Chemical and biological characteristics of reclaimed soils in the Most region (Czech Republic)

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ABSTRACT

Soil organic carbon content [C_{org}], pH_{H_2O}, pH_{KCl} and microbiological characteristics (microbial biomass carbon [C_{MB}], extracellular microbial carbon [C_{EX}], respiration, ammonification, and nitrification) were studied in 11 reclaimed soils, where the technical reclamation was carried out by Most Coal Mining Company in the year 2000 or 2001. These soils were immediately sown with legumes and grasses. C_{org} content in soil was rather wide ranging between 0.15–4.82%. The lowest value was determined in loess applied in the year 2001 at the locality No. 6 Mine Most, and the highest one at the locality No. 5 Mine Most amended with pulp wastes and sewage sludge (400 t and 200 t per hectare, respectively). pH_{KCl} was in the range: 5.1–7.4. Six indicators of microbial status and metabolic activity of living micro-organisms, were used for the evaluation of the reclamation technology, i.e. (1) µg C_{MB}/g dry soil, (2) µg C_{EX}/mg C_{MB}, (3) ratio C_{MB}/C_{org} in per cent (4), potential respiration with glucose, (5) potential ammonification with peptone, (6) potential nitrification with $(NH_4)_2SO_4$. The best results were found in the locality No. 5 Mine Most (reclaimed in 2000) amended with pulp wastes and sewage sludge (400 t and 200 t per hectare, respectively). The lowest values characterised the locality No. 1 Mine Slatenice (reclaimed in 2000) with a high content of coal powder and the lowest pH_{KCl} (5.1). The use of mycorrhizal inoculum SYMBIVIT resulted in a high biological activity in the locality No. 11 Mine ČSA that was the best among soils reclaimed in 2001.

Keywords: reclaimed soils; microbial biomass; extracellular microbial carbon; respiration; ammonification; nitrification; mycorrhizal inoculum; pulp wastes; sewage sludge

In Europe, ecosystems on mine-sites represent a rare example of de novo ecosystem development. As expected, it has been found that biocoenosis of ecosystems on mine-sites does not function entirely differently from comparable ecosystems on adjacent non-mined sites. Major differences, however, occur on sites with extreme substrate conditions such as spoil materials containing pyrite and/or geogenic, lignitic carbon. However, when these extreme sites are ameliorated chemically and planted with forest trees, pedogenesis and biocoenosis could be viewed as pointing towards normal development that occurs in comparable but non-mined forest areas (Hüttl and Bradshaw 2001).

The evaluation of reclaimed soils on the sites where coal mining was terminated is possible using several methods. Some authors (Harris and Birch 1989, Bentham et al. 1992, Růžek 1994, Dušek et al. 1997, Škoda et al. 1997, Voříšek et al. 1997, Šíša et al. 2000, Růžek et al 2001) preferred microbiological methods such as microbial biomass carbon determination, respiration, ammonification, nitrification, enzyme activities etc. Other authors concentrated on the soil organic matter content and its influence on the changes of physical characteristics of reclaimed soils (Insam and Domsch 1988, Delschen and Necker 1995, Hüttl 1997, Tenholtern et al. 1997, Trasar-Cepeda et al. 1997). Biological methods are very often used for the study both in contaminated soils (Mühlbachová and Růžek 2000, Mikanová et al. 2001, Mühlbachová 2001, Wyszkowska et al. 2002a, b) and in undisturbed soils (Kolář et al 2000).

The aim of this study was to determine the variability of important biological criteria after different amendments to reclaimed soils during the initial phase of reclamation.

MATERIAL AND METHODS

Soil samples were collected in the years 2001 and 2002 at eleven sampling sites reclaimed by Most Coal Company Inc. Samples were taken from the profile (0–200 mm) using the sampler *Eijkelkamp agrisearch equipment*. Soil samples were transported in a cooling box (temperature 6–12°C) and were subsequently adjusted, sieved (mesh 2 mm), and stored in a refrigerator (4–6°C). 24 hours before the analyses, the samples were pre-incubated at room temperature (22 ± 2°C).

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Several tests were used for the soil samples characterisation and microbial activity determination (additionally, several ratios were calculated): organic carbon (C_{org}, Sims and Haby 1971), pH (H_2O), pH (KCl), microbial biomass carbon (C_{MB}, Blagodatskiy et al. 1987), microbial extracellular carbon (C_{EX}, Badalucco et al. 1992), basal respiration, potential respiration with ammonium sulphate, potential respiration with glucose (Novák and Apfelthaler 1964), potential ammonification with peptone (Pokorná-Kozová et al. 1964), potential nitrification with ammonium sulphate (Löbl and Novák 1964).

List of localities

Locality No. 1: Mine Slatenice, field MaP, reclaimed in 2000, acid locality (pH_{KCl} 5.1) high content of coal powder
Locality No. 2: Mine Slatenice, field VP, reclaimed in 2000, acid locality (pH_{KCl} 5.4) medium content of coal powder
Locality No. 3: Mine Slatenice, field MeP, reclaimed in 2000, acid locality (pH_{KCl} 4.7) high content of coal powder
Locality No. 4: Mine Slatenice, loess, reclaimed in 2001, coal powder overlaying by loess
Locality No. 5: Mine Most, loess amended with pulp wastes (400 t per hectare) and sewage sludge (200 t per hectare), reclaimed in 2000
Locality No. 6: Mine Most, loess, reclaimed in 2001
Locality No. 7: Mine Most, loess, reclaimed in 2000
Locality No. 8: Mine Most, original non-reclaimed yellow clays with a higher content of aluminium
Locality No. 9: Mine ČSA, field VP, reclaimed in 2000
Locality No. 10: Mine ČSA, field MaP, reclaimed in 2000
Locality No. 11: Mine ČSA, reclaimed in 2001 and amended with SYMBIVIT (powder inoculum with five species of genera *Glomus* – vesicular-arbuscular mycorrhizal fungi)

Soil management

After the technical reclamation, the amendments mentioned above were added and the experimental fields were sown with a mixture of grasses and legumes: red clover *Trifolium pratense* L. (57%), white clover *Trifolium repens* L. (14%), bluegrass *Dactylis glomerata* L. (29%).

Results (four replications) were statistically evaluated using analyses of variance (multiple range test) including Fisher *LSD* method.

RESULTS AND DISCUSSION

Soil organic matter carbon (C_{org}) in soil ranged between 0.15–4.82% (Table 1), the lowest value was found in pure loess applied in the year 2001 in the locality No. 6 Mine Most with a very limited plant growth. A similarly low content of C_{org} (0.46%, 0.66%) was again characteristic for Mine Most localities No. 7 respectively No. 8. The amendment with pulp wastes and sewage sludge (400 t and 200 t per hectare, respectively) resulted into the highest C_{org} content in the locality No. 5 Mine Most. Probably, this treatment contributed to the best status of the experimental site.

Microbial biomass carbon (C_{MB}) is a very important indicator of the living part of soil organic matter and it therefore belongs to the most used criteria for the soil evaluation. The average C_{MB} content in the topsoil profile (0–200 mm) was determined as 372–499 µg/g dry soil (Růžek 2001) and in the reclaimed soils 404 ± 150 µg/g dry soil. Similar data for the top-soil profile were published by Robertson et al. (1993).

Our experimental sites were characterised by a wide range of C_{MB}: 0–1716 µg C_{MB}/g dry soil (Table 2). The locality No. 5 where pulp waste and sewage sludge were

Table 1. Chemical parameters of reclaimed soils (2001–2002)

Locality	C_{org} (%)	SO[a] quality (E 400/E 600)	$N\text{-}NH_4^+$ (mg/100g dry soil)	$N\text{-}NO_3^-$ (mg/100g dry soil)	pH (H_2O)	pH (KCl)
1. Mine Slatenice, field MaP[e]	4.36 ± 1.81	6.93	5.1 ± 4.1	15.6 ± 17.0	5.4	5.1
2. Mine Slatenice, field VP[e]	4.47 ± 2.10	6.76	1.8 ± 0.3	21.2 ± 23.5	5.9	5.4
3. Mine Slatenice, field MeP[e]	4.65 ± 1.29	6.88	6.4 ± 0.0	3.5 ± 3.4	5.2	4.7
4. Mine Slatenice, loess[f]	1.32 ± 1.40	5.79	5.4 ± 1.7	21.6 ± 24.0	8.0	7.2
5. Mine Most, pulp wastes + sewage sludge[b, e]	4.82 ± 1.83	7.10	40.4 ± 23.8	10.2 ± 3.0	7.4	7.1
6. Mine Most, loess[f]	0.15 ± 0.12	7.43	1.7 ± 1.2	1.7 ± 1.4	7.8	6.9
7. Mine Most, loess[e]	0.46 ± 0.08	6.32	5.3 ± 3.4	1.7 ± 1.3	7.8	6.9
8. Mine Most, non-reclaimed yellow Al-clays	0.66 ± 0.35	7.36	14.4 ± 14.3	2.8 ± 1.4	6.6	6.1
9. Mine ČSA, field VP[e]	2.61 ± 0.27	5.36	15.3 ± 2.8	32.9 ± 37.0	7.8	7.2
10. Mine ČSA, field MaP[e]	3.26 ± 0.82	6.08	25.6 ± 2.9	61.8 ± 69.5	7.9	7.3
11. Mine ČSA, SYMBIVIT[f]	1.63 ± 0.43	5.29	4.7 ± 2.7	54.0 ± 61.0	7.9	7.4
LSD[d] $d_{\alpha\ min}$ 0.05 (0.01)	1.72 (2.31)		12.47 (16.76)	46.24 (62.12)		

[a]soil organic matter, [b]pulp wastes (400 t) + sewage sludge (200 t) per hectare, [c]mean ± standard deviation, [d]Fisher's Least Significant Difference, [e]technical reclamation was finished in 2000, [f]technical reclamation was finished in 2001

Table 2. Biological parameters of reclaimed soils

Locality[c]	C_{MB}[a] (µg/g)			EX-MB (µg C_{EX}[b]/mg C_{MB}[a])			Ratio C_{MB}/C_{org} (%)		
	2001	2002	mean	2001	2002	mean	2001	2002	mean
1. Slatenice	316.7 ± 38.7	382.1 ± 47.4	349.4 ± 51.7	343.1 ± 59.4	360.0 ± 41.6	351.6 ± 43.0	1.13	0.64	0.89
2. Slatenice	793.7 ± 38.7	449.1 ± 85.3	621.4 ± 206.2	147.8 ± 0.2	243.2 ± 46.2	195.5 ± 61.2	2.99	0.71	1.85
3. Slatenice	238.5 ± 16.6	412.2 ± 137.5	325.4 ± 128.3	347.1 ± 82.1	271.7 ± 142.3	309.4 ± 104.4	0.67	0.72	0.69
4. Slatenice	46.9 ± 11.1	365.3 ± 33.2	206.1 ± 184.9	85.7 ± 20.2	197.8 ± 11.5	141.7 ± 66.1	4.48	1.44	2.96
5. Mine Most	1372.4 ± 5.5	1716.0 ± 104.3	1544.2 ± 207.3	59.1 ± 3.3	99.9 ± 10.2	79.5 ± 24.4	4.24	2.68	3.46
6. Mine Most	70.4 ± 11.1	114.0 ± 37.9	92.2 ± 34.0	43.8 ± 26.5	323.7 ± 222.1	183.7 ± 206.9	15.68	4.43	10.06
7. Mine Most	191.6 ± 5.5	221.2 ± 28.4	206.4 ± 23.9	87.3 ± 38.6	145.1 ± 18.7	116.2 ± 41.6	4.86	4.14	4.50
8. Mine Most	0.0	103.9 ± 14.2	51.9 ± 60.5	0.0	236.9 ± 43.8	118.4 ± 139.1	0.00	1.09	0.54
9. Mine ČSA	774.2 ± 0.0	288.2 ± 0.0	531.2 ± 280.6	49.2 ± 1.8	98.8 ± 24.7	74.0 ± 32.0	2.72	1.21	1.96
10. Mine ČSA	899.3 ± 44.2	650.2 ± 37.9	774.8 ± 147.7	40.5 ± 9.7	70.0 ± 0.4	55.0 ± 17.7	3.52	1.63	2.58
11. Mine ČSA	277.6 ± 5.5	311.7 ± 52.1	294.6 ± 36.1	59.7 ± 13.7	128.6 ± 59.5	94.2 ± 53.2	2.22	1.56	1.89
LSD[d] $d_{\alpha\ min}$ 0.05 (0.01)		101.4 (137.8)			135.1 (183.6)			3.18 (4.28)	

[a]microbial biomass carbon (Blagodatskiy et al. 1987), [b]microbial extracellular carbon (Badalucco et al. 1992), [c]see Table 1

applied had a significantly higher content of C_{MB} in both years. The application of available carbon resulted in an intense development of soil microbial associations. We supposed that in the future the decrease of C_{MB} should follow but the favourable situation in the microbial soil status will continue. Similarly, a significantly high level of C_{MB} was found in locality No. 10 Mine ČSA where pulp waste and sewage sludge had also been applied (80 t, respectively 40 t per hectare). Probably these amendments caused that this locality ranked in the second position behind the locality No. 5 according to the six biological criteria (Table 4).

Five localities reached the average level of C_{MB} (295–621 µg/g dry soil), which is close, both to our former results (404 ± 150 µg/g dry soil, Růžek 2001) and to the average of all eleven localities evaluated in this experiment (454 ± 429 µg/g dry soil). The high level of the standard deviation is very logic because of the high variability of C_{MB}, which was mentioned above.

The last four localities (Table 2) were characterised by a significantly low C_{MB} level (52–206 µg/g dry soil). Especially non-reclaimed yellow Al-clays at the locality No. 8 Mine Most reached the lowest measured value (52 µg/g dry soil), which is typical for a bad-quality subsoil. Also, shortly after the application, the pure loess (No. 6 Mine Most) had a low content of microorganisms.

The accumulation of the extracellular extractable carbon (C_{EX}) of microbial origin (Badalucco et al. 1992, Růžek 1994, 1995) related to 1 mg C_{MB} (µg C_{EX}/mg C_{MB}) marked the inability of soil microbial associations to utilise their own

Table 3. Soil biological activity

Locality[a]	Basal respiration[b]	Potential respiration[b] with $(NH_4)_2SO_4$	Potential respiration[b] with glucose	Potential ammonification[c] with peptone	Potential nitrification[d] with $(NH_4)_2SO_4$
1. Mine Slatenice	0.27 ± 0.09	0.36 ± 0.03	0.67 ± 0.02	64.63 ± 0.52	2.50 ± 2.65
2. Mine Slatenice	0.35 ± 0.10	0.60 ± 0.20	0.90 ± 0.05	76.83 ± 28.03	6.41 ± 6.96
3. Mine Slatenice	0.52 ± 0.14	0.74 ± 0.24	0.95 ± 0.22	71.38 ± 58.43	1.82 ± 1.76
4. Mine Slatenice	0.37 ± 0.15	0.55 ± 0.24	1.30 ± 0.64	141.78 ± 52.97	11.59 ± 12.82
5. Mine Most	0.66 ± 0.59	0.75 ± 0.53	2.55 ± 2.03	194.87 ± 70.32	177.28 ± 141.82
6. Mine Most	0.21 ± 0.20	0.43 ± 0.05	0.83 ± 0.09	63.44 ± 6.14	3.66 ± 3.64
7. Mine Most	0.19 ± 0.14	0.47 ± 0.03	0.91 ± 0.12	98.35 ± 42.12	4.97 ± 4.83
8. Mine Most	0.23 ± 0.03	0.30 ± 0.02	1.05 ± 0.77	73.65 ± 26.17	3.52 ± 3.73
9. Mine ČSA	0.65 ± 0.27	1.05 ± 0.58	1.88 ± 1.11	263.98 ± 107.04	234.72 ± 268.88
10. Mine ČSA	0.36 ± 0.17	0.67 ± 0.44	1.67 ± 1.14	205.87 ± 52.16	112.82 ± 94.41
11. Mine ČSA	0.67 ± 0.25	0.99 ± 0.29	3.42 ± 1.78	161.81 ± 11.71	89.98 ± 95.61
LSD[e] $d_{\alpha\ min}$0.05 (0.01)	0.34 (0.46)	0.44 (0.60)	1.44 (1.92)	73.57 (98.85)	144.37 (193.95)

[a]see Table 1, [b]mg CO_2/h/100g dry soil (Novák and Apfelthaler 1964), [c]mg N-NH_4^+/24 h/100g dry soil (Pokorná-Kozová et.al. 1964), [d]mg N-NO_3^-/8 days/100g dry soil (Löbl and Novák 1964), [e]Fisher's Least Significant Difference

extracellular metabolites. The explanation for this situation, which is typical for reclaimed soil may be the stress that induced the death of the soil microbial population.

The usual level (Růžek 2001) of this parameter in topsoil (0–200 mm) is 81–110 µg C_{EX}/mg C_{MB}, in reclaimed soils 140 µg C_{EX}/mg C_{MB}. The wide range of 5–352 µg C_{EX}/mg C_{MB} (Table 2) indicates a different quality of the reclamation process. Especially in two localities (Mine Slatenice, No. 1, 3), where microbial associations had been stressed by a high content of coal powder, we found extremely high levels: 352, respectively 309 µg C_{EX}/mg C_{MB}. In contrast, favourable values lower than 95 µg C_{EX}/mg C_{MB} characterised four localities; on two of them pulp wastes and sewage sludge had been applied, one had been treated with mycorrhizal inoculum SYMBIVIT.

The third biological criterion, the ratio C_{MB}/C_{org} (Table 2) used for the evaluation of the sites tested specified three localities No. 5–7 (Mine Most) with a higher level of living part of soil microbial associations. Our results have shown that the value of this ratio may be problematic in soils with extremely low level of C_{org} (No. 6, 7). In such a situation, the high ratio cannot indicate a higher microbial activity in soil. On the other hand, the locality No. 5, where pulp wastes and sewage sludge were applied, with the level of the ratio C_{MB}/C_{org} (3.46 ± 0.91%), should be appreciated positively. Spoil materials (yellow clays, locality No. 8) containing aluminium were absolutely the worst (0.54 ± 0.63%). A similarly bad situation was found with the substrates having a high content of coal powder (No. 1, 3).

Microbial metabolic activities are very often tested by means of mineralisation of carbon organic substances. The average level of basal respiration (Novák and Apfeltaler 1964) of topsoil (0–200 mm) was 0.50 ± 0.26 mg CO_2/h/100 g dry soil, potential respiration with ammonium sulphate is slightly higher (110% of basal respiration) on the soils where nitrogen is not a limiting factor. Potential respiration with glucose in the microbial active soils reaches approximately 700% of basal respiration.

The available nutrients could be a limiting factor for the successive microbial development. The level of basal respiration (0.41 ± 0.28 mg CO_2/h/100 g dry soil) was slightly lower (Table 3) which is typical for freshly reclaimed soils. The response to respiration on nitrogen amendment was remarkable (154% of basal respiration) and is logically connected with a low level of available nitrogen in reclaimed soils. The amendment with glucose stimulated the respiration (361% of basal respiration) but the response was not as high as expected. This result is probably connected again with the lack of nitrogen which limits glucose mineralisation.

Mycorrhizal inoculum SYMBIVIT (locality No. 11) had a positive effect on all measured respiration activities: basal (165%), ammonium sulphate (244% of basal respiration, 158% of average of respiration with ammonium sulphate), glucose (842% of basal respiration, 234% of average of respiration with glucose). There were seventeen significant increases in respiration activity in the frame of thirty comparisons which it was possible to do.

Table 4. Ranking based on six biological criteria[1]

1.	Mine Most, pulp wastes + sewage sludge, 2000 (5)[2]
2.	Mine ČSA, field MaP, 2000 (10)
3.	Mine ČSA, field VP, 2000 (9)
4.	Mine ČSA, SYMBIVIT, 2001 (11)
5.	Mine Most, loess, 2000 (7)
6.	Mine Slatenice, loess, 2001 (4)
7.	Mine Slatenice, field VP, 2000 (2)
8.	Mine Most, loess, 2001 (6)
9.	Mine Most, original non-reclaimed yellow Al-clays (8)
10.	Mine Slatenice, field MeP, 2000 (3)
11.	Mine Slatenice, field MaP, 2000 (1)

[1]six biological criteria:
1. µg C_{MB}/g dry soil (C_{MB} – microbial biomass carbon)
2. ratio C_{MB}/C_{org} (%)
3. µg C_{EX}/mg $C_{MB.}$ (C_{EX} – extracellular microbial carbon extractable by 0.5 mol/l K_2SO_4)
4. potential respiration with glucose
5. potential ammonification with peptone
6. potential nitrification with $(NH_4)_2SO_4$

[2]locality number

Yellow Al-clays (locality No. 8) which were very often characterised as the worst were surprisingly quite active in the potential respiration activities. According to the basal respiration they should be marked as non-active but the reaction on nutrient amendment was adequate (ammonium sulphate 133%, glucose 462%) which is the sign of vitality of the soil microorganisms.

The content of NH_4^+ in the top-soil reached in our former experiments 18 ± 6 mg N-NH_4^+/100 g dry soil. The reclaimed soils tested (Table 3) were characterised by a wide range of ammonia N content (1.75–40.43 mg N-NH_4^+/100 g dry soil), statistically significant differences were found between marginal values. Two highest values belong to the localities where pulp wastes and sewage sludge were applied (No. 5, 10); there are statistically significant differences between seven localities characterised by low levels of ammonium content. These two localities were evaluated by the six criteria as the best ones (Table 4).

The content of NH_4^+ after the amendment with peptone (potential ammonification) in the top-soil reached in our former experiments 180 ± 50 mg N-NH_4^+/24 hours/100 g dry soil. Potential ammonification in the six localities of the reclaimed soils tested (Table 3) was very low (63.44–98.35 mg N-NH_4^+/24 hours/100 g dry soil), four localities were close to the average level and in one locality (No. 9) was this activity significantly higher. These five localities with high-potential ammonification activity agree with the evaluation by the six criteria (Table 4).

In our former experiments, the content of nitrates in topsoils was 2 ± 2 mg N-NO_3^-/100 g dry soil. This level was found in four localities, others were characterised by higher content (Table 3).

Potential nitrification is very often used as an indicator of soil microbial activity. In our tests, we used the amendment with ammonium sulphate and the usual content of nitrates was 12 ± 10 mg N-NO_3^-/8 days/100 g dry soil. Only one locality (No. 4) reached the average, six localities were at the bottom (1.82–6.41 mg $N\text{-}NO_3^-$/8 days/100 g dry soil) of the average range, and four localities were characterised by a very high potential nitrification activity. It is important that five localities with high nitrification activity had also high potential ammonification activity and they belong to the top ranking localities evaluated by the six criteria (Table 4).

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ABSTRAKT

Chemické a biologické charakteristiky rekultivovaných půd na Mostecku

U jedenácti půd, technicky rekultivovaných v letech 2000 a 2001 Mosteckou uhelnou společností (MUS, a. s.) a bezprostředně poté osetých leguminózami a trávami, byl sledován uhlík půdní organické hmoty [C_{org}], pH_{H_2O}, pH_{KCl} a mikrobiologické charakteristiky (uhlík biomasy půdních mikroorganismů [C_{MB}], extracelulární uhlík mikrobního původu [C_{EX}], respirace, amonifikace a nitrifikace). C_{org} se nacházel v extrémně širokém pásmu 0,15–4,82 %, nejnižší hodnota byla zjištěna v čisté spraši, aplikované v roce 2001 na lokalitě No. 6 Lom Most, a nejvyšší na lokalitě No. 5 Lom Most, na kterou byla v roce 2000 po technické rekultivaci aplikována krátká celulózová vlákna (400 t/ha) a kaly z čistírny odpadních vod (200 t/ha). Půdní reakce se nacházela v pásmu 5,1–7,4 (pH_{KCl}). K evaluaci úspěšnosti rekultivačních technologií bylo použito šest indikátorů stavu půdních mikrobních společenstev a jejich metabolické aktivity: (1) µg C_{MB}/g sušiny, (2) µg C_{EX}/mg C_{MB}, (3) poměru C_{MB}/C_{org} v procentech, (4) potenciální respirace s glukózou, (5) potenciální amonifikace s peptonem, (6) potenciální nitrifikace s $(NH_4)_2SO_4$. Nejlepší stav byl nalezen na lokalitě No. 5 Lom Most a nejhorší na lokalitě No. 1 Lom Slatenice (technicky rekultivované rovněž v roce 2000) s vysokým obsahem uhelného prachu a nízkým pH_{KCl} (5,1). Přídavek mykorrhizního inokula SYMBIVIT významně podpořil biologickou aktivitu půdy na lokalitě No. 11 Lom ČSA a zařadil ji v evaluaci podle šesti kritérií na první místo mezi lokalitami technicky rekultivovanými v roce 2001.

Klíčová slova: rekultivované půdy; mikrobní biomasa; extracelulární mikrobní uhlík; respirace; amonifikace; nitrifikace; mykorrhizní inokulum; papírenské odpady; čistírenské kaly

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