This paper was peer-reviewed for scientific content.
Pages 623-626. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Organic Matter Formation in Post Mining Soils in Central Poland

*Mirosława Gilewska, Jan Bender and Stanislaw Drzymała**

ABSTRACT

One of the most negative site effects of open mining in central Poland are quite large areas of post-mining dump deposits which have to be reclaimed and restored to the previous use. Effective rehabilitation of this land, especially for agricultural or forestry usage need organic matter in surface layer of a raw post-mining materials similar to humus horizon in natural soils. This paper described relatively fast way of forming organic matter in dump soils and its characteristics.

After 20 years of post-mining deposits reclamation, the soil shows well-developed Ap horizon: 25-35 cm thick with about 1.5% of organic matter. Most properties of this organic matter are similar to the organic matter in natural soil of the investigated area except for significantly lower N content (2.8%) and wider C:N ratio (16:1) than in natural soils.

Post mining soils having well-developed organic matter horizon (Ap) show good and stable agricultural production under conventional tillage system and hundreds hectares of these soils are successfully cultivated in central Poland.

INTRODUCTION

The Konin – Turek region in central Poland is one of the most important brown-coal mining areas. The reclamation of post-mining (dump) materials based on scientific research has lasted for more than 20 years. More than 4.000 ha have already been reclaimed and are used as agricultural lands. For many years in central Poland, dominant method of reclamation of post-mining materials and other waste deposits was based on different " pioneering plants". However, this method needs many years and it is not effective enough to reintroduce productive plants. The successful recultivation of these lands was possible under very high mineral fertilization mainly with nitrogen (Bender 1983, 1995). Bender and Waszkowiak (1989) have found that post - mining raw material, containing reasonable amount of clay minerals, show high sorptive ability to NH_4^+ cations. Therefore, the ammonium forms of nitrogen [$(NH_4)_2$ SO_4 and NH_4 NO_3] could be used in yearly doses, reaching 300-400 kg of N per hectare, without negative impact on environment-especially on surface and ground waters. Many field experiments conducted for several years in 1960s and 70s allowed introducing the new method of biological reclamation of post-mining and spoilt deposits (Bender 1983). The new method was based on three elements: almost every arable plant can be used as a pioneering plant, very high mineral fertilization would be needed as a chemical improvement of post-mining waste materials, and an intensive mechanical tillage would be needed to improve the physical characteristics of the dump deposits.

The most important problems in the reclamation process of post - mining materials of different geological origin is the formation of new organic matter in the surface layers. The organic matter in these soils play very important, positive role improving many physical properties (structure, porosity, bulk density, water capacity etc.) and biological activity (Gilewska, 1991; Gilewska and Otremba 2000). In addition, in other European Countries the organic matter play very important role in post-mining land reclamation (Haigh, 1998; 1998a). Often the post-mining waste materials are covered by thin layer of natural soil contain organic matter, but in some cases this way is ineffective. (Haigh, 1998).

The objective of this study was to determine the properties of organic matter formed during 20 years of reclamation of the post-mine-dump materials, in comparison to the natural soils occurring in these areas.

MATERIALS AND METHODS

The investigation was carried out on a productive 60 ha experimental field of dump soil after 20 years of reclamation. The dump materials ware composed mainly of post-mining loamy deposition of the Riss and Würm glaciation with admixture of sandy and clayey materials. The biological reclamation in initial stage was based on pioneering plants (*Melilotus albus* and *Medicago sativa*) lasting 7 years. After 3 years arable ray (*Secale cereale*) under conventional tillage and fertilization were introduced resulting in poor yields of less than 0.2 Mg ha^{-1}. Following this non-effective method, a new method for dump reclamation proposed by Bender (1983), was introduced.

During 13 years of reclamation using the new method, the cereals: ray, barley (*Hordeum sativum*) and wheat (*Triticum vulgare*) and winter rape (*Brassica napus ssp. Oleifera*) were cultivated with a rate of mineral fertilization 400-525 kg NPK ha^{-1} yr^{-1} including 160-200 kg ha^{-1} of nitrogen. The yields after about 10 years of this management begun to be relatively stable: 2.5- 5.0 Mg ha^{-1} of cereals and 2.0-3.0 Mg ha^{-1} of winter rape. The straw was always collected for other uses so that organic matter was formed only from roots and harvesting residues.

*Miroslawa Gilewska and Jan Bender Department of Waste Land Reclamation of Agricultural University of Poznań; Stanislaw Drzymała, Department of Soil Science of Agricultural, University of Poznań, ul. Mazowiecka 42 Poznań. *Corresponding author: rrsp@owl.au.poznan.pl

After 20 years, (7 years of pioneering plants and 13 years of intensive crop cultivation) of forming and the Ap horizon, the organic matter and its properties were determined. The investigation comprised of four profiles of post-mining soil and one characteristic profile of a natural soil from area adjoining to the dump land. Soil samples were collected from the surface layer (Ap), ranging from 25 to 35 cm thickness in the dump-field.

The following characteristics were determined:

– Soil texture, by hydrometric method (Mocek et al., 1997)
– $CaCO_3$ content, by volumetric method using 10% HCl (Mocek et al., 1997)
– Available forms P and K by Egner - Rhiem method (Mocek at al. 1997)
– pH, in 1 *M* KCL (Mocek et al., 1997)
– Exchangeable cations (H^+, Ca^{+2}, Mg^{+2}, K^+, Na^+) in 1 *M* CH_3COONH_4 at pH 7.0 (Mocek et al., 1997)
– Organic matter characteristics such as: total C content, humus – fractions, elemental analysis of humic acid, optical density of Na humates, and IR spectra, by methods described by Kononowa (1968) and Drozd (1978).
– Total N was determined by the Kjeldahl method, (Mocek et al., 1997)

All determinations of chemical properties were carried out in three replications.

Mean values and standard deviations were calculated for dump soils.

RESULTS AND DISCUSSION

During seven years of pioneering plants and thirteen years of reclamation of the post - mining materials according to Bender (1983) method, the organic matter horizon (Ap) was developed. The thickness of this horizon was equal to depth of mechanical tillage (25-35 cm) with content of organic carbon 0.6-0.9% about which is 1.3 –1.5% of organic matter (50-75 Mg ha^{-1}). The Ap horizon morphologically did not differ from the surface horizon of natural arable soils, and was well homogenized showing an

Table 1. Texture of dump and natural soils

Soil-profile No	Percentage of fractions of diameter in mm: sand 2-0,05	silt 0,05-0,002	clay < 0,002
Dump soil			
1	78	15	7
2	71	19	10
3	65	25	10
4	47	22	31
Mean	65.25	20.25	14.5
Standard deviation	13.28	4.27	11.09
Natural soil			
5	65	27	8

Table 2. Chemical properties of dump and natural soils

Soil-profile No	pH H_20	pH 1*M* KCL	$CaCO_3$ gkg^{-1}	C org. gkg^{-1}	N total gkg^{-1}	Ratio C:N	P acc. Egner-Rhiem mg kg^{-1}	K acc. Egner-Rhiem mg kg^{-1}
Dump soil								
1	7.8	7.4	3.4	7.6	0.38	19.7	92	79
2	7.9	7.3	2.5	6.3	0.45	13.9	89	142
3	8.0	7.4	7.0	8.6	0.48	17.9	54	142
4	7.7	7.1	4.3	8.6	0.62	13.9	81	223
Mean	7.8	7.3	4.3	7.7	0.48	16.3	79	146
Standard deviation	0.13	0.14	1.94	1.09	0.10	2.92	17.30	59.02
Natural soil								
5	7.1	6.0	0.0	0.57	0.50	11.4	59	85

Table 3. Exchange capacity and cautions of dump and natural soils

Soil-profile No.	H^+	Ca^{+2}	Mg^{+2}	K^+	Na^+	TEB	CEC	% BS
	cmol (+) kg^{-1}							
Dump soil								
1	0.5	7.7	2.1	0.2	0.2	10.2	10.7	95.4
2	0.6	9.4	2.9	0.4	0.3	13.0	13.6	95.6
3	0.5	15.6	3.9	0.4	0.6	20.5	21.0	97.5
4	0.6	21.1	3.8	0.5	0.7	26.1	26.7	97.7
Mean	0.5	13.4	3.2	0.3	0.4	17.4	18.0	96.5
Standard deviation	0.0058	6.13	0.85	0.13	0.24	7.22	7.24	1.22
Natural soil								
5	1.3	3.5	0.8	0.5	0.2	5.0	6.3	80.0

Table 4. The fractional composition of humus according to Tiurin′s method (Kononowa 1968)

Soil-profile No.	Fractions and soil	Humic acid-C mg kg^{-1}	Fulvic acid-C mg kg^{-1}	Ratio HumicC / Fulvic C
	Free humus compounds extracted with 0.1 *M* NaOH without decalcification			
1	**Dump soil**	880	1730	0.5
2		640	1550	0.4
3		720	1870	0.4
4		280	240	1.2
Mean/Sx		630/ 253.77	1347/ 749.86	0.6/ 0.39
5	**Natural soil**	910	1730	0.5
	Fixed humus compounds extracted with 0.1 *M* NaOH after decalcification			
1	**Dump soil**	2230	1040	1.5
2		1530	910	1.7
3		2220	1030	2.2
4		1490	1000	1.7
Mean/Sx		1867/ 413.15	995/ 59.16	1.7/ 0.30
5	**Natural soil**	1370	1480	0.9
	Strong fixed humus compounds extracted alternately with 0.1 *M* H_2S0_4 and 0.1 *M* NaOH after decalcification **Dump soil**			
1		450	170	2.6
2		320	160	2.0
3		480	200	2.4
4		570	270	2.1
Mean/Sx		455/ 103.44	200/ 49.66	2.2/ 0.27
5	**Natural soil**	310	190	1.6

Table 5. Elemental composition of humic acids

Soil-profile No.	Ash %	Content on ash-free basis(%) C	N	H	O	Ratio C:N
Dump soil						
1	5.3	55.6	2.7	4.7	36.8	20.6
2	1.6	57.0	2.8	5.1	35.4	20.4
3	1.0	58.5	2.9	4.6	33.8	20.2
4	5.3	55.6	2.9	4.4	37.6	19.2
Mean	3.3	56.6	2.8	4.7	35.9	20.1
Standard deviation	2.32	1.38	0.096	0.29	1.67	0.62
Natural soil						
5	1.9	53.2	4.9	5.0	37.0	10.9

Table 6. Optical density of Na-humates in visible light in extinction values

Soil-profile No.	Wavelengths (nm) 726	665	61 9	574	533	496	465	Ratio of extinction values at 465 and 665 nm.
Dump soil								
1	0.094	0.150	0.225	0.325	0.460	0.630	0.810	5.4
2	0.075	0.130	0.200	0.295	0.430	0.590	0.790	6.1
3	0.092	0.150	0.240	0.350	0.510	0.680	0.850	5.7
4	0.070	0.125	0.205	0.310	0.470	0.690	0.830	6.6
Mean	0.083	0.139	0.217	0.320	0.47	0.65	0.82	5.99
standard deviation	0.012	0.013	0.018	0.023	0.033	0.046	0.026	0.52
Natural soil								
5	0.080	0.135	0.210	0.305	0.420	0.560	0.750	5.5

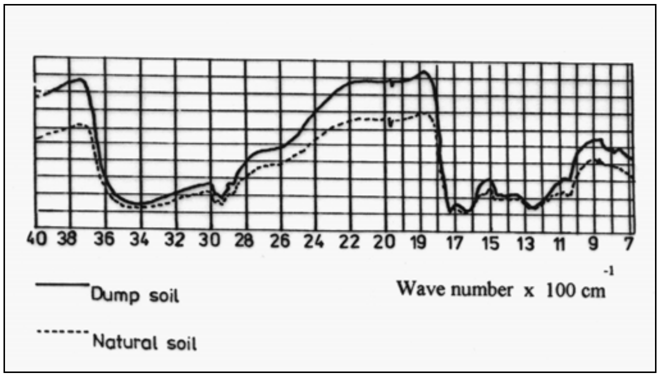

Figure 1. IR-spectra of humic acid of dump and natural soils.

abrupt border with the lower layers. The basic properties of the surface horizons of dump and natural soils are shown in Tables 1-3. The results show that dump materials are quite homogenous, except profile No. 4, where clay content is much higher than in other profiles. The post-mining soils contain calcium carbonates; therefore show alkaline reaction whereas natural soils are slightly acid. The elemental composition of humic acids (Table 5) was quite similar in both soils with the exception of the N content which is significantly smaller in the dump soil (2.8%) than in natural soil (5%). Therefore, the C:N ratio was much wider in dump soil (20:1) than in natural soil (11:1).

The low level of nitrogen and wide ratio of C:N in post-mining soils are the main reason for their low productivity. The high and stable productivity of these soils is only possible under very high nitrogen fertilization (Bender and Gilewska, 1999). The other microelements are also necessary but in less range. It depends on chemical properties and compositions of post-mining materials, which are mostly quite rich in potassium, low in phosphorus, and do not contain nitrogen (Gilewska, 2000). The fractional analyses of organic matter shows that content of “fixed” humus compounds in the dump soil was clearly higher than in natural soil (Table 4). The other humus fractions (“free” and “strong fixed”) and other determined properties of organic matter (optical density and IR -spectra) were similar in dump and natural soils (Table 6, Fig. 1).

The results show that good organic matter horizon in post-mining deposits (in many aspect similar to natural soils) can be developed within several years, under specific biological method of reclamation.

CONCLUSIONS

(1) Reclamation of post-mine row materials by cultivation of almost every useful productive plant under very high mineral fertilization (minimum 400 kg NPK ha^{-1} yr^{-1}) with special rate of nitrogen (minimum 160 kg $N \cdot ha^{-1}$ yr^{-1}), and intensive mechanical tillage can cause good development of Ap horizon within about 10-15 years.

(2) The properties of organic matter formed under such way of biological reclamation are quite similar to the organic matter of natural soils except N - content, which is almost 2 times lower in dump soils and ratio of C:N which is significantly wider in the last soils.

REFERENCES

Bender, J. 1983. Theoretical base of industrial landscape recultivation. In Proc. Int. Conf. Matr. Coal Min. Co. Göngyös, 113-118.

Bender, J. 1995. Reclamation of post-mining soils in Poland (in Polish with English abstract). Zesz. Probl. Post. Nauk. Rol. 418, 142-152.

Bender, J. and M. Gilewska. 1999. The influence of organic-mineral fertilizer on productivity of dump soils and low class bonitation (in Polish with English abstract). Rocz. AR. Pozn. CCCX, Melior. Inż. Środ, 20, cz.II:113-123.

Bender, J. and M. Waszkowiak 1989. Ammonium ion adsorption by overlayers of brown coal mine “Konin” (in Polish with English abstract). In Arch. Ochr. Środowiska 1-02, 125-133.

Drozd, J. 1978. Studies of chemical and physicochemical properties of humus compounds of some taxonomic soil units (in Polish with English abstract).Rozprawy Naukowe, Zeszyt 13, AR Wrocław p 65.

Gilewska, M. 1991. Biological reclamation of post-mining soils in brown coal mine “Konin” (in Polish with English abstract). Rozprawy Naukowe, Zeszyt 211, AR Poznań p 59.

Gilewska, M. 2000. The role of macroelements in reclamation of dump soil (in Polish with English abstract). Rocz. AR. Poz. CCCXVII, Roln. 56: 391-400.

Gilewska, M. and K. Otremba 2000. Physical features of dump soils originating in the process of reclamation (in Polish with English abstract). Rocz. AR Poz. CCC XVII. Roln. 56: 357-365.

Haigh, M.J. 1998. Promoting better land husbandry in the reclamation of surface coal-mined land. Adv. in GeoEcology 31, 767-733, Catena Verlag GMBH, Reiskivahen, Germany.

Haigh, M.J. 1988. Towards soil quality standards for reclaimed surface coal- mined land. Advances in Geo Ecology 31, 775-779, Catana Verlag GMBH, Reiskirche Germany.

Kononowa, M. 1968. Soil organic matters. PWRiL Warszawa p. 390 (in Polish).

Mocek, A., S. Drzymała and P. Maszner 1997. Genesis, analysis and classification of soils. AR Poznań p. 416 (in Polish).