GOSPODARKA SUROWCAMI MINERALNYMI

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Forestation as the method of the remediation of soilless areas of the Lignite Mine Turów

Introduction

In Poland the organized reclamation activities started in mid 1950s, on the waste heaps of the hard coal mining (Skawina 1956; 1958; Greszta 1972). At the beginning forestation was a pioneer form of reclamation activities both in Poland and abroad (Heuson 1928; Skawina 1956; Greszta 1972). With the improvement of the methods of the recognition of the heap formations properties and the techniques of the implementation, reclamation was seen as a process shaping qualitatively new ecosystems (Bender 1995; Krzaklewski 1996).

The basic task of the reclamation of soilless areas is a proper direction of the soil reconstruction process. In the most waste heaps from the open cast mining in Poland, meant to be converted into forests, technical and biological reclamation method is applied. In the first phase melioration of physical and chemical properties of the ground are examined and in the further stage, the function of the formation of soil making processes is passed to properly selected stands of trees. As a result of such measures the overburden formations, often coming from great depths, change their properties in a short time and transform into a productive soil (Siuta 1978). Thus, reclamation is a process of bringing back life on devastated areas. This is quite an accurate expression because heap objects are built not only of the formations without vegetation, but also without humus and organisms participating in the soil forming process. Such formations are often defined as "crude". As a result of reclamation it is necessary to speed up the formation of forest ecosystems, including different biocoenoses. This process develops naturally with a minimum human intervention, limited to

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the stimulation and the correction of certain factors, according to the established goal (Krzaklewski 1996).

1. The goal and methods of studies

The goal of the carried out studies was the assessment of the selected properties of initial soils formed on the reclaimed for forestry waste heap made from the overburden formations characterised with a great compactness and strong acidification. The presented results make a fragment of extensive works carried out by the authors, with the co-operation of the Mine, on the documentation of the process of the formation of a forest ecosystem in post-mining areas of the Mining and Energy Enterprise Lignite Mine (PGE KWB) „Turów". To visualise the soil changes in time, for detailed studies presented in this publication, 4 surfaces were selected. They were forested c.a. 10 and 30 years ago. Taking into account the influence of the species composition of forestations on the soil processes within each age category, the studies were carried out in forestations predominantly composed of destination species (the white birch *Betula verrucosa*, poplar *Populus* 'H-275') and phytomelioration species (the black alder *Alnus glutinosa*). On each experimental field, among the three randomly distributed soil profiles, of the depth up to 60 cm, samples were taken from the levels of the accumulation of organic matter, i.e.: Ol, Ofh and A and from deeper horizons. In the samples, selected physical and chemical properties were determined, according to methods generally accepted in soil science (Lityński et al. 1976).

2. The study object

The studies were carried out in the reclamation forestations, established on the slopes of the external part of the waste heap of the Lignite Mine „Turów" in Bogatynia. This object is of about 2200 ha area and its relative height is about 200 m (470 m a.s.l.). At present the building of the last horizons of the heap was finished and basic reclamation work was done. According to respective administrative decisions, for the whole object a forest option of management was decided. A considerable part of the reclaimed areas (c. 2/3) has already been under the administration of *PGL Lasy Państwowe* (State Forest Holding), forest district Pieńsk, on a part of the heap the reclamation was regarded finished.

2.1. Eco-climatic conditions

The region of KWB „Turów" is in the Sudety (F) ecoclimatic zone, sub-mountainous macroregion. The vegetation period here belongs to the longest in Poland and is 200–220 days and annual sum of atmospheric precipitation ranges from 700 to 800 mm. The region of the heap has a specific microclimate, strongly influenced by the neighbouring mountain

areas, mining excavation and the power station of „Turów". Regarding the nature-forestry classification this area is classed as VII – the Sudety Nature-Forestry Country, the Quarter of the West Sudety, Mezoregion of West-Iserian Foothills. Due to the altitude of the heap, the formed habitats were classified as upland habitats.

2.2. Properties of waste heap formations

The overburden of the "Turów" deposit is built from the Tertiary and Quaternary formations. The dominant ones are Tertiary kaolin loams (c. 90%), which on the predominant part of the heaps make their close to surface layer. According to the soil science nomenclature most of them can be classified to the granulometric sub-group – heavy clay. Sporadically there are formations of the composition of medium clay, dust medium clay or loam. The content of very small particles (< 0.02 mm) is 40–80% with a large participation of the colloidal loam (< 0.002 mm – 20–40%). Due to the granulometric composition and the lack of the structure, these formations can be regarded too compact. Thus, in the initial phase of reclamation they are difficult in cultivation and have unfavourable atmospheric and hydrological properties for the development of plants (Skawina 1958; Wysocki 1988; Krzaklewski, Wójcik 2001). The results of the examinations of the overburden formations showed the occurrence of iron sulfides (pyrites, marcasite and others) in some series of coal-bearing Miocene loams. The majority of them show also a great (1–6%) content of sulphur-containing organic carbon, contained in the fine-grained lignite substance. The content sulphur ranges from 0.07% to 0.6%, reaching maximal values in lignite – c. 1%. The products arising as a result of the process of its oxidation i.e. sulphuric acid and sulphates of aluminium and iron destructively affect the properties of the ground, sometimes causing acidification (pH in KCl < 3.0) and strong phytotoxical properties (Krzaklewski et al. 1997). Too strong acidification directly or indirectly affects negatively the development of higher plants and soil micro-flora. The complicated geological structure of the deposit and non-selective method of disposing overburden cause differences in acidification of the formations – form extremely acid (pH in KCl < 3.0) to strongly alkaline (pH in KCl 3.5–5.0) and sporadically neutral (pH in KCl > 7).

The full assessment of the properties of grounds on waste heaps allows the statement that, potentially, after melioration measures; they will be characterized by a high fertility (Krzaklewski, Wójcik 2001).

2.3. The tasks of the reclamation of waste heap formations

Physical and chemical properties overburden formations KWB „Turów" determine a very high degree of difficulties at the reclamation and cause that the process of making "raw" waste heaps grounds productive requires the application of special integrated technical and agrotechnical phytomelioration measures. On the fields subjected to biological reclamation the series of protective measures is taken: formation of the surface and constructing a drainage

network and roads, neutralization of acidification, agrotechnical measures and introduction of herbal and arboreal vegetation. Multi-component neutralization (calcium oxide, dolomite, phosphates) apart from the liquidation of excessive acidification have also fertilizing function, through the introduction to the ground the lacking nutrients, especially calcium and phosphorus. To neutralize the surface grasses and legume plants (*Fabaceae*) are introduced, and then properly selected trees and shrubs species are grown. The basic task of the vegetation is to secure the surface from erosion and to activate soil-forming processes. The important factor are legume plants (especially large-leaved lupine *Lupinus polyphyllus*) and alder. Due to agrotechnical and phytomelioration measures the plants change unfavourable properties of the formations. Large significance for the success of the reclamation process is also attributed to the cultivation measures such as protecting the young plants from being grazed by animals, mineral and organic fertilization and cultivation cuttings. They stimulate the growth of trees and form a proper structure of species, preventing unfavourable processes that can take place in unstable phytocoenoses. A part of areas on the waste heap, especially of the highest degree of difficulties in reclamation, was "humused", i.e. the layer of humus soil taken from the forefield of the working is brought and distributed over the surface.

The applied on the heap reclamation method is supposed to lead (after basic treatment) to spontaneous reconstruction of main components of the forest ecosystem, with a minimal human intervention (Krzaklewski, Wójcik 2001). Taking into account ecological demands of introducted species of trees and their developmental trends, in the initial phase; such treatment was designed so that biological processes are initiated by providing initial energy dose in the form of organic matter and nutrients. Both mineral and organic fertilization is applied at this stage, as well as multi-directional impact of humus-forming herbal vegetation, especially legume plants. Later on (after c. 5 years) the role of dynamic factor empowering the whole system is attributed to the alder, which, due to the symbiosis with microorganisms binding free atmospheric nitrogen, this rare in the raw waste heaps nutrient can be provided subsequently. The black alder and gray alder, as young trees show great tolerance for the habitat conditions, perfectly fulfilling phytomelioration functions, as well as make a shield for slower growing main species, which in further perspective should form a destination tree stand. Thus the basic factor reconstructing forest environment is a tree stand, as an element forming soil, the microclimate and stimulating the development of soil micro-flora and micro-fauna. Due to the use in the forest stands, the application of the species of genus *Alnus,* fulfilling phytomelioration and protection tasks, the applied method is called „biodynamic" (Krzaklewski 1996).

3. Results and discussion

Formations occurring within the areas covered by the survey have quite homogenous granulometric composition. Definitely predominant are compact heavy clays (tab. 1). The basic process initiating the origin of soils from the overburden formations on the heap, besides

TABLE 1

Selected physical properties of the formations in experimental fields on the external part of the waste heap of the Lignite Mine „Turów"

TABELA 1

Wybrane właściwości fizyczne utworów na objętych badaniami powierzchniach zwałowiska zewnętrznego KWB „Turów"

Experimental Field	Horizon [cm]	Content of particles of the respective diameter [%]				Density [g/cm^3]		General Porosity [%]
		1–0.1	0.1–0.02	0.02–0.002	< 0.002	specific	volume	
Alder 10 years	0–10	24	15	27	34	2.42	1.42	41.3
	10–20	25	15	25	35	2.48	1.50	39.5
	30–60	25	12	25	38	2.51	1.51	39.8
Birch 10 years	0–10	32	15	24	29	2.59	1.34	48.2
	10–20	28	11	28	33	2.60	1.37	47.3
	30–60	30	10	26	34	2.63	1.38	47.5
Poplar 30 years	0–10	31	12	30	27	2.44	1.18	51.6
	10–20	31	12	30	27	2.46	1.19	51.6
	30–60	27	12	31	30	2.44	1.13	53.7
Alder 30 years	0–10	33	16	40	11	2.40	1.07	55.4
	10–20	25	15	31	29	2.49	1.15	53.8
	30–60	29	12	30	29	2.44	1.14	53.3

weathering there is a process of the accumulation of organic compounds witch is relatively quick, although the speed of their mineralization and humification varies on the experimental fields. The development of soil has in this stage an initial character, however they already have morphologic and genetic layers: plant litter (Ol) and overburden humus (Ofh) of total thickness 3–5 cm and the initial humus horizon (A) – on thickness from c. 5 cm to c. 10 cm. Strict marking the borders of the humus horizon is however difficult due to the dark colour of the loams.

Together with the progressing soil-making processes, physical properties of the formations are getting improved. Organoleptically it was also found that the structure of the top 10 cm layer shows the disappearance of compactness and creation of numerous aggregates on the grain and prismatic structure. A significant change is also affecting the chemical properties of the ground. The level of the observed changes shows strict correlation with the time that passed from the reclamation measures and species composition of the forestations.

3.1. Fields reclaimed 10 years ago

The characterized age group is represented by two surfaces with a distinct dominance of species such as black alder (*Alnus glutinosa*) and white birch (*Betula verrucosa*).

In the ground samples taken from the examined fields a significant diminishing of volume density was observed in the upper soil horizons. In the raw formations it usually ranges from 1.6–1.8 g/cm^3, while the horizon 0–10 cm of the examined fields show values 1.3–1.4g/cm^3. Change of the volume density values as well as (although to less degree) proper density consequently leads to the growth of the total porosity of the ground. The value of this property was (respectively to the analysed surfaces) 41 and 48 per cent in the horizon of 0–10 cm and 39 and 47 per cent in the horizon of 20–40 cm. This shows a gradual improvement of air-water balance in strongly compact loams (tab. 1).

In the field with the alder the formed humus has a mull character with weakly marked Oh horizon (c. 3 cm). The pH of this horizon is close to acid (pH in KCl 4.6), which with strongly acid pH of the deeper horizons of the soil profile has an important influence on soil-making processes (tab. 2).

TABLE 2

Selected chemical properties of the formations in experimental fields on the external part of the waste heap of the Lignite Mine „Turów"

TABELA 2

Wybrane właściwości chemiczne utworów na objętych badaniami powierzchniach zwałowiska zewnętrznego KWB „Turów"

Experimental Field	Horizon [cm]	pH		Content of assimilable components [mg/100 g]			Hydrolytic acidity	Exchangeable aluminium
		H_2O	KCl	P_2O_5	K	Mg	[cmol (+)/kg]	
Alder 10 years	Oh	5.1	4.6	17.8	75.1	62.4	21.6	0.18
	0–10	5.2	4.6	1.1	12.8	33.2	7.7	0.16
	10–20	4.5	3.9	0.6	16.3	30.8	10.4	0.88
	30–60	4.7	4.2	0.2	20.7	34.8	8.0	0.35
Birch 10 years	Ol	5.5	5.0	53.6	109.9	31.0	16.90	0.08
	Ofh	5.8	5.4	0.6	11.8	25.3	10.65	0.01
	0–5	4.1	3.5	0.2	14.6	17.9	17.85	2.45
	5–10	4.0	3.3	0.4	15.2	20.0	22.95	1.64
	10–20	4.0	3.3	0.0	13.8	18.4	25.90	2.12
	30–60	4.1	3.2	0.1	14.6	19.6	24.35	2.02
Poplar 30 years	Ol	6.3	5.9	16.0	115.3	66.7	16.87	0.00
	Ofh	5.5	4.7	2.8	44.0	29.8	15.56	0.26
	0–10	4.9	4.0	0.3	27.0	12.1	15.75	2.36
	10–20	4.5	3.6	0.0	23.3	10.0	21.00	3.25
	30–60	4.7	3.9	0.4	21.5	11.8	14.40	2.22
Alder 30 years	Oh	5.9	5.4	16.0	127.2	65.3	21.00	0.00
	0–10	5.2	4.2	0.6	11.5	17.7	14.62	1.10
	10–20	5.0	4.2	0.2	19.5	15.3	11.25	1.15
	30–60	4.8	4.0	0.0	19.0	10.5	14.02	2.40

In this horizon there is a clear accumulation of nitrogen rich organic substance. The content of organic coal is 18%, and of nitrogen is 1.19%. A high content of nitrogen and favourable C:N ratio (15), indicate a proper course of the humification process and mineralization of organic compounds. Accumulated in this horizon organic matter is also rich in other nutrients, especially occurring in the heap formations in minimal quantities calcium and phosphorus (tab. 3).

TABLE 3

The total content of the elements in the formations on experimental fields on the external part of the waste heap of the Lignite Mine „Turów"

TABELA 3

Całkowita zawartość pierwiastków w utworach na objętych badaniami powierzchniach zwałowiska zewnętrznego KWB „Turów"

Experimental Field	Horizon [cm]	Na	Mg	K	Ca	P	Corg.	N total	S total	C : N
		[mg/kg]					[%]			
Alder 10 years	Oh	580	2 540	5 060	5 540	950	18.00	1.193	0.241	15.1
	0–10	800	2 880	9 780	1 840	490	5.04	0.134	0.168	37.6
	10–20	740	2 820	9 360	1 140	420	4.98	0.091	0.236	54.7
	30–60	880	2 880	9 800	1 040	450	5.58	0.087	0.224	64.1
Birch 10 years	Ofh	146	1 166	2 834	6 744	910	28.72	0.986	0.204	29.1
	0–5	768	2 736	10 390	5 982	380	12.40	0.199	0.341	65.6
	5–10	938	2 436	12 350	1 081	300	10.50	0.160	0.261	65.6
	10–20	524	1 646	7 342	1 342	310	12.87	0.151	0.439	85.2
	30–60	752	2 066	11 624	1 589	320	13.19	0.154	0.391	85.6
Poplar 30 years	Ol	463	2 090	2 260	14 805	700	37.05	1.182	0.166	31.3
	Ofh	625	1 903	5 673	3 645	230	11.58	0.400	0.102	29.0
	0–10	693	2 078	9 775	808	140	5.08	0.122	0.087	41.6
	10–20	690	2 205	11 450	618	230	7.23	0.115	0.125	62.9
	30–60	570	2 142	10 360	624	190	5.15	0.107	0.099	48.1
Alder 30 years	Oh	623	2 108	3 893	10 293	690	32.28	1.470	0.177	22.0
	0–10	1048	2 450	10 733	1 688	210	6.58	0.231	0.156	28.5
	10–20	813	2 100	8 658	1 218	130	4.65	0.095	0.098	48.9
	30–60	1 070	2 418	10 053	913	150	4.89	0.119	0.094	41.1

This horizon possesses a high cation sorption capacity equalling 51.9 cmol(+)/kg, with over 58% saturation of the sorption complex with alkalis. The exchangeable alkaline cations are those of calcium and magnesium (tab. 4). These features prove high buffer abilities of the examined soil horizon in terms of acidification.

TABLE 4

The composition of the cations and parameters of the exchangeable sorption complex formations on experimental fields on the external part of the waste heap of the Lignite Mine „Turów"

TABELA 4

Skład kationów oraz parametry kompleksu sorpcji wymiennej utworów na objętych badaniami powierzchniach zwałowiska zewnętrznego KWB „Turów"

Experimental Field	Horizon [cm]	Content of cations				Parameters of the sorption complex			
		Ca	Mg	Na	K	Alkalis in total	Hh	T	V%
		[mg/100 vg]				[cmol[+]/kg]			
Alder 10 years	Oh	408.10	100.10	5.45	57.20	30.30	21.60	51.90	58.4
	0–10	141.00	43.00	3.20	19.00	11.20	7.70	18.90	59.3
	10–20	77.00	38.00	6.70	23.00	7.85	10.40	18.25	43.0
	30–60	75.00	44.00	11.15	27.00	8.54	8.00	16.54	51.6
Birch 10 years	Ofh	357.82	34.14	4.35	8.98	21.08	10.65	31.73	66.44
	0–5	92.88	22.32	6.21	12.69	7.06	17.85	24.91	28.34
	5–10	82.72	21.12	5.61	12.54	6.43	22.95	29.38	21.89
	10–20	84.38	20.19	5.42	12.12	6.42	25.90	32.32	19.9
	30–60	76.89	21.67	4.86	13.57	6.18	24.35	30.53	20.2
Poplar 30 years	Ofh	378.90	134.20	89.90	16.40	32.95	16.87	49.82	66.14
	0–10	276.30	37.40	61.80	12.70	19.00	15.56	34.56	54.97
	10–20	61.70	12.10	19.30	7.30	4.89	15.75	20.64	23.67
	30–60	53.80	11.20	14.40	4.90	4.19	21.00	25.19	16.62
Alder 30 years	Oh	627.10	103.30	104.20	4.70	42.66	21.00	63.66	67.01
	0–10	114.90	21.70	23.90	5.40	8.36	14.62	22.98	36.39
	10–20	88.30	17.30	17.20	10.30	6.72	11.25	17.97	37.38
	30–60	61.50	11.40	9.90	4.60	4.46	14.02	18.48	24.13

Explanations: H_h – hydrolytic acidity, T – sorption complex volume, V% – the degree of the saturation of the sorption complex with alkalis.

The accumulation and transfer into deeper horizons of soil profile the rich in colloids and alkaline compounds of overburden humus has a great influence on the lower situated levels. This especially refers to initial humus horizon (A). This influence is expressed, among others the improvement of its physical and chemical properties. An accurate assessment of the accumulation of organic carbon is in this horizon difficult, because the ground is enriched in carbon coming from lignite substance. Nevertheless, this is distinct, which is seen as characteristic darker colouration and the growth of the content of organic carbon and total nitrogen, compared to deeper horizons. The content of organic carbon was in this horizon about 5% and was only slightly higher than in deeper horizons. However, the accumulation

of nitrogen was distinct. Its content was by 0.047% (i.e. c. 50%) higher than in the horizon of 30–60 cm. The confirmation of accumulation of the matter susceptible to microbiological decomposition of the organic matter is also significant narrowing down in this horizon, compared to deeper horizons and C:N ratio. Due to the addition of lignite carbon C:N ratio did not reflect the real humification processes and mineralization of the accumulated organic matter.

Slightly different is the humus accumulation in the fields with birch. The decrease in the humification rate is observed, which leads to the formation of Ofh horizon, and humus has the character of moder. The content of organic carbon, compared to the field with the alder was in ectohumus (Ofh) significantly higher (28.7%), while definitely lower was the content of total nitrogen (0.986%) and consequently C:N ratio (tab. 3) increased. These features indicate a lower rate of humification and mineralization of the organic matter, and consequently slower process of including these components into a microbiological cycle. Compared to the fields with the alder organic matter accumulated in this field in Ofh horizon was characterized by slightly lower acidification (pH in KCl 5.0), larger content of calcium in an exchangeable way bound in the sorption complex and total calcium, as well as higher degree of saturating the sorption complex with alkaline cations.

In this field, in the initial humus horizon (A) a higher content of total nitrogen (0.199%) was found than on the surface with the alder. The zone of accumulation was here about a half of the thickness in the other field (up to 5 cm). Also the content of nitrogen in lignite should be included into the balance, because in the studied formations the addition of organic carbon was about twice as big. As stated by Strzyszcz (2004), nitrogen contained in this substance occurs in heterocyclic combinations and is, to great extent unavailable for plants. The found in horizon A content of total nitrogen, was by 0.022% (i.e. c.19%) higher compared to horizon 30–60 cm, which proves the enrichment with humus compounds. The growth of the content of the organic matter is also confirmed by the decrease of C:N ratio from c. 80 to c. 66 in the compared horizons.

In both analysed fields the accumulation of organic matter occurs also in the sub-humus horizon, although to small degree. This indicates the growth of the nitrogen content and diminishing the C:N ratio (tab. 3).

The changes in other assessed chemical properties of the formations covered with the studies in experimental fields, at this stage of the development of soil-forming process are the most visible in 0–10 cm horizon. First of all it shows a much lower degree of acidification than deeper layers. Regarding the fact that the effect of the carried out neutralization covered a zone of c. 20 cm (Krzaklewski, Wójcik 2001), one can confirm de-acidifying properties of the accumulated and moved to deeper layers organic matter. The direction of these changes is similar in both analysed fields. In the 0–10 cm horizon the growth pH values in KCl by 0.2–0.4 units can be found also for deeper layers. It also shows significantly lower values of other acidification indexes, i.e. hydrolytic acidity and exchangeable aluminium then deeper horizons (tab. 2). In the assessed fields the range of these changes strictly depends on initial values of acidification, especially on the content of sulphur-containing organic matter of

lignite (tab. 3). The sorption complex of 0–10 cm shows clear enrichment in calcium and magnesium. This is reflected in the degree of saturation with alkalis. In 0–10 cm horizon it is 59.3% in the field with the alder and 25.1% in the field with birch, while in the 30–60 cm horizon it is 51.6 and 20.2%, respectively (tab. 4). It should be underlined that the level of gradual alkalization is equalled by the acidifying reaction of sulphur oxidation products. The addition of lignite causes high values of the content this element in the formations of studied fields (0.26–0.44%). High acidification in the horizons of 30–60 cm manifests in, among others, acid reaction (pH in KCl 3.3), hydrolytic acidity up to 26 cmol(+)/kg and concentration of movable aluminium up to 2.5 cmol(+)/kg (tab. 2).

The analysis of plant nutrients (tab. 3) shows the growth of the content in surface horizons of the ground, such as Ca and P, and – in less degree – K and Mg. This is connected with relatively high natural content of potassium and magnesium in the overburden formations.

Based on the presented results it can be stated that useful for the soil formation changes of properties in the examined formations occur gradually with time. The most dynamic humus-forming process was observed in the field with the alder.

3.2. Fields reclaimed 30 years ago

The assessed age group is represented by two fields: with the predominance of the black alder (*Alnus glutinosa*) and of the poplar 'H-275' (*Populus* 'H-275'). Like on the surfaces discussed above, changeable and usually large addition of lignite makes an accurate assessment of the changes in physical and chemical properties difficult.

The results of the carried out studies indicate that the direction of the changes in the properties of the ground, observed after c. 30 years is similar as on discussed earlier newer plantations. The improvement of basic physical properties was observed. Low values of volume density (1.07–1.18 g/cm^3) and proper density (c. 2.4 g/cm^3) make the total porosity of the ground in 0–60 cm horizon exceed the level of 50% (tab. 1). As the results of detail studies show (Krzaklewski, Wójcik 1991) the effect of these changes is the improvement of the aeration of strongly compact formations and the increase of the quantity of water available for plants.

In the course of the humus forming process there was also the trend to form the mull humus under the forestation consisting mainly of the black alder and moder under the destination species – the poplar. This is certainly caused by better susceptibility of alder leaves for the processes of microbiological decomposition (Jaworski 1995).

In the mineral part of the profile of both studied surfaces the enlargement of the range of the humus horizon (A) to c. 10 cm is found, and the symptoms of the accumulation of the organic matter is also found in the transition horizon AC (10–20 cm).

The formations occurring on the field with the poplar 'H-275' have a high content of the organic matter coming from the addition of the lignite substance (5.2– .2% Corg.). While the content of total sulphur ranges from 0.099 to 0.125%. Taking place in this field the soil forming processes are reflected in the formation of the horizons of the accumulation of

ectohumus: Ol and Ofh. In the mineral part of the soil profile there is a clearly structured, darker than deeper horizons, initial humus horizon of the thickness of 10 cm and the transition horizon AC (10–20 cm). The morphology of the profile shows that the moder type humus is being made. The mass of the organic material accumulated in Ol horizon was 26 400 kg/ha, of the content of total nitrogen 1.182%, and organic carbon 37.05%. Thus it can be calculated that on 1 ha of the field in this horizon, 9781 kg Corg. and 312 kg total N were accumulated. The extended C:N ratio (c. 31) indicates that this material is moderately susceptible for the processes of biological decomposition (tab. 3, fig. 1).

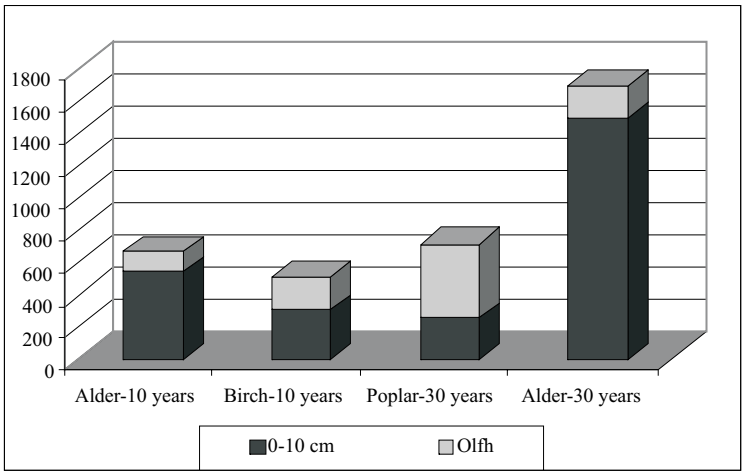

Fig. 1. The content of total nitrogen (net value) in the organic and mineral horizons of soils in experimental fields [kg/ha]

Rys. 1. Zapas azotu ogólnego (netto) w poziomach organicznych i mineralnych gleb na powierzchniach badawczych [kg/ha]

In the second distinguished organic sub-horizon Ofh 36 160 kg/ha of organic material of the content of 0.400% of nitrogen and 11.58% carbon were accumulated. Based on the calculations it can be stated that the accumulation was 4187 kg/ha Corg. and 145 kg/ha total N. (fig. 1). Slightly smaller C:N ratio (29) shows a similar degree of susceptibility of the organic matter of the decomposition processes. The horizons of the overburden humus (Olfh) make also a rich reservoir of other nutrients easily available for plants, especially those that are deficient in heap grounds, such as Ca and P (tab. 3).

The reaction of the Ol horizon, of poorly advanced process of mineralization and humification is slightly acid (pH in KCl 5.9), while in partially humificated Ofh horizon is lowered to acid (pH in KCl 4.7) (tab. 2). The Ofh horizon has a high cation sorption capacity, equalling 49.8 cmol(+)/kg, at about 55% degree of saturation with alkalis. Among exchangeable alkaline cations clearly predominant are calcium and magnesium (tab. 4). These features indicate great buffer abilities of the formations of the assessed soil horizon compared to acidification.

Like on the other assessed fields it was difficult to assess the degree of Corg. Accumulation in the formed in the mineral part of the soil profile humus horizon (A), due to the addition of lignite. The course of this process confirms the growth of the total N content, reaching here 0.122% and is by 0.015% (i.e. o 14%) higher than in the 30–60 cm horizon, as well as diminishing of C:N ratio (tab. 3). Based on the obtained results one can assess that the humus horizon (A), together with organic matter of lignite 59 950 kg Corg. and 1440 kg total N is accumulated. Comparing these values to the ones found in deeper horizons of the profile it can be estimated that about 85% of total N content is contained in poorly decomposable lignite. Another indicator of a favourable course of the processes connected with the accumulation of the organic matter in this horizon is the growth of the content of other nutrients, compared to deeper layers. This first of all refers to the possible to assimilate by plants forms of potassium, magnesium and calcium and total content of these elements.

Due to soil forming processes, and especially the accumulation of rich in alkaline components organic matter the surface horizons of soil are de-acidized. Now the humus horizon shows pH in KCl 4.0, which is by c. 0.4 unit higher than in the lower horizon (10–20 cm) (tab. 2). The level of the saturation of the sorption complex with alkalis is also higher, growing from c. 17 to 24% (tab. 4). The reaction of the formations of the horizons on the depth 30–60 cm can be characterized as strongly acid (pH in KCl 3.9). The remaining acidification indexes are also on a high level, hydrolytic acidity is 14.4 cmol(+)/kg, while the content of exchangeable aluminium is 2.2 cmol(+)/kg (tab. 2). The degree of the saturation of the complex of exchangeable sorption with alkaline cations is also very low – c. 16% (tab. 4).

The course of the soil forming processes on the surface with the black alder, with a similar granulometric composition of the formations building soil (gc), was slightly different. In the soil profile Ol horizon was not found, which indicated a quick biological decomposition of alder leaves. The organic matter was mainly accumulated in the organic Oh horizon and mineral part of the profile in horizon A, which was c. 10 cm thick. The formed humus was of mull type.

In the horizon of the overburden humus Oh on 1 ha of the surface c. 13 440 kg of organic material of the content 32.28% Corg. and 1.470% total N was accumulated. Based on this one can calculate that it contains 4338 kg/ha Corg. and 198 kg/ha N. The horizon of the overburden humus makes also a rich reservoir of other nutrients easily available for plants, especially those that are deficient in heap grounds, such as Ca and P. The formed 22 C:N ratio indicates a relatively good susceptibility of organic matter for the processes of biological decomposition and thus the contained nutrients can be quickly includes into the biological cycle (tab. 3).

The matter accumulated in Oh horizon shows a slightly acid reaction (pH in KCl 5.4). It is characterized by a high cation sorption capacity (c. 64 cmol(+)/kg), with 67% degree of the saturation with alkalis. The dominant alkaline cations are definitely calcium, magnesium and sodium (tab. 4).

Taking place in the soil formations of this field processes were marked with moving the humificated organic matter to the mineral part of soil profile. This indicates the growth of

content in the humic horizon of total nitrogen by c. 0.12% (i.e. c. 90%) and organic carbon by c. 2% (i.e. c. 40%) compared to deeper horizons. This results in a clear diminishing of C:N ratio, which in horizon A is 28.5 (in deeper horizons c. 45). Based on the obtained results one can assess that in the humus horizon (A) together with the organic matter of lignite there is 70400 kg Corg. and 2470 kg of total N. Comparing these values to those found in deeper horizons of the profile it can be assessed that about 75% of total Corg. content and c. 50% total N content is contained in difficult to be decomposed lignite (fig. 1). The accumulation of the organic matter, apart from the growth of C and N contents also leads to the enrichment of the humus horizon with other nutrients i.e. Ca, Mg, K and P (tab. 3).

The results of the analyses show that the range of the de-acidifying impact of the organic matter in this profile reaches 20 cm. The reaction of this soil horizon is strongly acid – pH in KCl 4.2, and the degree of saturation of the sorption complex with alkalis reaches the level of 37%. In horizon 30–60 cm pH in KCl drops to the values of 4.0, and the degree of saturation of the sorption complex with alkalis drops to c. 13%. The horizon of 0–20 cm indicates also distinctly lower values of hydrolytic acidity, and exchangeable aluminium then the ones situated deeper (tab. 3, 4).

The comparison of the effects of soil forming processes in both analyzed fields shows their more favourable course in the field with the alder. It is probed by, among others, greater total reserves of organic carbon and nitrogen in the levels of accumulation (O and A) and resulting from better susceptibility for biological decomposition of organic matter, the content and availability of plant nutrients.

4. Final remarks

The assessment of the course of the soil making process in the waste heap formations of the Lignite Mine „Turów" is very complicated. This is related to a great changeability of the petrographic overburden, as well as results from changeable content of lignite addition in the organic matter.

The basic soil making process taking place in the reclaimed formations is the accumulation of organic compounds. This process leads to a gradual change of unfavourable properties of compact and strongly acidified waste heap formations. The surface layers of soil are getting structured, and consequently their total porosity grows. The results of the studies indicate that the process makes favourable changes in the oldest fields. This covers the soil profile horizon up to 20 cm of depth. The excessive compactness of the waste heap formations makes the main mass of plant roots concentrate in the horizon up to 30 cm, so the range of the influence of soil making processes gets limited. This factor significantly limits also the development of soil biota and consequently the possibility of quick increase of the thickness of humus horizon. This is however a phenomenon widely observed in forests in reclaimed areas (Węgorek 2003; Wójcik 2007). A large quantity of rich in nitrogen, carbon and other important for the development of plants elements organic matter is stored in the

overburden humus (O) and gradually fills the mineral part of soil profile. On the oldest (c. 30 years old) experimental fields the humus horizon reached the thickness of about 10 cm. The formed as the result of the humification process humus colloids gradually increase the capacity of the complex of exchangeable sorption of cations. The humus making process gradually lead to the enrichment of „raw" waste heap grounds in basic biogenic elements, important for the functioning of the soil. This first of all refers to organic carbon and nitrogen, as well as calcium and phosphorus. The high content of nitrogen in the accumulation layer and favourable C:N ratio indicate the correct course of the process of humification and mineralization of organic compounds and good circulation of nutrients. The character of the formed humus is of mull or moder type. This is typical of fertile and moderately fertile forest habitats.

The formed soil humus shows definitely smaller acidification than the bedrock. As shown in the analyses, it is in more than 50% filled with alkaline cations, where calcium and magnesium are predominant. De-acidifying influence of organic matter in the relation to mineral formations is clearly shown in a distinct pH growth in surface layers and the degree of the saturation of the sorption complex with alkalis. The carried out in the examined fields the procedure of neutralization, as well as the natural process of the accumulation of rich in alkaline components organic matter cause that despite still large content of total sulphur in some formations, the threat of drastic increase of acidification does not occur. It is because of balancing of easily available alkaline components and potential acidifying factor that can appear as a result of the oxidation of reduced forms of sulphur (Krzaklewski, Wójcik 2001).

The described processes are particularly intensive and favourable in the forestation with a large proportion of alder. A similar impact of this species on the process of the reconstruction of soils in the reclaimed areas was also observed on other reclaimed objects (Greszta 1972; Węgorek 2003; Wójcik, Krzaklewski 2007). A faster process of accumulation, in the studied soils, in the fields with the black alder was possible due to the abilities of symbiotic binding atmospheric nitrogen. The estimated combined net amount (after subtraction of the values found in the formations of 30–60 cm horizon) in the humus horizon and transition horizon of 30 years old forestation with the domination of the black alder was: organic carbon about 24.5 Mg/ha and total nitrogen 1690 kg/ha (including c. 77% in horizon A) (fig. 1). Thus the mean annual accumulation of organic carbon in these levels was 0.8 Mg/ha and the one of nitrogen was c. 56 kg/ha (fig. 2).

These are values c. 30% lower than given in literature for forestation with the alder of natural ecosystems and reclamation forestations in other objects (Brożek 1993; Wójcik, Krzaklewski 2007). This is probably because of extremely unfavourable habitat conditions in the external waste heap of KWB „Turów". In both analysed age groups the accumulation of nitrogen in forestations with the alder was definitely higher than accumulation of this element in forestations consisting mainly of destination species (fig. 2). The comparison of the described properties with literature data indicates great similarity to the occurring in the Turoszów waste heap initial soils to the soils formed on other such objects of mining industry (Gilewska 1991; Katzur et al. 1999; Węgorek 2003; Wójcik, Krzaklewski 2007).

Fig. 2. Accumulation of total nitrogen (net value) in horizons Olfh and A of soils in experimental fields on the external part of the waste heap of the Lignite Mine "Turów" [kg/ha/year]

Rys. 2. Akumulacja azotu ogólnego (netto) w poziomach Olfh i A gleb na powierzchniach badawczych [kg/ha/rok]

The obtained results indicate great potential fertility of forest habitats formed on the studied object. This fact is confirmed by the parallel to soil studies phytosociological and dendrometric studies. Their results indicate that the development of forest ecosystems goes toward the units similar to the mixed upland forest and even fresh upland forest (Krzaklewski, Wójcik 2001).

Conclusions

1. The applied on the external waste heap of the overburden of KWB „Turów" method of reclamation allows the formation of plant ecosystems, gradually changing the unfavourable properties of these formations.

2. The results of the carried out studies clearly indicate the positive direction of soil changes. They are expressed by the range of favourable changes in physical and chemical properties of raw grounds, proving their gradual, years-lasting transformation into a forest soil. The arising at present stage of development soils still have initial character, they however possess characteristic for forest soils genetic horizons and layers.

3. The lack of phyto-toxicity in the studied soil profiles of the ground confirms the efficacy of the neutralization carried out on the waste heap. While gradual de-acidification of surface removes the threat to the stability of the forestations introduced here.

4. The obtained results indicate that the reconstruction of efficiently functioning forest ecosystems on soilless areas is a slow process, where time is an important ecological factor. It is however possible to stimulate its speed by designing a proper species composition with the participation of the alder, adjusted to the potential habitat of forestation.

5. A positive effect of the alder on the process of the formation of initial soils and forest ecosystem was confirmed. This results from its dynamic growth when young, which makes the possibility of fulfilling protective functions for more demanding destination species. Its favourable impact on the soil forming processes by the enrichment of soil with large amount of nitrogen-rich organic matter is also significant. This allows the limitation of the cultivation procedures, as well as nitrogen mineral fertilization.

6. Due to the properties of the bedrock, which is Tertiary kaolin loam, one can predict that the soils on the waste heap will be relatively fertile, however acid. They will make the main component of forest habitats of a high ecological value.

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FORESTATION AS THE METHOD OF THE REMEDIATION OF SOILLESS AREAS OF THE LIGNITE MINE TURÓW

Key words

Remediation, waste heap, forestation, physical and chemical properties of soil

Abstract

The paper presents the results of the impact assessment of the remediation forestation on the external waste heap of the Lignite Mine KWB Turów, on the processes of gradual transformation of raw overburden rocks into soil. Changes of selected physical and chemical properties of the ground, taking place after 10 and 30 years during human-controlled and natural processes on the surfaces representing different species composition of forestations, were analysed. The results of the studies indicate beneficial effects, especially on humus-forming processes of the phyto-remediation species, i.e.: the black alder (*Alnus glutinosa*) and grey alder (*Alnus incana*).

ZALESIENIA JAKO METODA REKULTYWACJI TERENÓW BEZGLEBOWYCH W PGE KWB „TURÓW"

Słowa kluczowe

Zwałowisko nadkładu, rekultywacja leśna, właściwości gleby

Streszczenie

W pracy przedstawiono wyniki oceny wpływu zalesień rekultywacyjnych wprowadzonych na zwałowisko zewnętrzne KWB „Turów", na procesy stopniowego przekształcania „surowych" skał nadkładu w glebę. Analizie poddano zmiany wybranych właściwości fizycznych i chemicznych gruntu jakie zaszły po okresie 10 i 30 lat w toku sterowanych przez człowieka oraz samoistnych procesów, na powierzchniach reprezentujących zalesienia o różnym składzie gatunkowym. Wyniki uzyskanych badań wskazują na korzystne oddziaływanie, zwłaszcza na procesy próchnicotwórcze, gatunków z grupy fitomelioracyjnych, tj.: olszy czarnej i olszy szarej.