Forest topsoil organic carbon content in Southwest Bohemia region

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ABSTRACT: The aim of this study was to evaluate organic carbon content (SOC) in the surface layers of forest soils in the two Natural Forest Regions situated in Southwest Bohemia, namely Západočeská pahorkatina (NFR 6) and Český les (NFR 11). The study is based upon on two consecutive soil sampling campaigns during autumn 2003 and 2004. While the sampling of 2003 was inadequate to estimate bulk density, the consecutive campaign used a defined sample volume to permit an estimation of bulk density and quantification of soil organic carbon (SOC) for soil organic layers and the upper mineral horizon. The total sampling depth was 30 cm including both organic and mineral layer. SOC of organic horizon was on average 1.99 kg C/m^2. It differed by stand site type ranging from 0.70 to 3.04 kg C/m^2. The organic layer SOC was smallest under beech (1.03 kg C/m^2), whereas it was higher under pine (2.19 kg C/m^2*)* and spruce (2.09 kg C/m^2). SOC in the mineral layer was in average 7.28 kg C/m^2. SOC differed significantly by the major tree species and reached 10.6; 5.67 and 7.5 kg C/m^2 for beech, pine and spruce sites, respectively. The average SOC for the total soil layer (0–30 cm) reached 9.33 kg C/m^2. The methodological aspects of regional estimation of SOC and the potential of utilization of the national forest inventory program are also discussed.

Keywords: soil organic layer; mineral horizon; bulk density; soil carbon stock

Soil carbon content and its changes represent some of the basic indicators of terrestrial ecosystem status. It has since long been recognized that soils play one of the key roles in the global carbon balance (Schimel et al. 1994; Liski et al. 1999; Gardina, Ryan 2000; Post, Kwon 2000). Therefore, the estimation of soil carbon stock changes are an integral part of the emission inventory of the LULUCF (Land Use, Land Use Change and Forestry) sector as a part of the obligation to transparently report green-house gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). The importance of soil component increases in connection to the Kyoto Protocol, which commits their parties to reduce their emissions of greenhouse gases. That also concerns soils and the LULUCF sector, as the parties have to report activities such as afforestation, reforestation and deforestation and optionally estimate, among others, the effect of forest management on carbon stock changes and associated greenhouse-gas emissions. Forest soil may represent both source and sink of carbon and carbon fluxes exhibit specific daily, seasonal and inter-annual pattern. However, it is mainly the long-term carbon stock changes on regional scale that are of importance. They require a representative and transparent sampling approaches to estimate soil carbon pools. Based on such scheme, a repeated sampling performed in sufficiently long time may provide the critical information on long-term soil carbon stock changes. In the recent study from United Kingdom, a country-wide repeated soil sampling indicated emissions from soils that might actually offset the forestry sink on the national scale during the recent decades (Bellamy et al. 2005).

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Regional soil carbon stock estimation is generally challenging due to a large natural variability of soil carbon content, high spatial and temporal heterogeneity of soil processes, and long-term effect of the previous land use and ecosystem management, to name at least some of the important items. To aid and harmonize the estimation of ecosystem carbon pools, the Intergovernmental Panel on Climate Change (IPCC) has continuously been working on improving the corresponding applicable methodologies. The most recently adopted material of Good Practice Guidance for LULUCF (IPCC 2003) stressed the need of considering the specific conditions in individual countries, effectively utilizing the available inventory programs and other country-specific studies supporting transparent and practicable estimation of ecosystem carbon storage and its changes.

Organic soil carbon is a part of soil organic matter (SOM). The amount of SOM varies depending on soil type, soil depth and soil horizons. Most carbon is held in organic soils (peat), which are not included in this study. As for the mineral soils, most commonly, SOM decreases exponentially with soil depth, but concentration there is actually more in weight per unit area than in O horizons for many soils. The relative amount of carbon is determined as oxidable carbon (C_{ox}) in the laboratory, which represents one of the basic analytical procedures related to soils. To provide absolute quantity of carbon, soil bulk density (BD) is needed. If BD is not available, some of the approximate approaches and published reference values may be used.

The aim of this study is evaluation of organic carbon content in the surface layers of forest soils in the so-called Natural Forest Regions (NFR) situated in SW Bohemia. The evaluation is based on two consecutive soil samplings during 2003 and 2004. Apart from the quantified carbon storage in litter, humus layers and the upper mineral horizon for the pilot region, the study also discusses methodical problems and provides recommendations to soil carbon inventory that may be included in the scheme of the Czech National Forest Inventory program.

MATERIALS AND METHODS

Soil sampling

Soil sampling strategy was based on the information on the distribution of forest site types, which was derived from typological maps and information from the Regional forest development plans (www.uhul.cz). Forest site type maps for the Natural forest regions (NFR) 6 and 11 differentiated the major (non-extreme) ecological categories (detail description can be found in the Czech Forest Act (No. 289/1995 Col.). For each of these ecological categories, the representative forest site types of the major tree species were selected. The major tree species considered included pine (*Pinus sylvestris* L.), beech (*Fagus sylvatica*) and spruce (*Picea abies* [L.] Karst.). Totally, the soil inventory included 240 sample plots. The stratification of the plots is shown in Table 1.

Two consecutive soil sampling campaigns were conducted in two National Forest Regions (NFR), namely Západočeská pahorkatina (NFR 6) and Český les (NFR 11) situated in SW Bohemia (Fig. 1). In 2003, soil samples were taken from 240 sites, whereas in 2004, 120 sites were revisited. The sampling scheme reflected the spatial representation of the major forest management types in the region, which was assessed from the database of Forest Management Plans (FMP) (www.uhul.cz). Additional criterion for the selection of sites to be sampled was the representation of the main ecological categories.

The sampling methodology differed between 2003 and 2004. In the fall of 2003, soil samples were taken from four points within a circle with radius of 6 m. The samples of humus layer (each sample including L – litter, F – fermentation layer, H – humic layer) and mineral horizon (only A layer) were taken, noting the depth of organic layer and the sampling depth. The samples of individual layers were mixed *in situ* and taken as a mixed sample at each location. There was no defined volume of the samples that could be used to estimate bulk density. Altogether, 480 samples from 240 sites were taken in this campaign.

In the fall of 2004, the consecutive campaign was performed taking soil samples of organic layer (sepa-

Table 1. The stratification of sample plots for soil sampling according to the natural forest regions (NFR), forest vegetation zones (FVZ), edaphic category (of the Czech typological system; for details see Add. 2 of the Czech Forest Act) and major tree species

Region	FVZ	Edaphic categories	Spruce	Pine	Oak	Beech	Sum
NFR 6	0, 2, 3, 4, 5	A, B, H, I, K, M, N, O, P, Q, S	66	59	15	11	151
NFR 11	4, 5, 6, 7	B, G, K, O, S	62	5	0	22	89
Total			128	64	15	33	240

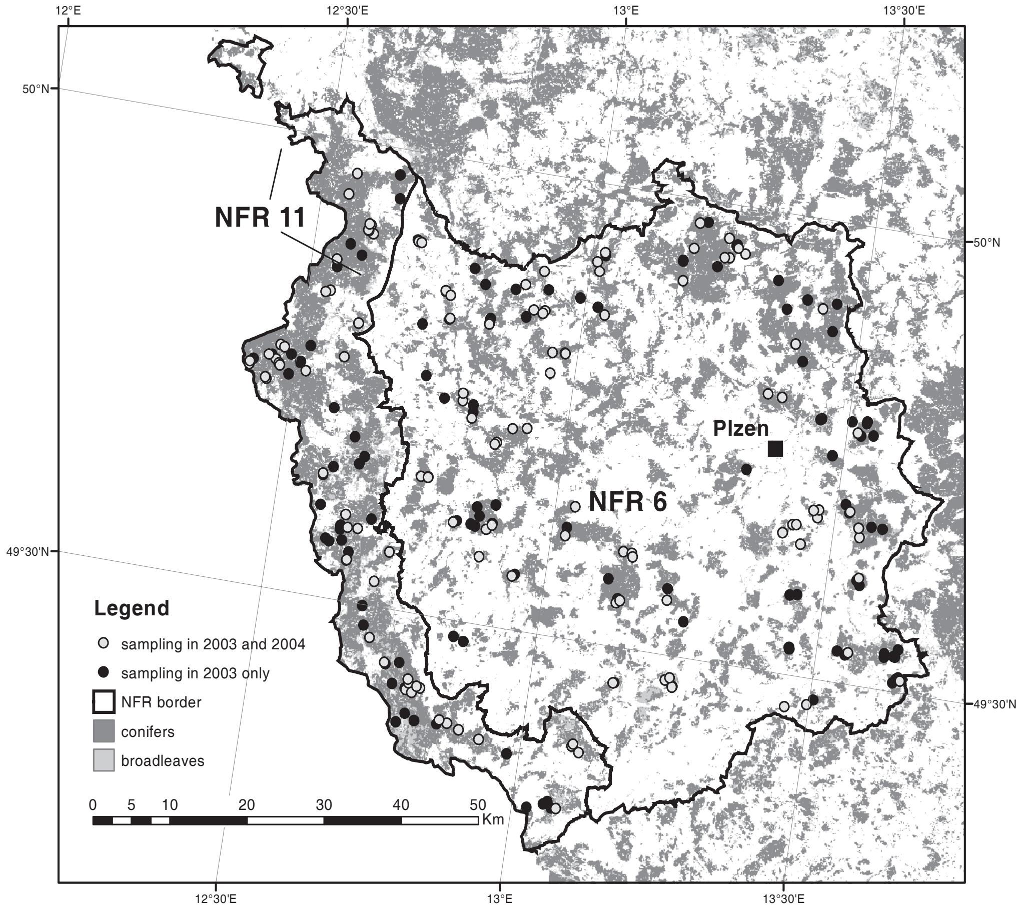

Fig. 1. The map showing the SW Bohemia and the location of the Natural Forest Regions 6 and 11. The sampling points are shown by symbols separating 2003 and 2004 campaigns, overlaid on shaded areas showing mostly coniferous or broadleaved forests

rately as L and F+H layers) and mineral layer until the depth of 30 cm from overall 120 locations. On these, 115 locations could be safely linked to the sampling sites of the previous campaign and the same locations, while the 5 remaining sites were excluded from the analysis. During the 2004 campaign, the depth was recorded for the individual horizons and samples were taken with a defined volume to permit subsequent laboratory determination of bulk density (BD). The organic horizons (L, FH) were sampled from a frame 25 × 25 cm. The mineral horizon was sampled taking cores by soil tubes with a volume of 100 cm^3 (with diameter 3.57 cm). Altogether 360 samples from 120 were taken in this campaign. To permit analysis with respect to stand and forest site type, the soil sample sites were categorized by the major tree species and forest site type associations, which could be performed for 115 locations (Table 2). These units are called as stand site types in this study. These associations are based on the Czech typological classification, reflecting site conditions, basic soil properties, altitude and major tree species (Průša 2001). The stand site types used in this study are herewith abbreviated by the dominant species

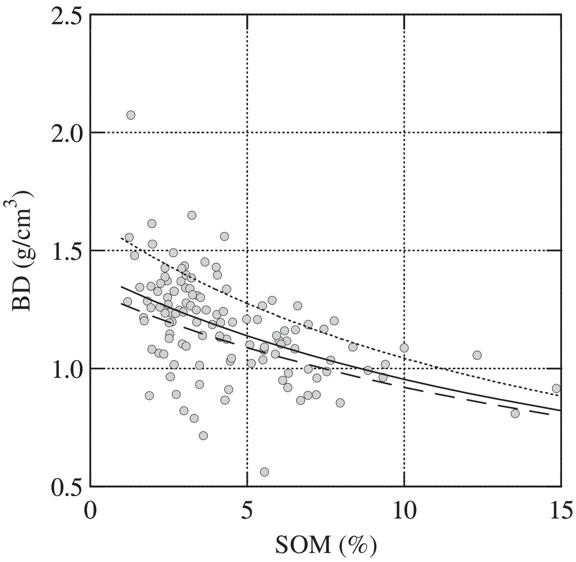

Fig. 2. Approximation of Adams (1973; Eq. 3) for the estimation of bulk density (BD) in relation to known values of soil organic matter, which are represented by the measurements (symbols) of the 2004. The fitted equation (solid line) corresponds to the MBD constant (Eq. 3) of 1.41. The other values found in literature indicate underestimation (MBD 1.33 – Rawls, Brakensiek 1985, dashed line) or overestimation (MBD 1.64 – Mann 1986, dotted line)

(beech = BE, pine = PI, spruce = SP) and the additional classifiers as used in Průša (2001), denoting vegetation zone and major soil edaphic category.

Soil analysis

The soil samples were analyzed in the laboratory (Forest Management Institute, Brandýs nad Labem). The samples were assigned to appropriate humus forms according to depth and humus, layer types. The pretreatment of the soil samples excluded roots and stones by soil sieving to 2 mm. Organic carbon (C_{ox}; %) was determined by oxidation of organic compounds by potassium dichromate in sulphuric acid environment (Štíhel 2001).

Since the sampling depth of 2003 was taken only in a shallow layer below the organic horizon, the estimated C_{ox} must be adjusted so as to correspond to the standard soil sampling procedure as performed in 2004, i.e. to the total sampling depth of 30 cm. This was performed so that the samples were grouped according to stand site type (Table 2). Secondly, the estimated C_{ox} in the laboratory for the soil samples from 2003 and 2004 was plotted against their corresponding sampling depth. For each stand site type category, the exponential function was fitted relating C_{ox} to sampling depth (H_s) as

$$C_{ox}(H_s) = a \times EXP(b \times H_s) \qquad (1)$$

where: *a, b* – parameters to be fitted on the level of individual stand site types.

According to the parameterized equations (see results), C_{ox} for the samples from 2003 could be corrected so as to correspond to the sampling depth of 30 cm, i.e., identical as for the sampling in 2004.

The dependence of the organic matter (*SOM*) on the soil organic concentration (C_{ox}) was expressed as

$$SOM = C_{ox} \times 1.724 \qquad (2)$$

where: *SOM* – soil organic matter (%),
C_{ox} – soil organic concentration (%),
1.724 – empirical coefficient assuming humus share of 58% of organic carbon (Weiner 2000; Stevenson, Cole 1999; Lyman et al. 1982).

Bulk density

Soil sample bulk density (*BD*) is given as soil dry weight per defined soil sample volume at fresh (*in situ*) conditions. *BD* could be directly estimated for the sampling from 2004 that applied a defined volume for each sample. Hence, the *BD* for the samples of 2003 must be approximated by some other means.

As for the organic layer, *BD* from 2004 was aggregated as medians on the level of stand site types and used for quantification of absolute carbon content for the samples from 2003.

For the mineral layer, soil samples from 2003 that lacked the usable information on sample volume, an approximation by the equation of Adams (1973) was used:

$$BD = \frac{100}{\dfrac{SOM}{0.244} + \dfrac{100 - SOM}{MBD}} \qquad (3)$$

where: *SOM* – soil organic matter (%),
MBD – the reference mineral bulk density.

Table 2. The categorization of soil sample locations according to the Czech forest site type classification with number of plots, major soil type and dominant tree species noted (see Methods)

Stand site type	*N* (plots)	Soil type	Species
PI_0K	9	Cambisol modalic	pine
PI_0M	12	Podzosol modalic	pine
PI_2K	7	Cambisol modalic	pine
SP_3HI	13	Cambisol luvisolic	spruce
PI_3K	10	Cambisol modalic	pine
SP_3S	9	Cambisol modalic	spruce
BE_4B	7	Cambisol modalic, skeleton	beech
SP_4S	7	Cambisol modalic, skeleton	spruce
SP_5BS	10	Cambisol modalic	spruce
BE_5BS	4	Cambisol modalic, skeleton	beech
SP_5K	9	Cambisol modalic, podzolic	spruce
BE_6K	4	Cambisol podzolic	beech
SP_6K	14	Cambisol podzolic, modalic	spruce

MBD for the mineral A forest soil layer is often set to 1.64 g/cm^3 (Mann 1986; Paul et al. 2002) or 1.33 (Rawls, Brakensiek 1985). The final value of *MBD* applicable for *BD* approximation for the samples from 2003 was determined from a non-linear least square analysis of Eq. 4 (Fig. 2). It used the identical sites sampled in both 2003 and 2004 (n = 115) to estimate *MBD* on the measured *BD* values from 2004. The estimated coefficient *MBD* was 1.41 g/cm^3 (SE 0.025, r^2 = 0.26, 95% confidence interval from 1.36 to 1.46 g/cm^3). The fitted Eq. 4 was located in between the equation forms using the cited reference *MBD* values as above (Fig. 2). Finally, the values of *BD* for the samples in 2003 were calculated by Eq. (4) using the fitted *MBD* and *SOM* based on the measured C_{ox} values corrected using the Eq. (2) and the procedure described above.

Soil organic carbon (SOC)

The absolute amount of organic carbon per surface area (i.e., in kg C/m²) was calculated as

$$SOC = C_{ox} \times BD \times T \times CF \times 10 \quad (4)$$

where: C_{ox} – the organic carbon concentration,
BD – bulk density (g/cm^3),
T – the thickness of the soil sample (m),
CF – a coefficient to discount coarse fragments (applicable for stony soil samples; not the case of the samples in this study, hence CF = 1) and factor 10 corrects the expression (4) to yield the desired unit of kg C/m^2.

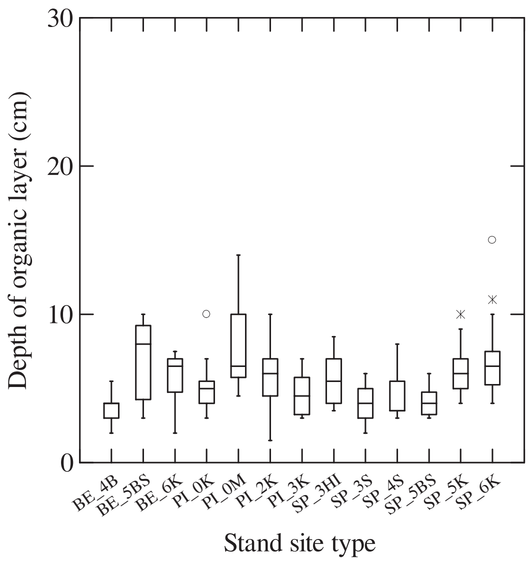

Fig. 3. The depth of organic layer including all humus horizons (L, F, H) stratified by stand site type; the measurement campaign of 2003 and 2004 are included and merged. The box plot shows the range of the central 50% of the values (given by the length of each box), asterix and circle symbol indicate outliers and far outside values, respectively (see SYSTAT 2004)

RESULTS

THICKNESS OF SOIL HORIZONS

Organic layers

The average thickness of organic (humus) layer estimated from the sampling campaigns in 2003 and 2004 was in both cases 5.48 cm with the standard deviation (SD) 2.90 (n = 240) and 1.85 cm (n = 120), respectively. The basically no difference between the averages indicates a consistent sampling of the humus layer in the both campaigns. When comparing the identical sites by the paired t-test, it confirmed the insignificant differences between the humus thickness estimated from the two consecutive campaigns (mean difference 0.08 cm, p = 0.614). The thickness of the individual layers L and FH separately sampled in 2004 was estimated to be 1.7 and 3.8 cm, i.e., their proportion is roughly about one to two.

Classified by the major tree species at the site, the thickness of organic layer for beech, pine and spruce locations reached 4.9, 5.8 and 5.7 cm, respectively. Although the thickness of organic layer was generally smaller under beech as compared to both conifers, these differences were statistically insignificant (ANOVA, p = 0.98). Finally, classified by stand site types, the only significantly larger thickness of humus layer (about 7.5 cm) was observed for the poor pine sites (stand site type PI_0M) as compared to other stand site types (Fig. 3).

Bulk density

The average bulk density (BD) for organic layer estimated from the sampling in 2004 reached 0.113 g/cm^3. The average values per stand site type ranged from 0.076 (BE_5BS) to 0.136 (SP_4S; Fig. 4). The differences of BD for individual stand site types were statistically insignificant, although it was obvious that the BD for organic layer under beech stand site types were generally lower as compared to the coniferous stand site types.

The average BD estimated from the sampling in 2004 for the mineral layer reached 1.17 (SD 0.22) g/cm^3. The average values per stand site type ranged from 0.925 (SP_6K) to 1.478 (PI_0K; Fig. 4). Generally smaller values of BD were found for beech stand site types and some of the spruce types located on higher elevation; some of these differences were statistically significant, such as several cases of beech vs. pine categories and pine vs. the upper elevation spruce category.

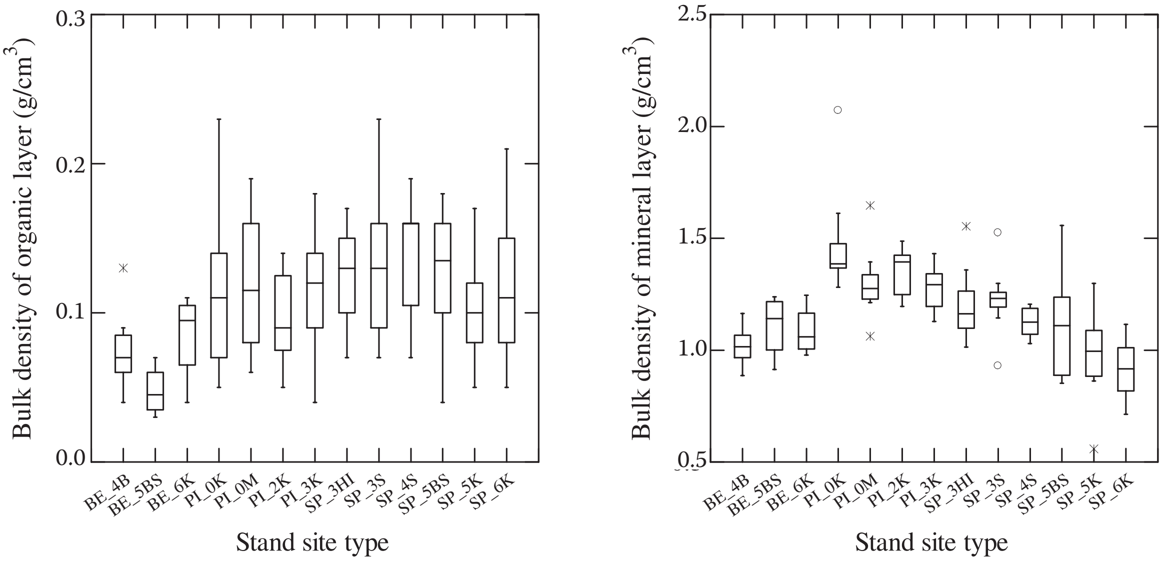

Fig. 4. The estimated bulk density for organic (left) and mineral (right) layer for the measured soil samples from 2004 stratified by stand site type

Organic carbon concentration – C_{ox} (%)

All linked samples from both campaigns showed a decreasing trend of C_{ox} with depth, which was observed for all stand site types (Fig. 5). Obviously, the variability becomes larger towards the layer surface, whereas the samples located deeper were scattered less. Table 3 shows the parameter values of the Eq. (2) and other regression statistics.

The mean values of C_{ox} for soil organic layer of major stand site types ranged from 24.1% (BE_4B) to 35.0% (SP_5K; Fig. 6). Generally, the mean values were similar and the differences insignificant. The exception was the lowest value observed for the beech category BE_4B, which was significantly lower than all other stand site types apart from beech.

The mean values of C_{ox} for soil mineral layer of major stand site types ranged from 1.55% (PI_0K) to 5.54% (BE_5BS; Fig. 6). The highest values were observed for beech stand site types, which were all significantly higher as compared to the other (coniferous) stand site types with exception of spruce on higher elevation (SP_5BS, SP_5K, SP_6K). The lowest values of C_{ox} were observed for pine stand site types; their values were significantly lower as compared to beech stand site types and spruce on higher elevation. Note that C_{ox} also included the corrected data of 2003.

Table 3. The parameter values (*a*, *b*) Equation (1), asymptotic standard errors (A.S.E; shown in parenthesis) and the mean corrected r^2 of the regression estimate

Stand site type	Parameter values		r^2
	a	*b*	
BE_4B	11.223 (1.337)	–0.068 (0.015)	0.705
BE_5BS	13.035 (4.457)	–0.039 (0.027)	0.288
BE_6K	17.564 (4.530)	–0.083 (0.025)	0.712
PI_0K	8.087 (1.960)	–0.086 (0.028)	0.483
PI_0M	8.586 (2.261)	–0.079 (0.024)	0.371
PI_2K	9.313 (2.081)	–0.082 (0.020)	0.588
PI_3K	13.904 (3.190)	–0.116 (0.032)	0.608
SP_3HI	9.011 (1.588)	–0.071 (0.018)	0.454
SP_3S	10.176 (1.418)	–0.093 (0.019)	0.737
SP_4S	10.268 (2.197)	–0.087 (0.025)	0.599
SP_5BS	7.643 (1.497)	–0.051 (0.020)	0.311
SP_5K	15.533 (3.621)	–0.082 (0.022)	0.519
SP_6K	23.719 (5.188)	–0.096 (0.022)	0.516

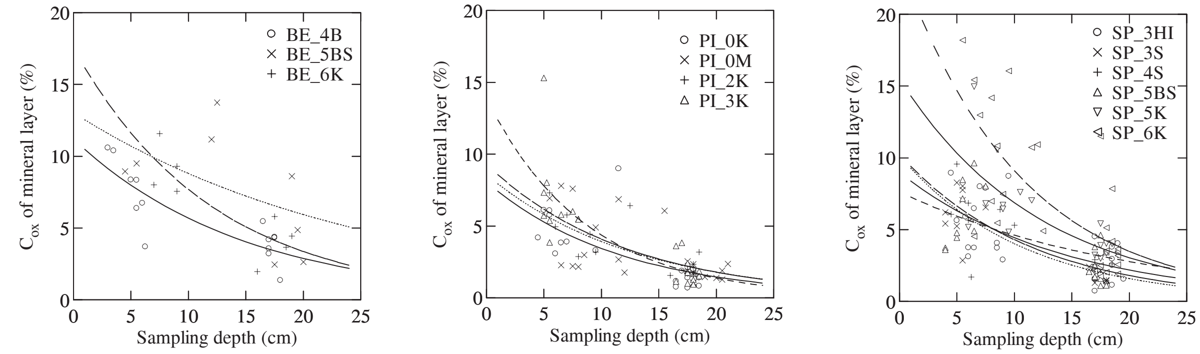

Fig. 5. The generated fit functions of C_{ox} in the mineral layer on sampling depth from the two different campaigns of 2003 and 2004 categorized by stand site type. The figures are grouped by species into beech (left), pine (middle) and spruce (right) stand site types

Soil carbon stock

The average soil organic content (SOC) of organic horizons including L, F and H layers was on average 1.99 (± 0.07, denoting SE of mean) kg C/m^2. The average SOC per stand site type ranged from 0.70 kg C/m^2 for a beech category BE_4B to 3.04 estimated for a pine stand site type category PI_0M (Fig. 7). In general, the pine stand site types together with spruce stand site types on wet soils or on higher elevations were those with the highest SOC, whereas it was smaller for the sites under beech trees. When classified by the major tree species, the mean SOC of organic layer was smallest under beech, reaching 1.03 (± 0.17) kg C/m^2, whereas SOC under pine and spruce were both significantly ($p < 0.001$, ANOVA and Tukey post hoc test) larger with the mean values of 2.19 (± 0.11) and 2.09 (± 0.09) kg C/m^2, respectively. Carbon content in organic layer also significantly differed by humus form. The lowest values were generally found for the mull form of moder with 0.97 (± 0.23) kg C/m^2. The highest values were observed for mor categories reaching in average 2.59 (± 0.14) to 2.85 (± 0.29) kg C/m^2. The moder categories had a medium SOC, which ranged from 1.56 (± 0.26) to 2.01 (± 0.12) kg C/m^2.

In the mineral layer, the mean amount of SOC reached 7.28 (± 0.18) kg C/m^2. The highest values were found for the beech stand site type categories, where the mean SOC reached around 10 kg C/m^2. In pines and lower elevation spruce stand site types, the mineral soil layer SOC was mostly between 5 to 7 kg C/m^2, whereas for spruce stand site types on higher elevation sites it ranged around 8 to 8.7 kg C/m^2.

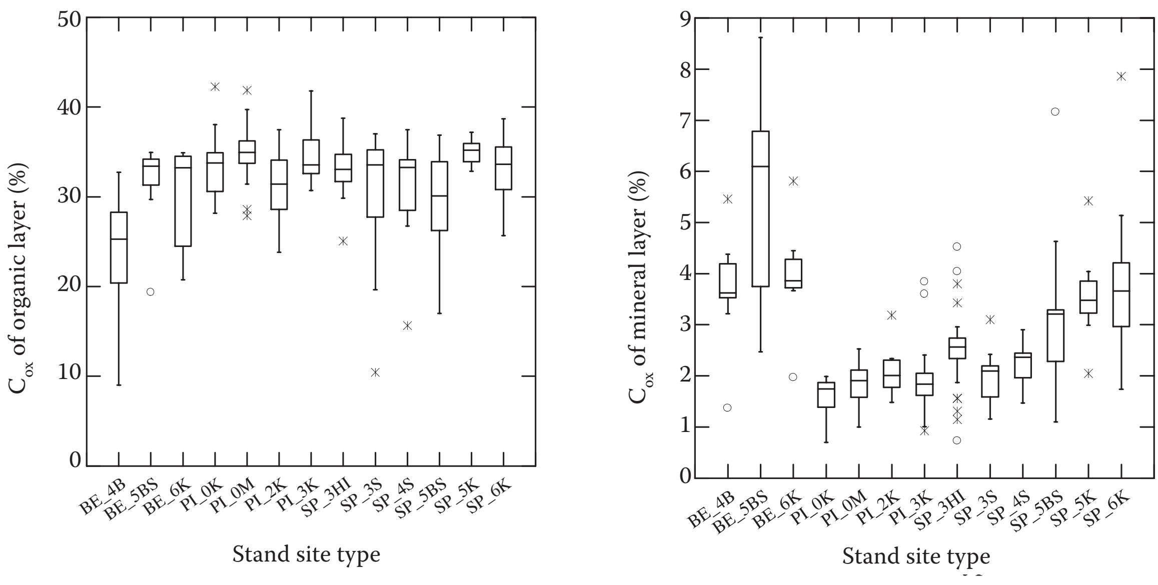

Fig. 6. Organic carbon (C_{ox}; %) of organic (left) and mineral (right) layer. In the case of mineral layer, C_{ox} contains the measured values of 2004 and the corrected values as shown in Fig. 5. For box plot symbol explanations see Fig. 3

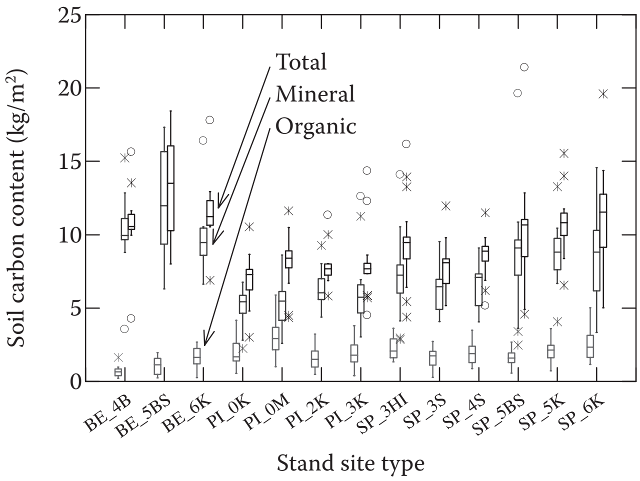

Fig. 7. Soil carbon content in organic layer (lowest bar), mineral layer (middle bar) and the total carbon stock (upper bar) for the individual stand site types. For box plot symbol explanations see Fig. 3

However, there was relatively large variability among the samples and only the differences between beech stand site types and pines with low elevation spruce types were statistically significant ($p < 0.001$). Evaluated by the major tree species, the mean values of SOC were significantly different ($p < 0.001$) among all pairs of the located tree species and reached 10.6 (± 0.43), 5.67 (± 0.26) and 7.50 (± 0.21) kg C/m^2 for beech, pine and spruce sites, respectively.

The average SOC for the total soil layer (0 to 30 cm) estimated from the samplings in 2004 and 2003 reached 9.33 (± 0.18) kg C/m^2. The average SOC for major stand site types ranged from 7.0 (± 0.52) kg C/m^2 (PI_0K) to 13.3 (± 0.84) kg C/m^2 (BE_5BS; Fig. 7). The highest values of SOC were observed for beech stand site types, which were all significantly higher than the other (coniferous) stand site types with exception of spruce on higher elevation (SP_5BS, SP_5K, SP_6K). The lowest values of were observed for pine stand site types (PI_0K, PI_2K, PI_3K); where SOC was significantly lower as compared to that under beech stand site types and spruce on higher elevation. Similar information provides the classification of sites by the major tree species represented in the study area. It resulted in the significant differences ($p < 0.001$) among all pairs of species with the highest SOC for soils of beech forests with the mean value of 11.7 (SE 0.44) kg C/m^2. The spruce locations were intermediate with SOC of 9.59 (± 0.22) kg C/m^2, whereas pine sites had generally lowest SOC reaching 7.86 (± 0.27) kg C/m^2.

DISCUSSION

A rigorous estimation of forest soil organic content (SOC) is challenging due to the inherent high spatial variability of SOC. Once considering larger spatial scales, the soil sampling density is seldom adequate enough. This applies specifically if the changes in SOC are to be estimated (which are typically small as compared to the large associated pools) on the basis of insufficient sampling density (House et al. 2003; Janzen 2004).

In this study, the differences in SOC observed for various classifiers proved to be often insignificant with respect to the heterogeneity of the sample. Anyway, the sampling was adequate enough to detect basic differences for major stand site types and tree species in the pilot region. Typically, the highest values of SOC in organic layers were observed for the sites under coniferous stands, which may reflect a generally slower decay as compared to the sites of deciduous trees. In the case of mineral horizon, the opposite pattern was observed. The highest SOC was identified under deciduous stands (beech) and lower for the sites under conifers. Note, however, that a slight bias was included in our analysis of mineral soil layer by tree species due to a different thickness considered. This was given by the observed depth differences of organic horizons. Since this difference accounted for only about 1 cm, it actually represented a fraction of about 1/25 of the mineral soil thickenss differences that was safely considered negligible.

In the Czech Republic the studies aimed at regional evaluation of soil carbon stock are particularly infrequent. The by far most extensive sampling of forest soils in the country was performed under the program of the National Forest Inventory (NFI; officially called Forest Inventory of the Czech Republic; www.uhul.cz), which was conducted during 2001 to 2004. However, this sampling included only broad description of the upper soil organic layers and sampling of the upper 10 cm of the mineral horizon. By the time of writing this material, no evaluation of soil carbon content from the NFI program has been released yet. It is obvious that NFI sampling would only permit a relative estimation of C_{ox} due to the applied methodology of soil sampling.

On the other hand, the comparative information can be found in the foreign literature. The most relevant guidance for the purpose of emission inventories in the LULUCF sector, namely the Good Practice Guidance of IPCC (2003) provides the mean reference values of SOC within the upper 30 cm. They range from 1.7 to 4.2 kg C/m^2 for the organic layer and from 5.0 to 9.5 kg C/m^2 for the mineral layer. This corresponds well to the values estimated in our study. Other European resources include, e.g., the study of Thürig (2005) from Switzerland, which reported forest SOC in organic layers up to 3.9 kg C/m^2 and 3.6 to 15.0 kg C/m^2 for the mineral layer. Baritz et al. (2005) published the results of soil analysis covering Western and Central Europe. The values of soil carbon content in organic layer reported for Germany and Austria ranged from 1 to 3 kg C/m^2 in cambisols and gleysols, with even larger values for podzols. As for the mineral layer and the reference depth of 20 and 30 cm for Austria and Germany, respectively, the values of carbon stock ranged from 2 to 12 kg C/m^2 including cambisols, luvisols, podzols and gleysols. These soil types were also identified in the pilot region of our study. Finally, an excellent source of comparative information on SOC is the recent evaluation of forest soils in Belgium of Lettens (2005). She gave the average content of SOC in 0–30 cm layer as 8.7 kg C/m^2 for deciduous stand site types, 9.2 kg C/m^2 for coniferous and 9.3 kg C/m^2 for mixed forests.

The absolute quantity of soil carbon stock is derived from three basic parameters, namely depth of soil layer, bulk density and carbon concentration. It is therefore vital to ensure that each of these components is estimated rigorously.

Soil depth is the common information sampled in forest inventory programs nowadays. The evaluation of the first cycle of the Czech NFI (see www.uhul.cz) indicates that the mean depth of the organic layers F+H varied largely; with the most common depth recorded of 3 cm. This is somewhat smaller that the average depth of organic layer found in this study, which might be attributed to different sampling methodology used. Since the Czech NFI data are not available from the Forest Management Institute for any analysis, no rigorous comparison of organic layer depth sampled for this study and that in the NFI program could be performed.

Bulk density is a critically important variable to estimate total carbon stock, but its estimation is very laborious and therefore seldom performed. The studies on carbon stock often utilize the available approximation formulas to estimate BD of mineral horizons such as that used also in our study (Adams 1973). Even more infrequent are the reference *BD* values for the organic soil horizons. Loomis and Gerakis (1975) reported *BD* of L, F and H horizons to be 0.017, 0.0457 and 0.0616 g/cm^3, respectively. Vejre et al. (2003) reported a *BD* value for organic horizons for broadleaved and coniferous forests as 0.04 and 0.12 g/cm^3, respectively. These findings correspond well to the values estimated in our study.

Of the tested classifiers, both tree species and several of the stand site type categories revealed significant differences in SOC in both organic and mineral layer. This is vital for the purpose of regional extrapolation, which should be based on the classifier that suitably reflects the overall site conditions, including climate, soil type and type of forest vegetation. In this respect, the categorization based on forest site types as used in the Czech forest typology seems to be promising. Forest type categories integrate the key site parameters and provide good approximate characteristics that affect SOC. Although this study provides a good foundation for categorization of SOC by stand site types, it is obvious that further analysis is needed and it should involve also other regions of the country. Since the map of forest site types is already available in digital form for the whole country (Macků – unpublished results), it could be used to target the most important forest site types and optimally stratify additional soil sampling needed. A critical point to mention is the potential of NFI, which should be adapted and complemented so as to also provide a basis for the country-wide estimation of SOC and its changes. The current NFI methodology concerning soil is clearly insufficient for providing information usable for detection of potential changes in SOC in connection to emission inventory of the LULUCF sector in line with the recommendation of Good Practice Guidance (IPCC 2003). On the other hand, the distribution of NFI sampling points across the country makes the program ideal from the point of sampling design. Obviously, an optimization analysis is needed to estimate the required soil sampling density with respect to the expected heterogeneity, expected accuracy and detectable change of SOC. Additionally, linking soil sampling to the NFI grid ensures the much needed link to the detail information on forest biomass, which is required to permit analysis of the feedbacks between vegetation and soil carbon.

CONCLUSIONS

This study reports forest soil carbon stock in relation to the major tree species and forest site types (stand site types), including both organic and mineral soil layers. The identified differences of soil organic carbon among the stand site types provide a good basis for regional extrapolation. The national forest inventory program should be utilized and adapted so as to also provide the much needed information on forest soil carbon stock and its potential changes.

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Obsah organického uhlíku ve svrchních horizontech lesních půd v oblasti jihozápadních Čech

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ABSTRAKT: Cílem studie bylo vyhodnocení obsahu organického uhlíku (SOC) ve svrchních horizontech lesních půd ve dvou přírodních lesních oblastech České republiky (PLO 6 – Západočeská pahorkatina a PLO 11 – Český les). Studie vychází ze dvou po sobě opakovaných půdních vzorkování, která proběhla na podzim r. 2003 a 2004. Stanovení redukované objemové hmotnosti (BD) bylo možné pouze z odběrů z roku 2004. Průměrná hodnota SOC pro organickou půdní vrstvu byla 1,99 kg C/m^2. Hodnoty se lišily v závislosti na typu stanoviště od 0,70 do 3,04 kg C/m^2. Nejmenší hodnoty SOC byly na stanovištích bukových porostů (1,03 kg C/m^2), větší pak pro lokality smrkových a borových porostů (2,19, resp. 2,09 kg/m^2). Průměrná hodnota SOC pro minerální horizont (do celkové hloubky 30 cm) dosáhla 7,28 kg C/m^2. Hodnoty SOC minerální vrstvy se významně lišily v závislosti na převládající dřevině porostu a dosahovaly hodnot 10,6; 5,67 a 7,5 kg C/m^2 pro stanoviště buku, borovice a smrku. Celková průměrná hodnota SOC (vrstva 0–30 cm) dosáhla 9,33 kg C/m^2. Diskuse rozvádí metodické aspekty regionálního stanovení SOC a možnost využití programu Národní inventarizace lesa České republiky pro tento účel.

Klíčová slova: organická vrstva; minerální horizont; redukovaná objemová hmotnost; zásoby uhlíku

Studie je zaměřena na kvantifikaci zásoby uhlíku v nadložním humusu a povrchovém minerálním horizontu lesních půd přírodních lesních oblastí Západočeská pahorkatina (PLO 6) a Český les (PLO 11). V těchto oblastech proběhlo opakované vzorkování půd, a to v podzimních měsících roku 2003 a 2004.

Vzorkování v roce 2003 bylo provedeno na 240 odběrných místech podle standardně používané metodiky šetření lesních půd. Každé odběrné místo bylo zaměřeno, opatřeno fytocenologickým zápisem a byla změřena mocnost odebraných vrstev. Organická vrstva zahrnovala horizonty L, F, H, zatímco minerální vrstva zahrnovala pouze horizont A. Na podzim roku 2004 proběhlo opakované půdní vzorkování, které využilo polovinu původních ploch z roku 2003. Půdní vzorky byly odebrány do jednotné hloubky 30 cm pro organické horizonty (odděleně L a F+H) a pro svrchní minerální vrstvu. Vzorkování roku 2004 bylo, na rozdíl od předešlého roku, prováděno pro definovaný objem, což umožnilo následné stanovení redukované objemové hmotnosti (*bulk density*, *BD*).

Podle změřené mocnosti a přítomnosti jednotlivých humusových vrstev byl každý odebraný vzorek přiřazen k příslušné humusové formě a podle obsahu jílnatých částic byly vzorky zařazeny k jednotlivým půdním druhům. Odebrané vzorky obou šetření byly po částečném vysušení odeslány k rozboru do laboratoře Ústavu pro hospodářskou úpravu lesů v Brandýse nad Labem, kde byly vysušeny do konstantní hmotnosti, zváženy a byl stanoven obsah oxidovatelného uhlíku (C_{ox}). Pro analýzu vzhledem k typu dřeviny a stanovišti bylo 115 odběrných míst pilotní oblasti zařazeno do 13 významných kategorií podle dominantní dřeviny (nad 90 %) a příslušného souboru lesních typů (SLT) stanoviště. Pro srovnání s plným textem v anglické verzi jsou označení uváděna s přepisem anglické zkratky hlavní dřeviny (tj. buk = BE, borovice = PI, smrk = SP) a konkrétního SLT. V rámci studie byly aplikovány specifické metodické postupy a výpočty založené na vztazích mezi měřenými veličinami (závislost C_{ox} na hloubce půdy) za účelem propojení dat z obou půdních vzorkování (r. 2003 a 2004).

Zjištěné mocnosti organických horizontů v závislosti na převládající dřevině dosáhly průměrně 4,9 cm v bukových porostech, 5,8 cm v borových porostech a 5,7 cm v případě smrkových porostů. Průměrná redukovaná objemová hmotnost organické vrstvy lesní půdy stanovená ze vzorkování v roce 2004 dosáhla hodnoty 0,113 g/cm^3 (interval od 0,076 g/cm^3 pro lesní typ BE_5BS do 0,136 g/cm^3 pro typ SP_4S). Průměrná hodnota redukované objemové hmotnosti minerální vrstvy, stanovená ze vzorkování v roce 2004, dosáhla 1,17 g/cm^3 s rozmezím 0,925 g/cm^3 (SP_6K) až 1,478 g/cm^3 (PI_0K). Relativní obsah organického uhlíku (C_{ox}) v organickém horizontu se pohyboval v rozpětí 24,1 % (BE_4B) až 35,0 % (SP_5K). C_{ox} v minerálním horizontu dosahoval průměrně 1,55 % (PI_0K) až 5,54 % (BE_5BS). Průměrná absolutní hodnota obsahu uhlíku (SOC) v organické vrstvě lesních půd zahrnující L, F, H horizonty dosáhla 1,99 (± 0,07) kg C/m^2, přičemž hodnoty pro různé kategorie lesních typů byly v rozmezí od 0,70 kg C/m^2 pro stanoviště bukových porostů (BE_4B) do 3,04 kg C/m^2 pro stanoviště borových porostů (PI_0M). Průměrná hodnota obsahu uhlíku (SOC) v minerální vrstvě (do 30 cm hloubky) byla 7,28 (± 0,18) kg C/m^2 a hodnoty se významně lišily pro stanoviště porostů hlavních dřevin: 10,6 (± 0,43) kg C/m^2 pro buk, 5,67 (± 0,26) kg C/m^2 pro borovici a 7,50 (± 0,21) kg C/m^2 pro smrk.

Celkový obsah organického uhlíku v lesní půdě, zjištěný ze dvou vzorkování, dosáhl 9,33 (± 0,18) kg C/m^2. Průměrné hodnoty se lišily v závislosti na dominantní dřevině porostu a půdní kategorii v rozpětí od 7,0 (± 0,52) kg C/m^2 (PI_0K) do 13,3 (± 0,84) kg C/m^2 (BE_5BS).

Zjištěné hodnoty obsahu organického uhlíku v lesních půdách korespondují s referenčními hodnotami studií z jiných oblastí obdobné zeměpisné šířky. Výsledky studie lze využít pro revizi postupů monitoringu půd v rámci statistické (národní) inventarizace lesa (NIL). Současná metodika NIL poskytuje, pokud jde o půdu, nedostatečné informace pro věrohodnou detekci změn SOC v půdních horizontech. Na druhé straně je rozložení sledovaných ploch NIL na celé území ČR ideálním předpokladem pro regionální kvantifikaci změn obsahu uhlíku v půdě, analýzu podle charakteru porostu a propojení s podrobnými údaji o lesní biomase, což by umožnilo stanovení celkové bilance zásob uhlíku v lesích.

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