Biological activity of anthropogenic soils after spoil-bank forest reclamation

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ABSTRACT: The paper presents the results of relatively long-term research focused on spoil bank revitalization processes in the North Bohemian Brown Coal Basin after the first three years of observations. The biological activity of soil (namely catalase and phosphatase activity), indicators of basal and potential soil respiration, ammonification and growth, development and nutrition status of forest plantations were selected as indicators of this revitalization process. These parameters were determined in five localities of different age of reclamation where different technological approaches and tree species compositions were used. The results confirm the distinct time dependence of revitalization processes. From the aspect of biological activity older reclamations are close to natural forest soil. The enrichment of top soil layer with organic matter before the plantation (by ploughing in cellulose fibres and peat addition) increased some parameters of soil biological activity. The positive amelioration effect of black alder (*Alnus glutinosa*) was also confirmed.

Keywords: afforestation; forest stands; respiration; ammonification; enzyme activities; amelioration

The disruption level of natural ecosystems reached a larger extent in the Czech Republic in the second half of the 20th century mostly in connection with the expansion of power engineering and heavy industries. The extraction of raw materials caused that there originated large areas where almost the full destruction of the landscape occurred. The extraction is followed by so-called technogenic transformation of the landscape where the destruction occurs in the lithosphere, hydrosphere, pedosphere and biosphere. This process is connected with the disturbance of functions of all ecosystems of the forest and agricultural landscape. The restoration of lands damaged by human activities is a very important problem in the Czech Republic (Podrázský et al. 2003; Štýs 1981) as well as in many other countries in Europe (Hütl, Schneider 1998; Hütl, Bradshaw 2001; Filcheva et al. 2000).

The North Bohemian Krušnohorská Basin is an area mostly destroyed by the opencast mining of brown coal in the Czech Republic. So far about 20 thousand ha have been damaged. Moreover, after the mining out of the North Bohemian Krušnohorská Basin the expected annexation is supposed to be about 70 thousand ha.

The way of restoring the ecological balance of such a degraded environment is to reclaim the defect to its original function, i.e. to agricultural use. At present due to the limited financial resources and for the reason of land resource delimitation forest reclamations are preferred.

The soil formation on the reclamation plot is a long-term process, the soil-forming factors and processes that have an influence on substrates (Jonáš 1985). Besides the formation of a new soil, there is also a significant handling of soil-forming substrates that are used for biological reclamations, i.e. their selective stripping and storing in depository (Štýs 1981).

The aim of the agricultural (and forest) reclamation of destroyed plots is to form anthropogenic soils that will perform the production function besides their ecological function in the landscape (Kohel 1997). The forest reclamation creates forest stands on spoil

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banks providing all environmental services to the landscape and their inhabitants as well as starting an amelioration process in anthropogenic substrates (Kupka, Dimitrovský 2006).

Due to significantly diverse conditions it is not possible to generalize the reclamation process but it is necessary to access individually to the reclamation of each plot. Different technological processes are used in the forest reclamation with the aim of biological renewal and humus enrichment through the surface horizon soil to fertilize soil-forming substrates. The direct reclamation with the surface improvement of spoil bank materials is used and also in combination with peat addition into the surface horizon. Conditions for the gradual regeneration of forest stands are created in this way. The evaluation of development of the newly formed anthropogenic soil is a very important part of reclamation processes. It is ensured through the basic complex pedological survey which includes a detailed description of stratigraphy and morphology of separate soil horizons, including possible signs of the soil-forming processes (Kohel 1997). The study of the biological activity of anthropogenic soils seems to be a suitable indicator of the soil revitalization process on reclamation plots. Biological processes connected with settlement and activities of soil microflora are a very important part of the soil-forming process. Their level on the surface horizon (ploughing layer in agricultural reclamation and top soil in forest reclamation) is decisive (Hýsek, Hejdová 1997; Růžek, Dušek 1997). The level of the biological activity of anthropogenic soil makes it possible to evaluate a success of various types of realized reclamations (Harris, Birch 1989; Šíša 1993; Růžek 1994; Šíša et al. 1997, 1999, 2000; Voříšek et al. 1997).

The condition, growth and development of vegetation, which is one of the main pedogenetic factors (Šály 1978), are also of great importance for the evaluation of successful reclamation. The tree species composition of forest ecosystems determines substantially the composition of forest litter, its decomposition and the amount and quality of matter originating in this process. A source of nutrition for the primary production of trees is another direct way how the tree species influence the soil condition and development. These factors mostly have an influence on the top soil horizon, i.e. they mostly determine the character and the development of humus forms (Green et al. 1993). The vegetation type and the litter quality seem to be of higher importance for soil microbial activity than substrate quality on the reclaimed spoil heaps (Šourková et al. 2005). Different soil-forming potentials of tree species are utilized in the restoration of degraded sites of forest ecosystems. They are generally called methods of biological amelioration of soil (Melzer et al. 1980; Podrázský et al. 2003). The status of tree growth on the reclamation plots and their pedogenetic influence appear as a significant indicator of reclamation success.

MATERIAL AND METHODS

Biological activity of the soil after spoil-bank forest reclamation was investigated in the years 1998–2000 in six localities. The localities representing young forest reclamation at an early stage of the formation of anthropogenic soil and the localities representing older forest reclamation (approximate age of 30 years) were chosen. After a five-year break the soil-forming process was evaluated in 2005 and 2006.

For the evaluation of soil biological activity, samples were taken from two horizons in the chosen localities: 0–150 mm and 150–300 mm.

Research localities

Střimice A spoil bank – forest reclamation with grey clays and addition of Tertiary sands. This locality was planted by sycamore maple (*Acer pseudoplatanus* L.) into the prepared soil surface (cellulose fibres and peat addition in a dose of 400 t/ha, medium ploughing) in 1997. The permanent monitoring plot was numbered as 1, the soil samples were marked as number 1 and 2.

Střimice B spoil bank – forest reclamation with grey clays and addition of Tertiary sands. In 1993, the locality was planted by black alder (*Alnus glutinosa* Gaertn.) and sycamore maple (*Acer pseudoplatanus* L.) into the prepared soil (bark substrate addition in a layer of 50 mm). After the plantation, the stands were fertilized with a dose of 30–50 g NPK to each plant in 1995 and 1998. The permanent monitoring plot was numbered as 2, the soil samples were marked as number 3 and 4.

Lobkovic spoil bank – forest reclamation with clays, slope soils and mudflows. In 1970 this locality was directly planted by different forest tree species into the spoil bank material, it was black alder (*Alnus glutinosa* Gaertn.) at the place where soil samples were taken. The care of the plantation was repeated in three-year intervals (repair planting, hoeing, and fertilization with NPK in a dose of 30–50 g per plant, cleaning). This area was handed over by the company Lesy České republiky, s. p. (Forests of the Czech Republic, state enterprise) in 1996. The soil samples had number 5 and 6.

Rač locality – a natural area with naturally developed and formed forest soil. The Rač hill is mostly built of phonolite, which is changed to puffstone rocks by weathering (the pedogenic substrates of heavy basic soils). The soil samples were marked as number 7 and 8.

Žichlice spoil bank – forest reclamation with loess loams probably with addition of grey Tertiary clays. In the area of soil observations, the technical reclamation started in 1996 and in 1997. The surface was prepared before planting with cellulose fibres and with sewage from waste-water treatment plants of Štětí Paper Factory in the amount of 200 t/ha with the subsequent application into the depth of 150 to 200 cm. The plants of oak (*Quercus* sp.), maple (*Acer pseudoplatanus* L.), lime (*Tilia* sp.) and black alder (*Alnus glutinosa* Gaertn.) were set out at this site. The soil samples were marked as number 9 and 10.

Lochočice spoil bank – forest reclamation with post-Tertiary loess loams with Tertiary grey clays. The planting with common birch (*Betula verrucosa* Ehrh.) and maple (*Acer pseudoplatanus* L.) was realized directly into the unprepared spoil bank substrate in 1996 in the area where soil samples were taken. In 1997 and 1998 the plants were hoed and fertilized with three SILVAMIX (slow-released fertilizer) tablets to each plant. Additional care of the culture consisted in hoeing and mechanical and chemical (ROUNDUP) weed control and game protection. The soil samples were marked as number 11 and 12.

All biotransformations in soils are connected with enzyme activities as biocatalyst. That is why research on the activity of soil enzymes was conducted in many countries (Kiss et al. 1993, 1996, 1998) and therefore the activities of three soil enzymes were included in this research:

– catalase activity – the information about oxidation-reduction processes (Ambrož 1956),
– invertase and phosphatase activity – to find out the level of hydrolytic processes (Tabatabai, Bremner 1969; Frankenberger, Johanson 1983).

Mineralization activity was also studied using a respirometric test (Novák, Apfeltaler 1964) in four variants:

– basal respiration,
– potential respiration with amendment NH_4^+, glucose, NH_4^+ + glucose.

In addition, these characteristics were also determined:

– C_{ox} (Sims, Haby 1971),
– total N,
– granularity,
– soil reaction (pH_{H_2O}).

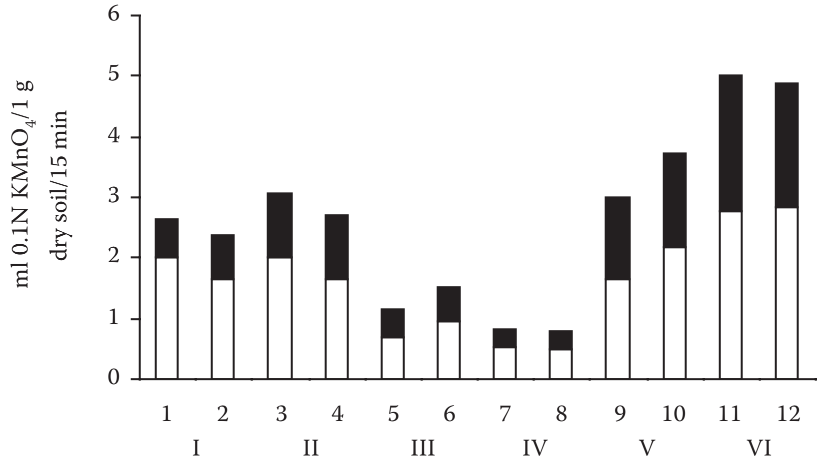
The samples were adjusted by sieving and the closed cases were stored for 2–3 months in a refrigerator (3–6°C).

The status of nutrition was monitored on the basis of bioelement determination in assimilatory tissues of the particular species.

Statistical evaluation of the parameters of soil biological activity was calculated by the analysis of variance (ANOVA), by multiple comparison (Scheffe) using the statistical software SPSS.

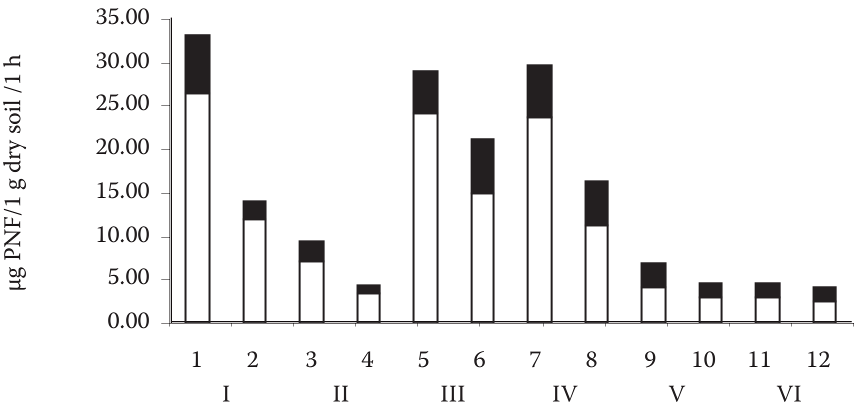
RESULTS AND DISCUSSION

Catalase activity of soil (informing about oxidation-reduction processes in soil; Fig. 1)



■ standard deviation	0.64	0.71	1.08	1.04	0.45	0.57	0.29	0.29	1.34	1.55	2.23	2.06
□ average	2.00	1.66	2.00	1.65	0.69	0.95	0.52	0.49	1.66	2.17	2.78	2.83

Fig. 1. Catalase activity of soil on reclamation plots



■ standard deviation	6.71	2.03	2.25	1.02	4.86	6.23	5.09	2.92	1.65	1.47	1.60
□ average	26.42	12.04	7.22	3.38	24.14	14.99	11.19	4.07	3.07	3.07	2.46

Fig. 2. Phosphatase activity of soil on reclamation plots

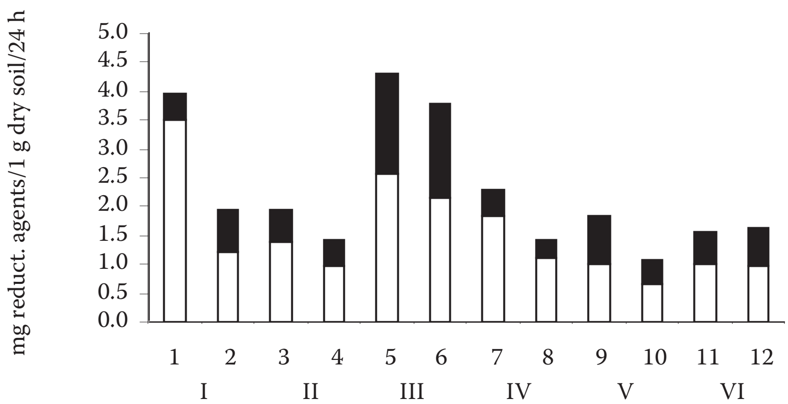
The lowest value was determined in unspoiled natural forest soil in Rač locality (locality IV, sample 7 and 8) with statistically significant differences for all young reclamations (localities I, II, V, VI). The low catalase activity of soil was also found at the oldest observed reclamation of Lobkovic spoil bank (locality III, sample 5 and 6, statistically significant difference from locality VI). Quite a clear trend is presented by a fact that the highest values of catalase activity of soil were found at young reclamations aged 1–6 years from their establishment (locality V and VI, samples number 1–4).

Similar results were described in the catalase activity of agricultural (ploughing) soils and anthropogenic soils of agricultural reclamations (Šíša et al. 2000) where the lowest catalase activity was determined in ploughing soil in a good condition and at the most successful agricultural reclamation of soil, on the contrary, the highest catalase activity was detected at the least successful agricultural reclamation of soil.

From this point of view, catalase activity of soil appears to be a suitable indicator to check the level of soil degradation and degree of its revitalization.

Invertase and phosphatase activity of soil (informing about hydrolytic processes in soil; Figs. 2 and 3)

The results of determination of these parameters show that the maximum level of hydrolytic processes was in the surface horizon of Střimice reclamation (locality I, sample 1) which was enriched within the establishment by ploughing in cellulose fibres and peat addition. Statistically significant differences were confirmed between the invertase and phosphatase activity of Střimice reclamation and the other young reclamations (locality II, V, VI). Quite a high value of invertase and phosphatase activity was found in the older Lobkovic reclamation of soil (locality III, samples 5 and 6) and also in the naturally formed and developed forest soil in Rač, natural reserve (locality IV, samples 7 and 8). Differences from locality II, V, and VI were statistically significant



■ standard deviation	0.48	0.73	0.56	0.43	1.71	1.61	0.46	0.29	0.82	0.4	0.57	0.66
□ average	3.49	1.2	1.4	0.98	2.58	2.16	1.83	1.12	1.02	0.66	0.99	0.96

Fig. 3. Invertase activity of soil on reclamation plots

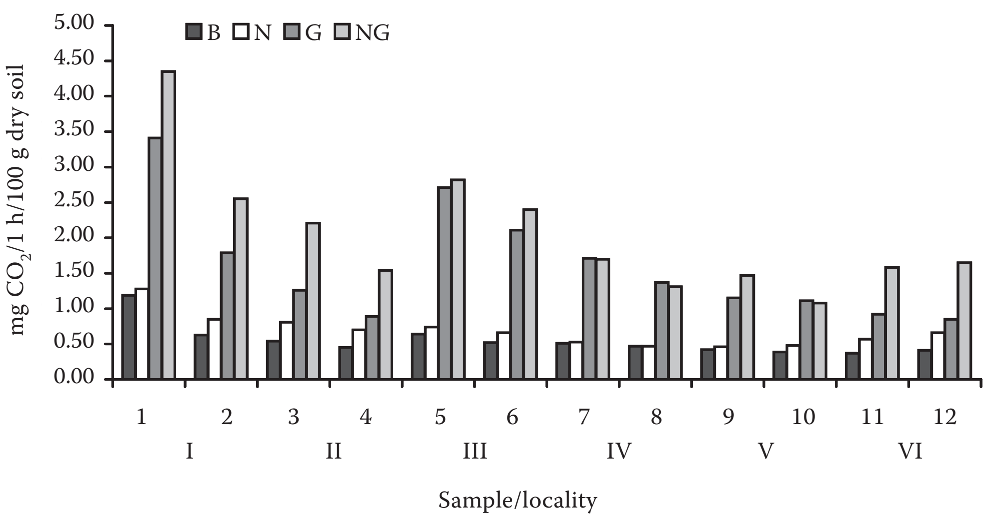


Fig. 4. Basal and potential respiration of soil on reclamation plots
B – basal respiration, N – potential respiration with N addition, G – potential respiration with glucose addition, NG – potential respiration with N and glucose addition

again. The lowest level of hydrolytic processes was determined in young forest reclamations, i.e. spoil banks Lochočice (locality IV, samples 11 and 12) and Žichlice (locality V, samples 9 and 10).

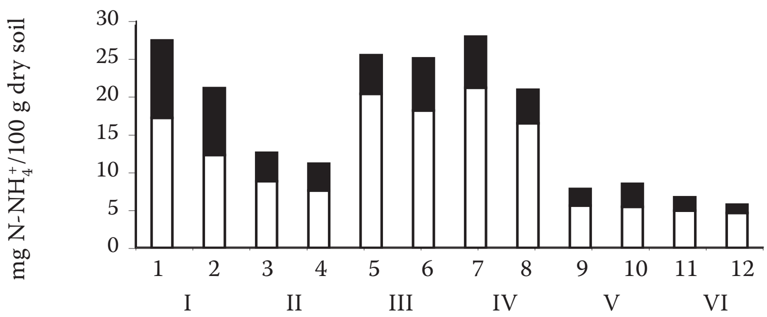
Respirometric tests (providing information about microflora mineralization activity; Fig. 4)

The highest values of basal respiration with statistically significant differences in the top soil layer from the other localities were determined in Střimice reclamation (locality I, samples 1 and 2). At the other localities the basal respiration was approximately on the level of natural forest soil in Rač natural area. The lowest values of basal respiration were measured in the soil samples of Žichlice and Lochočice spoil banks (locality V and VI). The level of basal respiration on the older forest reclamations was higher than in case of fresh agricultural reclamations in the Most region (Růžek et al. 2003). On the other hand, it was lower than in humus layers in forest stands (Formánek, Vranová 2003).

The determination of C_{ox} carbon content also corresponds with these results, the highest content was found in the surface horizon of Střimice reclamation (locality I) and older Lobkovic reclamation (locality III). The lowest values of C_{ox} were measured in the samples of young reclamations of localities I, VI, VII.

From the aspect of the potential ability of soil microflora to utilize easily available sources of N and C it is possible to say that the influence of the addition of an easily available source of N on respiration was very small. The potential ability of soil microflora to react to the addition of an easily available source of C as well as to the combination of easily-available sources of C and N was markedly higher. The increased respiration of Lobkovic (locality III) and Střimice (locality I) spoil banks confirmed it. A slightly lower potential respiration was observed in the Rač natural area (locality IV). The lowest potential ability of soil microflora was again in the youngest reclamations of Žichlice and Lochočice spoil banks (locality V and VI).

The respiratory ratio NG:B provides information about the stability of soil organic matter. The maxi-



■ standard deviation	10.3	8.88	3.78	3.56	5.13	6.92	4.42	2.23	3.08	1.78	1.12
□ average	17.3	12.3	8.88	7.67	20.4	18.2	16.6	5.66	5.48	4.98	4.69

Sample/locality

Fig. 5. Actual ammonification on reclamation plots

mum value of this ratio was determined in the older soil reclamation of Lobkovic spoil bank (locality III); on the other hand, minimum stability of soil organic matter was detected in the Rač natural area (locality IV).

Ammonification tests (provide an overview of the level of mineralization processes taking place in soil while the intensity of soil microflora activity can be considered in this way).

The highest actual content of N-NH_4^+ (actual ammonification, Fig. 5) was determined in forest soil samples of Rač natural area (locality IV), in the older soil reclamation of Lobkovic spoil bank (locality III) and further in Střimice reclamation, where cellulose fibres and peat addition were applied before planting. Positive effect of pulp wastes and sewage sludge addition on the content of NH_4^+ in the top-soil was confirmed also from the other reclaimed sites (Růžek et al. 2003). Again, the lowest one was in the samples of the spoil bank reclamations Žichlice and Lochočice (locality V and VI – statistically significant differences).

The highest potential ammonification was in Střimice reclamation (locality I), Žichlice reclamation (locality V) and further in Lobkovic reclamation (locality III), the lowest ammonification was found out in the natural soil of Rač area (locality IV).

The results of actual ammonification correspond with the total content of nitrogen. The organic soil matters are an important depot of nitrogen for plant nutrition. Its formation and maintenance of its stable level are fundamental problems in anthropogenic soils. The rate of mineralization and nitrogen release depend on the C:N ratio of decomposed material. If this ratio is wider than 20, ammonium is not released into the air because it is used by the soil microflora for its own biomass formation. During the decomposition of organic matter the level of carbon is decreased by CO_2 production, so the ratio C:N is getting narrower. If it reaches the value 10, mineralization is connected with the release of ammonium into the air. A wider ratio of C:N was found in the spoil bank soil of Lochočice (locality VI) and both Střimice reclamations (locality I and II) where the ratio exceeded 20:1. On the contrary, the narrowest ratio was found in Žichlice spoil bank (locality V) where it was equal 10:1. These results correspond with the results reported by Hýsek and Hejdová (1997), who evaluated the anthropogenic soil reclamation of spoil banks in the area of the town of Most by similar tests. They found out a broken C:N ratio, low content of the main nutrients and also lower populations of soil microflora and a low level of the processes under way.

The soil reaction also belongs to the basic characteristics of the observed soil (Fig. 6). An unambiguous gradient was found at the evaluated sites. The lowest pH value approximately 4.35, with statistically significant differences from all other localities, was recorded in Rač natural area (locality IV), followed by slightly alkaline or alkaline reactions (pH between 7.5 and 8.1) in older reclamations and other localities of young reclamations. This high pH values correspond with data from the other reclaimed soils in the Most region (Růžek et al. 2003). From this aspect, the environment was markedly unnatural for the growth of domestic forest tree species (Andersson et al. 2004). Development of the pH value between the first and the second monitoring period documents a gradual decrease in the soil reaction on the research plots (approximately about 0.5 degree after 5 years). Similar decreasing time trend in pH development was confirmed also from the other reclaimed sites in the North Bohemian Krušnohorská Basin (Šourková et al. 2004).

Nutrition status of forest plantations

The nutrition status of tree species follows from the determined content of biogenic elements in assimilatory tissues (Table 1). The content of available nitrogen and magnesium in soil is a frequently

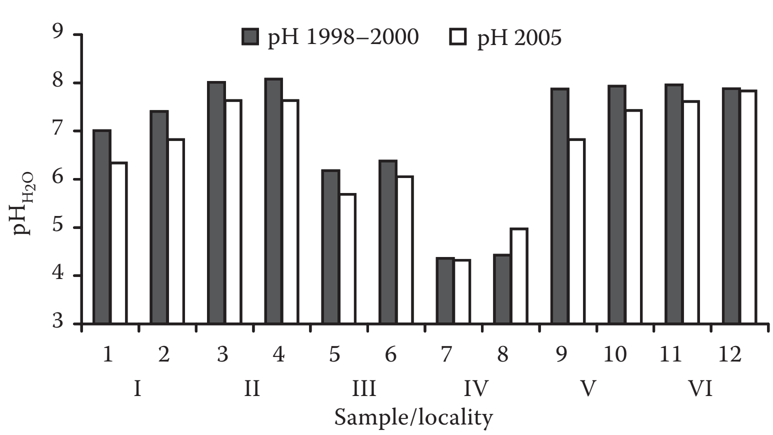


Fig. 6. Soil reaction on reclamation plots in the period 1998–2000 and in 2005

Table 1. Nutrition status of different tree species on reclamation plots (mg/kg)

Spoil bank	Species	Year	N	P	K	Ca	Mg
Střimice	*Acer*	2000	6.16	0.78	5.20	15.10	4.230
Střimice	*Alnus*		16.02	1.46	8.10	6.40	4.250
Střimice	*Acer*		10.66	1.00	8.00	13.70	4.160
Žichlice	*Tilia*		11.60	2.44	12.00	12.80	2.880
Lochočice	*Betula*		13.06	1.36	8.20	10.60	3.860
Střimice	*Acer*	2005	10.60	2.08	4.95	6.33	2.090
Střimice	*Alnus*		19.20	1.81	6.15	1.50	1.544
Střimice	*Acer*		9.50	2.57	5.31	6.67	2.064
Žichlice	*Tilia*		14.70	1.70	6.84	5.71	1.631
Lochočice	*Betula*		11.50	2.66	4.05	4.31	2.161

limiting factor for the growth of forest trees. In the selected localities, the content of magnesium (and calcium) is sufficient or even surplus from the aspect of species nutrition. The content of these elements exceeded the limit values several times and it approached the level identifying the toxic content of these elements in soil. This status corresponds with very high (alkaline) pH on the reclamation plots.

The content of potassium and phosphorus, and nitrogen as well, seems to be less deficient (except the lime tree at locality V). In this connection the positive amelioration influence of alder was confirmed (from the aspect of its ability to fix the air nitrogen). In the same locality the content of nitrogen in assimilatory tissues of alder is almost three times higher compared to its content in maple leaves (Fig. 7). Important positive amelioration and stand-forming potential of alder was documented also from the other devasted sites (Podrázský et al. 2003).

CONCLUSION

Since 1998 the research project has been focused on the evaluation of biological activity of soil and development of new forest stands on forest reclamation plots in the area of the North Bohemian coal basin. Localities representing young reclamations (age of 7–12 years), older reclamations (age of 35 years) and also a place of the entire forest in the natural area Rač were chosen. The selected indicators of enzyme activity of soil (catalase, invertase and phosphatase activity), basal and potential respiration, actual and potential ammonification, pH, C_{ox} and total nitrogen were analyzed. From the aspect of these indicators, the anthropogenic soil of older forest reclamation (locality III – Lobkovic spoil bank), which was established in 1970, is the closest to natural forest soil. The forest soil of Smiřice spoil bank reclamation (locality I), which was established in 1997 and its top horizon was enriched with organic matter before the

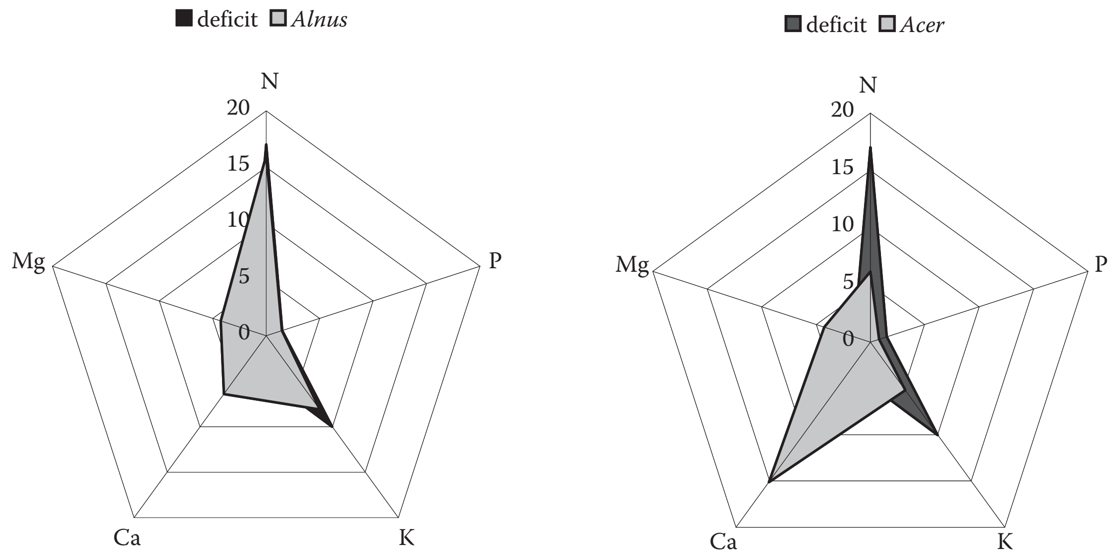


Fig. 7. Nutrition status of sycamore maple and black alder on Střimice spoil bank (locality I)

plantation by ploughing in cellulose fibres and peat addition, has also developed relatively favourably. The reclamations shortly after the establishment of spoil bank reclamation Žichlice (locality V) and Lochočice (locality VI) have the lowest biological activity of soil.

The development of plantations was always observed on the research plots at a place where the soil samples were taken. The results confirmed that the use of black alder seems to be an advantage in first stage of forest reclamation, both from the aspect of quick formation of vegetation cover of reclamation plots and from the aspect of soil-forming and amelioration process. Growth and stand formation of sycamore maple were relatively fast. It is a species suitable for forest reclamation in the area concerned, but it is often damaged by game. The common birch is mostly used as a pioneer species which is able to grow in very bad conditions. Considering a small amelioration function and a low stand-forming potential, it is necessary to complement the tree species composition of pioneer stand by other suitable climax species. The found status of nutrition shows a slight deficiency of some elements (N, P, and C) and a significant surplus of calcium and magnesium.

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Biologická aktivita antropogenních půd po lesnické rekultivaci výsypek

ABSTRAKT: Příspěvek dokládá výsledky výzkumu revitalizace půd výsypek v Severočeském hnědouhelném revíru po první tříleté periodě sledování. Jako indikátory tohoto revitalizačního procesu byly použity: biologická aktivita půdy (konkrétně katalázová a fosfatázová aktivita), ukazatelé bazální a potenciální respirace půdy, amonifikace. Stav půdy úzce souvisí s výživou lesních porostů. Ta byla hodnocena na základě rozborů makroelementů v asimilačním aparátu dřevin. Všechny uvedené parametry byly stanovovány na pěti lokalitách různě starých rekultivací při použití odlišných technologických postupů a vysazených dřevin. Výsledky potvrzují výraznou časovou závislost revitalizačních procesů. Starší rekultivace jsou z hlediska biologické aktivity půdy nejblíže půdě přirozeně vzniklé. Obohacení svrchních vrstev půdy směsí celulózových vláken a rašeliny před výsadbou sazenic se projevilo zvýšením některých parametrů biologické aktivity půdy. Při volbě dřevin byl potvrzen pozitivní meliorační účinek olše.

Klíčová slova: zalesňování; lesní porosty; respirace; amonifikace; enzymové aktivity; meliorace

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