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# **The Content of the Organic Carbon and Total Nitrogen in the Soil of the Reclaimed Repository of the Sulphur Mine “Machów” after Many Years of Agricultural and Forestry Management\*\***

## **1. Introduction**

The processes of the development of soil on the reclaimed post-mining areas built from the overburden formations are met with the particular interest of researchers. This is due to the role of soil in the environment and its significance for the correct restoration of ecosystems on post-mining areas. Soil makes the main reservoir of carbon stored in natural environment, which must be particularly investigated, especially in indicial ecosystems formed in the reclaimed areas.

The task of the reclamation soilless areas in agricultural and forest direction is initiation and stimulation of soil-forming and habitat-forming processes leading to getting the useful value of economic or social character.

In case of the repositories of open cast mining, on which the overburden formations are deposited. They often come from large depths, we have soilless grounds of the properties often diverting from the properties of the agricultural and forest soils.

In such conditions the accumulation of the organic matter being the main source of nitrogen and other biogenic components is a basic factor stimulating the process of the transformation of “raw” grounds in soil. Numerous literature positions [4, 5, 7, 8, 19] indicate its beneficial influence on the improvement of chemical and physical properties of the grounds and initiation of the carried out biochemical processes. The selection of plants also influences the dynamics of accumulation of the organic matter and the course of soil-forming processes [1, 7, 10, 17, 19]. Practically the whole deposit of active at soil-making organic carbon and nitrogen in the reclaimed formations of the overburden is in the organic matter coming from the process of its accumulation or from fertilization. Found in some formations of the overburden, additive of substances with carbon are usually not active in soil-forming.

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Initial soils of ecosystems made in the reclaimed areas are usually characterized by a great dynamics of the content of the organic carbon, however depending on the way of management.

The goal of the studies the results of which were included in the paper, the results of which were put in the paper, was the assessment of the content of the organic carbon and total nitrogen in the grounds of selected surface of the external repository of the former Open Cast Sulphur Mine “Machów”, forested or agriculturally managed, after about 30 years from the performing of the reclamation measures.

## 2. The Object of the Studies

Building the external repository of the “Machów” Mine (the object of the studies) the formations of the overburden of the sulphur deposit, despite their non-selective management are characterized by a great uniformity. According to the studies carried out after its formation [3], the upper storey of the repository, in about 90% consists of Miocene Tertiary formations – Krakowiec loams with the intrusions of (among others) hard limestone, marl and marl shale. These grounds have granular composition of loams or heavy clays, of very high content of colloid loam sub-fraction (usually above 40%), in the composition of which there is montmorillonite. The high content of the calcium compounds caused that they had a slightly alkaline reaction and higher value of conductivity (electrolytic conductance) (Tab. 1). With time, under the influence of soil processes, the values of conductivity and in smaller degree pH were decreased in the surface layer.

## 3. Materials and Methods

The studies were carried out on two plots on the top of the repository, reclaimed for the agricultural management and three on the scarp reclaimed as forest. The reclamation on these areas was carried out in 1977–1978. Both plots on the top were in 1978 sown with medick (*Medicago*) and grasses, and in the area of one of them (plot R1) in 1981 a strict plot experiment was carried out to optimize the technology of the cultivation, especially fertilization of four plant species cultivated in shifts (field beet (*Beta vulgaris* subsp. *vulgaris* var. *alba*), barley (*Hordeum vulgare*), Italian ryegrass (*Lolium multiflorum*), common wheat (*Triticum vulgare*). Two cycles of shifts were carried out and the whole field was sown with medick and grasses and was extensively used as permanent grassland [9, 10]. The other plot (R2) sown by the mixture of medick and grasses, practically all the time (over 30 years) was extensive used as mown meadow. Nowadays on both plots grass vegetation with a great participation of various weeds is predominant and medick is in small quantities.

**Table 1.** Basic values of the studied grounds on the surface on the repository of the Sulphur Mine "Machów", 30 years after the reclamation

Plot	Depth	Fractions [%]		Bulk density	pH	EC*	CaCO <sub>3</sub>
	[cm]	< 0.02 mm	< 0.002 mm	[kg·dm <sup>-3</sup> ]	in KCl	[mS·cm <sup>-1</sup> ]	[%]
Forestry managed							
L1	0–10	56	34	1.60	7.29	0.204	14.25
	10–20	67	40	1.61	7.46	0.146	17.90
	20–30	74	44	1.72	7.56	0.206	14.20
	30–50	73	44	1.70	7.37	1.953	19.10
	50–70	81	36	1.73	7.41	1.952	14.50
L2	0–10	63	37	1.54	7.26	0.25	7.20
	10–20	75	46	1.74	7.51	0.171	9.35
	20–30	61	43	1.76	7.5	0.183	9.20
	30–50	74	44	1.77	7.62	0.193	9.80
	50–70	78	43	1.78	7.56	1.12	9.10
L3	0–10	88	51	1.63	7.45	0.21	8.70
	10–20	90	54	1.68	7.53	0.26	10.25
	20–30	89	48	1.76	7.51	1.01	9.80
	30–50	87	48	1.75	7.44	2.02	10.60
	50–70	88	55	1.79	7.47	2.00	9.20
Agriculturally managed							
R1	0–10	75	48	1.75	7.4	1.16	7.25
	10–20	78	49	1.80	7.5	2.05	7.39
	20–30	81	50	1.81	7.6	2.04	8.23
	30–50	78	47	1.87	7.6	2.20	6.56
	50–70	90	46	1.87	7.6	2.25	7.25
R2	0–10	65	40	1.63	7.5	0.76	5.58
	10–20	69	43	1.66	7.5	2.04	5.86
	20–30	65	42	1.70	7.5	2.01	4.88
	30–50	68	46	1.72	7.6	2.05	4.90
	50–70	66	44	1.74	7.6	2.10	5.60

\* electrolytic conductivity

The forested experimental plots are on the northern scarp of relatively small slope (15–20%). The forestations were carried out with biodynamic method [11, 12] meaning the introduction of groups of final species with the lining of phytomelioration species – black alder *Alnus glutinosa* and grey alder *Alnus incana*. On each study plot different three species dominate: pendulate oak *Quercus robur* (L1), grey alder *Alnus incana* (L2), European larch *Larix decidua* (L3).

On all the study plots 3 excavations were made and soil samples were taken from five layers:

- 0–10 cm;
- 10–20 cm;
- 20–30 cm;
- 30–50 cm;
- 50–70 cm.

In the mean soil material (of three individual samples) the following parameters were analysed: granulometric composition with Casagrande's aerometric method with Prószyński's modification, volume density according to PN-88/B-04481, pH by potentiometric method according to PN-ISO 10390:1997, PEW by conductometric method (relation ground: water 1:5), CaCO<sub>3</sub> with Scheibler's method, organic C with Tiurin's method, general nitrogen with Kjeldahl's method.

To define statistic significance of differences in the assessed of the values of ground between individual layers in soil profiles, one-factor variance analysis was carried out and LSD<sub>0.05</sub> was calculated.

#### 4. Results and Discussion

Thirty years after carrying out reclamation measures and introduction of vegetation in initial soils of the repository "Machów" managed in forestry and agricultural way, a clearly differentiating with a different colour initial humus level was formed. One can differentiate its zones 0–10 cm of higher accumulation of humus compounds and 10–20 cm with lighter colour, indicating the lower content.

These observations were reflected in the results of laboratory analyses of content C and N (Tabs 2, 3).

On the agriculturally used plots the mean content of organic carbon in layer 0–10 cm was 3.06%, and the one of total nitrogen 0.22%. The higher accumulation of these elements was in case of the area that was intensively cultivated for the first 10 years.

In layer 10–20 cm the contents of C and N in the case of both analysed plots were already ca. 50% lower and on average they equalled for C<sub>org</sub> 1.58% and N<sub>tot</sub> 0.10%. Further layers are characterized by much lower content of these components, with a slight decreasing trend deeper towards the profile.

**Table 2.** The content of  $C_{org}$  and  $N_{tot}$  in grounds of the study plots in the agriculturally managed repository parts of Sulphur Mine "Machów", 30 years after taking reclamation measures

Plot	Depth [cm]	$C_{org}$	$N_{tot}$	C/N
		[%]		
R1	0–10	3.34	0.231	14.45
	10–20	1.69	0.112	15.09
	20–30	1.53	0.103	14.90
	30–50	1.28	0.084	18.21
	0–70	1.15	0.087	14.71
R2	0–10	2.77	0.199	13.92
	10–20	1.46	0.09	16.22
	20–30	1.12	0.065	17.23
	30–50	0.94	0.061	18.36
	50–70	0.88	0.056	16.79
Mean	0–10	3.06	0.215	14.2
	10–20	1.58	0.101	15.7
	20–30	1.33	0.084	16.1
	30–50	1.11	0.073	18.3
	50–70	1.02	0.072	15.8
LSD <sub>0.05</sub>		0.13	0.010	–

**Table 3.** The content of  $C_{org}$  and  $N_{tot}$  in the grounds on the forested areas of the repository of the Sulphur Mine "Machów", 30 years after taking reclamation measures

Plot	Depth [cm]	$C_{org}$	$N_{tot}$	C/N
		[%]		
L1	0–10	4.94	0.320	15.42
	10–20	1.35	0.08	16.88
	20–30	1.07	0.068	15.74
	30–50	0.96	0.057	16.84
	50–70	1.00	0.064	15.63
L2	0–10	5.67	0.440	12.89
	10–20	1.58	0.097	16.29
	20–30	1.29	0.084	15.36
	30–50	1.09	0.073	14.93
	50–70	1.35	0.075	18.00
L3	0–10	2.32	0.155	14.97
	10–20	1.66	0.105	15.81
	20–30	1.52	0.091	16.70
	30–50	1.33	0.088	15.11
	50–70	1.45	0.086	16.86
Mean	0–10	4.31	0.31	14.43
	10–20	1.53	0.09	15.91
	20–30	1.29	0.08	15.93
	30–50	1.13	0.07	15.63
	50–70	1.27	0.08	16.83
LSD <sub>0.05</sub>		0.32	0.03	–

Ratio C:N in accumulated organic matter can be found good, similar to the level of fertile soils [13].

Strict comparison of the rate of the organic matter accumulation in very compact repository formations is difficult, mainly because of its natural addition in sedimentary rocks, as well as occurring, especially in deeper levels, strong reduction conditions influencing the results of the analyses. Calculated in the relation to the state in deeper layers (30–50 cm and 50–70 cm), increase in the content of both carbon and nitrogen can inform about real accumulation of the organic matter. Based on the carried out calculations it was stated that in layer 0–10 cm it was 2.12% of  $C_{org}$  and 0.145%  $N_{tot}$  on agricultural plots intensively cultivated and 1.86% C and 0.140% N on extensively cultivated plots. In layer 10–20 cm the growth of the content of these elements was about 4 times smaller and was formed on a similar level in case of both surfaces, was on average 0.52%  $C_{org}$  and 0.04%  $N_{tot}$  (Figs 1, 2). A small increase of the C and N content was found in layer 20–30 cm indicates the extension of the zone of organic matter accumulation, which can be the effect of earlier agro-technical measures (ploughing).

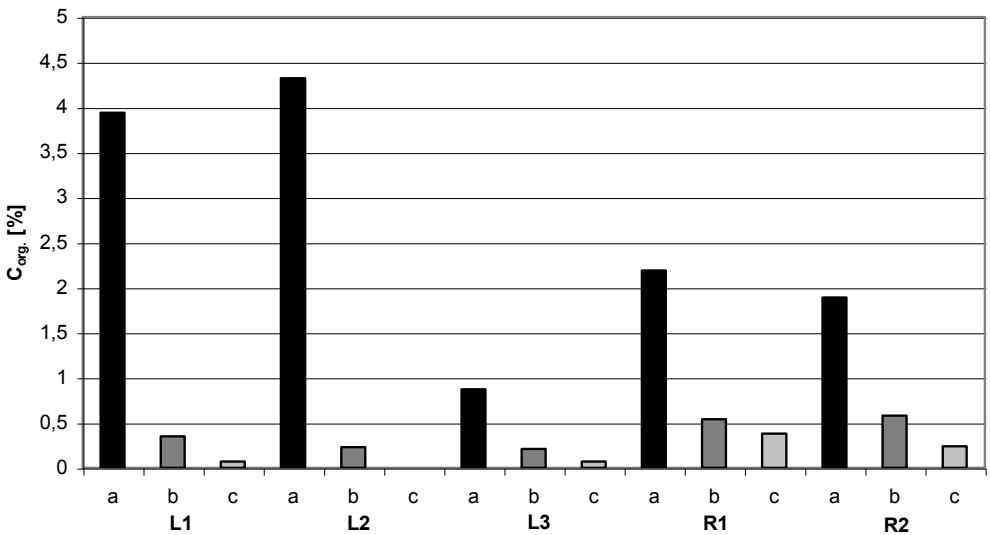
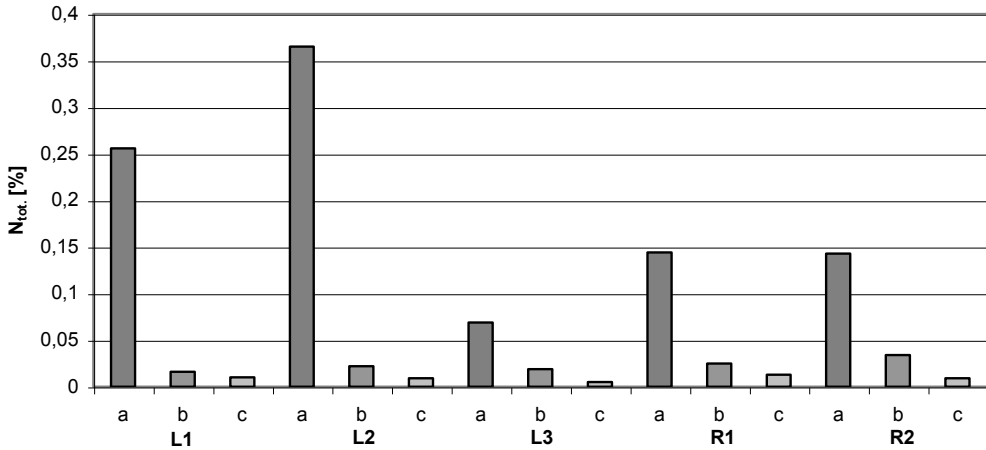


Fig. 1. The increase of the  $C_{org}$  content in the grounds of the repository of the Sulphur Mine "Machów", 30 years after taking reclamation measures

Accumulation of the organic carbon and nitrogen on the plots reclaimed in forest direction depended on the species composition of the forest. The highest content of these elements was found on the plot with the predominance of the black alder. In the layer 0–10 cm 5.67% of C and 0.44% of N was found. In layer 10–20 cm the contents of these elements were ca. 3.5–4 times lower and equalled 1.58% C and 0.097% N, respectively.



**Fig. 2.** The increase content  $N_{tot}$  in the grounds of the repository of the Sulphur Mine "Machów", 30 years after taking reclamation measures

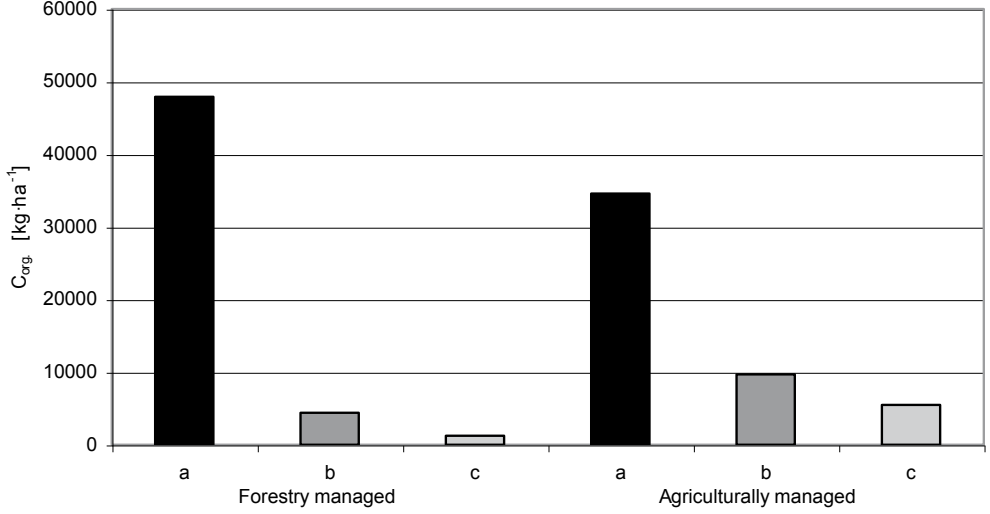
The calculated for the 2 deepest layers increase of  $C_{org}$  and  $N_{tot}$  contents in layer 0–10 cm was 4.45% and 0.365%, respectively while in layer 10–20 cm the percentage was much more times lower – 0.36% C and 0.022% N. The increase of the content of these components in layer 20–30 cm was minimal. Thus one can state that the accumulation of C and N was mainly on the level of 0–10 cm, and to smaller extent on the level 10–20 cm and only in a minimal extent in layer 20–30 cm.

Slightly lower content of C and N was stated on the surface with the predominance of oak. The increase of their content in the relation to deeper layers was 3.96% of C and 0.256% of N in layer 0–10 cm and 0.37% C and 0.16% N in layer 10–20 cm. Similarly, on previous plot the increase of C and N content in layer 20–30 cm was small.

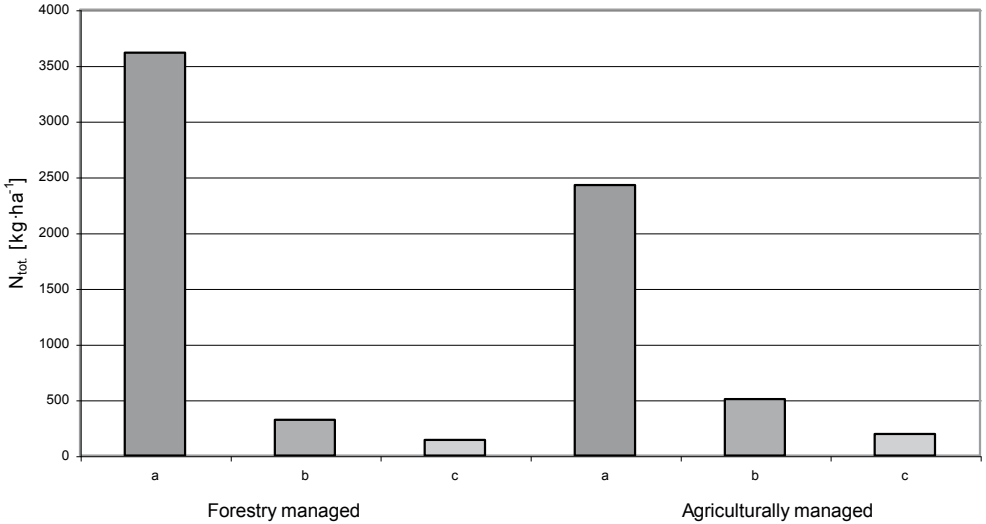
The lowest content of these components was stated in soils formed under forests with larch (Tab. 3). In layer 0–10 cm the increase of  $C_{org}$  was 5 times, and  $N_{tot}$  over 5-times smaller in case of the plot with alder. In layers 10–20 cm and 20–30 cm was on a similar level as in case of the plots with alder and oak. Ratio C:N in accumulated organic matter can, similarly as in case of earlier examined surfaces, regard good.

Mean annual accumulation of the organic carbon on the study plots used for forestry was 0.10% in layer 0–10 cm and 0.06% in layer 0–20 cm. These are values higher than found during the studies carried out in the post-agricultural grounds of Bieszczady, where mean annual increase of organic carbon in the period of 20 years, in the humus level of brown soils under the alder, was 0.041% [2]. It is also accumulation higher than in 25 and 30 years old forests on heavy formations of the repository of lignite mines, where mean annual increase of the content of  $C_{org}$  was 0.06% [1, 19, 20]. On the agriculturally used plots the increase of  $C_{org}$  was 0.068% in layer 0–10 cm and 0.043% in layer 0–20 cm. These are values similar to the obtained in the arable layer of reclamation plantations on loess, clay and loam (0.02–0.10%) [4, 7, 8, 10].

The comparison of the accumulation level of carbon and nitrogen in surface layers of soil up to the depth of 30 cm for 3 forested plots and 2 agriculturally used plots were presented in Figures 3 and 4.



**Fig. 3.** Accumulation of  $C_{org}$  in grounds of the studied plots on the repository of Sulphur Mine “Machów”



**Fig. 4.** Accumulation of  $N_{tot}$  in grounds of the studied plots on the repository of Sulphur Mine “Machów”



The Figures 3 and 4 show that after 30 years from taking the reclamation measures, the accumulation of the organic matter occurs on forest plots, especially with the participation of alder and oak. The total mean increase of the organic carbon content in layer 0–30 cm of forested surfaces was 55 527 kg·ha<sup>-1</sup>, including the plot with the predominance of alder 71 760 kg·ha<sup>-1</sup>, while on the agricultural plot 49 718 kg·ha<sup>-1</sup>, including the plot with temporary intensive plantation of 54 920 kg·ha<sup>-1</sup>. Similar differences occurred in case of nitrogen, where on forest plots the mean increase in layer 0–30 cm was 4 073 kg·ha<sup>-1</sup> (plot with alder of 6 162 kg·ha<sup>-1</sup>), while on agricultural plots – 3 127 kg·ha<sup>-1</sup>. Mean annual accumulation of the organic carbon on forest plots was 1784 kg·ha<sup>-1</sup>, a total nitrogen 136 kg·ha<sup>-1</sup>. On agriculturally used plots in was 1657 kg·ha<sup>-1</sup> of C<sub>org</sub> and 104 kg·ha<sup>-1</sup> N<sub>tot</sub>.

In the above assessment the deposit of carbon and nitrogen contained in the organic matter of the level of humus overburden, which as a result of mineralization and humification will successively enrich mineral humus level. In case of the agricultural plots smaller accumulation of C and N is mainly connected with obtaining crops.

The level of the accumulation of nitrogen stated in the carried out research is 2–3 times higher than found by some researchers in initial soils under forests and agricultural land on the repositories of sulphur mines, lignite mines and hard coal mines [1, 4, 6, 14, 18, 21]. High accumulation of rich in nitrogen organic matter in initial soils on the repository of the Mine “Machów” is surely the result of the impact of species able to bind nitrogen in symbiosis with bacteria – black alder in the forests and medick on the agricultural land. Numerous literature data indicate significant impact of these species in the process of soil enrichment in nitrogen [5, 10, 15, 18, 19]. Surely the influence on the stabilization of the arising in the humification process humus compounds is also connected with the high content of the calcium compounds in repository formations.

The level of the accumulation of the organic matter in the studied soils much exceeds the level given by Siuta [16] for very well remediated areas. Also given by Gołda [5] criterion of the assessment of soil-forming activity based on the annual increase of total nitrogen was in case of the assessed plots exceeded for the category – very high.

## 5. Conclusions

1. The results of the studies carried out on the reclaimed 30 years ago plots of the external repository of the Sulphur Mine “Machów” indicate the dynamic course of soil-making processes, which was clearly reflected in the marked humus level containing large amount of rich in nitrogen organic matter.
2. The highest accumulation of the organic matter took place in the soil layer 0–10 cm, in much extent in layer 10–20 cm and in minimal degree in layer 20–30 cm.

3. Large accumulation of the organic carbon and total nitrogen in initial soil of the studied plots increased the value found in many other objects, suggest the participation of alder on the forested scarps and lasting many years plantation of medick on agricultural surfaces.
4. The comparison of the accumulation of organic carbon and total nitrogen in soil of the agricultural and forested surfaces indicates very dynamic course of this process on the latter.

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