyard manure + NPK[b]	1905–1914	3.96	3.06	7.65	5.84
	1995–2004	9.30	6.77	11.76	10.39
Top yield in Bad Lauchstädt		**12.2**	**10.3**	**16.0**	**17.0**

[a] 60 kg P ha^{-1} and 230 kg K ha^{-1} to root crops, 170 kg N ha^{-1} to sugar beets, 80 kg N ha^{-1} to spring barley, 140 kg N ha^{-1} to potatoes, 100 kg N ha^{-1} to winter wheat

[b] 28 kg P ha^{-1} to root crops, 110 kg K ha^{-1} to root crops, 150 kg N ha^{-1} to sugar beets, 60 kg N ha^{-1} to spring barley, 120 kg N ha^{-1} to potatoes, 80 kg N ha^{-1} to winter wheat

winter wheat and spring barley without any fertilization, are an expression of the high soil fertility of these Chernozems. Further causes for increasing yields are successes in plant breeding, application of plant-protective agents, and the increased input of mineral N by 30 to 40 kg ha^{-1} y^{-1} as well as the atmospheric-N deposition.

The highest yields achieved so far at this site indicate the yield potential and allow one to recognize the possibilities for further yield increases at these soils. The practical yields hardly ever fall short of the experimental yields. For example, on the neighboring fields of >100 ha, winter wheat yields of up to 10.8 t ha^{-1} and sugar yields of 14.5 t ha^{-1} were achieved. So, even in the Central German dry region, under consideration of by-products such as straw and sugar-beet leaves, up to 20 t ha^{-1} of dry mass can be harvested annually on Chernozems developed from loess. This represents a decrease for the atmosphere of around 8 t of C or approx. 30 t of CO_2 ha^{-1}, provided that this C is sensibly used.

The results of the **N balances** over a long time period are also important. According to the results of the experiment, the N uptake is greater than the input of fertilizer on Chernozem at all levels of fertilization at constant soil N pool. Parts

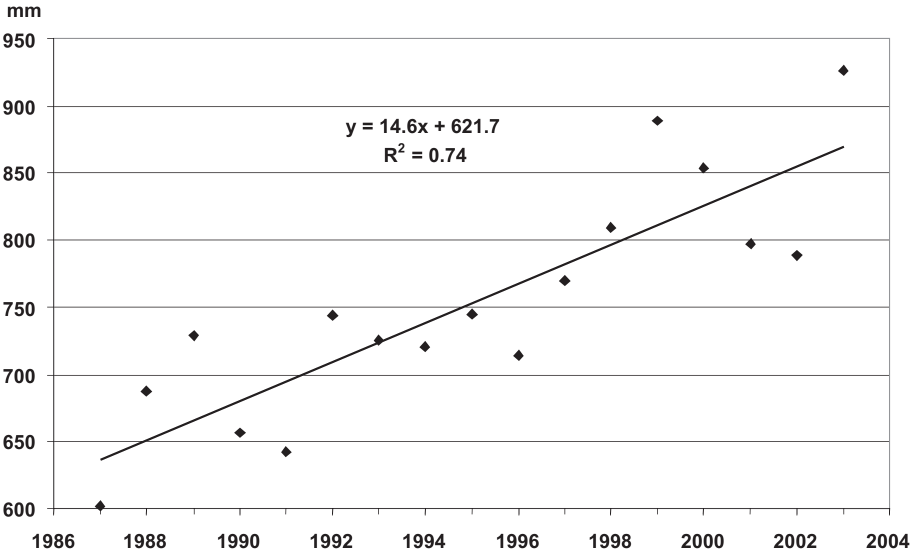


Figure 4: Potential evapotranspiration in Bad Lauchstädt (1987–2003, data measured by the meteorological station of UFZ in Bad Lauchstädt).
Abbildung 4: Potenzielle Evapotranspiration in Bab Lauchstädt (1987–2003, Messwerte der UFZ-Wetterstation in Bad Lauchstädt).

of atmogenic-N inputs (>50 kg ha^{-1} y^{-1}) are used for plant production. The generally high N exploitation can be attributed to the given site conditions. Low precipitation, high water-storage capacity of the soil, and a rooting depth of down to 2 m determine the very slight N loss. The immeasurable value of Chernozem for biomass production and for our environment can be seen in these examples.

The distribution of Chernozem is primarily linked to semihumid areas, which is particularly valid for the Central German dry area with average annual precipitation of <500 mm. At the experimental research station Bad Lauchstädt, the **development of the temperature and the precipitation** during the last 100 y period was monitored. The average precipitation of the most recent decades have not significantly changed, but the average annual temperature within the last decade, as compared to the last century, has increased by approx. 1°C. Correspondingly, the increase in potential evapotranspiration during the last 15 y (Fig. 4) already shows a clear change in growth conditions. Thus, water could become, in the next few years more than ever, a yield-limiting factor.

7 Conclusions

Due to their structure and their chemical, physical, and biological properties, Chernozems are particularly suited to optimally fulfil the most differentiated soil functions. From this we can extrapolate the high need for protection of Chernozems, especially since these soils cannot develop anymore in Germany. Each loss of Chernozem due to erosion or deprivation in soil surface area will result in a serious loss of overall potential for the soil cover to fulfil multiple ecological functions. For example, due to erosion in the last 50 y, the proportion of eroded Chernozems has clearly increased. Furthermore, approx. 3% of the Chernozem surface of Sachsen-Anhalt has been lost over the last 150 y due to devastation. Soil utilization for settlements and traffic areas is still raising this statistic. Soil protection for Chernozem sites must be prioritized to minimizing the deprivation of soil surface area, erosion, and input of pollutants. Furthermore, incorrect agricultural use can lead to soil compaction, which again raises the susceptibility for erosion.

Although soil consumption has not increased in Germany during the last few years, the requirement must be still to decrease soil wastage on a minimum. The high-yielding soils—including Chernozems—are mostly impacted by the need for building areas, since settlements historically develop in regions with high soil fertility (*TAB*, 2004).

It has not yet been realized by the public that destruction of soil, particularly of Chernozem sites, does not only negatively affect the present and future yield potential, rather it represents a harmful and sustained impact for all of the environment. A loss of Chernozems must be compared to a loss of animal and plant species.

Therefore, the results of soil research for preservation and protection of our soils must be more comprehensively implemented, and soil scientists must be strongly included within the soil politics. The implementation of an area-wide, detailed mapping, recording, and evaluation of soils and their functions in an increasingly globalized world, based on most recent insights, is an indispensable task for soil researchers for the coming years and decades. Only then, appropriate decisions regarding soils, their usage, and preservation can be made. For acceptance of these goals among the general public, the “Soil of the Year” should be able to give distinct impulses.

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