SOIL ORGANIC CARBON DENSITY AND STORAGE IN PODZOLS – A CASE STUDY FROM RALSKO REGION (CZECH REPUBLIC)

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ABSTRACT

The aim of this paper is the characterization of Carbic Podzols in the Ralsko region (Czech Republic) and their role in the soil carbon balance. The emphasis was put on soil carbon density and storage in the subsurface mineral horizons. Soil organic carbon density calculated for the studied podzol in the Ralsko region was 49.97 t ha^{-1}. More than 53% of this carbon is located in the subsurface horizons, below the depth of 30 cm.

The soil organic carbon density was visualised for all soil horizons. The reasons for spatial variability in soil carbon densities were sketched. Carbon density, besides other things, depends on the soil horizon's thickness which is very variable in the case of Carbic Podzols. Therefore, the horizon thickness and its course were visualised as well.

Keywords: Carbic Podzol, soil carbon density, visualisation, carbon sequestration

1. Introduction

There is an attempt to quantify the carbon stock and fluxes in the nature, and soils were identified as an important carbon sink, both agricultural and forest. Podzol is a global spread soil. It can be found mainly in boreal and taiga zone as a typical zonal soil type. Other podzols can be found on mineral-poor substrates in tropics and mid-latitudes as well as on glacial sediments. Podzols have high soil carbon stock under the surface organic horizons. This stock has high variability in its spatial distribution; the variation coefficient can be up to 146% (Batjes 2002).

Organic horizons are homogenous in terms of carbon content (Dégórski 2007; Liski and Westman 1997). Then the quantification of the soil carbon density in organic horizons is quite simple. However, the carbon density is underestimated by exclusion of mineral horizons deeper than 30 cm which can be rich in carbon as well. It is the case of chernozems, fluvisols and podzols. In some cambisols the soil organic carbon in mineral subsoil can be up to 47%, in podzols up to 75% (Rumpel et al. 2002).

2. Podzols

Podzols can be divided into two groups – zonal and intrazonal. Zonal podzols are typical for boreal and taiga zone and for higher altitudes and are determined by climate. Intrazonal podzols are not limited by climate condition and are typical for mineral poor substrates. In the Czech Republic, zonal podzols can be found in high altitudes with high precipitation. On the contrary, intrazonal podzols mostly occur in lowlands with sandstones. In the World reference base for soil resources (IUSS Working Group WRB 2007) the zonality or azonality of podzols is not distinguished. In azonal podzols the organic matter is transported prior to sesquioxides in contrast to zonal podzols (Němeček et al. 1990). Then, these podzols are called humic podzols, similarly as a Humods in the US Soil Taxonomy (1999) and Carbic Podzols in FAO WRB (2007). Czech soil taxonomy (Němeček et al. 2011) use the term "podzol arenický", with typical stratigraphy O-Ah-Ep-Bhs-Bs-C. Pedogenetic process is called podzolization. Organic carbon, Fe an Al ions are translocated from upper (elluvial) part of soil profile downward. Here the illuvial horizon is formed. The translocation is mostly determined by excess of precipitation in cold climate, which lead to percolation of water throw the soil (Schaetzl and Anderson 2005). But, as we mentioned previously, podsolization can be initialized not only by climate. The impact of vegetation and its acidic litter or geological bedrock is also very important. The iluvial Bs horizon can be subdivided into two horizons: Bhs and Bs according to prevalence of the organic matter or sesquioxides. In Bhs and Bs horizons, the content of organic matter can be more than 5% (Němeček et al. 2011). The irregular boundary between E, Bhs and Bs horizons called 'tonguing', as can be seen in Figure 1, is typical for a podzol profile.

As podzols occur in forested areas in most cases three throws have considerable influence on their stratigraphy. When a tree is uprooted, a pit and a mound are formed. In the pit the podzol stratigraphy is more developed than in the undisturbed area and in the mound (Schaetzl and Anderson 2005; Schaetzl 1990; Veneman et al. 1984). Herein, in consequence of accumulation organic matter in pits (Borman et al. 1995; Šamonil et al. 2010) a lower cation exchange capacity, lower pH and soil reaction are detected (Veneman et al 1984). Higher differentiation

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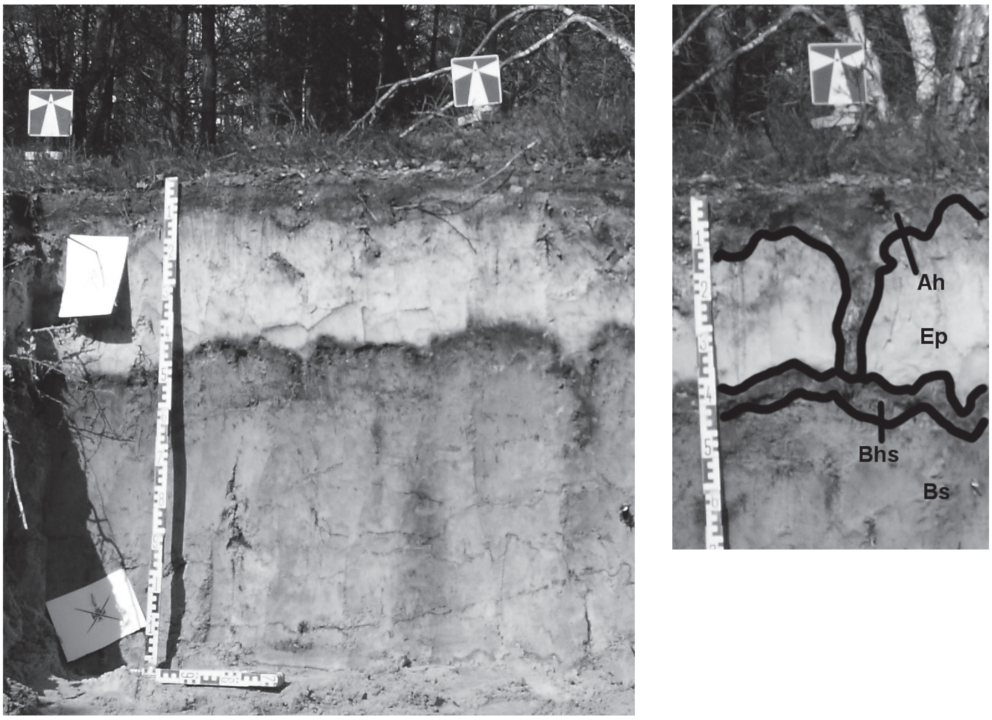

Fig. 1 Podzol stratigraphy, studied podzol profile with tonguing between Bhs and Bs horizons.

of the podzol stratigraphy is caused by concentration of runoff from precipitation and longer snow persistence in pits (Schaetzl 1990; Schaetzl and Anderson 2005). These facts lead to higher water percolation through the soil in pits and more intensive transport of organic matter from surface organic to subsurface mineral horizons. In other words, the process of podzolization is more intensive in pits.

2.1 Soil organic carbon and its density in soil

Soil organic matter in soil is a complex of organic remnants of microbial, vegetable or animal origin in various levels of decay (Nierop 1998; Schaetzl and Anderson 2005). Organic carbon represents 45–60% of soil organic matter (van Breemen and Buurman 2002). The soil organic matter composition is biased by input and decay of material from roots and by podzolization (Rumpel et al. 2002). Soil organic carbon is transported through the podzol profile in form of dissolved organic carbon which originates primarily in surface organic horizons (Rumpel et al. 2002).

According to Post et al. (1990) approximately two-thirds of the carbon reserves in forest ecosystems are preserved in form of soil organic matter. The spatial variability of these reserves is conditioned by bulk density, thickness of horizons, coarse fragments content and, of course, the amount of soil organic carbon. If talking about the vertical distribution of carbon reserves in the soil, the largest stock is in surface organic horizons. Soil organic carbon in these horizons is usually younger and more homogenous than in deeper horizons (Liski et al. 1997 in Degórski 2007) but because of the nature of podsolization process it is not a rule (van Breemen and Buurman 2002). The situation in mineral horizons of podzols is similar: the soil organic matter content is decreasing with depth with exception of the Bhs horizon. This horizon is enriched with carbon compared to adjacent horizons (Degórski 2007). The variability in the soil organic matter in podzol is considerable thanks to high spatial variability of horizons transition (e.g. tonguing).

Soil carbon stock is usually higher in regions with humid climate. Degórski (2007) analysed podzols of North and East Europe and found higher values of carbon stocks in northern and eastern parts of the area. Similarly, this was observed for podzols in Scandinavia (Liski and Westman 1995) and northern part of the USA (Michaelson et al. 1996).

2.2 Soil carbon quantification in the Czech Republic

Soil carbon quantification is quite common in the world, for example Batjes (1996, 2002) or Schwartz and Namri (2002). There were a few attempts to quantify the carbon stock in the Czech Republic. While the carbon stock in plant biomass is in interest of many studies (e.g. Forest condition monitoring, National forest inventorying project), the soil carbon quantification is quite overlooked. An exception is the CzechCarbo project which was aimed at the “investigation of the ability of the Czech landscape to absorb the carbon dioxide from atmosphere, accumulate this carbon and slow down the global warming process” (ÚSBE 2003–2007). Under the project, besides other aspects, the soil carbon in agriculture and forest soil was quantified.

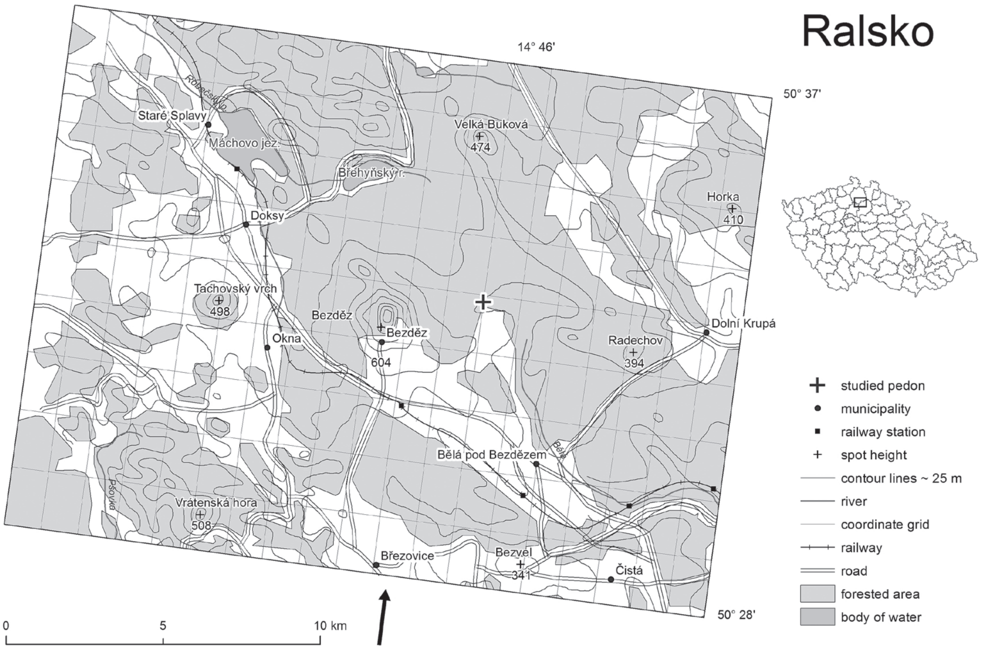

Fig. 2 Location of the studied podzol pedon.

The quantification of soil carbon in forest soil under the CzechCarbo project was carried out for the upper 30 cm, which is considered by Marek et al. (2011) to be crucial for the soil carbon balance. But the only output of this study is the map with charts of the soil carbon stock. The map does not represent the real soil carbon stock, due to exclusion mineral subsoil deeper than 30 cm. However, a considerable amount of carbon can be accumulated deeper than 30 cm: in case of podzols up to 66% according to Batjes (2002) or up to 75% according to Rumpel et al. (2002). Therefore, the aim of this paper is to make an attempt to quantify the soil organic carbon density in whole soil profile of podzol, not only for the upper 30 cm.

3. Methods and study area

Study area is located in the former army area in Ralsko region (Figure 2). Ralsko region is known as locality with well-developed Carbic Podzols. Studied pedon was chosen as representative of Carbic Podzol both in Ralsko and Czechia. Pedon was not obviously disturbed. Tonguing is frequent in locality.

The underlying bedrock is thick-bedded sandstone approximately 85–95 million years old (Chlupáč et al. 2011). The vegetation is represented by *Pinus sylvestris, Betula pendula, Vaccinium idaea, Vaccinium myrthillus L.* and *Calluna vulgaris*.

Soil samples for carbon and bulk density estimation were taken from centres of all horizons. More samples (7) were taken from Bhs horizon because of presence of the ortstein in this horizon. Soil organic carbon was estimated by modified Tjurin method.

Calculation of soil organic carbon density was taken according to Cienciala et al. (2006) for each horizon:

$$SOC = Cox \times BD \times T \times CF \times 10 \tag{1.1}$$

Where *SOC* is the final soil carbon density (kg m^{-2}) in horizon, *Cox* is the soil carbon content (%), *BD* is the bulk density (g cm^{-3}), T is the thickness of the horizon (m) and *CF* is the coefficient for estimation of coarse fragments (absent coarse fragments, *CF* = 1). Similarly, see Batjes (1996) and Schwartz and Namri (2002).

Dataset of soil carbon densities for each horizon was put into a grid by kriging by Surfer SW and then visualised. The course of the carbon in the soil profile (~ photography) was depicted as a diagram of soil carbon density in individual horizons and as a sum of all carbon densities in the soil profile. Also, the spatial variability of all horizons was visualised.

3.1 Visualization of the soil spatial variability

As is evident from Fig. 1, the course of the podzol horizons and their boundaries is very irregular and variable in space. This fact makes the carbon stock quantification more difficult because the horizon thickness is one of the criteria for carbon density calculation. For better understanding of the soil spatial variability, the visualisation of the podzol profile has to be done.

For the purpose of discovering the podzol spatial variability a set of photographs was taken. The soil profile was cleaned and then photographed. Then the soil profile was dug 10 cm away, cleaned and photographed again. This was repeated several times and the final set is comprised of seven photographs which cover around 230 × 60 cm area. The scheme can be seen in Fig. 3. Photographs were processed in Topol application, grid creation and 3D visualisation of studied profile was done in Surfer SW.

In order to determine the horizon thickness as accurately as possible we have to capture a spatial variability of

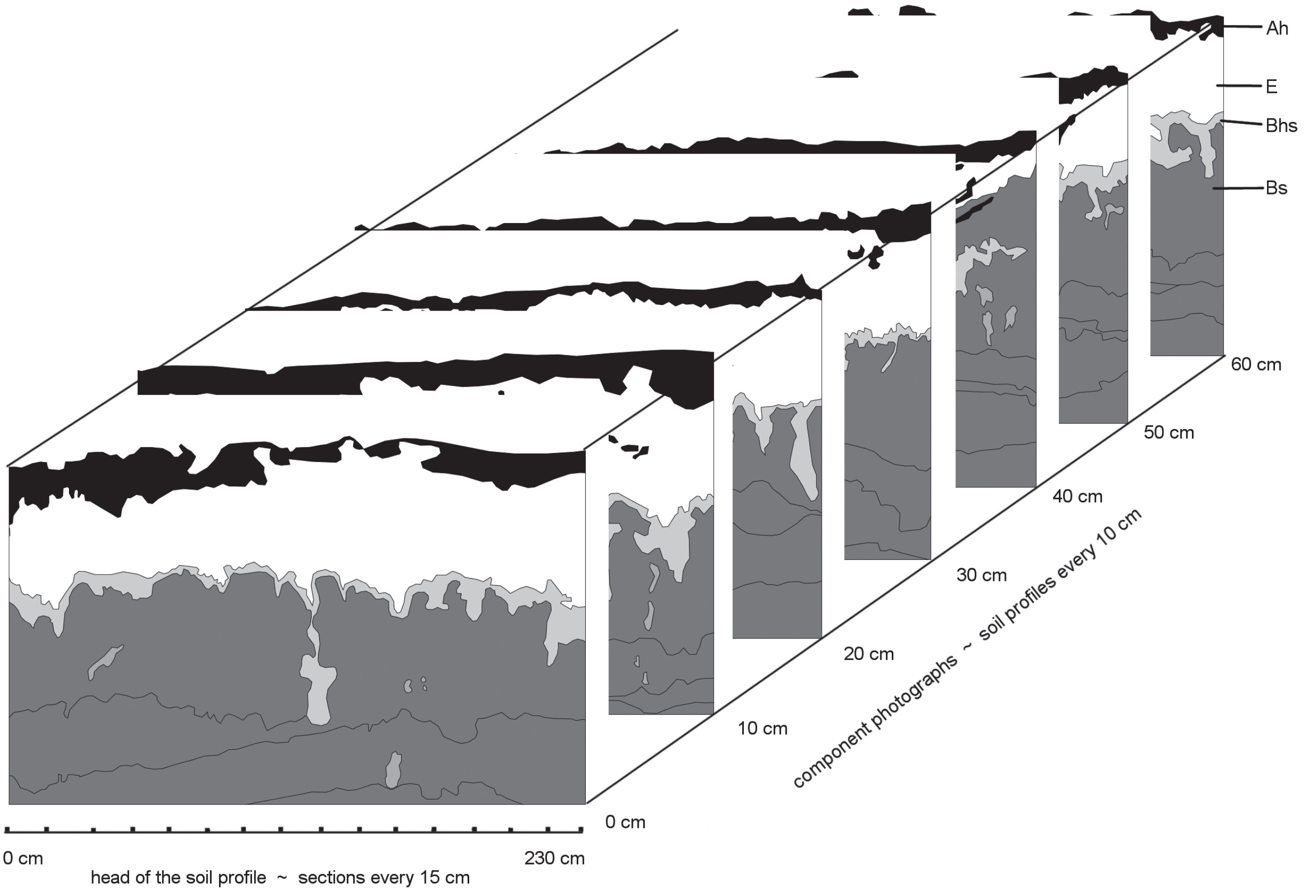

Fig. 3 The scheme of the mesh of 'boreholes' and photographs.

horizon transitions. For these purposes a mesh of fictive boreholes ~ sections was made. It comprises one borehole every 15 centimetres on each photograph (as can be seen in Figure 3). In nodal points the thickness of horizons was assessed and carbon density was calculated.

4. Results

Selected attributes of the analysed podzol pedon are summarized in Table 1.

Tab. 1 Selected characteristics of podzol horizons in Ralsko (*average value from seven samples for Bhs and two samples for Bs).

Horizon	Horizon thickness (m, average)	Horizon thickness (m, Median)	Bulk density [g.cm^{-3}]
Ah	0.109	0.096	1.053
E	0.301	0.308	1.353
Bhs	0.078	0.056	1.306*
Bs	0.712	0.728	1.438*

Figures 4–7 visualize the podzol horizon transitions. The most variable is Bhs/Bs transition (Figure 7). According our field observations, this deep tonguing is caused by tree roots. A lot of organic matter is accumulated around the roots and transported along them.

The second factor affecting the spatial variability of horizon transitions are pedoturbations, especially tree uprooting. This factor is mostly evident in Ah/E transition (Figure 5).

The E/Bhs transition (Figure 6) is less variable than expected. The copying of Bhs/Bs transition is not expressed in E/Bhs boundary.

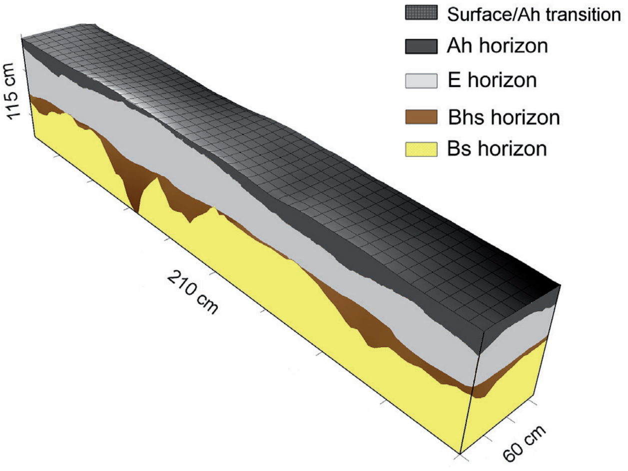

Fig. 4 Visualisation of the whole studied podzol pedon with all horizons. O (litter) horizon was discontinuous at the locality, hence it is included in Ah horizon.

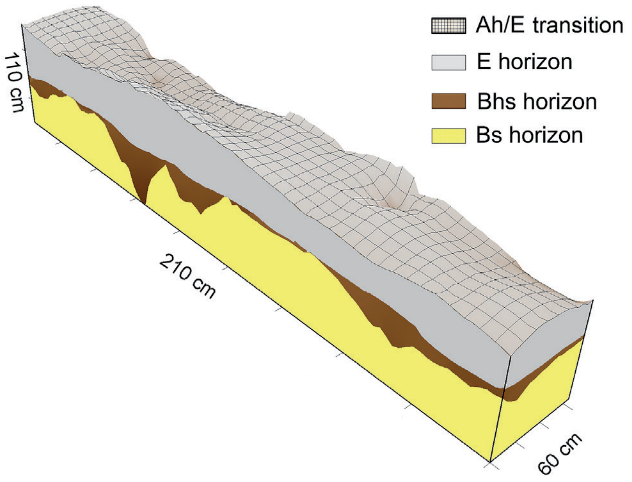

Fig. 5 Visualisation of the boundary between Ah and E horizons.

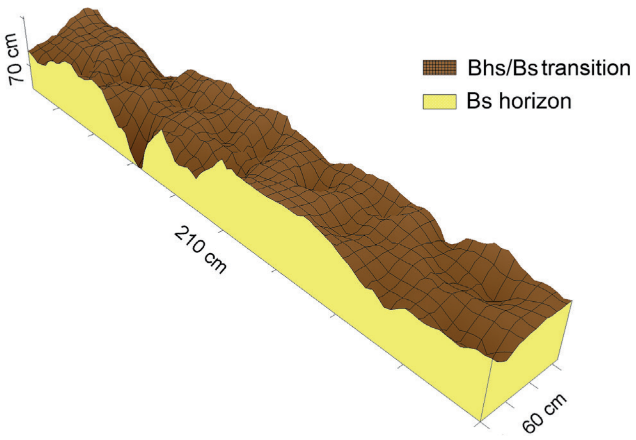

Fig. 7 Visualisation of the irregular boundary between Bhs and Bs horizons.

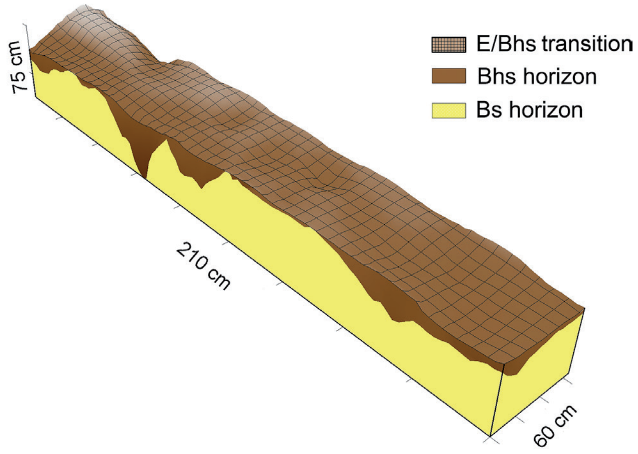

Fig. 6 Visualisation of the boundary between E and Bhs horizons.

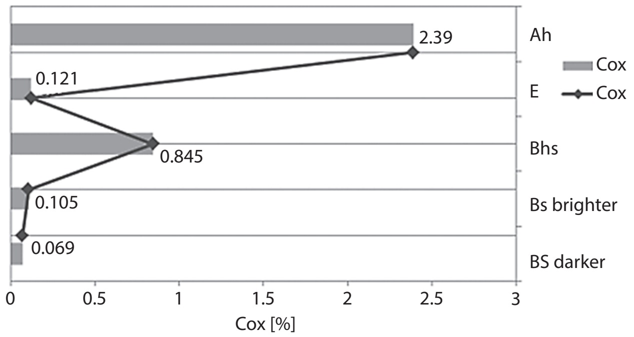

Fig. 8 The organic carbon content (Cox [%]) in the podzol horizons. For Bhs the average value from two samples is used (0.845%).

4.1 Soil organic carbon content

The course of soil carbon content is typical for podzol soils (Figure 8). The differentiation of Bs horizon according to organic matter content to Bs1 (darker, upper, more Cox) and Bs2 (brighter, lower, less Cox) is apparent. As a matter of interest, the carbon content in dark "veins" was estimated, as they were common in Ralsko (0.12% Cox).

4.2 The soil carbon density and its visualization

The soil carbon density characteristics in analysed podzol profile are summarized in Table 2. The total carbon density in whole soil profile is 4.997 kg m^{-2}. The most variable is the carbon density in Bhs horizon (0.088 to 4.238 kg m^{-2}). Soil organic carbon density calculated for whole podzol pedon in Ralsko ranges from 3.452 to 5.842 kg m^{-2}, with mean value 4.997 kg m^{-2}.

The course of the carbon densities in horizons is depicted in Figure 9. The carbon density depends on horizon thickness. First of all, carbon stock in the whole soil profile is determined mainly by carbon density in Ah horizon. But, where the tonguing is appearing (higher thickness of Bhs horizon), the total carbon density is considerably affected.

The soil carbon densities in studied podzol pedon were visualized. The carbon densities were calculated in nodal points for each horizon and then interpolated and

Tab. 2 Soil carbon density characteristics.

Kg m^{-2}	Mean	Mode	Minimum	Maximum	Skewness	Standard deviation	Variance
Ah	2.753	2.416	0.503	7.448	0.965	1.539	0.003742
E	0.494	0.565	0.072	0.835	−0.611	0.148	0.008157
Bhs	0.857	0.442	0.088	4.239	2.092	0.730	0.004378
Bs	0.894	0.903	0.417	1.089	−1.592	0.114	0.008215

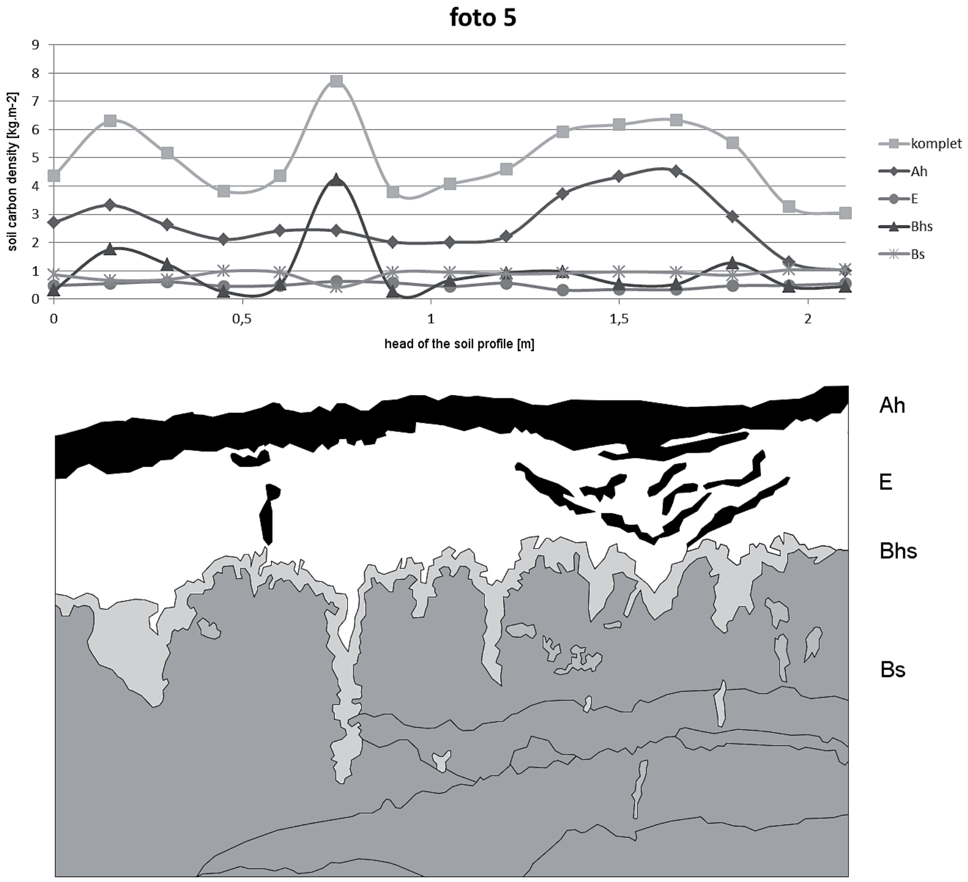

Fig. 9 The course of the soil carbon densities in each horizon and in the whole profile ('komplet'). Carbon stock in the whole soil profile is determined mainly by organic carbon from Ah. But, where the tonguing is appearing (thickness of Bhs horizon is higher), total carbon density is considerably affected.

visualised (Figure 10 and 11). The total carbon density was calculated and visualised as well (Figure 12).

For comparison with the work of Marek et al. (2011) the quantification of carbon densities below and above the level of 30 cm was done (Table 3). It is clear that the omission of subsoil below the 30 cm border can lead to inaccurate information about the soil carbon density.

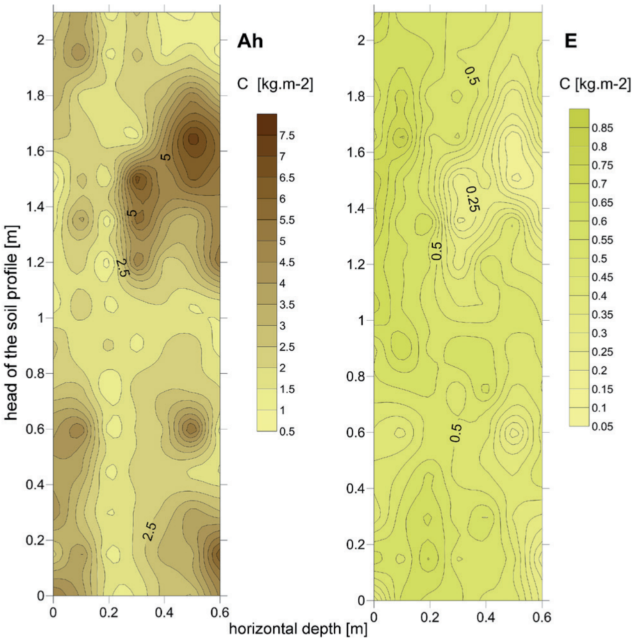

Fig. 10 Soil carbon densities in studied pedon in Ah and E horizons.

Tab. 3 The soil carbon stock below and above 30 cm.

Soil depth	Carbon density t ha⁻¹
Above 30 cm (Ah + E)	32.47
Below 30 cm	17.51
Loss by exclusion of subsoil	53%

5. Discussion

The soil organic carbon content in the podzol is decreasing with the depth, with the exception of Bhs horizon. The same trend was detected for example in works of Degórski (2007) and Mokma et al. (2004).

The soil carbon densities in entirestudied profile range from 3.452 to 5.842 kg m^{-2}. According to Degórski (2007), the carbon densities in the whole podzol profile range, on average, from 11.6 to 19.9 kg m^{-2}. The average carbon density of podzol in Sweden is 8.2 kg m^{-2} according to Ollson et al. (2009), who quantified the carbon density for the upper 50 cm of the soil. This is in accordance with the work of Fröberg et al. (2006), who analysed soil carbon densities in Swedish podzols as well. The carbon densities detected by Fröberg et al. (2006) were from 5 kg m^{-2} in well-drained podzols to 10.2 kg m^{-2} in poor-drained podzols. Batjes (2002), who quantified the carbon density in Central and Eastern European soils in the upper meter, gives 29.6 kg m^{-2} for podzols and 49.8 kg m^{-2} for carbic podzols, respectively.

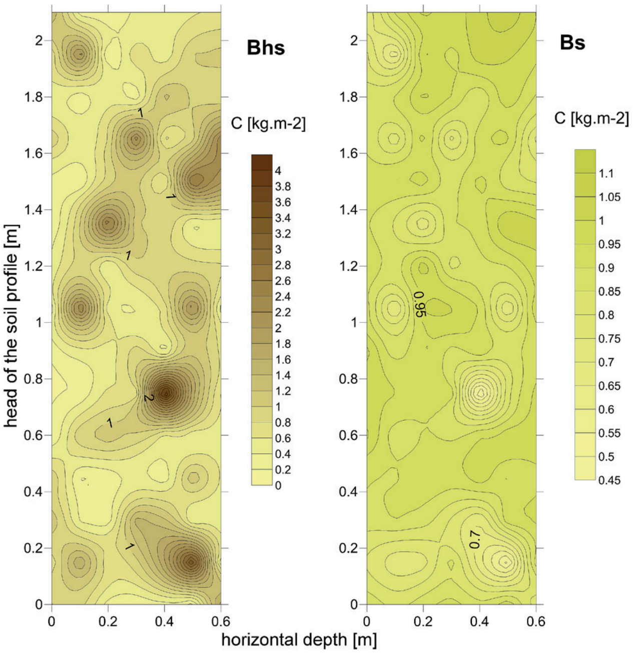

Fig. 11 Soil carbon densities in studied pedon in Bhs and Bs horizons.

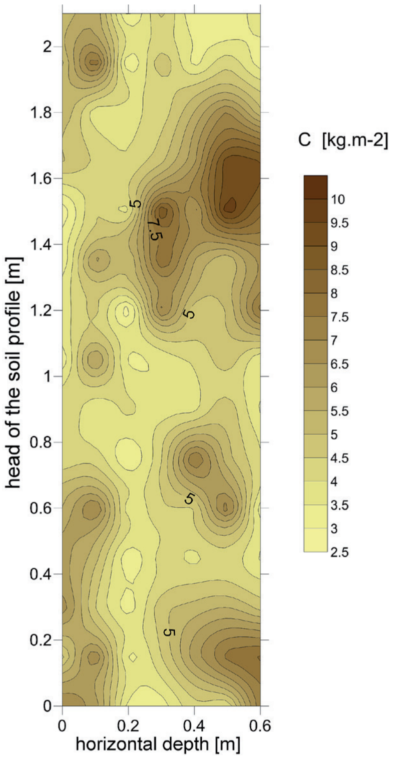

Fig. 12 Soil carbon densities in whole studied pedon.

However, there is no research in the Czech Republic focused on soil carbon quantification according to single soil type or group. Cienciala et al. (2006) found out the carbon density 7.22 kg m^{-2} in mineral soil, but various soils were classified together in one group (cambisols, podzosols, luvisols and gleysols). The result from National forest inventorying project would be convenient, but the data will not be published until the end of the project in 2014. The comparison with the Forest monitoring project data (2004) does not come into consideration either, because no surveys of this project took place on Carbic Podzols.

The comparison can only be made with the map of soil carbon density from Macků et al. (2007 in Marek et al. 2011). This map shows that the carbon density for podzols in Ralsko is about 5.1–6.0 kg m^{-2}. Another result in the work of Marek et al. (2011) quotes a value of carbon density in forest soils to 6.21 kg m^{-2} on average. But these values represent the carbon density only in the upper 30 cm of the soil. In comparison with these findings, the carbon density in the studied podzol is lower although the density is calculated for the whole profile. This can be caused by low or almost no thickness of O horizon in studied area. It is necessary to keep in mind that the results in the work of Marek et al. (2011) were taken in forest soils where the O horizon is usually rather thick.

6. Conclusion

The aim of this study was to accurately determine the soil carbon density in a podzol. For these purposes the profile of Carbic Podzol in Ralsko region was chosen. The horizon transitions were visualised, for better understanding of the specific podzol spatial variability. The carbon densities were estimated and visualised. The total carbon density in whole soil profile is 4.997 kg m^{-2}. The exclusion of the mineral or organic horizons below the 30 cm leads to shrinkage of the total carbon density up to 53%. The average carbon density is highest in Ah horizon, but a large amount can be found in Bhs horizons. It is a reason why mineral horizons cannot be excluded from carbon density estimation.

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RESUMÉ

Zásoby uhlíku v nížinných podzolech – případová studie z Ralska

Tato práce se zabývá nížinnými podzoly v Česku, s důrazem na sekvestraci uhlíku v jejich podpovrchových horizontech a jejich roli v uhlíkové bilanci půd. Pro tyto účely byla v ČR vybrána lokalita s arenickými podzoly, nacházející se v bývalém vojenském výcvikovém prostoru Ralsko. V této lokalitě byla spočítána zásoba uhlíku ve všech horizontech a byly analyzovány vybrané vlastnosti půdy ovlivňující tuto zásobu. Průměrná zásoba půdního organického uhlíku ve studovaném pedonu v Ralsku je 49,97 t ha^{-1}. Značná část této zásoby se přitom nachází v podpovrchových horizontech pod hranicí 30 cm (53 %).

Profil z Ralska byl dále zpracováván – proběhla vizualizace zásob uhlíku v jednotlivých horizontech a její průběh. Protože zásoba uhlíku v daném horizontu je závislá na jeho mocnosti, která je u nížinných podzolů značně proměnlivá, byla provedena trojrozměrná vizualizace průběhu horizontů v rámci půdního profilu z Ralska. Byly také nastíněny možné příčiny této variability.

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