# The increase of soil organic carbon as proposed by the “4/1000 initiative” is strongly limited by the status of soil development. A case study along a substrate age gradient in Central Europe

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# Abstract

During the 21st Conference of the Parties (COP 21), Paris 2015, several states and organizations agreed on the “4/1000” initiative for food security and mitigate climate change. This initiative aims to increase world's soil organic carbon (SOC) stocks by 4 ‰ per year. Although it is known that soil status and soil intrinsic properties have important influence on SOC dynamics, their influence is usually not considered in studies. Therefore, we analyse SOC accumulation under (semi-)natural and cropping systems along a soil age gradient to show if and how strong soil status influences the increase of SOC.

SOC stocks (0-40 cm) and accumulation rates developed during the Holocene (10- 17.000 years) in alluvial soils of the Danube River in the Marchfeld (eastern Austria) were analysed. The analysed fluvisoils and chernozems have been used as forest, grassland and cropland for decades or hundreds of years. The results showed that there is a fast build-up of OC stocks in young soils (age < 350 years) reaching a rate of 0.13 t ha-1 a-1 OC accumulation almost independent of the land use within the upper 40 cm. In contrast, we found in the chernozems with a substrate deposition age older than 2.000 years an accumulation rate of less than 0.02 t OC ha-1 a-1 in the first 40 cm.

Radiocarbon dating showed that the young soils consist mainly of “modern” carbon indicating a fast carbon cycling. Interestingly, also the oldest forest site with a maximum substrate deposition age of 17.000 years showed an uncalibrated 14C age of only 40 ± 40 BP. However, 1~~4~~~~C in the~~ carbon compounds in subsoil are less exposed to decomposition and OC can be stored at long- time scales in the subsoil (14C age of 3670 ± 35 BP) with an annual accumulation rate of ~ 0.01 t ha-1 in depth >40 cm.

In view of the “4/1000” initiative, those soils with constant carbon input (forest & grassland) fulfil the intended 4 ‰ growth rate of SOC stocks in the first approx. 60 years of soil development, but reach lower rates in older soils. Our data show that even a land conversion from croplands, which have the lowest SOC stocks in the study area, to a forest or grassland could not contribute to the “4/1000” initiative in the Chernozems of the Marchfeld on the long term. We proclaim that under the present climate in Central Europe, the annual increase of SOC stocks in soil is strongly affected by the developed soil status.

# Introduction

Soils and its OC (Organic Carbon) content play an important role for food security and in the global carbon cycle and in climate change. Worldwide, soils are the largest terrestrial pool of organic carbon and store about 2500 Pg of C to 2 m depth in the form of soil organic matter (SOM) (Batjes, 1996; Scharlemann et al., 2014; Trumbore, 2009). Due to land use and land cover changes, emissions from terrestrial ecosystems are the second largest anthropogenic source of carbon into the atmosphere (Scharlemann et al., 2014). The loss of SOC from agricultural land is identified as one of the eight major threats to soils (EC, 2012) as it negatively influences soil fertility and the soils function providing ecosystems services (Haddaway et al., 2016). In Europe, a too low SOC content in agricultural soil is also one of the most limiting factors for soils to be resilient against negative environmental impacts and to perform on high levels (Schiefer et al., 2016). Such a high resilience and production capacity of soils is the basis for a sustainable intensification as it allows intensive agriculture with high yields but without the massive negative environmental impacts (Buckwell et al., 2014; Schiefer et al., 2015).

The importance of SOC for food security and climate change was also recognised during the 21st Conference of the Parties (COP 21) launched in Paris, France, in December 2015. At COP 21 the "4 per mille- Soils for food security and climate change" initiative was introduced. This "4 per mille" or “4/1000” initiative tries to increase global soil carbon by 4 ‰ annually of the existing carbon in the first 40 cm of agricultural soils in the next 25 years (Rhodes, 2015; Lal, 2016). This increase could compensate for the global greenhouse gas emissions and climate change, ensure food security and contribute to the UN sustainable development goals (http://4p1000.org). To reach this ambitious goal, management strategies such as conservation agriculture, mulch farming, cover cropping, agroforestry, biochar application, improved grazing and/or restoration of degraded soils are suggested (Lal, 2016).

However, for the “4 per 1000” initiative it is also important to maximize the residence time of additional C in soils (Dignac et al., 2017) and to define C saturation levels to identify realisable C-accumulation potentials (Minasny et al., 2017). Studies showed that soils can reach a maximal soil C level showing no response to increasing C inputs due to a carbon saturation in soil (Gulde et al., 2008; Six et al., 2002; Stewart et al., 2007, 2008; West and Six, 2007). Besides the finite capacity of soils to store OC, it must also be considered that the process of carbon storage is reversible (Powlson et al., 2011). Zehetner et al. (2009) showed that along the floodplain soil chronosequence in the Marchfeld, carbon is rapidly accumulated in the first years of soil development and shows equilibrium and stabilization in various humus fractions already within 100 years.

The main objective of this study is to analyse the influence of the soil development status on the accumulation potential of SOC in the top and subsoil in the long-term. To our knowledge, we evaluate the first time for how many years soils show a C -accumulation potential of (more than) 4 ‰ per year under the actual land use and management practices.

Soils along the substrate age gradient developed on the same parent material under the same climate. The soil chronosequence includes the whole Holocene and includes a maximum sediment deposition age of 17.000 years whilst the youngest soils have only recently developed on fresh river sediments (<40 years). We analysed the carbon stocks and accumulation rates in the upper 40 cm as proposed by the “4/1000” initiative and performed radiocarbon dating for a better understanding of OC dynamics along the soil chronosequence.

# Material and Methods

## Study Area and Soil Sampling

The study area is located in the Marchfeld, a Danube floodplain downstream of Vienna/ Austria (Figure 1) showing little variation in topography and climate. More information and a detailed description of the study area can be found in Lair et al., (2009a, 2009b) and Zehetner et al., (2009). The area is located in a continental climate with a mean annual temperature of ~ 9°C and a mean annual precipitation of about 550 mm in the past 30 years. The Marchfeld is situated in the tectonically active Vienna Basin. The formation of the Vienna basin terrace staircase has been controversially discussed, especially with regard to the role of climatic vs. tectonic forcing factors. An overview about this discussion was recently provided by (Lüthgens et al., 2017).The study area is strongly influenced by the Danube River which was regulated from 1870 to 1875. From 1882 to 1905 a flood control dike was built (Figure 1) which disconnects the older part of the floodplain from the Danube River. The land close to the river experiences regular floods. The selected sites (except islands) are located close to the dike, which are only slightly affected by inundations and accompanied sediment input.

The history of land use in the Marchfeld area can be exactly retraced till the late 18th century (Hartmann, 2003). However, the first settlement in this area was very sparse in the Neolithic period. Since the Copper Age a more or less dense population on higher elevations on the border to the Marchfeld can be retraced and since the Middle Age settlements and agricultural production is documented (pers. Comm. Univ. Wien, Institute of History).

The soil sampling campaigns took place between 2010 and 2014. Soil samples were carefully chosen based on aerial photographs and landscape evaluation. Each study site (Figure 1) was sampled at least in triplicates at the corners of an equilateral triangle of 10 to 20 m. A fixed-depth interval sampling method (using an 8-cm core drill with a core height of 15 cm from Eijkelkamp Agrisearch Equipment) was combined with a horizontal sampling method (in soil pits) down to a soil depth of 60 to 100 cm, depending on the depth of the AC horizon.

Figure 1: Study area of the Danube floodplain in the Marchfeld, east of Vienna/Austria.

## Soil characteristics and soil age

All analysed soils developed on Danube sediments of same parent material. The mineralogy of the river sediments consists of quartz (~35%), calcite and dolomite (~ 26 %), chlorites (5%), Illites/Muscovites (15%), Feldspar (~15%) and Smectites/ Vermiculites (~1%). Clay minerals show no transformation along the chronosequence, which can be explained by the carbonate buffered soil system. Regularly floods lead to a deposition of predominantly silt- and fine sand-sized particles at sites within the dike. However, these depositions are only ~0.05 mm per year (pers. Communication, National Park “Donau-Auen”). Older soils outside the dike have a finer texture mainly categorised as loamy silt. The young soils are classified as Fluvisols (within the dike) and show a progressing development to Chernozems with increasing soil age and distance to the Danube.

Soil pH is slightly alkaline across the whole chronosequence (pH: 7.6-8.0 in 0-10 cm). With increasing soil age, carbonate contents in the subsoil strongly increases (from ~20% to ~45%) reflected by increasing soil pH (from ~7.6 to ~8.6).

The age of individual soil layers was determined by 137Cs to assess short-term sedimentation and soil development at decadal time scales. The ratio of oxalate- to dithionite-extractable iron (Feo/Fed) (degree of iron oxide crystallinity) was additionally used for soils with sediment deposition ages of 100-2.000 years. A detailed description of the analysis can be found in Lair et al. (2009a).

OSL dating was used to determine the ages of sediment deposits from the beginning of the Holocene until the 18th century (Fiebig et al., 2009; Lair et al., 2009a). A detailed explanation of the analysis can be found in “supplementary Information”.

### Radiocarbon dating

Radiocarbon determinations in IOM (insoluble organic matter (??)) of bulk soil samples were performed at the VERA Laboratory (Vienna Environmental Research Accelerator). The soil samples were ground and homogenized. The amount of CaCO3 and the total amount of organic carbon present in the sample were determined in subsamples of the soils (see below).

For 14C sample preparation a sample amount containing approx. 2 mg organic C after chemical treatment – considering also losses - was estimated from the OC determinations. The 14C samples were pretreated with 1 M HCl at 60°C, after 1 hour the HCl was renewed and the treatment continued for another 1 hour in order to remove CaCO3. Subsequently the samples were washed to near neutral pH, centrifuged and dried. Details about further sample processing and 14C measurement with accelerator mass spectrometry (AMS) are given e.g. in Wild et al. 2004 and Steier et al. 2004, respectively.

Referenzen:Wild E.M., Neugebauer-Maresch Chr., Einwögerer Th., Stadler P., Steier P. and Brock F.: 14C-Dating of the Upper Paleolithic Site at Krems-Hundssteig in Lower Austria, Radiocarbon 2008, Vol 50/1:1-10

###  Steier P., Dellinger F., Kutschera W., Rom W., Wild E.M. Pushing the precision of 14C measurements with AMS. Radiocarbon 46/1 (2004) 5-16Physicochemical soil analysis

The carbonate content was quantified gas-volumetrically by measuring the volumetric release of CO2 after adding 10% HCl to the soil in a calcimeter.

Total organic carbon contents were quantified by dry combustion using an elemental analyser (Carlo Erba, Milano). The organic carbon (OC) content was calculated as the difference of total and inorganic carbon (carbonate) content. It is important to mention, that the organic carbon content of the soils of the active floodplain (Sites 1, 2, 3, 4, 5 in Table in the supplementary materials) were corrected by the OC input along with the river sediments, which present usually also eroded soil within the catchment. Measurements of sediments showed that carbon contents of the sediments are on average 7 g/kg (see Zehenter et al., 2009).

# Results

## Development of the soil layer containing humified organic matter

The A horizon in soils presents the soil layer where organic matter is accumulating with time and its velocity of build-up reflects the formation rate of “living” soil. Along with soil age the depths of the A- horizons increases logarithmically (R2 = 0.9947) as can be seen in Figure 2. At the beginning of soil formation, the A-horizon increases up to 3 mm per year. This development is usually highly dynamic and is certainly also influenced by the Danube River (e.g. nutrient and water supply for fast pioneer-plant growth; Zehetner et al. 2009). After ~350 years of soil development, the soil formation rate is decreasing to ~1.0 mm per year. Soils older than ~350 years have a formation rate less than 0.1 mm per year. The A- horizons at the oldest sites with a sediment deposition age of maximum 17.000 years covering the whole soil formation in the Holocene, increases nowadays only 0.03 mm a-1 and reaches a soil depth of 60 cm. Older soils or naturally evolved soils with a mightier A- horizon were not found in the Marchfeld.

Figure 2: Development of the A- horizon (mm a-1) along the studied soil chronosequence in the Marchfeld

## Increase of SOC and stocks in time scale

Similar to the A horizon development, the SOC contents and stocks change with time along the age sequence. The OC contents increase very fast to ~25 g kg-1 in the first ~150 years of soil development in the topsoil. After 500 years of soil development the contents increase to 40 g kg-1. In the next thousands of years, OC contents only increase very slowly and reach contents of ~45 g kg-1 at the oldest study site (Figure 3).

The OC content decreases down the soil profile. However, with increasing soil age the lower horizons contribute to total soil contents along the soil profile. Below 60 cm, only the oldest soils still contain ~13 g kg-1 OC. According to the velocity of soil formation (Figure 2), younger soils contain very less carbon below 60 cm depth.

Figure 3: Organic carbon contents (g kg-1) of selected forest sites in different depths and different soil ages

The initial OC content deposited along with sediment inputs is ~7g kg-1. Due to high organic matter inputs, forest sites rapidly build up to 50 t C ha-1 in the soil profile (Figure 4) within 30 years of soil development.

Soils with an age of ~100 years show an increase of its OC stocks to ~100 t C ha-1 at forest sites with an annual accumulation rate of ~0.82 t ha-1 a-1 (Figure 5). Grassland sites with the same age have a similar OC stock and accumulation rate (Figure 4+5). Cropland sites have an OC content of ~82 t C ha-1 at this stage of soil development (0-80cm).

OC accumulation is decreasing after 100 years of soil development at soils disconnected from the Danube River in the natural systems (forest + grassland). After ~350 years, the OC increase flattens rapidly in the topsoil. OC accumulation rates decrease to less than 0.2 t C ha-1 a-1 in soils with an age between 500 and 1000 years in the soil profile. The oldest forest sites with a maximum sediment deposition age of 17.000 years accumulates only 0.02 t C ha-1 a-1 and reaches an OC stock of ~200 t C ha-1 (0-80 cm).

OC stocks in the intensively managed cropland sites show no clear trend along the chronosequence (Figure 4). The accumulation rate of cropland soils is one-third lower compared to grassland soils (cropland: 0.82 t ha a-1; grassland: 1.35 t ha-1 a-1) at soil ages of ~100 years, and about the half with soil ages ~350 years (0.18 t ha-1 a-1: 0.39 t ha-1 a-1) and (0.08 t ha-1 a-1: 0.15 t ha-1 a-1) at soils with an sediment deposition age of ~1000 years (0-80 cm).

Figure 4: OC stocks (t ha-1) of Chernozems under different land use along a chronsoequence in the Marchfeld (0-80 cm).

Figure 5: Soil organic carbon accumulation rates (t ha-1 a-1) along the studied chronosequence in different land uses.

## Mean residence time of accumulated SOM indicated by radiocarbon dating

Radiocarbon ages determined for SOM in the topsoil (deposition age ~350 years) are mainly “modern” and “>modern” (Table 1), which reflects very fast decomposition and mineralization processes in the studied soils. The oldest forest site (maximum sediment deposition age of 17.000 years) yielded a 14C-age of 40 ± 40 years before present (BP). After thousands of years of soil development, the major part of OC is decomposed and only a very limited amount was stored in the soil indicated by the slight increase of 14C age.

The OC in the AC transition layers consists of much older radiocarbon ages than the topsoil (Table 1). The cropland and forest site (350 years) have an average 14C-age of ~ 450 years (BP) showing that the carbon is less exposed to decomposition processes than the topsoil. The grassland site with a soil age of 350 years has the lowest 14C age compared to other land uses with same soil age. However, the AC- horizon was also higher located. The forest site with a maximum sediment deposition age of 17.000 years has a radiocarbonage in the AC-horizon of 1990 ± 35 years (BP) and the cropland soil (maximum age of 12.000 years) has an average 14C-age of 3670 ± 35 (BP).

The δ13C showed no trend and ranged between -23.5 and -32.2 ‰.

Table 1: Radiocarbon age of different soils along the chronosequence in the topsoil (0-10cm) and the AC- transition horizon.

## Soil organic carbon accumulation potential in the 0-40 cm topsoil in respect to the 4/1000 initiative

Figure 6: Increase of OC (‰) based on the OC stocks. –The increase was calculated with logarithmic function based on measured values.

The grey box shows at which OC stocks soils in the Marchfeld could contribute to the 4 ‰ initiative (below dotted line).

Table 2: Calculated Soil Organic carbon stocks, accumulation rates and CO2 storage potentials along the chronosequence (0-40 cm) in natural systems. Based on measured values a logarithmic function was used for calculations.

A logarithmic function was derived from measured OC stocks in the 0-40 cm topsoils along the chronosequence (Figure 3, R2=0.769) similar to the accumulation of OC. This allows for the calculation of the annual increase of OC stocks. Based on this calculation, the accumulation of OC each year in semi-natural systems like the forest and the grassland in the Marchfeld is below 4 ‰ after only 59 years of soil development (Figure 6).

A clear trend of measured OC contents in croplands was not measured in the bulk soil with soil age. The median OC stock along the whole chronosequence is ~59 t C ha-1 in the topsoil. Considering this as initial C stock, even a conversion from cropland to a forest could not lead to an annual accumulation of more than 4 ‰ annually for more than 25 years at most sites according to our logarithmic function.

Using the conversion factor of C:CO2 of 3.67 reveals that after 50 years the potential to retain CO2 is below 1 t CO2 ha-1 a-1. Soils older than 300 years have a CO2 storage capacity of less than 0.2 t CO2 ha-1 a-1 (Table 2).

# Discussion

## Carbon stock build-up with time

Long-term studies analysing SOC dynamics under natural conditions over a time period of thousands of years is usually not possible. The chronosequence in the Danube floodplain in Austria (Marchfeld) used in this study offers the rare opportunity to analyse SOC build up along the whole Holocene.

Soil formation is usually very slow and dependent on the formation factors such as climate, organisms, parent material, topography and time which completely define the soils system (Jenny, 1994)

The analysed soil samples in this study developed on the same parent material and show a similar mineralogy and topography. Soil mineralogy and clay minerals do not change remarkably along the chronosequence as weathering is limited due to high soil pH (>7) along the chronsoequence. This allows the assumption that the only difference between the samples is its soil age (time).

Soil formation factors are linked to SOC accumulation and stabilisation processes. Our results show, that the build-up of the A- horizon is similar to the OC increase (Figure 2, 3). Soils can achieve a steady- state condition where certain properties are in a sort of equilibrium. This occurs when inputs of matter (e.g. OC) to the systems are ongoing but losses via mineralization cannot increase OC in the soil over medium to long timescales (Schaetzl and Anderson, 2005). However, also climatic changes in the past 20.000 years occurred in the studied region, which have affected total SOC stocks and possible “equilibrium” stages of soil during the whole Holocene. Our results show that most soil formation processes and the potential to increase the OC stocks are finished after ~100 years due to the dynamics of organic material and the continental climate.

With increasing soil age, the AC horizon which is the transition zone between the A- horizon and the C- horizon can be found in deeper depths. Chernozems with A- horizons more than 60 cm depth were not found along the chronosequence in the Marchfeld. This could be explained by the reached steady state conditions of soil moisture, gas exchange, freezing depth and soil biota.

Due to methodological differences of soil age estimation a distinction between the average soil age and maximum sediment deposition age was done in this study. The age from young soils was analyzed with 137Cs and/or Feo/Fed ratio for each soil horizon. An average soil age for each profile was calculated. However, the oldest soils had to be dated with OSL, which is only possible in the subsoil, where there is no bioturbation and no fine soil is infiltrated from the topsoil. Therefore we only know the maximum sediment deposition age and not the average soil age. We can assume that the topsoil is younger but still reaches an average soil age of several thousands of years.

The study by Zehetner et al. (2009) already showed the same steep increase of OC stock increase within 50 to 100 years of soil formation and the following levelling of the OC stock.

This study expanded the study site along the chronosequence and showed that although there is only a very small increase of OC stocks, there is still a minimal OC accumulation. In the study area, chemical weathering processes of minerals do not occur which also means, that no further adsorption sites for OC are created. As grassland and forest C stocks are similar in the bulk soil, we summarize them as “semi-natural” systems.

The young soils behind the dike show very fast dynamics influenced by the Danube River and the continental climate. OC contents increase very fast but also decomposition processes from the initial carbon in the sediments were detected within the first years of soil development. However, also older sites show fast dynamics. A radiocarbon study by Stemmer et al., (2000) showed that more than 90% of added carbon is mineralized within 40 years under different management systems (crop rotation, spring wheat) in a long term field trial in the Marchfeld. This fast decomposition processes are also reflected by the analysed radiocarbon age in our study.

Sites with a soil age of ~350 years mainly consist of “modern” carbon indicating high biological activity causing a fast SOC turnover. The oldest forest sites show only a slight increase of radiocarbon age. As the 14C age only represents a mixture of the soil age it cannot be clearly resumed if and how much carbon is stored in the soil on the long term. However, our results suggest that the dynamics are very fast and long term carbon storage of OC is very limited in the topsoil (Table 1).

More research on stable pools and the use of advanced techniques along the chronosequence can give further information on the OC storage potential and the mechanisms behind long term carbon storage.

The subsoil shows a different system compared to the topsoil as the AC horizon is not affected by land management and receives its carbon mainly due to roots and earthworms. The older OC in the subsoil can be explained by the limited input of fresh organic material and by a stabilisation interaction with the minerals where the mineral surfaces have not yet been saturated by OM (Rumpel et al., 2002). The high 14C ages in the subsoil lead to the assumptions, that carbon is stabilised in the subsoil. However, increasing radiocarbon ages in the subsoil do not necessarily indicate enhanced subsurface stability but rather show that microorganisms in the subsoil preferentially use fresh, translocated SOC for catabolism, retaining a pool of old (but not stable) carbon in their biomass (Hobley et al., 2017).

## 4 per 1000 and soil organic carbon for food security

The perception of soil organic matter as tool for climate change mitigation and food security is growing. Theoretically, the worlds cropland soils could sequester 62 t C in the next 50 to 75 years (0.8- 1.2 t ha-1 a-1) (Lal, 2016a) by restoration of degraded/desertified soils und by using new technological options such as conservation tillage, use of manures, and compost as per integrated nutrient management and precision fanning strategies, conversion of monoculture to complex diverse cropping systems, meadow-based rotations and winter cover crops, and establishing perennial vegetation on contours and steep slopes (Lal, 2003).

A summary of worldwide SOC accumulation rates of agricultural land suggests slightly lower potential accumulation rate of 0.2- 0.5 t C ha-1 a-1 after the adoption of best management practices (Minasny et al., 2017).

A common point to discuss is that many soils show a C saturation where no more storage is possible. Our study shows that there is still an increase of OC stocks in ~500 years old soils. However, this increase is very low (0.01 t C ha-1 a-1 at soils with a maximum deposition age of 17.000 years). C accumulation under natural conditions is strongly decreasing due to fast turnover processes in the topsoil in our study region.

Based on the OC stocks (0-40 cm) of the semi-natural systems, an equation was derived of the yearly increase. This equation allows determining the exact year when OC accumulation rates are getting below 4 ‰ in the Marchfeld (Figure 6, Table 2). The calculated time span of 59 years of soil formation on fresh river sediments is of rather low importance as the aim of this study was to estimate OC accumulations in soils covering the whole Holocene. However, a change of the maximum estimated soil deposition age to 6000 years would increase the year to only 69 years where an OC accumulation of 4 ‰ per year is possible.

It can be discussed, that also old croplands have a potential to increase its OC content as they do have much lower OC contents compared to semi-natural systems. However, even a conversion to forests would not allow an annual accumulation of 4 ‰ C in most croplands for many years. We can assume that even “best management practices” will not cause an increase of 4‰ per year on the long term in the Marchfeld.

Although the goal set by the “4/1000” initiative cannot be fulfilled in the Marchfeld, management practices should be introduced to increase OC stocks in the Marchfeld. A study by Schiefer et al. 2016 showed that chernozems in the Marchfeld have excellent soil properties ensuring a high soil performance and resilience. The only indicator out of range at some spots was a too low OC content. Therefore, OC contents in the agricultural land of Marchfeld, have to be increased above 1.5- 2 % SOC, the necessary threshold level for soil health and food security (Lal, 2016b).

Restoration of degraded lands to forest or grasslands increases soil C although usually at a slower rates than the original conversion losses (Conant et al., 2001; Guo and Gifford, 2002). As our study shows, high OC accumulation under each management cannot be fulfilled over a longer time period. Therefore we suggest that the main goal for climate change mitigation, but also for a sustainable food production, should be an avoidance of agriculture expanding to natural systems and protecting especially soils which developed over thousands of years.

# Conclusions

This study showed that soil development and accompanied processes such as SOC build- up is a very fast process at the beginning of soil development. In the first years the A- horizon builds up to 4 mm soil per year. This increase is accompanied by a fast build-up of OC contents in semi-natural systems within the first ~ 100 years. The oldest soil with a maximum substrate deposition age of 17.000 years shows very slow processes. The build-up of the A-horizon slows down to less than 0.03 mm a-1 with an accumulation of 0.01 t OC ha-1 a-1.

Radiocarbon dating showed that 14C content is similar along the chronosequence in the topsoil and mostly dated as “modern” and “>modern”at the oldest forest site (max. 17.000 years) due to fast turnover processes. In the subsoil, OC is stored in the long term as indicated by the increasing 14C age.

In view of the “4/1000” initiative our results show that under natural conditions soils in the Marchfeld cannot accumulate more than 4 ‰ each year after 59 years of soil formation under semi-natural conditions (forest and grassland systems). Considering that most soils are older than 60 years, Chernozems in the Marchfeld cannot contribute in the medium and long-term to this ambitious initiative under current climate, land use and soil management practices.

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# Acknowledgements

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