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APPLICATION OF MINERAL FERTILIZERS FOR FOREST RECLAMATION OF MINE SPOILS IN POLAND

ZYGMUNT STRZYSZCZ

Institute of Environmental Engineering, Polish Academy of Sciences, ul. M. Curie-Skłodowskiej 34, 41-819 Zabrze

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ZASTOSOWANIE NAWOŻENIA MINERALNEGO W REKULTYWACJI LEŚNEJ ZWAŁOWISK GÓRNICZYCH W POLSCE

W bezglebowej rekultywacji odpadów górniczych decydująca rola przypada doborowi odpowiednich dawek i form nawozów mineralnych. Dotyczy to szczególnie azotu, gdzie określoną rolę odgrywają formy mineralne, jak i organiczne. Wpływ na relację pomiędzy poszczególnymi formami ma skład petrograficzno-mineralny, procesy wietrzeniowe odpadów na zwałowisku, a także skład chemiczny i relacje pomiędzy głównymi pierwiastkami takimi, jak: wapń, magnez, sód i potas. Nie bez znaczenia są wprowadzone na zwałowiska gatunki drzew i krzewów, bowiem zapotrzebowanie na poszczególne składniki przez różne gatunki może być inne. Jak wykazały badania, decydujące o powodzeniu rekultywacji biologicznej są przeważnie pierwsze 2–3 lata i związane są głównie z nawożeniem azotem. Nawożenie fosforem odgrywa ważną rolę w okresie późniejszym, zaś potasem jest zbędne, bo odpady zawierają znaczne ilości potasu ogólnego, a także wymiennego i rozpuszczalnego w wodzie.

Summary

Suitable doses and forms of mineral fertilizers play a significant role in soil-less reclamation of mining wastes. It concerns especially nitrogen, because in this case its mineral and organic forms play a definite role. The relationship between each form is affected by a petrographic and mineral composition, weathering processes of waste material on the waste heaps, and also chemical composition and relationship between the main components, such as calcium, magnesium, sodium and potassium. Very important are also tree and shrub species introduced on the heaps, as different species can be characterized by individual nutrient requirements. The investigations showed that the period of first 2–3 years determines the success of interventions in biological reclamation. This refers mostly to nitrogen. Phosphoric fertilization plays an important role in later period, while potassium fertilization is not necessary, because waste material contains considerable quantities of total, and also of exchangeable and dissolvable in water potassium.

INTRODUCTION

In 2001 the area of hard-coal heaps in Poland exceeded 3,000 ha of which the central spoil heaps share amounted to over 1,160 ha. A production of 1 Mg of coal is accompanied by 0.4–0.5 Mg of wastes. During reclamation of coal heaps primary attention was paid to pioneer species whose occurrence on the heaps was connected with natural succession, namely birch, aspen, alder, and robinia. These species formed the main group practically for all afforestations. Apart from these, the target species as a biocenotic admixture like larch, ash, maple, oak, and sycamore were presented. According to the presence of the latter in afforestation a shortage of nitrogen was observed manifested by chlorotic decolouration of leaves and needles. This was due to a small stake in afforestation of trees species able to self-supply nitrogen compounds in the way of symbiosis with nodule bacteria or by mycorrhiza. At the same time an occurrence of nitrophile plants on such type of heaps was observed by many authors who testified to a rich supply of nitrogen compounds in the ground [9, 22–24]. Atmospheric precipitation rich in nitrogen was assumed to be the main source of nitrogen. If this is true, the nitrophilic vegetation should be presented on a significant area of the heaps, however, this phenomenon was observed only in a few sites.

The change in the concept of heap management (central heaps, mainly) towards dominant share of so-called target species in afforestation required explanation of the problem of nitrogen content in wastes and its effect on high vegetation introduced onto spoil heaps. The results of investigation presented in this paper aim to explain the following issues:

- content of total nitrogen in wastes differing in petrographic composition;
- share of mineral and organic nitrogen forms in wastes;
- effect of these forms on nutritional relations of spoil bed;
- factors influencing absorption of these compounds by plants;
- role of mineral fertilization in forest reclamation of spoil heaps.

It was noted that little attention was paid to these issues in all investigations devoted to biological reclamation of spoil heaps in both Europe as well as in the United States.

The first papers on the use of mineral fertilization in process of forest reclamation of mining-spoil heaps were published in 1973–1974 [12, 15, 32, 35, 41]. Somewhat earlier investigations on a role of mineral fertilization in the process of introduction of grasses onto spoil heaps were carried out. It should be noticed that phosphorous fertilization was preferred. In works with trees and shrubs slug, bone meal and other wastes were used [8, 11, 13, 17, 18, 36]. Wiggering investigated the problem of nitrogen forms in mining wastes again [38].

MATERIAL AND METHODS

Samples of carboniferous formation, such as: sandstone, argillite, and aleurollite as well as many samples of formations from particular mines and argillite deposits connected with the process of coal flotation were collected from central spoils to determine the content of nitrogen, its forms and fractions.

Total nitrogen was determined by the Kiejdahl method, and content of NO_3^- and NH_4^+ in water extract or 2 N KCl. Particular nitrogen fractions were determined by the Fleig method [1, 2, 21]. The contents of N-aminoacids and NH_4 in hydrolyzate were determined by the aminoacids analyzer BC-201. The concentration of heterocyclic nitrogen was calculated as the difference between total nitrogen and nitrogen hydrolyzed [2]. Organic carbon was determined by the Tiurin method including Fe^{2+} content [3]. The sorption of NH_4 was carried out according to the method recommended by Lityński [26]. Reduced size wastes sieved by 0.25 mm screen were taken for investigation.

RESULTS AND DISCUSSION

As seen in Table 1, the content of total nitrogen ranges from 0.022% to 0.088%, from 0.039% to 0.431%, and from 0.039% to 0.700% in sandstone, aleurollites, and argillite, respectively. Smaller differences in total nitrogen content are found in so-called aleurollite deposits, where it ranges from 0.384% to 0.618%. Significantly less oscillation in total nitrogen contents are observed in upper spoil layers (Tab. 2 and 3). Table 1 shows a great effect of organic substances on content of total nitrogen. This regards mainly aleurollites, and argillites and not always sandstones where at contents of organic both concentrations

Table 1. The content of total N and organic C in carboniferous waste material

Sample number	Place of sampling	Material	Total C %	Total N %	C/N
1	Central dump „Smolnica"	Sandstone	17.00	0.039	436
2	„	„	15.5	0.034	456
3	Central dump „Brzezinka"	„	2.38	0.035	68
4	Central dump „Przezchlebie"	„	2.77	0.087	32
5	„	„	3.65	0.033	111
6	„	„	6.27	0.067	94
7	„	„	0.59	0.022	27
8	„	„	2.77	0.088	32
9	Coal Mine „Debieńsko"	„	6.00	0.034	176
10	Central dump „Brzezinka"	Aleurollite	23.34	0.431	54
11	Central dump „Przezchlebie"	„	0.18	0.056	3
12	Central dump „Smolnica"	Aleurollite/Argillite	1.58	0.039	41
13	„	„	1.17	0.045	26
14	Central dump „Brzezinka"	„	1.78	0.062	29
15	Coal Mine „Debieńsko"	„	17.3	0.128	135
16	„	„	17.7	0.113	157
17	„	„	23.8	0.295	81
18	Central dump „Smolnica"	Argillite/Aleurollite	21.92	0.039	562
19	„	„	3.69	0.066	56
20	„	„	13.8	0.297	46
21	Coal Mine „Radzionków"	„	0.55	0.053	10
22	Central dump „Smolnica"	Argillite	14.67	0.064	229
23	„	„	3.86	0.101	38
24	„	„	16.92	0.353	48
25	„	„	20.64	0.415	50
26	Coal Mine „Szczygłowice"	„	10.36	0.075	138

Table 2. The content of total N and mineral forms in dumped mining wastes on the central dump in „Smolnica"

Sample number	Nitrogen content in mg/100 g				$N\text{-}NH_4/N\text{-}NO_3$	Mineral N as a % of total N
	N	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4 + N\text{-}NO_3$		
1	295	0.86	0.5	1.36	1.7	0.46
2	360	0.78	0.5	1.28	1.6	0.36
3	417	1.33	0.16	1.39	8.3	0.33
4	275	0.78	0.32	1.1	2.4	0.4
5	333	1.79	0.5	2.29	3.6	0.69
6	376	1.33	0.5	1.83	2.7	0.49
7	295	0.39	0.79	1.18	0.5	0.4
8	305	3.74	3.28	7.02	1.1	2.3
9	320	2.81	1.64	4.45	1.7	1.39
10	297	1.95	1.98	3.93	1.0	1.32
11	278	1.11	0.12	1.23	9.0	0.44
12	315	1.16	0.16	1.32	7.3	0.42
13	293	1.16	0.32	1.48	3.6	0.51
14	315	1.16	0.32	1.48	3.6	0.47
15	368	1.45	0.16	1.61	9.1	0.44
16	350	2.03	0.16	2.19	12.7	0.63
17	293	1.37	0.16	1.53	8.6	0.52
18	187	1.45	0.67	2.12	2.2	1.13
19	330	1.09	0.5	1.59	2.2	0.48
20	295	1.16	0.16	1.32	7.3	0.45
21	310	2.31	0.16	2.47	14.4	0.8

of total nitrogen matter of 2.38% and 15.50% are similar. The type of organic matter, its mode of formation and localization in petrographically differentiated wastes contribute to this phenomenon [4]. The contents of mineral forms of nitrogen and particularly nitrates and exchangeable NH_4^+ are of importance in terms of biological management of mining wastes. The investigation carried out in „Przedchlebie" and „Smolnica" central spoil heaps revealed rather low levels; they ranged from trace amounts up to 3.28% mg/100 g $N\text{-}NO_3$, and from 0.39% to 3.74% mg/100 g $N\text{-}NH_4$ for nitrates and exchangeable NH_4^+, respectively. The mean content of mineral nitrogen in wastes ranges from 0.5 to 0.6 mg N/100 g at a $NH_4 : NO_3$ ratio in the range of 0.5 to 17.1 (Tab. 2 and 3).

Mineral nitrogen absorbed by plants even at higher nitrogen level accounts for only about 2% of total nitrogen and the process is greatly influenced by mineralogical composition. When montmorillonites are dominant, the share of mineral nitrogen forms may reach even 25% of total nitrogen [34].

Table 3. The content of total N and mineral forms in dumped mining wastes on the central dump in „Przezchlebie"

Sample number	Nitrogen content in mg/100 g				$N\text{-}NH_4/N\text{-}NO_3$	Mineral N as a % of total N
	N	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4 + N\text{-}NO_3$		
1	266	1.41	0.32	1.73	4.4	0.65
2	273	1.21	0.32	1.53	3.8	0.56
3	224	1.11	0.22	1.33	5.0	0.59
4	259	1.01	0.32	1.33	3.2	0.51
5	266	0.97	0.12	1.09	8.1	0.41
6	276	1.17	0.4	1.57	2.9	0.57
7	266	1.61	0.34	1.95	4.7	0.73
8	284	0.6	0.32	0.92	1.9	0.32
9	385	1.01	0.12	1.13	8.4	0.29
10	301	1.91	0.32	2.23	6.0	0.74
11	252	2.33	0.32	2.65	7.3	1.05
12	263	0.9	0.32	1.22	2.8	0.46
13	280	0.84	0.12	0.96	7.0	0.34
14	224	0.76	0.32	1.08	2.4	0.48
15	189	0.76	0.16	0.92	4.8	0.49
16	224	1.17	0.5	1.67	2.3	0.75
17	266	1.33	0.12	1.45	11.1	0.55
18	252	0.76	0.32	1.08	2.4	0.43
19	255	0.97	0.32	1.29	3.0	0.51
20	245	0.76	0.2	0.96	3.8	0.39
21	238	2.05	0.12	2.17	17.1	0.91

It should be noted that the volume of mineral nitrogen is not able to supply the needs of trees introduced onto a spoil heap for this component because at a content of 0.5 mg/100 g N in 50 cm layer 25 kg/ha can be expected while the nutritional needs of trees are significantly higher, approximately 50–80 kg/ha [6]. In practice, symptoms of nitrogen shortage among trees introduced onto spoil heaps are observed. This mainly considers first three years after their introduction onto heaps.

However, there is a significant quantity of so-called non-exchangeable absorbed nitrogen (Tab. 4). It includes non-exchangeable NH_4 ion absorbed by some clay minerals and organic substance [5, 28]. This fraction accounts for 26% to 83% of total nitrogen. In common opinion this fraction is weakly taken in by plants. Lack of investigations of this nitrogen fraction released from wastes makes it impossible to assess the importance of this nitrogen source in terms of biological reclamation of spoil heaps. It is only known that with both time and acidification of heaps resulting from the weathering processes the increase in quantity of this fraction is observed [14].

Table 4. The content of nitrogen forms in carboniferous wastes

Sample number	Rock tips	C total (%)	N total (mg/ 100 g)	Content of N – fractions				
				$N\text{-}NH_4$ fixed	$N\text{-}NH_4$ exchange able	N – hydrolyzable		N – non-hydrolyzable (mg/100 g)
				(mg/100 g)		(mg/ 100 g)	including amino acid	
1	Argillite	10.36	75	2.7	62	56	3.00	19
2	,,	39.56	700	2.1	183	49	1.31	651
3	,,	10.87	201	2.3	78	81	1.22	120
4	,,	5.74	185	3.3	92	90	1.25	95
5	,,	0.11	43	11	25	43	18.2	0
6	Argillite/Aleurollite	0.55	53	4.3	29.5	53	9.12	0
7	Argillite	23.34	431	2.8	123	46	2.2	385
8	Aleurollite	0.18	56	1.4	32.6	35	1.43	21
9	Sandstone	2.77	88	1.2	31	27	7.67	61
10	Argillite	20.64	415	8.3	154	87	3.85	328

Organic nitrogen is the predominant nitrogen fraction in wastes. In terms of spoil heaps management the quantity of nitrogen being hydrolyzed is of importance because this quantity is a store of nitrogen compounds released through the weathering process, and mainly due to microorganism's activity. This investigation revealed differences among wastes in contents of particular fractions of organic nitrogen (Tab. 4). The higher the organic substances quantity the higher the total nitrogen contents which are observed. In such cases, heterocyclic nitrogen makes up a significant part of the total nitrogen, 79–93% in samples 2, 7, and 10 (Tab. 4). It is nitrogen bound with aromatic compound rings such as pyridine or nicotinic acid [16]. However, the quantity of organic substance is not always the main factor influencing quantity of heterocyclic nitrogen which is confirmed by the data of Table 4 referring to samples 1 and 3. At a similar quantity of organic substance the share of heterocyclic nitrogen amounts to 25% and about 58% in samples 1 and 3, respectively. The influence of the organic substance type in these cases is evident. No heterocyclic nitrogen in bentonite formations of „Radzionków" mine were found (samples 5 and 6). Nitrogen is completely hydrolyzed and at the same time significant quantity of N-aminoacids is detected (more than 40%). Therefore the presence of wastes containing montmorillonites in total mass located onto central spoil heaps is profitable in terms of biological reclamation. Also, an unfavourable C : N ratio is limited by nitrogen absorption (Tab. 1).

Apart from the above-mentioned factors influencing nitrogen distribution on spoil heaps, such as: petrographic and mineralogical composition of wastes, content and type of organic substance, content of total nitrogen and particular forms and fractions of nitrogen, other factors which also determine the possibility of adsorption of nitrogen compounds by plants should be taken into consideration when discussing nutritional relations existing in heap beds. The main candidates for this are pH value, sorption capacity of formations in relation to NH_4^+ and level of non-exchangeable sorption in this process, as well as the share of remaining cations in the sorptive complex.

It is well known that along with a pH value drop below 5.5 ammonium ions are worse sources of nitrogen when compared to nitrates. This also is true for trees [19]. During the spoil heaps weathering their gradual or rapid acidification is observed [34]. Consequently in the reclamation process ammonium nitrate fertilizers will be better nitrogen source for plants.

Table 5 presents the sorption capacity of particular formations in relation to NH_4^+. The table reveals significant differences and it should be taken into consideration when the system of bed fertilization in biological reclamation process is elaborated. No current data describing the level of non-exchangeable sorption of NH_4^+ by different heap formations exist. The differences result from the content of particular clay minerals, degree of formations weathering, their structure and ordering, and contribution of organic substance capable of sorption of NH_4^+ from solutions [10].

Table 5. NH_4^+- sorption by different carbonic rocks

Sample number	Type of rock	NH_4 – sorption	Proportion of some minerals in % of the total content of clay minerals			
			Kaolinite	Illite	Montmorillonite	Chlorite
1	Argillite	8.66	40	50	–	10
2	”	9.00	50	35	–	5
3	”	10.53	55	30	10	5
4	”	7.03	60	30	–	10
5	”	4.03	80	15	–	5
6	”	34.4	60	30	–	10
7	”	35.00	15	10	75	–
8	Argillite/Aleurollite	21.6	25	15	45	15
9	Aleurollite	9.2	40	35	5	20
10	Silty sandstone	5.2	60	25	–	15

A significant quantity of sodium (soluble and exchangeable) is probably of importance when sorption of NH_4^+ introduced onto heaps with mineral fertilizers is analyzed [34], because sodium reduces sorption of NH_4^+ by plants [40]. Under specific conditions potassium can play such a role in relation to NH_4^+ adsorbed in non-exchangeable way [25].

The above-mentioned factors essentially influence the sorption of particular forms of mineral nitrogen supplied onto heaps as mineral fertilizers. This is confirmed by field investigation carried out with different doses and forms of nitrogen on spoil heaps „Przezchlebie" and „Smolnica" [32].

HEIGHT INCREMENT OF TREES UNDER NITROGEN FERTILIZATION

All trees species introduced onto the spoil heap „Przezchlebie" responded positively to nitrogen fertilization. Differences in preference for nitrogen fertilization increase along with age of particular species. The increment in the third year is three times higher in the case of nitrogen fertilization. In 1973 a smaller increment was observed, when compared to

1972, on the site where nitrogen fertilization was not used. This refers mainly to both ash species and maple increments which were significantly smaller than in the previous year, as well as durmast whose mean increment was minimal in 1973 (Tab. 6). This does not apply to larch. In 1973 it was probably caused by weather conditions and mainly a draught period in August as well as low precipitation in autumn 1972 (57 mm in period of October – September 1972). It may also be concluded that in the particular case we are able to prevent or alleviate the adverse effect of draught on growth of introduced tree species using nitrogen fertilization. As seen in Table 6 the increment on the non-fertilized plot was in 1972, according to species, higher than in 1972 from 0.82 cm to 9.30 cm. It should be credited to an accumulation in heap material of some amount of mineral nitrogen forms NH_4^+ and NO_3^- originated from atmospheric precipitation as well as the weathering processes of heap material. In the absence of succession and biological sorption they can be used by introduced trees species. However, in the third year, when the need for nitrogen increases, its quantity available in heap material is too small to cover nutritional requirements of trees which are thus manifested by lack of trees increment.

Table 6. The mean increase in height (in cm) of tree species from the experimental area in „Przezchlebie" (non-fertilized and fertilized by nitrogen)

Tree species	1971		1972		1973	
	without N	with N	without N	with N	without N	with N
Fraxinus excelsior	2.26	2.76	4.02	4.94	2.56	11.91
Fraxinus americana	7.91	10.73	13.08	21.5	8.33	29.73
Acer pseudoplatanus	4.42	8.35	13.72	20.5	3.92	27.29
Quercus rubra	2.89	4.48	3.71	6.24	–	22.53
Quercus robur	3.43	4.9	4.75	10.45	5.05	10.75
Larix europaea	–	–	5.88	9.7	17.17	37.26
mean	4.18	6.24	7.53	12.22	7.41	23.25

HEIGHT INCREMENT OF TREES ACCORDING TO FORM OF NITROGEN FERTILIZATION

As seen from the data presented in Table 7 no significant differences between mean increments of tree species introduced onto heaps according to fertilization form in first two years are observed ($p < 0.90$). This is confirmed by calculating significance of mean differences. However, already in the second year the highest and the lowest increments in height were observed at nitrate form of mineral fertilization and ammonium and ammonium nitrate form, respectively. This trend is continued in the third year and differences in height increment according to nitrogen form are significant ($p = 0.9$–0.99). The above-mentioned trend is also observed when minimum and maximum increments of introduced tree species are analyzed according to the form of nitrogen fertilization (Tab. 8). The maximum and minimum mean increments were calculated from maximum and minimum increments of 5 or 6 tree species fertilized with one of the nitrogen forms. The data obtained show that already in the first year the maximum increment is observed in the case of nitrate form of fertilization. Moreover, very extensive range between maximum and minimum increment caused mainly by bed variation and adaptability of particular species and individual trees introduced onto spoil heaps is observed.

Table 7. The mean increase in height (in cm) of tree species from the experimental area in „Przezchlebie" depending on nitrogen forms

Tree species	Nitrogen forms																	
	non-fertilized			ammonium			nitrate			ammonium-nitrate			urea			urea + PK		
	1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
Fraxinus excelsior	2.26	4.02	2.56	3.41	4.58	9.68	3.44	6.37	24.14	1.93	5.74	7.34	1.86	2.69	7.4	3.18	5.3	10.98
Fraxinus americana	7.91	13.08	8.33	11.24	22.28	26.8	8.74	31.31	44.16	8.27	14.43	21.28	13.44	20.43	28.84	11.98	19.04	27.57
Acer pseudoplatanus	4.42	13.72	3.92	6.84	14.12	26.3	6.39	20.72	39.29	8.59	24.18	27.11	11.22	22.84	18.41	8.71	20.66	25.32
Quercus rubra	2.89	3.71	50.5	3.63	4.91	7.32	2.65	6.23	17.54	3.77	5.53	8.5	5.36	7.25	9.6	6.00	7.27	10.78
Quercus robur	3.43	4.75	–	4.76	8.98	13.38	4.54	11.97	37.73	3.01	4.75	–	5.74	11.55	16.92	6.44	12.36	26.24
Larix europaea	–	5.88	17.17	–	7.85	34.74	–	12.38	47.9	–	8.36	37.51	–	9.28	34.74	–	10.64	32.88
mean	4.18	7.53	7.41	6.18	10.54	19.7	5.15	14.83	35.13	5.11	10.94	20.82	7.26	12.55	19.32	7.26	12.56	22.3

Table 8. The mean minimal and maximal increase in height of tree species depending on fertilization

		1971	1972	1973
without N	min	0.52	1.1	1.9
	max	21.42	21.11	17.46
NH_4	min	1.48	1.92	2.4
	max	19.1	28.91	48.22
NO_3	min	0.58	2.92	7.43
	max	25.46	40.53	73.98
Urea	min	1.16	2.18	5.03
	max	23.7	32.18	58.46
Urea + PK	min	0.96	2.9	3.95
	max	20.8	39.21	45.81
NH_4NO_3 + PK	min	0.64	2.65	2.45
	max	18.84	27.63	48.15

In 1973 a distinct prevalence of the saltpetre form over others is observed. Evidently worse was the nitrate form and in particular ammonium nitrate. This is probably by exchangeable sorption of NH_4^+ ion by kaolinite-illite carboniferous aleurollites and argillites which limits the use of the ammonium form of nitrogen by vegetation introduced. As it already mentioned, the share of illite in argillite and aleurollite mass can reach 20% and among clay minerals it can reach even 50% [32]. Such a concept is also supported by observation of minimum mean increment of trees grown on ammonium nitrate in 1973. It is well known that ratio between both nitrogen forms in ammonium nitrate is more or less the same. Ammonium form was probably adsorbed non-exchangeable and vegetation used only the ammonium nitrate form i.e. not 100 kg N/ha but 50 kg, only.

Earlier investigation has shown that the ammonium nitrate form is most intensively washed out from 50 cm layer [33]. During 10 months from dose of 100 kg N/ha, at the sum of precipitation amounted to 540 mm, the following amounts of this component were washed out (in kg/ha):

calcium nitrate	10.0
ammonium nitrate	4.5
ammonium sulphate	2.5
urea (in bituminous envelope)	1.7
agramid	0.0

Despite this, the increments were the highest on this form. This was likely influenced by the type of fertilizer used: namely calcium nitrate was applied. Therefore, in addition to nitrogen, calcium in soluble form was supplied for introduced species which at shortage of the element in wastes can positively affect tree increment (Tab. 9).

Table 9. Chemical characteristic of mine spoil substances on the „Smolnica" tip in %

	Sample							
	1	2	3	4	5	6	7	8
Hygroscopic water	1.52	1.75	1.76	1.43	1.2	1.23	1.2	1.79
Loss due to burning	20.81	37.06	51.83	14.42	14.15	13.37	9.02	37.48
CO_2	1.36	0.6	0.47	0.00	0.00	0.41	0.31	0.97
S	0.27	0.34	0.64	0.3	0.29	0.01	0.12	1.01
SO_3	0.12	0.12	0.12	0.00	0.00	0.15	0.12	0.38
FeO	2.69	1.07	0.8	1.52	1.23	1.34	1.34	2.51
Fe_2O_3	1.16	0.41	0.77	0.45	0.51	0.52	0.99	0.69
SiO_2	44.87	34.6	26.13	50.23	50.48	52.34	55.8	33.87
Al_2O_3	23.49	21.59	15.77	26.07	16.96	36.22	23.76	17.81
TiO_2	0.7	0.41	0.17	0.95	1.03	0.62	0.6	0.65
P_2O_5	0.59	0.14	0.05	0.11	0.1	0.12	0.1	0.11
MnO	0.03	0.00	0.00	0.03	0.02	0.02	0.03	0.04
CaO	0.05	0.03	0.05	0.06	0.00	0.04	0.03	0.48
MgO	1.06	0.65	0.54	1.04	0.97	0.92	1.2	1.24
Na_2O	0.77	0.62	0.52	0.73	0.55	0.39	0.6	0.3
K_2O	2.35	1.85	1.28	3.17	3.21	2.97	4.01	2.22
C	10.36	24.64	39.56	5.74	10.87	4.41	1.75	20.64
N	0.08	0.67	0.72	0.19	0.2	0.3	0.07	0.42
C/N	130	37	55	30	54	15	25	49

The results of three-year-experiment show significant differences in the increment in height of particular tree species according to a form of nitrogen fertilization. Start of intensive increments of European ash takes place in the third year after introduction and in the case of maple and larch it was observed already in the second year. The differences in increments of both types of oak are also found. The increment of red oak is more intensive and starts in the second year whereas durmast does not reach big increments even in the third year. All introduced species starting from the third year reached maximum increment on a nitrate form of fertilization. In the first year apart from European ash the highest increment was observed using urea form of nitrogen. In the first two years both oak species had the highest increment on urea form of fertilizer with addition of phosphorus and potassium. In the third year, this form takes second place in the promotion of increment.

Table 10. Mean manual growth (in cm) of some tree species on the „Smolnica" tip

Tree species		years						
		1973	1974	1975	1976	1977	1978	1979
Ash	without N	5.5	4.0	13.8	18.3	6.3	6.6	5.5
	with N	3.7	9.8^{xxx}	29.6^{xxx}	32.7^{xxx}	14.9^{x}	17.3^{xx}	10.5
Larch	without N	–	5.8	12.2	15.8	15.1	33.2	29.3
	with N	–	11.2^{xxx}	26.4^{xxx}	30.6^{xxx}	54.2^{xxx}	52.5^{x}	75.9^{xxx}
Total annual rainfall in mm		686.7	844.8	802.2	742.8	950.7	677.1	720.4

$^{x}P = 0.95$
$^{xx}P = 0.98$
$^{xxx}P = 0.99$

Evidently the lowest increments are observed on ammonium and ammonium nitrate fertilizers. As mentioned earlier this is probably caused by the non-exchangeable sorption of NH_4^+ by illite. Plant preferences of nitrogen form of fertilization may be also caused by gradual acidification of heap material. Acidification of environment results in a difficulty to absorb ammonium form of nitrogen [19]. A similar phenomenon was observed on spoil heap „Smolnica" (Tab. 10) at the same time a decline in sycamore increment along with age is caused by an increase in bed acidification. In 1973 pH ranged from 5.8 to 6.2 but in 1979 from 2.8 to 4.5. Acidification leads to mobilization of NH_4^+, NO_3^-, and K which is confirmed by composition of solution collected in lysimeters placed in mining wastes (Tab. 11).

Parallel microbiological investigation has shown the most intensive growth of microflora when urea with the addition of phosphorus and potassium were used [39]. The smallest growth of microorganisms was observed in the case of calcium nitrate, whereas above mentioned increments were the highest. It may be assumed that addition of phosphorus and potassium influences positively the growth of microflora which in turn uses part of the mineral nitrogen in the form of fertilizer for its needs. The increase in biological sorption makes it impossible for tree species to use nitrogen of mineral fertilizers which is pronounced by a low C : N ratio. This explains minimal increments of trees grown on ammonium nitrate fertilizer where NH_4^+ can be non-exchangeable adsorbed and NO_3^- is used by microorganisms.

EFFECTS OF PHOSPHOR-POTASSIUM FERTILIZATION ON INCREMENT OF TREES IN HEIGHT

The effect can be traced by the comparison of increments on plot fertilized with urea and urea with phosphorus addition (50 kg/ha P_2O_5) as superphosphate and 50 kg/ha K_2O in the form of potassium salt (mostly KCl). As seen in Table 12, the effect of fertilization with phosphorus shows up not before the third and fourth year. This regards mainly white ash, maple, red oak, and larch. It can be explained by an increase with age of the needs of trees for phosphorus and potassium. In some cases the increments of trees growing on a bed without the addition of phosphorus and potassium are higher (European ash, red oak in 1974, larch in 1974) which may be caused by variable contents of total phosphorus in

Table 11. Nitrogen and potassium content in the infiltration water of the tip material depending on the pH value

Day of test	9.IV	21.IV	1.V	2.V	21.V
pH	8.2	7.1	4.4	4.5	3.5
NH_4^+	10.0	5.4	27.5	19.8	31.2
NO_3^-	2.4	8.6	4.3	3.9	8.4
K^+	71.0	–	–	–	320.0

Table 12. The mean increase in height (in cm) depending on fertilization

Tree species	urea				urea – superphosphate – potassium salt			
	1971	1972	1973	1974	1971	1972	1973	1974
Fraxinus excelsior	1.86	2.69	7.4	19.15	3.18^{xxx}	5.30^{xxx}	10.98^{xx}	15.43
Fraxinus americana	13.44	20.42	28.84	35.62	11.98	19.04	27.57	48.15^{xxx}
Acer pseudoplatanus	11.22	22.84	18.41	21.3	8.71	20.66	25.32^{xxx}	42.96^{xxx}
Quercus rubra	5.36	7.25	9.6	25.1	6.00	7.27	10.78	25.4
Quercus robur	5.74	11.55	16.92	36.9	6.44	12.36	26.24^{x}	–
Larix europaea	–	9.28	34.74	30.6	–	10.64	32.88	43.98^{xxx}

$^{x}P = 0.80$
$^{xx}P = 0.95$
$^{xxx}P = 0.99$

wastes. As it is seen from Table 9 the amounts of total phosphorus are in many cases sufficient to cover trees needs for this component [20].

Set-back of red oak increment in 1974 can be explained by local acidification which on the one hand, makes it easier to use the total phosphorus, while on the other after exceedance of the acidification limit retards phosphorus compounds and also makes it impossible to use the ammonium form of nitrogen which takes place also in the case of urea.

Acidification due to pyrite weathering changes the economy of macro- and microelements in wastes [4, 9, 29–31].

During the investigation an increase in weed-growth in plots fertilized with phosphorus was found. The following weeds were noticed: sticky groundsel (*Senecio viscosus* L.), groundsel (*Senecio vulgaris* L.), knot-grass (*Polygonum aviculare* L.), daisy fleabane (*Erigeron canadensis* L.), sorrel (*Rumex acetosella* L.).

Fertilization with potassium is unnecessary because of significant current and potential resources of this component in spoil heap formations. It is supported by results of analyses where significant amounts of potassium were found in water extract (5–29 mg K/100 g) as well as amounts determined by the Enger-Riehm method (23–31 mg K/100 g). Also, a high concentration of soluble potassium in 10% HCl was found (0.132–0.380). It is a very high abundance according to German criteria [37]. Richness of potassium compounds in carboniferous formations is caused by the presence of a great quantity of illite. Illite release is accelerated by weathering processes and increases with time in acid environment.

ROLE OF CALCIUM IN RECLAMATION AND MANAGEMENT OF SPOIL HEAPS

As mentioned earlier, shales are poor in calcium compounds and very rich in magnesium and sodium compounds (Tab. 9). On the basis of a 6-year-investigation of target species introduction this fact should be taken into consideration and substances rich in calcium such as ash from electro-filters and furnace wastes should be added onto heaps. The change in heaping technology would be needed while at the same time ashes from power stations and mining wastes should be dumped, particularly in the upper 5 m layer. A treble role would be played by ashes – supply of calcium for plants, neutralization of sulphuric acid formed by pyrite weathering, and counteraction against thermal activity on spoil heaps. It is well known that alkaline compounds are present in ashes mainly in oxide and carbonate forms. The form of calcium fertilizer is of importance due to slightly acid, neutral or even alkaline reaction of spoil heap material. The regulation of the Ca : Na, Ca : Mg, and Ca : Mg/Na ratios guarantees an adroitness, on such type of formations, of species with higher needs for calcium, such as beech, elm, oak, lime, and others [6, 20, 27]. This is very important, particularly when fresh spoil heaps are reclaimed where the advantage of sodium over calcium is manifested also in „soil solution" which is confirmed by concentrations of these elements in water extract as well as in water collected in lysimeters [34].

It can be assumed; that the reason of seedlings failure on newly spoil heaps is not the level of salinification but the types of salts and the antagonism between cations. The role of mineral fertilization on spoil heaps should be seen more broadly, not only in terms of the necessary components supply but also as interference in quantitative and qualitative relations between cations and anions.

CONCLUSIONS

1. Carboniferous wastes placed onto spoil heaps and submitted to biological reclamation show a small content of nitrogen which is one of the basic ecological components of a bed.
2. Plants use of particular forms and fractions of nitrogen from wastes is additionally limited by factors such as: mineralogical composition, significant dynamics of reaction and large quantities of exchangeable sodium.
3. The investigation carried out showed the usefulness of mineral fertilization, nitrogen in particular, in the first three years after trees introduction. This affects not only the growth and development of seedlings but also hardens them to the draught periods and spring frosts.
4. Ash and larch already respond to nitrogen fertilization in the second year after planting. For some species the third year after nitrogen application is crucial. This is true mainly for oak, European ash, and maple.

5. The application of nitrogen fertilizers is the most useful in calcium form, i.e. calcium nitrate and nitro-chalk with respect to a shortage of this element in spoil heap formations.
6. Taking into account bed permeability, the nitrogen dose should amount to 100 kg N/ha in the first year at spring planting with preference of ammonium nitrate form applied generally 2–3 weeks after the planting. In next years, or in autumn trees planting at the same dose, the ammonium nitrate form may be replaced with urea applied in early spring.
7. Phosphorous fertilization should be used in the third and fourth years after planting. Earlier phosphorous fertilization results in weeds growth. Due to a high current and potential level of potassium in wastes it is unnecessary to apply this component with fertilizer.

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