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CHANGES IN THE QUANTITY OF POTASSIUM MARKED IN POST-MINING GROUNDS IN THE ŁĘKNICA REGION

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Summary: The paper presents the results of analyses of the potassium content marked by means of the Egner-Riehm method (in lactate extract) and a subtotal form (in Aqua Regia), in reclaimed soils of post-mine waste dumps in the Łęknica region. The quantity of absorbable K in the soils under research was low, amounting on average to 49 $mg \cdot kg^{-1}$. The highest quantity of this form was found on the level of leaf litter (on average 161 $mg \cdot kg^{-1}$), and the quantity decreased with depth. Differences in the quantity of a potassium subtotal form in the analysed material were small, and average value was 1042 $mg \cdot kg^{-1}$.

Key words: potassium in soils, forest reclamation, former mining areas

1. INTRODUCTION

Brown coal mining causes considerable changes in soils over large areas. It results in the appearance of areas covered with overburden material with varied properties [Bender 1982, Greinert 1988, Gilewska 1991, Drab et al. 2005, Greinert et al. 2009]. The reclamation of former mining areas covered with these materials encounters a number of difficulties. Because of the fact that results of long-term reclamation are not always foreseeable safer variants are usually chosen, especially forest reclamation [Bender 1980, Krzaklewski et al. 1977, Greinert et al. 2009]. This is also in agreement with the tendency to systematically increase the area of Poland covered with forests.

Potassium is a nutritive component of cultivable plants (including forest plants), needed in large quantities, with relatively low bio-availability – a large ratio of fixation [Jalali 2007] and leaching especially from sandy soils [Jalali, Rowell 2003]. The fixation of potassium takes place in soil minerals, mainly clayey ones from the group 2:1. Minerals containing potassium in large quantities are also feldspars and micas, whose small particles co-constitute fractions of dust and clay [Pal et al. 1993]. The strength of bonding potassium by these minerals is great, but in conditions of great acidity the exchange of K^+/H^+ is possible. Controlled liberation of nitrogen from the abovementioned minerals takes place as a consequence of biological activity, mainly rhizosphere [Singh and Goulding 1997].

Research carried out by Tripler et al. [2006] indicated that soil potassium increased primary productivity of forest ecosystems. Lack of this element can decrease it considerably. Plants may also need more potassium in the case of extensive nitrogen and phosphorus fertilization [Rupta et al. 2003], which is a basic component of reclamation according to the model prepared by the Polish Academy of Science. Askegaard et al. [2004] showed that the phenomena of potassium sorption – desorption depend on the history of fertilization as well as soil characteristics influencing soil-moisture.

The purpose of the paper is to show changes in the content of two forms of potassium: absorbable and subtotal in soil samples taken from initial soils profiles of experimental reclamation fields, fertilized with varied doses of mineral fertilizers 20 years ago (1986, at the initial stage of forest reclamation cultivation).

2. RESEARCH METHODS

The experimental object is localized in Poland in the southern part of the Lubuski District, near the town of Łęknica (the area of the so called Mużaków Curve), on the premises of the former brown coal mine "Przyjaźń Narodów". The fields were localized on the external waste dump of the mine formed on the basis of technical reclamation of land devoid of soil excavated from overlay over-coal levels.

The land consisted mainly of Miocene sands with an addition of brown coal pyrite (FeS_2), and small amounts of mica [Skawina 1973, Wróbel 1985], with an uneven distribution of the components. The lands, in terms of soil-forming processes, had a mechanical composition of light clayey sand with a varied quantity of a dust fraction. A water volume of less than $30\%_{weight}$ was found in the dump mass, the quantity of organic matter was from 1.2% to 6.3% the wide ratio C:N – was often below 100:1. The content of subtotal form of the components was small, with the exception of the potassium content. Because of the biological oxidation of pyrite, the lands were being constantly acidified – often to a reaction of less than 3.0 pH.

The area was forest reclaimed in the seventies and beginning of eighties in XX^{th} Cetury. During the reclamation surface of the dumps was levelled, slopes were formed 1:4 and ditches were dug 1:3, the land was limed with an overall dose of 50 $Mg \cdot ha^{-1}$ (30+20) of waste magnesium lime from the steelworks "Miasteczko Śląskie", fertilised with a dose of 5 $Mg \cdot kg^{-1}$ of ground phosphate rock, after that common pines (*Pinus sylvestris* L.) were planted.

Because of bad reclamation results (bad condition of the trees – several dozen percent died, there were symptoms of extreme complex malnutrition), in 1986 the decision was made to correct the situation on the basis of a field experiment. Experimental fields were established in fields in areas: "A" – with 6 year-old common pines and "B" – with two-year old common pines. Different fertilization methods were used in the fields:

1. - without fertilization
2. - magnesium lime 8 $Mg \cdot ha^{-1}$
3. - N – 100, P_2O_5 – 70 $kg \cdot ha^{-1}$
4 - N – 100, K_2O – 160 $kg \cdot ha^{-1}$
5. – N – 100, P_2O_5 – 70, K_2O – 160 $kg \cdot ha^{-1}$
6. – N – 200, P_2O_5 – 140, K_2O – 320 $kg \cdot ha^{-1}$
7. – magnesium lime 8 $Mg \cdot ha^{-1}$, N – 100, P_2O_5 – 70 $kg \cdot ha^{-1}$
8. – magnesium lime 8 $Mg \cdot ha^{-1}$, N – 100, K_2O – 160 $kg \cdot ha^{-1}$
9. - magnesium lime 8 $Mg \cdot ha^{-1}$, N – 100, P_2O_5 – 70, K_2O -160 $kg \cdot ha^{-1}$
10. magnesium lime 8 $Mg \cdot ha^{-1}$, N – 200, P_2O_5 – 140, K_2O 320 $kg \cdot ha^{-1}$

Lime was used once in November 1986. Nitrogen, phosphorus and potassium were used in experimental combinations as fertilizers:

- N – ammonium nitrate 34% N
- P – simple dusty superphosphate 18% P_2O_5
- K – potash salt 50% K_2O

and were introduced in the first three months of 1986.

In 1987 additional mineral nitrogen fertilization in the middle of plots 6 and 10 has been added, in both experimental facilities. This resulted in separation of plots, respectively: A-6 (N - 200 P_2O_5 - 140 K_2O - 320 $kg \cdot ha^{-1}$), A-6b (N - 400 P_2O_5 - 140 K_2O - 320 $kg \cdot ha^{-1}$), A-10 (N - 200 P_2O_5 - 140 K_2O - 320 $kg \cdot ha^{-1}$), A-10b (N - 400 P_2O_5 - 140 K_2O - 320 $kg \cdot ha^{-1}$) and, by analogy: B-6a, B-6b, B-10a, B-10b. So in any combination, plot "a" was treated according to the scheme for 1986, and the plot "b" – fertilized with additional nitrogen at 200 $kg \cdot ha^{-1}$. Variants of fertilizer divided the research facilities to plots 35x8 m each (1-5 and 7-9, individual size 280 m^2) and 35x4 m (6 and 10, the surface of individual 140 m^2).

The growth and overall state of the plants were closely watched as well as changes in soil profiles, and laboratory analyses were carried out.

This paper presents the results of researches carried out in the autumn of 2004. At that time soil pits were dug in the experimental fields and average soil samples were taken from the soil profiles from the depths of 0-3 cm, 3-8 cm, 8-15 cm, 15-25 cm, 25-50 cm, 50-75 cm (field "B"), 50-100 cm (field "A").

The potassium content was marked in Egner-Riehm extract [Egner et al. 1960, Mocek et al. 2000], and after incineration in Aqua Regia [McGrath and Cunliffe 1985].

Results were statistically analysed calculating Spearman ratios of sequence correlation [Rudnicki 1991, Drab 2007].

3. RESEARCH RESULTS

Considerable differences were observed in the distribution of potassium marked in subsequent extracts in the soil profile, and also differences between experimental fields "A" and "B". The most uniform results were found while analysing the distribution of the subtotal potassium, which in the whole experiment was on average 1093 $mg \cdot kg^{-1}$, with the averages for the fields: 1087 $mg \cdot kg^{-1}$ ("A") and 1099 $mg \cdot kg^{-1}$ ("B"). Moreover, the depth from which samples were taken from the soil profiles did not have a significant influence on the quantity of this form of potassium (table 1).

The Egner Rhiem extract showed differences between the experimental fields, and also particular soil profiles. The average content of potassium marked in it was 31.5 $mg \cdot kg^{-1}$ for field "A", and 66.5 $mg \cdot kg^{-1}$ for field "B". The distribution of this form of potassium was clearly varied in the soil profiles – with considerably higher values for leaf litter, and lower ones for humus levels and systematically decreasing with depth in mineral soil.

Table 1. The content of absorbable and subtotal potassium forms ($mg \cdot kg^{-1}$), and the relation between these forms (%)

Field number	Depth (cm)	K_{ER}	K_{PT}	K_{ER}: K_{PT} ratio	Field number	Depth (cm)	K_{ER}	K_{PT}	K_{ER}: K_{PT} ratio
A-1 „0”	0-3	106	1020	10,4	B-1 „0” 3,4	0-2	240	1188	20,2
	3-8	28	830	3,4		2-4	77	1280	6,0
	8-15	16	1020	1,6		4-6	50	820	6,1
	15-25	12	940	1,3		6-15	28	890	3,1
	25-50	28	1044	2,7		15-25	15	682	2,2
	50-100	9	970	0,9		25-50	11	980	1,1
average		33	971	3,3		50-75	11	920	1,2
A-2 „0”Ca	0-2	46	1112	4,1	average		62	966	6,4
	2-8	17	940	1,8	B-2 „0”Ca	0-2	188	1470	12,8
	8-15	9	740	1,2		2-6	43	876	4,9
	15-25	9	1160	0,8		6-15	36	940	3,8
	25-50	12	1220	1,0		15-25	21	1040	2,0
	50-100	10	838	1,2		25-50	15	892	1,7
average		17	1002	1,7		50-75	15	820	1,8
A-3 NP	0-2	143	1140	12,5	average		53	1006	5,3
	2-8	32	1020	3,1	B-3 NP	0-2	248	1230	20,2
	8-15	13	800	1,6		2-4	91	1296	7,0
	15-25	10	1160	0,9		4-15	43	752	5,7
	25-50	11	1140	1,0		15-25	21	652	3,2
	50-100	9	1120	0,8		25-50	18	332	5,4
average		36	1063	3,4		50-75	15	384	3,9
A-4 NK	0-3	122	880	13,9	average		73	774	9,4
	3-8	25	780	3,2	B-4 NK	0-3	217	1416	15,3
	8-15	10	1196	0,8		3-8	86	1084	7,9

	15-25	10	1140	0,9		8-15	36	928	3,9
	25-50	9	1080	0,8		15-25	32	1068	3,0
	50-100	11	1140	1,0		25-50	36	1208	3,0
average		31	1036	3,0		50-75	32	1032	3,1
A-5 NPK	0-3	152	1440	10,6	average		73	1123	6,5
	3-8	22	1160	1,9	B-5 NPK	0-2	208	1404	14,8
	8-15	16	1250	1,3		2-4	148	1284	11,5
	15-25	15	940	1,6		4-8	65	944	6,9
	25-50	12	940	1,3		8-15	50	1084	4,6
	50-100	10	1000	1,0		15-25	32	1068	3,0
average		38	1122	3,4		25-50	21	962	2,2
A-6 2NPK	0-3	194	1410	13,8		50-75	18	928	1,9
	3-8	22	1140	1,9	average		77	1096	7,0
	8-15	13	970	1,3	B-6 2NPK	0-2	266	1636	16,3
	15-25	12	1044	1,1		2-4	65	1404	4,6
	25-50	10	940	1,1		4-8	29	1156	2,5
	50-100	13	1020	1,3		8-15	25	944	2,6
average		44	1087	4,0		15-25	18	858	2,1
A-7 CaNP	0-3	98	1080	9,1		25-50	21	1016	2,1
	3-8	19	780	2,4		50-75	21	682	3,1
	8-15	8	1020	0,8	average		64	1099	5,8
	15-25	8	1160	0,7	B-7 CaNP	0-2	232	1380	16,8
	25-50	8	1198	0,7		2-4	94	1260	7,5
	50-100	6	1220	0,5		4-8	28	944	3,0
average		24	1076	2,2		8-15	28	1202	2,3
A-8 CaNK	0-2	102	1020	10,0		15-25	32	1192	2,7
	2-8	12	740	1,6	average		83	1196	6,9
	8-15	9	780	1,2	B-8 CaNK	0-2	197	1135	17,4
	15-25	9	1198	0,8		2-4	80	1236	6,5
	25-50	8	880	0,9		4-8	72	1034	7,0
	50-100	8	1140	0,7		8-15	43	1004	4,3
average		25	960	2,6		15-25	29	962	3,0
A-9 NPK	0-2	132	1250	10,6		25-50	21	968	2,2
	2-8	22	800	2,8		50-75	25	940	2,7
	8-15	12	860	1,4	average		67	1068	6,3
	15-25	13	1112	1,2	B-9 CaNPK	0-2	132	1335	9,9
	25-50	9	1080	0,8		2-4	95	1328	7,2
	50-100	9	920	1,0		4-8	80	1050	7,6
śred average nia		33	1004	3,3		8-15	122	1102	11,1
A-10 Ca2NPK	0-3	122	970	12,6		15-25	58	1084	5,4
	3-8	24	744	3,2		25-50	32	1016	3,1
	8-15	16	660	2,4		50-75	21	1018	2,1
	15-25	14	1140	1,2	average		77	1133	6,8
	25-50	12	1160	1,0	B-10 Ca2NPK	0-2	80	1328	6,0
	50-100	11	720	1,5		2-15	21	1242	1,7
average		33	899	3,7		15-25	25	1043	2,4
field average		**32**	**1022**	**3,1**		25-50	21	1012	2,1
					average		37	1156	3,2
					field average		**66**	**1062**	**6,2**

In relation to the potassium subtotal form, the absorbable form was 3% for field "A" and nearly 6% for field "B". A difference was found in the index formulated in this way already in the control combination, where at the depth of 0-15 cm, in field "A" the average value was 5.1% and in field "B" 8.8%. There were not any

clear differences in lower soil strata in favour of any of the fields. After lime had been added to the ground of the control fields, the described ratio decreased, and the difference between the fields became clearer at the depth of 0-15 cm – for "A" 2.4%, and for "B" 7.2%. NPK fertilization and forest cultivation unified the analysed index at the depth of 0-3 cm, but at the depth of 0-15 cm the differences between the fields remained (6.0% vs. 9.0% in the combination NK, 4.6% vs. 11.0% in the combination NPK and 5.7% vs. 6.5% in the combination 2NPK). Also, regardless of the NPK fertilization, the difference between fields "A" and "B" at the depth 0-15cm was clear (5.4% vs. 9.3% in combinations without Ca and 4.3% vs. 7.3% in combinations with Ca). In terms of the average content of the absorbable form of potassium and the subtotal potassium form in the whole soil profile, the differences between the kinds of fertilization applied 20 years ago were negligible.
The linear correlation ratios calculated (r_s) for the absorbable potassium content and the potassium subtotal form showed lack of relation in samples taken from field "A" – earlier plantings of the common pine. A statistical analysis showed four cases of similar relations between the content of both potassium forms in samples taken from field "B" – later plantings of the common pine. From that three similar relations were observed in the case of fields fertilized with phosphorus (table 2).

Table 2. Sequence correlation ratios (r_s) for the quantity of the absorbable form and the subtotal form of potassium

	Field „A”	Field „B”
Control	0,55	0,40
Ca	0,23	0,46
NP	-0,22	$0,91^x$
NK	-0,02	0,43
NPK	0,69	0,79
2 NPK	0,80	$0,84^x$
CaNP	-0,22	0,70
CaNK	-0,25	$0,89^x$
CaNPK	0,09	$0,89^x$
Ca 2 NPK	-0,08	0,50

x – important relation
xx – very important relation

4. DISCUSSION OF RESULTS

While analysing how components behave in soil, and even on a larger scale during the formation of soils from lands devoid of soil which are being reclaimed it is necessary to make use of long-term experiments [Rasmussen et al. 1998]. The paper describes the experiment from the perspective of 20 years, which gives a good picture of changes which took place.

The former mining lands constituting an area intended for forest reclamation contained considerably less potassium in the total form than most arable lands [Krzywy 2000, Gorlach and Mazur 2002].

Lack of variation in the distribution of this form of potassium in the soil profiles should be associated with its geological characteristics. In this context attention should be paid to the quantity of muscovite (a mineral from the group of micas $KAl_2(OH, F)_2AlSi_3O_{10}$) – containing potassium [Wróbel 1085] in lands around Łęknica.

Because of the weathering of minerals, potassium is transformed from the total form to more soluble forms which are absorbable for plants. A number of authors emphasize great importance of the weathering of minerals containing potassium for the overall balance of this element in arable lands [Holmqvist et al. 2003]. This experiment confirmed this proposition in the context of the abundance of soils and lands, as well as the condition of cultivable plants. However, the absorbable form is not only ready to be absorbed by plants, but it is also washed away and retrograded because of repeated non-exchangeable bonding. The intensity of the retrogression of soil potassium depends on the mechanical composition, mineral composition, reaction, humidity and the quantity of organic matter. The retrogression of potassium can be reduced by enriching the solution washing away potassium with calcium ions, which induces the effect of the displacement of K^{++} from the sorption complex by Ca^{++} [Jalali and Rowell 2003]. It is an important proposition because of large doses of lime applied at early stages of the reclamation of former mining lands in order to neutralize them. However, on the basis of the experiment under discussion it is necessary to note that this effect is not the only one and it does not last long. Observations carried out 20 years after the reclamation fertilization showed that the effect the plants had on the land was a clearly stronger factor. It was noticed that in the land of the dump under the later plantings (where the abundance of the land was varied because of younger trees) processes of releasing potassium were more intense. This proposition was supported by a statistical analysis indicating more cases of similar correlations for the quantity of marked forms of potassium in soil samples from field "B".

According to Silberbush and Barber [1983], most authors use the relation between total and absorbable form as an indicator of strength of potassium bonding. In the field experiment under discussion a difference was noticed in the index illustrated by the ratio of the quantity of the absorbable form to the subtotal potassium form at the depth of 0-15 cm, between the fields where lime had been used and those where it had not. In the fields with lime it was lower – on average 5.8% in comparison with 7.4% in the fields without lime. For the fields fertilized with potassium this ratio was a little lower – 6.1% in the fields with lime vs. 7.1% in the fields without lime. For fields not fertilized with potassium the ratio was 5.3% in the fields with lime vs. 7.7% in the fields without lime.

The behaviour of potassium in grounds devoid of soil is the resultant of the characteristics of the ground itself and reclamation activities undertaken by people. It is difficult to show in this particular case a cause and effect influence of reclamation activities on the abundance of post-mining grounds in subtotal potassium. A period of a number of years without fertilization with a different growth of green plants and trees in the area reclaimed eliminated initial differences caused by differences in the abundance of the grounds.

5. CONCLUSIONS

The results make it possible to formulate the following conclusions:
- the content of the subtotal potassium form in the grounds in Łęknica is geological in character and for this reason the results obtained in both experimental fields are similar, regardless of the reclamation fertilization applied 20 years ago;
- the form of absorbable potassium for plants is varied in following layers of soil profiles – from the greatest content in leaf litter to smaller content deeper.
- in the ground of the experimental field with older common pine plantings there was twice less potassium than in the ground of the field with newer plantings;
- clear differences in the content of absorbable potassium between the experimental fields "A" and "B" were observed in the ground at surface layers – to 15 cm under the surface; deeper it was impossible to notice relations caused by reclamation activities;
- liming during reclamation does not influence the fixation of potassium as strongly as the growth and development of cultivable plants, which was confirmed by greater intensity of this process in the fields where lime had been used.

6. LITERATURE

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ZMIANY ZAWARTOŚCI FORM POTASU OZNACZONYCH W GRUNTACH POKOPALNIANYCH Z REJONU ŁĘKNICY

Streszczenie

W pracy przedstawiono wyniki analiz zawartości potasu, oznaczonego metodą Egnera-Riehma (w wyciągu mleczanowym) oraz zbliżonej do ogólnej (w wodzie królewskiej), w gruntach rekultywowanych zwałowisk pokopalnianych z rejonu Łęknicy. Zawartość K przyswajalnego w badanych gruntach była niska, wynosząc średnio 49 $mg \cdot kg^{-1}$. Najwyższą zawartość tej formy stwierdzono w poziomie ściółki (śr. 161 $mg \cdot kg^{-1}$), odnotowując spadek zawartości w głąb profilu glebowego. Różnice zawartości formy zbliżonej do ogólnej w analizowanym materiale były niewielkie, a średnia zawartość wyniosła 1042 $mg \cdot kg^{-1}$.