Carbon sequestration in beech stands on the example of the Chřiby uplands

Schneider Jiří[1], Vyskot Ilja[1], Kozumplíková Alice[1], Holušová Kateřina[2], Rychtář Jan[3]

[1]Department of Environmentalistic and Natural Resouces, Faculty of Regional Development and International Studies, Mendel University in Brno, Tř. Generála Píky 2005/7, Brno 613 00
[2]Forest Management Institute Brandýs n. Labem, branch Brno, Vrázova 1, Brno 616 00
[3]Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, Brno 613 00

Abstract. The article is a contribution to solutions of monitoring the storage of carbon in the woods and its emissions. Four permanent research plots were established in the area of the Chřiby uplands in the Czech Republic and became subject of targeted measurement. The plots are made of forest stands with nearly 100 % of European beech (*Fagus sylvatica* L.). The stands form simple spatial structures of about the same age (about 180 years). They represent however varying site conditions (dwarf acid beech stands, herb-rich beech stands, and transitions between them). For quantification of carbon storage, standard dendrometric methods and the Field-Map technology were used. The total amount of carbon was established as the sum of further documented carbon storages in the in the aboveground biomass, the belowground biomass, woody debris and the forest soil. Total carbon storage per hectare of stand is in average 370.2 t. Obtained outcomes support the quantitative results of latest research related to carbon in the woods.

Key words

biomass, carbon storage, Fagus sylvatica L., forest stands, simplified structure, woody debris.

Introduction

Introduction
In the forest ecosystem, carbon is present in various forms. Two basic forms are to be distinguished – carbon within the biomass of organisms; and carbon contained within the soil (Lal 2005). The carbon in the biomass means aboveground biomass and belowground biomass. Moreover, woody debris is added as the biomass of the vegetation (Tyrrell, Ross 2009). Carbon in the soil includes soil organic carbon (SOC) and soil inorganic carbon (SIOC). The litter is usually also taken into account, especially with respect to forest soil (Cienciala et al 2006c).
The share of carbon in woody vegetation is quantitatively assessed using the coefficient 0.5. Thus, the amount of carbon is often assessed by the amount of the biomass in the stand by means of transformational assessment. It has been proved however that young stands contain less carbon than the old ones (Tyrrel, Ross 2009). Also a different tree species composition leads to different storage of carbon. E.g. Joosten et al. (2004) state that the carbon storage in the biomass of a 120-year-old beech stand is 160 tonnes of C per hectare, Jandl et al. (2007) found 100 tonnes of C per hectare in a 100-year-old spruce stand.

The carbon is ascertained by means of two principal approaches – measuring the carbon storage and measuring its flux.
By measuring the amount of carbon we obtain what is called the carbon storage estimation. The measuring of the carbon flux is important to find out whether the stand in question is a source of carbon or whether it binds carbon. The following are used:: indirect measurement – measuring of changes in carbon storage which can be used to infer the carbon fluxes at a specific level of reliability; direct measurement – the results of carbon fluxes in the stand show how much carbon (in the form of CO2) is issued (+) or bound (-) in a specific period (Zhang et al. 2009)
The stand storage and the area of the stand soil represent the fundamental data for the quantification of the changes in carbon storage contained within the biomass. The quantification of carbon balance uses two main alternative methods. The first method is the fundamental one based on the quantification of increments and losses in the specific area (the corresponding forest category (i), climate zone (j), and management methods (k)) according to the equation:

$$\Delta C = \sum_{ijk} \left[A_{ijk} * \left(C_I - C_L\right)_{ijk} \right]$$

where A_{ijk} is the forest area in ha; C_I is the storage increment; and C_L is the loss of carbon storage.
The second approach is represented by the method of establishing the changes in the storage, where the change in carbon storage in the biomass is determined by the difference of the storage between two periods, i.e.:

$$\Delta C = \sum_{ijk} \left(C_{t2} - C_{t1}\right) / \left(t_2 - t_1\right)_{ijk}$$

where C_{t2} and C_{t1} are the carbon storage amounts in a unit of a forest ecosystem at moments t_2 and t_1 respectively (IPPC 2003).

Material and methods

In 2008, four comparative research plots were singled out in the area Chřiby for the purpose of the carbon study. The ridges of the Chřiby are covered in developed Cambisol both saturated and non-saturated, the slopes are covered with brown soil on loess loam. The territory is located in mild warm area with average temperatures ranging from 7.6°C to 8.2°C and annual precipitation around 650 mm. The territory of the Chřiby is forested nearly in its entire area.
Three of the research plots are 1 ha in area and one of them is 0.5 ha (limited by site conditions). There are beech stands of approximately the same age (180 y) with a simplified structure varying by site. According to the valid forest management plan, the studied stands are characterized by the following data:
The Máchova dolina research plot (0.5 ha) is a component of the Máchova dolina Natural Monument in stand no. 402Ea17. The stand area is 2.51ha. Further information: forest type group 3K6, tree species composition - beech 100%, age - 187 y, stocking - 8, rotation period - 150 years. Soil type is Cambisol, typical oligotrophic.
The Sever research plot (1 ha) is located in the northern part of the Holý kopec Nature Reserve, stand no. 203Ea17. The stand area is 34.7 ha. forest type group 4D – enriched beech stand, tree species composition - beech 100%, age - 162 y, rotation period - 150 years, stocking - 8. Soil type is Cambisol luvic (gley).
The Rynek research plot (1 ha) is located in the southern part of the Holý kopec Nature Reserve, stand no. 204Ea17. The stand area is 26.00ha. Further information: forest type group 3B – rich oak beech stand, tree species composition - beech 100%, age - 164 y, stocking - 8, rotation period - 150 let. Soil type is Cambisol, typical mesotrophic.

The Ocásek research plot (1 ha) is found in the proposed Ocásek Natural Monument, stand no. 57 Ba17/1. The area of the stand group is 3.27 ha. Further information: forest type group 3A – lime and oak beech stand, tree species composition – beech 99%, lime 1% and admixture of elm. Further information: age - 183/4 (age of regeneration in the young growth); stocking - 7/3 (young growth), rotation period - 140 years. Soil type is Cambisol, ranker (Schneider et al. 2008).

The basis for the concerned biometric measurements is the methodology presented in Developmental Dynamics of Virgin Forest Reserves in the Czech Republic (Vrška et al. 2002). The Field-Map technology was used to trace out the positions of all standing living trees. All trees with 10cm diameter in breast height with bark were measured and described. Concerning dendrometric characteristics, the diameter at breast height (DBH) was taken at the height of 1.3 m from the trunk foot. Another explored characteristic was the height of each tree. The tree height was measured with 0.5m accuracy by an ultrasound altimeter. These input data were used to establish the volume of trunks of timber.

The total volume of biomass in individual components was specified, based on biometric surveys, in order to establish the share of carbon - aboveground biomass, belowground biomass and forest soils.

First, the amount of the aboveground biomass was established. Several different methods based on the procedures referred to above were used. Table 1 lists the useful equations for the calculation of the aboveground biomass of European beech *Fagus sylvatica* L.

Table 1. *Equations for the calculation of the aboveground biomass (B) of* Fagus sylvatica *in dependence on the diameter at breast height (D) and the tree height (H)*

Source	Formula	β0	β1	β2
Muukkonen (2007)	$B = \beta_0 D^{\beta_1}$	0.240	2.322	
Cienciala (2005)	$B = \beta_0 D^{\beta_1} H^{\beta_2}$	0.047	2.121	0.697
Wutzler (2007)	$B = \beta_0 D^{\beta_1} H^{\beta_2}$	0.0551	2.11	0.589

The equation presented in Joosten et al. (2004) was used to calculate the amount of carbon in the aboveground biomass (Table 2).

Table 2. *Equation for the calculation of carbon content in the aboveground biomass (B) in dependence on the diameter at breast height (D) and the tree height (H) for* Fagus sylvatica *according to Joosten et al. (2004)*

Source	Formula	β_0	β_1	β_2
Joosten et al. (2004)	$\ln B = \beta_0 + \beta_1 \ln D + \beta_2 \ln H$	-3.7378	2.1596	0.6338

Comparatively, the estimation of aboveground biomass was carried out by means of BCEF (Kolektiv 2007) (Table 3).

Table 3. *Biomass conversion and expansion factor (BCEF) for the European beech (Kolektiv 2007)*

Source	Formula	p_1	p_2	P_3
CzechCarbo (2007)	$CBEF = p_1 * p_2 * e^{-A/p_3}$	0.558	0.246	100

The amount of the biomass is the result of multiplication of the volume of timber (V) and BCEF factor (Samogyi et al. 2006):

B = V *BCEF

To convert the biomass into the carbon amount, the coefficient of 0.5 was used (Joosten et al. 2004, Mund 2004).

To calculate the belowground biomass, two equations based on Wirth et al. (2003) (Table 4).

Table 4. *Equations for the calculation of the belowground biomass (y) in dependence on the diameter at breast height (D) of* Fagus sylvatica

Source	Formula	β0	β1
Wirth (2003)	$y = \beta_0 + \beta_1 * \ln D$	-3.88751	2.51218
Wutzler (2007)	$y = \beta_0 * D^{\beta_1}$	0.0292	1.70

To convert the carbon amount in the belowground biomass, we used the value of 0.5 in accordance with Brown (2002). The carbon content in the soil was generated on the basis of Macků in Kolektiv (2007) where the carbon content in the forest soil (including organic and mineral horizons) was established in dependence on the forest altitudinal vegetation zone and the ecological trofic and edafic classification. Within the various comparative plots the values of the carbon in the aboveground biomass according to various authors were compared by means of statistical methods (Drápela 2000). To compare the statistically significant differences of the calculated values among the authors, the single-factor dispersion analysis ANOVA and Scheffé's method of multiple comparison (at the level of significance p=0.05, i.e. at 95% probability) were used.

Results and disscussion

When assessing the volume of aboveground biomass the highest number of trees was found in the Máchova dolina PRP – 296 specimens; the lowest number of trees was found in the Rynek PRP. In the total sum for individual PRP, the highest storage is in the Sever PRP – 1000.11m3; the lowest storage is even after the conversion in the Máchova dolina PRP – 305.18m3. (Table 5).

Table 5. *Number of trunks and total storage5*

Permanent research plot	Number of trees (pieces)	Total storage (m^3)
Rynek	125	795.76
Sever	235	1000.11
Máchova dolina	296	305.18
Ocásek	128	798.98

In terms of the woody debris the most standing and lying trunks are found in the Rynek PRP – 34 pieces, the fewest are in the Máchova dolina PRP – 10 pieces. For each piece, the degree of decay and the volume were calculated on the basis of the trunk length and diameter. The highest amount of woody debris is in the Rynek PRP – 72 m3, the lowest in the Máchova dolina PRP – 7.04 m3. The total number of trunks and the storage of individual plots are presented in Table 6.

Table 6. *The total number of pieces of woody debris and their volume*

Permanent research plot	Lying wood		Standing wood		Total	
	volume (m^3)	Number (pieces)	volume (m^3)	Number (pieces)	volume (m^3)	Number (pieces)
Rynek	65.58	27	6.46	7	72.04	34
Sever	30.77	15	10.53	7	41.30	22
Máchova dolina	0.16	2	6.88	4	7.04	10
Ocásek	33.17	14	16.05	10	49.22	24

The amount of carbon was established as the sum of the carbon storage in the aboveground biomass, the belowground biomass, woody debris and the forest soil (including litter and mineral horizons).

Carbon in the aboveground biomass

The sums show the differing estimations of the amount in dependence on the used procedures. The highest values were achieved for the Sever PRP; the Rynek PRP and the Ocásek PRP are of approximately the same amount of carbon; the Máchova dolina PRP has the lowest amount (even when converted to 1 ha). The carbon amounts in the AGB related to the individual methods are best shown in Table 7.

Table 7. *Carbon storage in the aboveground biomass*

PRP	C storage in AGB (t/ha)				
	Muukkonen	Cienciala	Wutzler	Joosten	Cbef
Rynek	232.22	243.12	183.86	230.61	252.94
Sever	266.40	298.95	225.98	280.40	318.38
Máchova dolina	171.88	118.59	97.46	115.58	95.75
Ocásek	250.76	250.24	190.50	238.48	250.66

Carbon in the belowground biomass

The results show that the largest storage in the BB is in the Sever PRP, the smallest in the Máchova dolina PRP. In comparison with the amount in the AGB in the other plots, the difference is not significant. In the Máchova dolina PRP we can see a high dependence of the BB amount on the number of trees per an area unit. Table 8 shows the carbon content estimations for the PRP according to the equations used. Statistically, both values are significant; therefore, they were taken account of in the consequent calculations of the total carbon content.

Table 8. *Carbon storage in the belowground biomass*

PRP	C storage in BB (t/ha)	
	WUTZLER	WIRTH
Rynek	36.40	44.44
Sever	41.08	48.68
Máchova dolina	26.06	29.97
Ocásek	36.40	48.16

Carbon in woody debris

The highest total carbon storage was found in the Rynek PRP (12.73 t/ha). The lowest storage was again found in the Máchova dolina PRP (1.15t/ha). The largest storage of standing wood is in the Ocásek PRP. The total values of particular plots are presented in Table 9.

Table 9. *Carbon storage in woody debris*

PRP	Lying wood		Standing wood		Total carbon (t/ha)
	volume (m^3)	carbon (t)	volume (m^3)	carbon (t)	
Sever	30.77	6.07	10.53	1.92	8.00
Rynek	65.58	11.29	6.46	1.18	12.47
Ocásek	33.17	8.34	16.05	3.39	11.73
Máchova d.	0.16	0.03	6.88	1.12	1.15

Carbon in the soil

The highest value of 65.2 t/ha has been found for the Sever PRP, the lowest for the Ocásek PRP.

Total carbon storage of forest stands

The storage of the stands was calculated on the basis of the data obtained through the results of individual PRPs. The hectare storage was multiplied by the area of the stand groups. The resulting values are presented in Table 10.

Table 10. *Total carbon storage in the stands*

PRP	Total carbon (t/ha)	Stand area (ha)	Total carbon in the stand (t)
Rynek	348.25	26.00	9054.37
Sever	399.72	34.70	13870.26
Máchova d.	196.45	2.51	493.09
Ocásek	340.03	3.27	1111.89

Conclusions

The aim of the research was to quantify and evaluate the total carbon storage in the selected beech stands on explicated research plots.

The survey shows that even though all four plots were beech stands with a simplified structure, there were differences among them concerning the total carbon storage. The highest C storage was found in the Sever plot. In total this plot retains 395.25 tC/ha: its aboveground biomass accumulates 280.40 tC/ha; the belowground biomass has 48.68 tC/ha, and its woody debris retains 8 tC/ha. The storage of soil carbon is 58.17 tC/ha.

The Rynek and Ocásek stands resemble to a great degree. The total carbon storage in the Rynek PRP is 352.72 tC/ha: 230.61 tC/ha in the aboveground biomass, 44.44 tC/ha in the belowground biomass, 12.47 tC/ha in the woody debris. The storage of soil carbon is 65.2 tC/ha.

The total carbon storage in the Ocásek PRP is 350.60tC/ha: 238.48 tC/ha in the aboveground biomass, 48.16 tC/ha in the belowground biomass, 11.73tC/ha in the woody debris. The storage of soil carbon is 52.24 tC/ha. It means the difference is "only" 1.12 tC/ha. The storage is different in different places of storage (AGB, BB, soil, debris).
The lowest value was found in the Máchova dolina PRP – 185.87 tC/ha on average. Its aboveground biomass sequesters 115.58 tC/ha, the belowground biomass 29.97 tC/ha, the woody debris only 1.15 tC/ha. The forest soil contains 38.18 tC/ha.

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References

Adams, J. .M. , Post, W. M.: A preliminary estimate of changing calcrete carbon storage on land since the last glacial maximum. Global ana planetary change 20, 1999, str. 243 – 256

Brown, S.: Measuring carbon in forests: current status and future challenges, Environmental Pollution 116 / 2002, str. 363-372

Cairns, M. A. et al.: Root biomass allocation in the world's upland forests, Oecologia 111 /1997, str. 1– 11

Cienciala, E., Henžlík, V., Zatloukal, V.: Assessment of karbon stock change in forests – adopting IPPC LULUCF Good Praktice Guidance in the Czech Republik. Forestry journal 52, 2006 a, str. 17 – 28

Cienciala, E. et al.: Biomass functions applicable to European beech, Jornal of forest science 51, 2005, str. 147- 154

Cienciala, E. et al.: Forest topsoil organic karbon kontent in Southwest Bohemia region, Journal of forest science, 52, 2006 c, str. 387 – 398

Claus, A.: FORCAST (Forest Carbon -Nitrogen Trajectories) databáze, 2003 <http://www.dow.wau.nl/natcons/NP/FORCAST/files_database_forcast2.htm>.

Drápela, K. (2000): Statistické metody II. Skriptum MZLU Brno, 152s.

Gurney, K.R. et al.:Towards robust regional estimates of CO2 sources and sinks using atmospheric transport models. Nature 415, 2002, str. 626-630

IPCC . Good Practice Guidance for Land Use, Land-Use Change and Forestry. Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K. and Wagner F. (Eds.), 2003, IPCC/OECD/IEA/IGES, Hayama, Japan. ISBN 4-88788-003-0.

Jandl, R., et al.: How strongly can forest management influence soil carbon sequestration ?, Geoderma 137/ 2007, str. 253 – 268

Joosten, R. et al.: Evaluating tree karbon predictions for beech (Fagus sylvatica) in western Germany, Forest Ekology and Management 189, 2004, str. 87-96

KOLEKTIV: Závěrečná zpráva řešení projektu VaV/640/18/03 CzechCarbo – studium cyklu uhlíku v terestrických ekosystémech České republiky, 2007

Korpel, Š.: Dynamika štruktúry a vývoj bukových prírodných lesov na Slovensku. Acta Facultatis Forestalis, 24, Zvolen, 1987, str. 59-85

Lal, R.: Forest soil and carbon sequestration, Forest Ecology and Management 220, 2005, str. 242- 258

Muukkonen, P.: Generalized allometric volume and biomass eguations for some tree species in Europe, Eur J Forest Res 126, 2007a , str . 157-166

Mund, M.: Carbon pools of European beech forests (Fagus sylvatica) under different silvicultural management, Dissertation zur Erlangung des Doktorgrades der Fakultät für Forstwissenschaften und Waldökologie der Georg-August-Universität Göttingen, 2004

Schneider, J.: Možnosti využití syntézy ekosystemových charakteristik lesních porostů v tvorbě a ochraně krajiny. Odborná zpráva z řešení projektu IGA č 57/ 2008 LDF MZLU v Brně

Somogyi, Z. et al.: Indirect methods of large-scale forest biomass estimation, Eur J Forest Res 2006

Šimek M.: Základy nauky o půdě – 3. Biologické procesy a cykly prvků, Biologická fakulta JU, České Budějovice, 2003, 151 s. ISBN 80-7440-630-5

Tyrrell, M. L., ROSS, J.:Carbon Dynamics of Temperate Forests, In: Forests and Carbon: A Synthesis of Science, Management, and Policy for Carbon Sequestration in Forests, 2009 Yale School of Forestry & Environmental Studies

Vrška, T., a kol.,: Dynamika vývoje pralesovitých rezervaci v České republice.

Svazek 1 Českomoravská vrchovina-Polom, Žákova hora. Academia, 2002, Praha, 214s.

Wirth, C. et al.:Dynamik der Kohlenstoffvorräte in den Wäldern Thüringens. Abschlussbericht zur 1. Phase des BMBF-Projektes „ Modelluntersuchung zur Umsetzung des Kyoto-Protokolls ' ' . Max-Planck Institute for Biogeochemistry, Jena 2003, 328s.

Wutzler, T. et al.: Generic biomas functions for Common beech (Fagus sylvatica) in Central Europe – predictions and components of uncertainty, Canadian Journal of Forest Research 38, 2008 str. 1661-1675

Zhang, X. et al.: Methods of Measuring Carbon in Forests, In: Forests and Carbon: A Synthesis of Science, Management, and Policy for Carbon Sequestration in Forests, 2009 Yale School of Forestry & Environmental Studies