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An Overview of Humus state in reclaimed lands, Bulgaria. Bulgarian experience in Wales, UK

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Преглед на състоянието на хумуса в рекултивирани земи, България. Българският опит в Уелс, Великобритания

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Резюме. Процесът на формиране на почвата е придружен от натрупване на органична материя. Почвеното органично вещество е важен компонент на физични и физико-химични характеристики, образува органо-минерални комплекси при естествени почви и определя почвеното плодородие. Големи територии в света са нарушени, при открит и подземен добив на въглища, което изисква биологична рекултивация. Залесяването с различни дървесни видове и затревяването са добре познати подходи и практики. Знанията и опитът за почвообразуващите процеси и образуването на хумус в началния етап изясняват посоката и интензивността на тези важни процеси при рекултивацията на земята. В статията се обсъждат съдържанието на органичен въглерод и състава на органичното вещество за различни тестови участъци на рекултивирани земи в „Марица-изток“ ЕАД и Перник ЕАД. Представена е информация за рекултивацията на земите със зеолитови материали в „Марица-Изток“ ЕАД. Описан е българският опит при рекултивация от открит въгледобив в Уелс, Великобритания.

Ключови думи: рекултивирани земи, органичен въглерод, хуминови киселини, фулво киселини, неекстрахиран органичен въглерод.

Abstract. Soil forming process is accompanied by the accumulation of organic matter. Soil organic matter is an important component of soil physical characteristics, physico-chemical characteristics, formation of organo-mineral complexes for natural soils and determines soil fertility. All over the world large territories are disturbed after open-cast and underground coal mining processes demand biological land reclamation. Worldwide, forestation with different tree species and grasses are well known approaches and practices. Knowledge and experience on soil forming processes and humus formation in the initial stage clarify the direction and intensity of these important processes in land reclamation. Content of organic carbon and organic matter composition for different test plots of reclaimed lands in “Maritsa Iztok” JSCo and Pernik coal basin is discussed. Information on the land reclamation with zeolite materials in “Maritsa Iztok” JSCo is presented. Data on the Bulgarian experience of afforestation in Wales, UK is described.

Keywords: reclaimed lands, organic carbon, humic acids, fulvic acids, unextractable organic carbon.

Introduction

A great number of studies, including articles on reclaimed lands for agriculture and forestry are referred to the problems of soil reclamation with or without of humus layers in the areas affected by the open coal mining activities in Bulgaria (Banov, 1989; Banov et al., 1989, 1994, 1995; Banov and Hristov, 1997; Banov and Marinkina, 2000; Hristov and Trejkyashki. 1982; Hristov et al., 2003; Filcheva et al., 1998, 2000a, 2000b; Gencheva et al., 1995; Gencheva and Haigh, 1988; Gencheva and Filcheva, 1995, 2000; Haigh et al.,1995; Krastanov et al, 2000; Petrova and Noustorova, 2000; Zheleva et al, 1994). The present study describes land reclamation experience in two regions of Bulgaria: region of “Maritsa Iztok” JSCo and Pernik, processes of zeolite amended clay banks in the region of “Maritsa Iztok” JSCo, and Bulgarian experience on afforestation in Wales, UK.

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Experience in the region of Maritsa Iztok JSCo damaged land reclamation

Soil organic matter accumulation and composition of reclaimed lands with and without humus layers for different period of management (5, 10 and 20 years) and different land use: (i) cultivation: (ii) grassland and forest lands have been studied (Banov, 1989; Banov et al., 1989, 1994, 1995; Hristov and Trejkyashki. 1982; Hristov et al., 2003). The highest content of organic carbon, from 2.12 to 10.28% was calculated for reclaimed lands with 20 years of management. The 5-year profile is characterized with the high amount of total carbon in grass land compared with arable lands. It is found a tendency of accumulation of organic matter with the specific conditions – age and type of land use. The high amount of organic carbon in 20-year profile is a result of organic mass of grass vegetation and inherited admixture of coal dust and partial contamination of the surface layer with wastes from the nearby Thermal electric power station and the Briquette plant. Trends of sharp decrease of organic carbon in the second layer compared to the surface layer for the grassland and forest, and where in cultivation profiles organic carbon gradually decreases were found. Data received from the organic matter composition show predomination of humic acids (HA) prevail fulvic acids (FA). For all profiles studied ratio C_{HA}/C_{FA} (carbon content in humic acids and carbon content in fulvic acids) increased, which determined the humic type of humus probably due to organic carbon rich admixture. The soil forming process is related to the specific conditions in the region of "Maritsa Iztok" JSCo. It is found under cultivation by predomination of HA complexed with Ca over complexed with R_2O_3. This process is favored by the presence of carbonate materials forming the profile of reclaimed lands. For all studied profiles, a large amount of unextractable carbon is determined, probably due to formation of strong organo-mineral association according by Fatkulin, (Banov et al., 1994). Data received for the optical characteristic show low degree of aromatization and condensation. Lands reclaimed by humus horizon coverage are characterized by an amount of total organic carbon from 2.05% (0–5 cm) to 0.78 (40–60 cm). Analytical data for the organic matter composition show the same distribution characteristics as for the Leached Cinnamomic Forest soil (Chromic Luvisol, FAO) used for the reclaimed lands coverage.

Experience on Maritsa Iztok JSCo damaged land reclamation with zeolite materials

In biological land reclamation without humus coverage of clay banks in the region of "Maritsa Iztok" JSCo the most discussed problem is the restoration of the soil structure. Based on the fundamental significance of organic carbon in soil formation we examined its accumulation as a part of soil forming processes, as being formed in the clay substratum. The influence of natural clinoptilolite and organo-zeolite compost on the accumulation of organic matter and organic matter composition and their meliorative effect on the yellow and green clay materials in the region of "Maritsa Iztok" JSCo (Filcheva et al., 2002) was investigated.

Soil formation and humus formation are slow releasing processes. New formed humic substances increased in zeolite amended areas according to the relation: $y = 1.028+0.458x$, $r = 0.496$, where y = amount of humic like substances, x = amount of applied zeolite, % in the surface layer 0–20 cm. The maximum of HAs was found in the case of 10 t/ha and 30 t/ha per 0–20 cm and 20–40 cm layers, respectively. HAs are characterized by low degree of condensation and aromatization.

After the third year of land reclamation, it was established that with the increasing of applied zeolite, the degree of land degradation enhances and the clay substratum was compacted ($r = 0.407$). The results obtained show that in the case of high level of carbonate, the role of Ca^{2+}/K^{+} ratio and Cation-Exchange Capacity (CEC) are more important factors for humus like substances accumulation than the amount of zeolite in the media ($r = 0.610$; $r = 0.649$). The natural zeolite role is more indirect due to enrichment of exchangeable K^{+} ($r = 0.602$) (Filcheva et al., 2002).

Well, known different methodologies exist for reclamation of land disturbed after open coal-mining: with/without humus coverage, forestation, application of Thermal power station ash, different waste organic materials, and variety of humic substances. The proposed method includes the application of natural and modified zeolites and organo-zeolite composts. The results show that this method improved soil forming processes, increased fertility of clay substrates, and assure good benefit at the first year. The technology was licensed by the Bulgarian Ministry of Agriculture. The method without humus layers reclamation with zeolite products is in conformity with the requirements of Regulation 26/1996 State Gazete 86/1996 and 30/2002 (Hristov et al., 2003).

Long-term pot and field experiment with geological materials from the region of "Maritsa Iztok" coal basin confirms the role of zeolite materials in the restoration of the clay banks. *In situ* experiments in Kovachevo village, Troyanovo and Mednikarovo banks were carried out. They demonstrated the possibility to manage some physico-chemical properties of the clay substratum and to create favorable conditions for accumulation of biogenic elements. This is related to the initial soil forming processes accelerated in soils amended with zeolite. Bio productivity of the clay substrate is close to those of lands reclaimed with humus horizon (Chakalov et al., 2002; Filcheva et al., 2002b).

Experience on damaged land reclamation in Pernik region

Large territories disturbed after open-cast and underground coal mining processes demand biological land reclamation. Forestation with different tree species and grassed are well known approaches and practices all over the world (Akala and Lal, 1999; Banov 1989; Banov et al., 1989; Banov et al., 1994, 1995; Filcheva et al., 1998, 2000a; Gencheva et. al, 1994; Gencheva and Filcheva, 1995; Noustorova et al, 1998). Knowledge and experience on soil forming processes and humus formation in the initial stage clarify the direction and intensity of these important processes in land reclamation.

Coal basin Pernik area is the oldest coal-mining region in Bulgaria. The processes of coal mining have started over than 100 years ago and occupied 50 km^2. The experimental territories included two sites spoils from open-cast coal mining – marls, coal, cinders and coaly shale. These spoil bank terraces were created in the period of 1962–1965 and 1970–1971 for the underground and surface coal mining, respectively. The spoil surface has been exposed for approximately over 30 years and affected by forestation and grassing more than 25 years. Areas have been planted by Black pine (*Pinus nigra*), Plane tree (*Platanus Occidentalis*), Ash tree (*Fraxinus Exelsior*), Lindan (*Tilia sp.*), Betula alba (*Betula Verucosa*), Phalse acacia (*Robibia Pseudoaccacia*) and Ash tree (*Fraxinus Americana).* Long period of forestation and self-set grassing gives an opportunity to study some peculiarities of the initial stage of humus formation and humus accumulation.

Information for the organic matter content and composition of the initial process of humus formation from surface and underground coal mining under different tree species was compared to characteristics for grass land. The amount of humic and fulvic acids decreased along the profile depth following the total organic carbon. It was established that the humus formation for the substrates, under the tree species are characterized with the higher ratio C_{HA}/C_{FA} compared to the grass land, despite the higher content of humic acids for the substrates of underground coal mining. Humic acids are bound with Ca in the most profiles from the surface coal mining substrates where they are partly bounded with Ca for underground ones, because of both reasons – lower pH, and Ca content (Gencheva and Filcheva, 1995; 2000).

The results in Filcheva et al. (1998; 2000a) confirm the beneficial impact of different forest species on pedogenesis in surface coal mine spoils. Twenty-five years after forestation Black pine (*Pinus nigra*) has created a thicker litter layer than Phalse acacia (*Robibia Pseudoaccacia).* Litter more rapid decomposition in evinced by a higher C/N ratio = 21/14 and more organic carbon in the organo-mineral ones. This layer is also thicker under *Pinus nigra* than *Robibia Pseudoaccacia* (16.18/8.21 t/ha).

The lowest amount of HA (0.20 abs. %) are determined for the unvegetated control site. The HA amount, in abs. %, ranges upwards from 0.21 to 0.55 on the Black pine (*Pinus nigra*) experimental site and ranges from 0.18 to 0.28 under Phalse acacia (*Robibia Pseudoaccacia*). The humus layer shares a high level of total organic carbon and HAs. A major contribution comes from the coals in the mine spoils and may facilitate humus accumulation. Most of humic acids are Ca-complexed, especially in the surface layers in the unvegetated and Black pine tests thanks to the presence of large amount of clay and exchangeable Ca. The C_{HA}/C_{FA} ratio for the Black pine (*Pinus nigra*) is 0.45 and that for the Phalse acacia (*Robibia Pseudoaccacia*) is 0.8 in the 0–5 cm layer of the spoil substrate. In addition, the quantity of the FA under Black pine is about 2.5 times greater than in 0–5 cm layer under Phalse acacia (Filcheva et al., 2000a).

Bulgarian experience in Wales, UK

The Bulgarian experience in Wales is presented in two articles (Noustorova et al., 1999; Filcheva et al., 2021), where variants with tree species and fertilization are described by Filcheva et al. (2021). Soil samples were collected from 0–150 mm depth in 1998 and again in 2018 from the same Varteg test plots "Svetla" (named to Prof. Svela Gencheva, Bulgaria). Samples were analyzed in the same laboratory in Sofia, Bulgaria, ISSAPP "N. Poushkarov" for total organic carbon and organic matter composition. The results, presented in Table 1 show increasing of total organic carbon in the surface 0–150 mm from 4.21 (1998 Svetla 2, control to 6.32 Svetla 3). Table 2 presents the different fertilization for the studied plots. Most of the Svetla plots with exception 6 (Svetla3-91 MC) and 7 (Svetla 4-92 MC+2.SRF+RA) the type of humus is fulvic-humic, that means HA prevalence over FA. HAs are bound

Table 1
Content and composition of soil organic matter, Varteg, Wales, second sampling.

Таблица 1
Съдържание и състав на почвеното органично вещество, Вартег, Уелс, второ пробовземане

Reclaimed plots by variants fertilization		TOC %	Organic carbon (OC), % in $Na_4P_2O_7$+NaOH				$\frac{C_{HA}}{C_{FA}}$	None extractable OC (%)	OC in H_2SO_4 (%)	Optical density of HAs (E_4/E_6)		OC in NaOH, (%)
			HA+FA	HAs connected with R_2O_3	HAs connected with Ca	FA				total	free	
1.Svetla1-91 MC	Var. 1	5.68	1.17[a] / 20.60[b]	0.66 / 90.41[c]	0.07 / 9.59	0.44 / 7.75	1.66	4.51 / 79.40	0.12 / 2.11	4.04	4.04	1.17 / 20.60
2.Svetla1-91 MC+BF	Var. 2	6.11	1.24 / 20.29	0.77 / 12.60	0.00	0.47 / 7.69	1.64	4.84 / 79.71	0.12 / 1.96	4.14	4.09	1.24 / 20.29
3.Svetla2-91 MC+SRF	Var. 3	5.80	1.21 / 20.86	0.49 / 80.33	0.12 / 19.67	0.60 / 10.34	1.02	4.59 / 79.14	0.12 / 2.07	5.05	5.58	1.20 / 20.69
4.Svetla2-91 MC+BF+SRF	Var. 4	4.21	1.27 / 30.17	0.73 / 17.34	0.00	0.54 / 12.83	1.35	2.94 / 69.83	0.12 / 2.85	4.54	4.71	1.24 / 29.45
5.Svetla3-91 MC+BF	Var. 2	5.26	1.60 / 30.42	0.61 / 70.93	0.25 / 29.07	0.74 / 14.07	1.16	3.66 / 69.58	0.15 / 2.85	5.02	4.37	1.54 / 29.28
6.Svetla3-91 MC	Var. 1	6.32	1.94 / 30.70	0.61 / 9.65	0.00	1.33 / 21.05	0.46	4.38 / 69.30	0.15 / 2.37	5.23	5.54	1.86 / 29.43
7.Svetla4-92 MC+2.SRF+RA	Var. 5	4.84	1.10 / 22.73	0.45 / 9.30	0.00	0.65 / 13.43	0.69	3.74 / 77.27	0.12 / 2.48	5.67	3.70	1.10 / 22.73

Indications: *a* – % of the soil sample, *b* – % of the total carbon, *c* – % of the total content humic acids.
Optical characteristics: Ratio of extinction at 465 nm over 665 nm (E_4/E_6); HA – humic acids, FA – fulvic acids.

Table 2
Additional information for the fertilization in the Variants (Filcheva et al., 2021)

Таблица 2
Допълнителна информация за торенето във вариантите (Filcheva et al., 2021)

No	Variants	No	Variants
1.	Control – only spent mushroom compost (MC) as planting medium	4.	Organic, i.e. bone meal fertilizer plus spent mushroom compost, plus osmocote slow-release fertilizer (SRF) tablets
2.	Organic, i.e. bone meal fertilizer plus spent mushroom compost (MC + BF).	5.	Spent mushroom compost, plus a double dose of mineral fertilizer: osmocote slow-release fertilizer (SRF) tablets plus a 'remineralization agent'
3.	Spent mushroom compost, plus mineral fertilizer: osmocote slow-release fertilizer tablets (MC + SRF).	6.	Spent mushroom compost, plus double dose of mineral fertilizer: osmocote slow-release fertilizer (SRF) tablets.

with R_2O_3, making them more available nutrients to plants; – optical characteristic increase in both, condensation and aromatization of HAs decrease, respectively (exception 7 – Svetla 4-92 MC+2. SRF+RA). Organic carbon in the NaOH extract is nearly equal to those in pyrophosphate extract and confirmed the absence of metals bound to the HAs.

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