ACCUMULATION OF SOIL ORGANIC CARBON IN RELATION TO OTHER SOIL CHARACTERISTIC DURING SPONTANEOUS SUCCESSION IN NON RECLAIMED COLLIERY SPOIL HEAPS AFTER BROWN COAL MINING NEAR SOKOLOV (THE CZECH REPUBLIC)

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Abstract

Frouz J., Kalčík J.: Accumulation of soil organic carbon in relation to other soil characteristic during spontaneous succession in non reclaimed colliery spoil heaps after brown coal mining near Sokolov (the Czech Republic). Ekológia (Bratislava), Vol. 25, No. 4, p. 388–397, 2006.

Accumulation of soil organic carbon together with changes in thickness of humus and fermentation layers, pH bulk density and total phosphorus content were studied in chronosequence of 15 plot (2–41 year old) on colliery spoil heaps, overgrown by spontaneous vegetation. Heaps were formed by alkaline (pH about 8) tertiary clay material. Only scarce herb and grasses occur in sites 2–14 years old, 15–25 year old sites were covered by willow (Salix caprea) shrubs and tree (Betula sp. and Populus tremula) dominated in 25–41 year old sites. Even youngest sites contain about 4% of organic carbon. Thickness of organic soil horizons and content of carbon in mineral soil increased during succession. Thickness of fermentation layer peaked in 15–25 year old sires, humus layer appears on 25 year old sites and its thickness gradually increases with plot age. Accumulation of organic carbon during the first 40 years of succession in average 93g m^{-2} $year^{-1}$. As a consequence of organic matter accumulation in soil, bulk density of soil and soil pH gradually decreased with succession age. Content of total phosphorus did not change with succession age.

Key words: Carbon accumulation, succession, soil formation, reclamation

Introduction

Open cast coal mining often results in large-scale disturbance of the landscape. Soils in large areas are completely destroyed either by excavation in the pit or by deposition of spoil material in tailings (Štýs, 1981). Adverse properties of these substrates such as sensitivity to erosion, high conductivity, extreme pH, unsuitable water regime or nutrient deficiency may reduce plant development and ecosystem functioning on post mining areas (Bradshaw, 1983).

Consequently one of the most important issues in reconstruction of functional ecosystems in post-mining landscapes is soil formation. Typically, spoil material contains low amount of recent organic matter. However, it may contain various amount of fossil organic matter. Accumulation of soil organic matter is thus important part of soil forming process in post mining sites it result, directly or indirectly, in improvement of physical, chemical and biological soil properties , such as water holding capacity, soil sorption, microbial activity and nutrient turnover (Allison, 1973; Leeper, Uren, 1993).

There are many studies dealing with soil formation and organic matter accumulation in post mining sited treated with technical reclamation with planting various tree species (e.g. Roberts et al., 1981; Štýs, 1981; Rumpel et al., 1998; Šourková et al., 2005). There are also data about soil formation in non mining areas with spontaneous vegetation developed (e.g. Crocker, Dickson, 1957; Syers et al., 1970; Emmer, Sevink, 1994; De Kovel et al., 2000). However the data about soil organic matter accumulation in non reclaimed, spontaneously developing, post mining sites are rare. The main goals of this study are: i) to describe organic matter accumulation in spontaneously developing colliery spoil heaps near Sokolov, ii) to relate these changes in soil organic matter content with other selected soil properties and finally, iii) to compare organic matter accumulation in spontaneously developed sited with organic matter accumulation in alder reclamation studied in the same area by Šourková et al. (2005).

Material and methods

Description of the study sites

The study was carried out at reclaimed mine heaps in Sokolov brown coal mining district (Czech Republic). The average altitude of the study area is about 500–700 m a.s.l. Mean annual precipitation is 650 mm, and mean annual temperature is 6.8 °C (Štýs, 1981). Spoil material is formed by alkaline tertiary clay material coming from depth 0–200 m. For more details about the study area see Frouz et al. (2001) and Šourková et al. (2005). Chronosequence of 15 plots covered by spontaneous succession heaped 2–41 years ago were available for this study. The spoil dumps were formed by tertiary clay material with pH about 8, leading minerals were kaolinite, illite, calcium carbonate and quartz (Šourková et al., 2005; Kříbek et al., 1998). The surface was not levelled, and longitudinal depression and elevation formed by heaping process remain in all sites. Only scarce herb and grasses (Tusilago farfara and Calamagrostis epigeios) occurred on plots 2–14 years old. Shrubs (Salix caprea) occurred on plots 15–25 years old and tree cover (Populus tremuloides and Betula spp.) plots 25–41 years old. Litter input, both woody vegetation and herbs pooled, increased with succession age, it represent 80g m^{-2} $year^{-1}$ in 2–14 years old sites, 173 and 322 g m^{-2} $year^{-1}$ in 15–25 years old sites and 25–41 years old sites, respectively (Frouz, unpublished data).

Sampling and analyses

Samples were taken in May 2002 with cylindrical corer (diameter = 11.5 cm). Each sample was divided into four layers: litter layer (L layer) – not decayed dead organic matter; fermentation layer (F layer) – partially decayed remnants of dead organic material; layer 0–5 cm under F layer (0–5 cm layer) – upper part of this layer usually contained humus compounds mixed with mineral components; layer 5–10 cm under F layer (5–10 cm layer).

Five individual samples from corresponding layers were mixed, forming one composite sample. Two composite samples were taken of each layer of soil profile on each plot, one in depression and one in elevation.

Soil samples were weighed, air-dried and sieved through 2-mm screen. Dry weight of soil was determined gravimetrically. Litter was dried to constant dry mass at 90 °C and other samples at 105 °C. All analyses were made in < 2-mm soil fraction except samples of L layer, which were analyzed entire.

Exchangeable soil reaction was measured with pH Meter WTW 526/538, Germany, with combined electrode on individual composite samples at a soil: 1M KCl solution of ratio 1:10 w/v in F layer and 1:5 w/v solution in 0–5 cm and 5–10 cm layer.

Oxidizable carbon content (Cox) was determined using the method of wet acidified dichromate oxidation (Jackson, 1958). To compare the data from spontaneous sites with similar data obtained in reclaimed sites (Šourková et al., 2005) the Cox values were converted to total carbon (Ctot) values by equation Ctot = 1.348Cox + 0.192 (r = 0.997, $p < 0.01$) derived by Šourková et al. (2005).

Total phosphorus (Ptot) was determined in mixed samples by the method of mineralization with perchloric acid (Sommers, Nelson, 1972). P content in mineralized soil was measured according to Murphy and Riely (1962) in modification of Watanabe and Olsen (1965).

SPSS 9.0 for Windows (SPSS Inc., Chicago, Illinois) were used for statistical analyses ($p < 0.05$, n = 15 if it is not noted anything else). Linear regression was used primarily for description of trends in data in relation to plot age. Contents of Ctot were represented in weight percentage (%) and in gram per unit area ($g.m^{-2}$). The latter was calculated according to y Ctot.ms/500.S (y = carbon content in $g.m^{-2}$, Ctot = C weight percentage, ms = composite sample weight, S = probe area in m^2).

Results

Topsoil layers development

Changes in thickness of fermentation layer show apparent differences between depression and elevation. In elevation the thickness of fermentation layer gradually increased with plot age (Fig. 1a). In depression thickness of fermentation layer peaked in the 15–25 years old plot, in these shrub dominated sites thickness of fermentation layer was higher that in sites 1–14 and 26–41 years old (ANOVA, Tukey, $p < 0.05$). Humus layer was absent in the plots younger than 25 years, in older plots its thickness gradually increased with age, this increase was more pronounced in depression than in elevation (Fig. 1b). Bulk density of substrate peaked in sites about 10 years old and in older sites gradually decreased with plot age. This trend is similar in both depression and elevation, however in depression the decrease of bulk density is more pronounced.

Carbon accumulation

Carbon content in litter and fermentation layer did not change significantly with time (Fig. 2a). Carbon content with litter 31.0 ± 5.5% was significantly higher than in fermentation layer 20.6 ± 5.3% respectively (t-test, $p < 0.001$). In both litter and fermentation layer no significant differences were found between depression and elevation (t-test).

In mineral layer about 4% of organic carbon was found in 2 years old plot without vegetation. Carbon content in mineral layer gradually increased with time. This increase was more pronounced in the depression where it was significant for both layers studied (Fig.

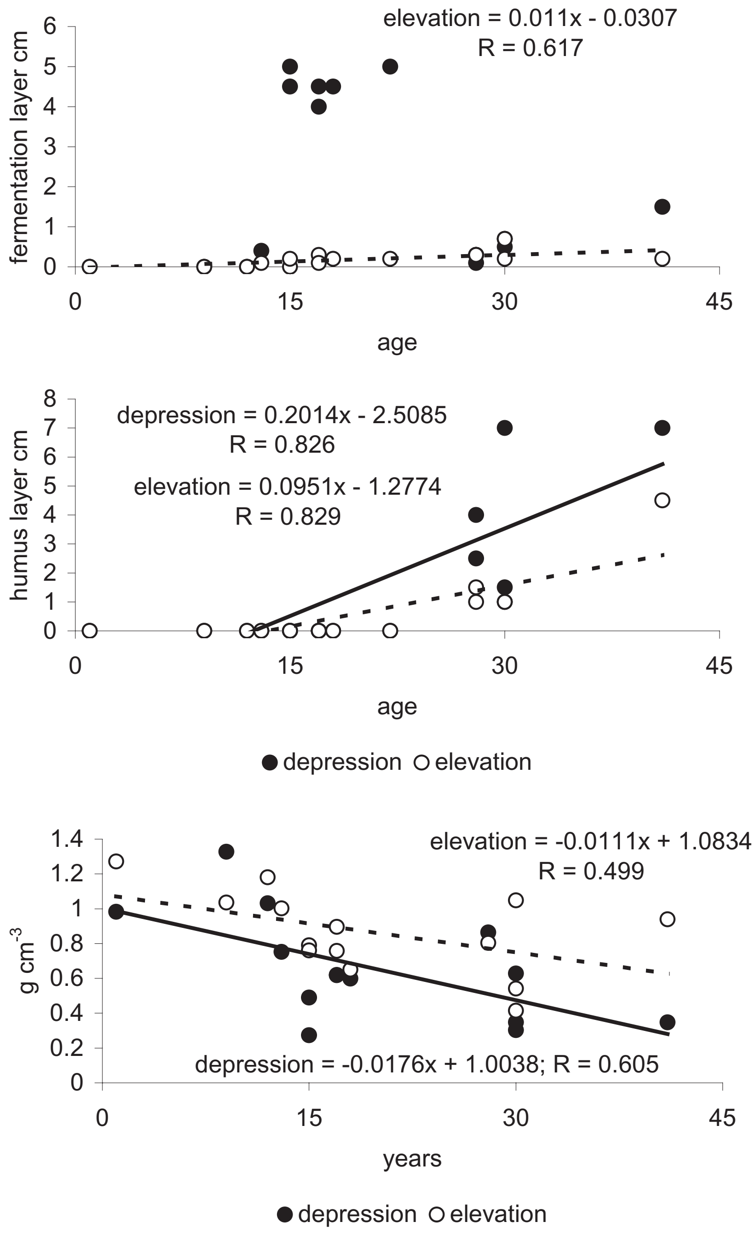


Fig. 1. Thickness of fermentation and humus layer and bulk density of soil in various sites 2–41 years old. Changes in individual parameters over time were fitted by liner regression. Statistically significant regression was plotted, solid line for depression, dotted line for elevation; if no significant correlation of individual parameters and time was found no line was plotted.

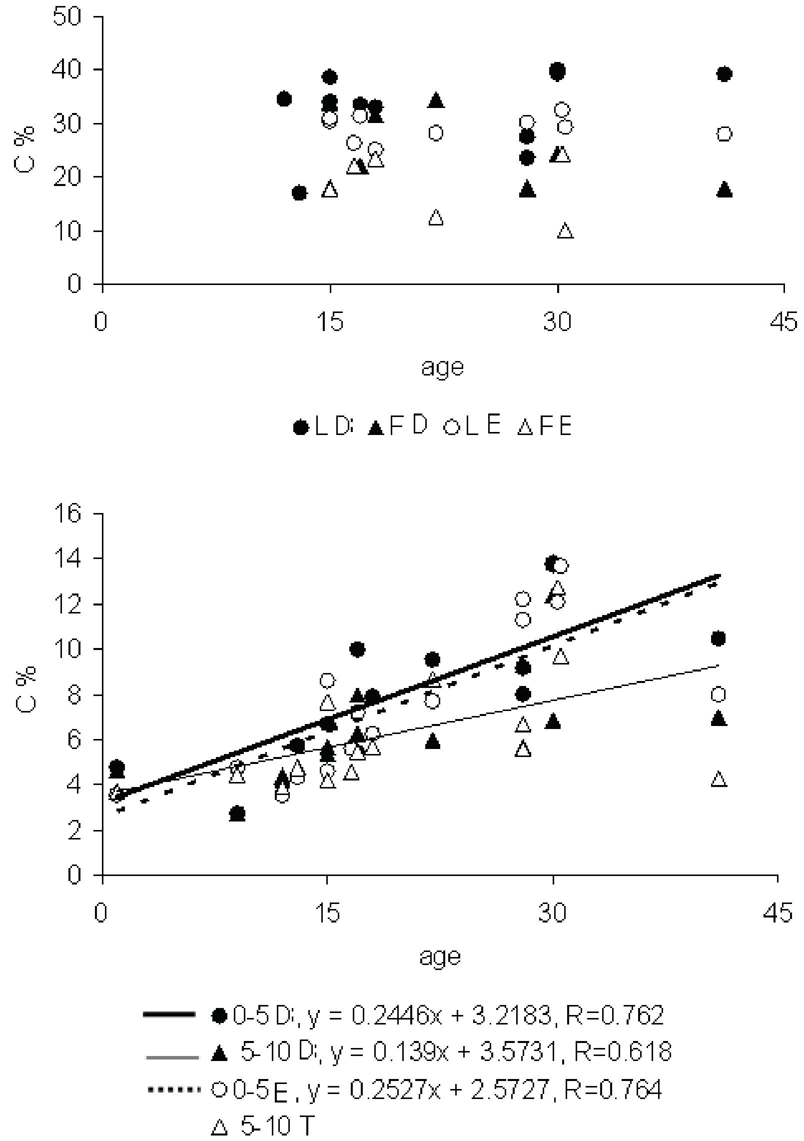


Fig. 2. Carbon content in litter and fermentation layer (a) and in mineral layer 0–5 and 5–10 cm below fermentation layer in various sites 2–41 years old. Changes in individual parameters over time were fitted by liner regression. Statistically significant regression was plotted; if no significant correlation of individual parameters and time was found no line was plotted. LD – litter layer depression, LE – litter layer elevation, FD – fermentation layer depression, FE – fermentation layer elevation, 0–5D mineral layer 0–5 cm below fermentation layer depression, 0–5E mineral layer 0–5 cm below fermentation layer elevation, 5–10D mineral layer 5–10 cm below fermentation layer depression, 5–10E mineral layer 5–10 cm below fermentation layer elevation.

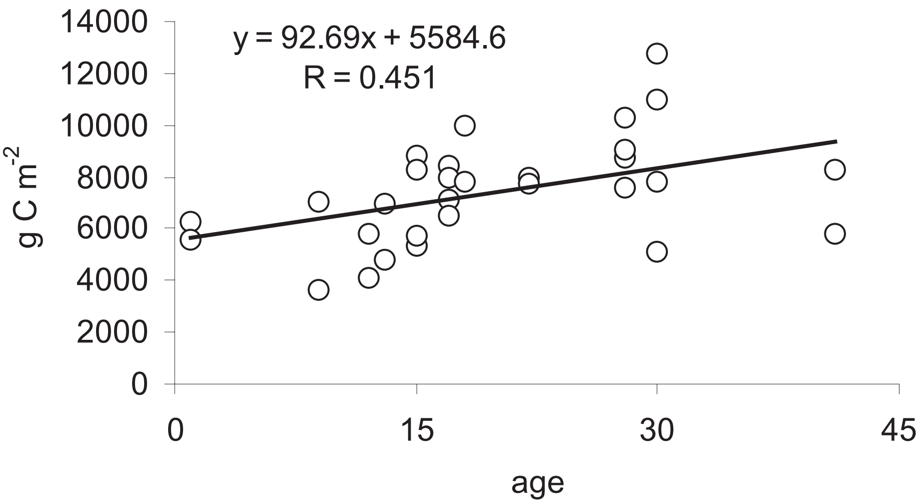


Fig. 3. Carbon stock (amount of carbon per m^2 in litter layer, fermentation layer and mineral layer 0–10 cm below fermentation layer pooled) in various post mining sites 2–41 years old, data from both depression and elevation pooled.

2b). In elevation the increase in carbon content was less pronounced and significant only for layer 0–5cm below fermentation layer, in deeper layer (5–10cm) no significant increase of C content was found.

Based on changes in C content in individual layers and mass of these layers per using area we calculated that C accumulation in spontaneous sites is 93g m^{-2} $year^{-1}$ (Fig. 3). During the first 40 years after heaping carbon content in soil increases from 5.6 kg m^{-2} to 9.4 kg m^{-2}.

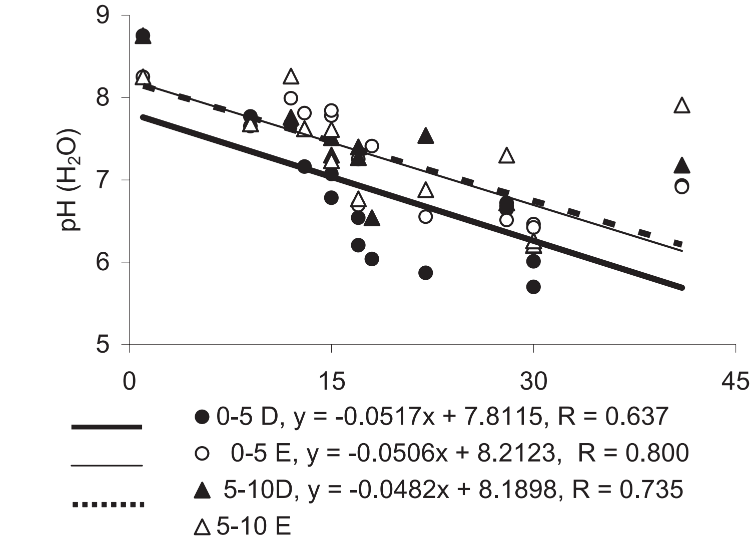
Changes in pH and phosphorus content

Soil pH in mineral layer gradually decreased with succession age (Fig. 4a). This decrease was more pronounced in depression and in topsoil layers. It was significant in both investigated layers in depression and in 0–5cm layer in elevation (Fig. 4a).

Content of total phosphorus did not change over time (Fig. 4b) and there were no significant differences in P content among individual mineral layers (ANOVA).

Discussion

Carbon stock per unit area or carbon content is difficult to compare with another studies because of proportion of fossil carbon in our sites. Thus we used for comparison annual



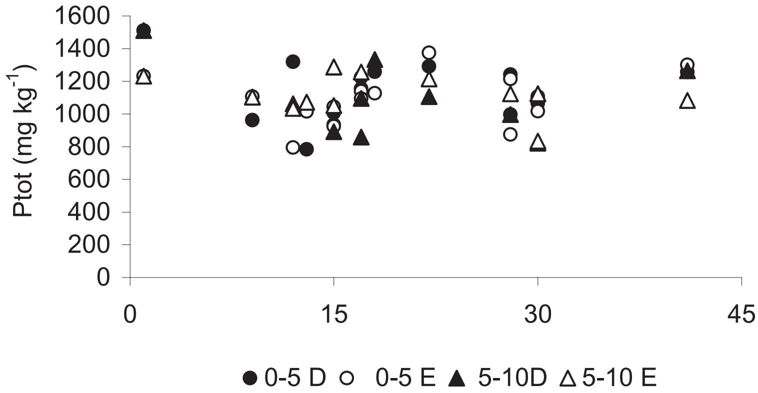


Fig. 4. pH(H_2O) (a) content of total phosphorus (b) in mineral layer 0–5 and 5–10 cm below fermentation layer in various sites 1–41 years old. Changes in individual parameters over time were fitted by liner regression. Statistically significant regression was plotted; if no significant correlation of individual parameters and time was found no line was plotted for abbreviation see Fig. 2.

increase in carbon stock. Annual increase in organic carbon topsoil layers in plots overgrown by spontaneous vegetation is slightly but nonsignificantly lower carbon accumulation in plots planted by alder trees in the same area (Šourková et al., 2005). The same is true for primary succession on china clays in Great Britain, based on data given by Roberts et al. (1981) average annual increase is about 102 g m^{-2} $year^{-1}$. However in china clays the estimation may be affected by the fact that initial sites were missing from analysis, which made slope of linear regression steeper. If we assume that the content of organic matter at the start is not negative (e.g. equal to zero), then average annual increase in carbon stock will be similar to our data from spontaneous succession near Sokolov. In conclusion we can say that the rate of carbon stock accumulation in non reclaimed post mining sites is comparable to another sites covered by spontaneous succession as well as to reclaimed sites in the same area.

In this comparison we used simplified assumption that content of fossil carbon is equal in all sites of investigated chronosequence. This may not be necessary true, because the content of fossil carbon in individual sites may vary, because variability in carbon content in excavated spoil material (Kříbek et al., 1998). Fossil organic matter consists mostly from kerogen of algal origin (Kříbek et al., 1998). There are also some indications that fossil carbon may be used by soil microflora (Filip, Smedhildmann, 1992; Kříbek et al., 1998) and eventually mineralized and its content may thus decreased over time.

Despite the fact that the rate of carbon accumulation over 40 years is comparable with reclaimed sites its temporal pattern is different. In spontaneous sites increase in carbon stock is more or less gradual over time or little bit slower in the first 10–15 years of succession (Fig. 3). On the contrary in reclaimed sites rapid carbon accumulation first occurs 15–20 years after tree were planted and after this period the rate of carbon accumulation slows down (Šourková et al., 2005).

In agreement with Crocker and Dickson (1957), Syers et al. (1970) and Emmer and Sevink (1994) we observed that the rate of carbon accumulation was higher in upper organic layers and slowed down with increasing soil depth. This pattern corresponds with accumulation of organic matter in topsoil layers and penetration of carbon into deeper layer due to leaching and bioturbation. Patterns of soil organic matter accumulation in topsoil layer correspond also with formation of fermentation and humus horizon. After 40 years of spontaneous succession thickness of fermentation and humus layer was observed in this study were similar to those given by Frouz et al. (2001) from 40 years old alder plantation established in mining sites. However temporal patterns in topsoil layer development differ between spontaneous and reclaimed sites. In spontaneous sites massive fermentation layer was formed in intermediate succession stages. On the other hand in reclaimed sites fermentation layer was less developed and humus layer more developed in intermediate succession stages (Frouz et al., 2001). These differences seem to correspond with higher abundance of macrofauna namely earthworms in reclaimed sites (Frouz et al., 2001, 2002), which may cause more intensive soil mixing on reclaimed sites. More intensive bioturbation may on the one hand accelerate formation of humus layer, on the other reduce fermentation layer.

Increase in soil organic matter content is connected also with changes of other soil parameters, namely pH. Unlike many other post mining sites which are acid due to weathering of sulphur compounds (mainly pyrite) (Katzur, Haubold-Rosar, 1996; Rumpel et al., 1998) soil material in our sites was alkaline and pH decreased in all layers in relation to plot age from alkaline to slightly acid values. The major cause of decrease in pH in our plots was likely connected with organic matter accumulation and forming acid compounds of soil humus. Decrease in pH during primary succession was recorded on sandy dunes (De Kovel et al., 2000) and on glacier moraines (Crocker, Dickson, 1957). The pH was the lowest in the upper layer (F) and increased with increasing soil depth. This is comparable to results presented by other authors (Crocker, Dickson, 1957; Wardenaar, Sevink, 1992).

In agreement with the results from other reclaimed plots (Varela et al., 1993) or primary succession (Crocker, Dickson, 1957) bulk density decreased with plot age as a result of organic matter accumulation (Schwendemann, 2000).

No significant difference in Ptot in $mg.kg^{-1}$ appeared in both mineral layer in relation to plot age. This is consistent with results of Šourková et al. (2005) in the same area. P values indicated that clays of cypris series are rich in mineral sources of P. This is probably also the reason why the redistribution of P by plant uptake had minor effect on P content in individual layers in comparison with other sources of variability namely between sites differences in P content given by variability of spoil material.

Conclusion

In conclusion the accumulation of carbon spontaneous sites during the first 40 years of succession is comparable with sites reclaimed by planting alder in the same area. Also development of soil horizons after 40 years of succession is similar to reclaimed sites of the same age even if temporal dynamic differ between both sites. In suitable substrates primary succession may in reasonable time result in formation of ecosystems with are in many aspects comparable with reclaimed sites. Another studies indicate that spontaneous succession may support diverse plant and animal communities (Frouz et al., 2001, 2002; Prach, 2003). These findings support an idea that in suitable conditions spontaneous succession process may by incorporated in reclamation practice (Bradshaw, 1997).

Translated by the authors

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Frouz J., Kalčík J.: **Akumulace uhlíku ve vztahu k ostatním charakteristikám půdy během spontánní sukcese na výsypkách v okolí Sokolova.**

Akumulace uhlíku v půdě byla sledována na chronoseqvenci patnácti nerekultivovaných ploch o stáří 1–41 let, zarostlých spontánní sukcesí na výsypkách po těžbě hnědého uhlí v okolí Sokolova. Průměrná rychlost akumulace půdního uhlíku na těchto plochách je asi 93 g m^{-2} rok^{-1} což je porovnatelné s rychlostí akumulace půdního uhlíku v rekultivovaných olšinách na výsypkách téže oblasti.