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STUDY ON ECOSYSTEM COMPONENTS OF TECHNOLOGICAL WASTE BANK RECLAIMED AFTER STEEL PRODUCTION

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Abstract

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Reclamation of land affected by past industrial activities is of major environmental concern worldwide. Major strategies involve the encouragement of better use of land, post industry, and these often focus on re-vegetation processes for forestry. Studies on the effectiveness of biological re-cultivation mainly focus on activities and techniques for the acceleration of soil formation processes. Relationships between substrate and plants is also of concern, in order to create viable and sustainable environments.
In this work, we report on a study of reforestation of a former industrial site ("7th September" 20 decares in size) located in the sub-urban system of the Sofia-Pernik agglomeration in Bulgaria. It consists of by-products from steel manufacturing deposited over 30 years. Post closure reclamation of the site was dependent on defining an appropriate technology for the biological reclamation. A detailed study of the hydro-physical and chemical parameters of soil substrates and forest vegetation was undertaken in order to institute recommendations for their improvement and utility under biological reclamation. We established that the properties of the substrates are quite similar to those of natural soils in the region. We determined the influence of the quantity of organic matter and the range of nutrient elements in the substates as determining parameters for further biological reclamation. This site is located in the lower forest zone of the country, where water content is the main limiting factor for plant survival. Consequently, nutrient elements are available for the tree species only in combination with an optimal water regime.

Key words: soil substrate, vegetation, biological reclamation

Introduction

The problem of reclamation of disturbed lands, after the creation of waste banks, is very important and of great scientific interest. The reconstruction of ecosystem function is one of the major challenges of restoration ecology (Aronson, van Andel, 2006), especially if the aim is to change degraded systems into ones that will be sustainable in the long term (Hobbs, Norton, 1996). Bradshaw (1984) underlined that we cannot have effective reclamation unless we understand the ecology of the site and of the materials we want to use. Many studies have focused on relationships between the substrate and plants to contribute to remediation of the reclaimed lands within the territorial system (Prokopiev, 1967, 1969; Donov et al., 1978; Zhelyazkov, 1990; Puneva et al., 1996; Petrova et al., 1999; Bech et al., 2000; Sokolovska et al., 2001, 2004). Others focused on the effectiveness of biological reclamation with respect to activities and techniques to accelerate soil formation processes (Trofimov, 1979; Kovalev, 1986). The potential of coal-spoil as a medium for plant growth with a view to reclamation was thoroughly reviewed by Kent (1982), identifying the physical, chemical and biological constraints to vegetation establishment. Therein, it was emphasized that problems of toxicity resulted from the weathering of pyrites and the marked spatial and temporal variations in toxicities and nutrient deficiencies in colliery shales.

Bulgaria's land reclamation policies require the removal, storage and reinstatement of topsoil from the pre-mining environment (Filcheva et al., 2000). Inevitably, the amount of humus-rich topsoil that can be stored is insufficient to provide a suitable cover for the entire post-mining landscape. Consequently, all available topsoil is reserved for the reclamation of those gently sloping surfaces suitable both for agricultural after-uses and forestation (Gentcheva-Kostadinova, Haigh, 1988). Filcheva et al. (2000) studied organic accumulation in microbial action in the mine soil in Pernik, Bulgaria and confirmed the positive impacts of forestation on initial soil-forming processes in surface coal mine spoils. Although the creation of mature soils by forest fallowing remains a long slow process, forest biological reclamation establishes the preconditions for self-sustaining natural soil development.

The aim of this study is to investigate natural ecological conditions, primarily soil substrate development on processing residues from steel production, and then propose an appropriate technology for biological reclamation which can form the basis of management strategies post-closure of industrial operations. The implications for successful demonstration would be that this land could be returned to beneficial re-use in a region under pressure from urban development.

Materials and methods

Study area

In this work we studied three parts of an industrial waste bank named "7th September" located at 1500 m a.s.l. in the green system of the Sofia-Pernik agglomeration in Bulgaria, with a total area of experimental plots of 20 decares. It consists of technological wastes produced by the steel industry formed more than 20 years ago. The studied area is situated southwest of "Stomana LTD" steel factory and northeast of the "Kalkas" residential district. It is included in the green protection zone of the town of Pernik, and there are certain planning conditions for this zone which the local government expects to be developed. The dominant tree species is European black pine (*Pinus nigra* A r.). The terrain of the waste bank presents a broken and very diverse terrain, excavated for different reasons, and there is also additional input of collections of building materials and anthropogenic technological wastes. The technological reclamation was implemented through embankment of a 30 cm organic soil layer and further afforestation with black pine (*Pinus nigra* A r.) combined with single trees of Scot's pine (*Pinus sylvesrtis* L.). The reclaimed waste bank was accepted by the State commission on 23rd of January1986. Experimental work herein followed a period of 10 years after planting.

At the time of experiment, some single groups with well developed canopy were established, while other trees were totally destroyed as a result of human activities in the proximity of the residential area (illegal wood collection was considered responsible). Silvicultural activities commenced following reclamation of the waste bank and biological reclamation of the tree groups.

Climatic elements

The limiting factor for successful biological reclamation is precipitation (Alexandrov, 2008), so distribution of precipitation in Pernik town is presented in Table 1. Because of low total precipitation and a relatively dry vegetation period, tree species with high dryness-tolerance during the vegetation period should be chosen for afforestation.

T a b l e 1. Mean monthly, seasonal and annual sum of precipitation (mm) in town of Pernik.

Month	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Sum (mm)	48	43	57	7	53	71	77	48	39	43	52	56
Season	winter			spring			summer			autumn		
Sum (mm)	128			162			165			152		
Mean annual precipitation MAP = 606 mm												

Methods

Eight experimental plots in different tree groups were chosen to investigate soil substrate. In each experimental plot, one representative soil profile with a 1x1x1.5 m depth was prepared and soil horizons/layers were differentiated and sampled.

The soil samples were then transported to the Laboratory of Soil Science at the FRI-BAS, air-dried and prepared for further analysis. Soil characteristics were analyzed according to the following methods: soil acidity – in distilled water with pH-meter "Pracitronic MV 88"; bulk density – using the method of Katchinski (Donov et al., 1974); the mechanical composition – using a pipette with HCl (Donov et al., 1974); total organic matter (%) – ISO 10694; total nitrogen (%) – Kjeldhal; CEC – Ganev (1990) and total forms of some heavy metals – AAS Perkin Elmer 370A. All methods are described in the Guidance for Soil Analysis (Donov et al., 1974), and in the ISO standards instructions (UN/ECE, ICP-Forest, 2006). Biometrical studies of black pine plantations were performed on each experimental plot.

Results and discussion

Soil substrate

The formation of the waste banks from local soils produces intra-zonal anthropogenic soils. The profile presents a combination of layers of different depth, quality and properties, taken from A- and B- horizons of Chromic Luvisols (FAO, 2006). These are the original forest soils from this area which have a heavy mechanical composition and a coarse texture with different incorporated materials. These soils cover the constructed depot for technological wastes and their thickness varies greatly (Table 2). As a result of physical processes and anthropogenic influences, in some places these layers have completely disappeared (P1 and P3). However, they remain preserved on the experimental plots where they currently form the waste bank surface with a lower content of incorporated materials (10%) and with lower thickness (up to 15–20 cm), mainly under grass vegetation – P6, P7 and P8. At the three P2, P4 and P5 sites, where the tree vegetation is well developed and forms groups with a high canopy height of 2–2.5 m, the formation of soils with normal morphological structure has begun as a result of natural processes. These soil conditions have great importance for vegetation propagation, especially in the rooting zone (Köstler et al., 1968; Brademaier et al., 1995; Torsten et al., 2000; Fletcher, 2001).

The mechanical composition of the substrate has become varied and surface layers of newly formed A-organic horizons are lighter, with loamy sand texture (Prokopiev, 1968; Donov et al., 1978). The layers are not compact because of the lack of incorporated materials and also root systems of the grass species (Lucot, 1994). The depth of the substrates is completely modified, and this varies according to the origin. Some substrates have a sandy texture which is well drained and have an admixture in their upper layer. Other substrates are characterized by a clay texture with low water permeability (Grozeva, 1996). Both types of substrate have a high percentage of materials incorporated at depth. These mainly comprise building rubble and processing by-products, and they provide a mosaic structure with high variation in visible parameters. Consequently, irregular depth variations in this soil do not allow comprehensive diagnosis of these horizons.

The relative density, bulk density, porosity and water-soil properties are presented in Table 2, and these determine the water-air regime of formed substrates (Grozeva et al., 1996). Table 2 data shows higher values for relative and bulk densities compared to natural soils in the region, with a tendency to increase towards deeper layers. Their influence on porosity is quite important, and in our study this proved negative. These substrates have lower porosity at 38–42% which causes compromised water permeability, lower mineralization and less aeration (Donov et al., 1978). The normal interchange of air between soil and atmosphere is also affected (Kulakov et al., 2009). Under these conditions plant species form superficial root systems, with concentrated fine roots in the upper 30 cm. This unfavourable air regime and the associated problem of substrate over-moisturization in some periods can cause diseases in aboveground vegetation (Zheleva, 1975; Grozeva et al., 1996).

Hydrological properties of the soil layers also vary compared to the original soils in the region, based on mechanical properties and the water retention capacity of the substrates. Both extremes of over-moisture and dryness have negative influences on vegetation (Donov et al., 1969). At the time of this assessment, the moisture contents were estimated to be above permanent wilting, but functional diseases of plants were observed in relatively short periods of excess moisture, as described by Zheleva (1975).

T a b l e 2. Physical properties of soil substrates.

Depth profile (cm)	Bulk density (g/cm³)	Relative density	Porosity (%)	Hygroscopic moisture (%)	Moment moisture (%)
P1 I. 0–10	1.47	2.44	40	5.02	15.61
II. 10–20	–	2.50	41	6.43	17.90
III. 20–30	–	2.47	41	5.11	18.96
P2 Ah 0–16	1.57	2.22	29	5.30	18.10
P3 I. 0–30	1.41	2.28	38	7.66	22.97
P4 Ah 0–15	1.33	2.55	48	5.26	14.37
P5 Ah 0–19	1.48	2.37	38	5.34	23.55
B 19–36	–	2.39	38	8.17	27.38
P6 Ah 0–8	1.44	2.43	41	4.76	16.26
II. 8–30	1.50	2.60	42	4.21	20.37
P7 Ah 0–12	1.13	2.26	50	4.98	15.31
II(B) 12–80	1.25	2.55	51	6.14	17.50
P8 Ah 0–12	1.28	2.44	48	6.08	19.69
II(B) 12–40	1.43	2.46	42	4.52	17.11

Chemical composition and properties determine the soil substrate's nutritional regime (Table 3). The soil organic matter (SOM) content in the superficial layers of studied waste banks is up to 2%, which is 3 to 5 times lower than in natural soils in this region. According to the Knop classification, these substrates are poor in organic matter content (Donov, 1993). In experimental plots under tree groups where newly formed soil horizons were observed (P5 and P7), SOM content was relatively high at 1.62–1.74%, but this decreased with increasing depth to 0.47–0.52%. In other profiles, the depth distribution of soil humus is similar (P1) or has a slight decrease (P6 and P8). The content of total nitrogen follows the trend of SOM (Table 3). Nitrogen varied from 0.025 to 0.128%, indicating very low nitrogen storage in the substrates. This derived from initial nitrogen content of the organic layers or was formed as a result of the mineralization of organic substances (Grozeva et al., 1996). The intensity in the processes of transformation of nitrogen into available forms decreased under the prevailing climatic conditions, so that the plants suffered permanent nitrogen deficiency. Moreover, the assimilation of phosphorus was also lower and this affected plant nutrition (Gentcheva, 1983; Donov et al., 1974). However, we established that nitrogen content under pure coniferous groups was higher, and well differentiated throughout the profile, especially in P5 and P7.

Consequently, despite the diversity of substrate layers, the influence of afforestation on the direction, intensity and detail of soil formation processes here is only minor. This is supported by results obtained for the C:N ratio, which indicated the level of decomposition of organic substances (Table 3). Although this ratio is between 7 and 18 for the typical Chromic Luvisols in this region (Grozeva et al., 1996), most substrates studied here did not fit these limits, and had lower ratios, between 4 and 11. The narrowing of the ratio in pre-operatively determined organic substances in these forest plantations can be explained by high nitrogen content emanating from mineral, inorganic or non-exchangeable fixed-ammonium sources (Black, 1973). In our case, the general determining factor is the chemical content of the fresh litter; with increased nitrogen, followed by mineralogical structure of the substrate.

The bio-available phosphorus concentrations are quite low and quickly immobilized (Gentcheva, 1983). The stock of available P (P_2O_5) in substrates showed a medium degree of storage at between 6 and 12 mg/100 g, compared to original soils in the region, which varied between 10 and 22 mg/100g (ICP-"Forests", 2006). Sources of phosphorus in soil substrates vary according to parent material, biological fixation and accumulated aggregates (Gorbanov et al., 2005). Phosphorus is a critical nutrient for plant development, and the alkaline pH > 8 at this site reduced P availability (Table 3).

Potassium content in soils mainly depends on mineral composition of parent materials while additional potassium accumulates in biological organisms (Nikolova, 2010). Our data indicates that soil substrates in the waste bank are rich in potassium (0–30 cm), which indicates over 30 mg/100g, but this value decreases with depth. Since potassium assimilation by plants depends on its concentration in the soil solution, the composition of soluble ions and pH and the antagonism between potassium and calcium availability is strongly expressed (Nikolova, 2010). The high pH of soil materials once again means that K availability is reduced and any plant growth will rapidly deplete available stock and lead to deficiency of this element**,** which is a precondition to establish balance between the three nutrient elements of N, P, and K (Gentcheva, 1983; Grozeva et al., 1996).

The total sum of exchangeable cations (Ca, Mg, K, Na) in the soil is an index which characterizes the absorption capacity of soil substrates and this plays an important role in root plant nutrition (Raitchev, 1996). This index here has the relatively high values of 40–50% compared with original soils at 15-28%, determined mainly by Ca^+ ions (in Grozeva; 1996),. This parameter is informative for soil formation processes in younger techno-genic soils. The cation exchange capacity of soils varies according to soil organic matter content and quality and quantity of clay minerals (Raitchev, 1996). In the studied soils of techno-genic origin, the clay mineral content plays a very important role. Lack of exchangeable Al and H provides evidence for the alkaline reaction of the soil solution at pH > 8. Whilst there is no clear differentiation of exchangeable bases observed with depth (Table 3), the short term evolution of exchangeable cations in the soil solution gives a critical limit for fertility, as soil vegetation develops.

The results obtained for the content of potentially toxic and other elements in the soil substrates are of particular interest for potential risk to both the wider environment and the

T a b l e 3. Chemical composition and acidity of soil substrate.

Depth profile (cm)	SOM %	Total N %	P_2O_5 mg/100g	K_2O mg/100g	pH (H_2O)	Sum of exch. basis mgeq/100g	C:N
P1 I. 0–10	1.74	0.128	5.45	42.8	8.20	40.77	8
II. 10–20	1.26	0.082	5.91	32.0	8.35	49.18	9
III. 20–30	1.43	0.075	8.22	22.8	8.40	50.03	11
P2 Ah 0–16	1.31	0.086	5.63	38.4	8.30	50.24	9
P3 I. 0–30	1.03	0.075	9.21	35.2	8.50	48.56	8
P4 Ah 0–15	1.02	0.062	11.15	28.8	8.40	50.03	10
P5 Ah 0–19	1.74	0.109	6.07	34.4	8.40	47.92	10
B 19–36	0.47	0.042	3.09	13.6	8.10	36.57	7
P6 Ah 0–8	0.93	0.075	10.05	38.8	8.05	41.41	7
II. 8–30	0.38	0.043	8.63	18.8	8.45	49.40	5
P7 Ah 0–12	1.62	0.110	3.98	42.4	8.35	46.45	9
II(B) 12–80	0.52	0.046	6.89	26.2	8.45	50.45	7
P8 Ah 0–12	0.60	0.044	3.27	17.6	8.15	36.57	8
II(B)12–40	0.17	0.025	5.70	13.6	8.25	41.20	4

development of fertile substrates for vegetation (Table 4). The origin of many of the materials from industrial processing provides inputs of iron and calcium as major controls on substrate development as well as potentially more toxic substances such as lead, zinc and copper. In addition, the inputs from atmospheric deposition from vegetation capture can be enhanced in the surface layers over time (Raikov et al., 1984). Due to the alkaline conditions (pH > 8) the quantities of Pb and Zn in the soil substrates exceed the Threshold Limit Value (TLV) by 1.5 to 2, (BOG, 2008). The nature of the potentially toxic element, and also the presence of high quantities of other elements, can have important influences on soil microbiota and also on development of the soil substrate (Jokova, 1999).

The expression of soil moisture and nutrient elements as a percentage (%) does not give actual information about their quantity in soil substrates, and are best delivered based on storage (in t/ha). The hydrological parameters of the substrates are broadly similar to the original soil types in this region, with only minor variations observed across the layers. The climatic control on water availability is the most overwhelming factor limiting growth, and our assessment suggests that soils on this site do not differ from the natural soils in this region. However, availability of nutrient elements and soil organic matter are likely to be the

T a b l e 4. Heavy metals and calcium contents in soil substrates.

Profile depth (cm)	mg /1000 g soil					
	Pb	Cu	Zn	Mn	Fe	Ca
P1 I. 0–10	236	88	232	1223	41500	11600
II. 10–20	60	49	232	1058	26000	6200
III. 20–30	166	101	240	2700	48900	21100
P2 Ah 0–16	186	86	495	1223	35300	12775
P3 I. 0–30	72	58	310	815	22400	4275
P4 Ah 0–15	181	94	700	1220	34700	12300
P5 Ah 0–19	144	84	350	1015	34700	6775
B 19–36	38	61	180	885	30200	1700
P6 Ah 0–8	46	51	160	845	30400	6650
II. 8–30	32	42	110	842	24900	10800
P7 Ah 0–12	40	122	790	903	24800	6150
II(B)12–80	65	50	79	1375	19200	8800
P8 Ah 0–12	89	45	78	1450	22300	8775
II(B)12–40	37	58	73	1100	22600	1600

main limiting factors. Based on estimated stock we established that the studied substrates are in the "low fertile soils" category (Donov, 1993). The following values alllied; soil organic matter content up to 200 t/ha, total nitrogen up to 15 t/ha, available phosphorus up to 60 kg/ha and the available potassium up to 120 kg/ha. Here, only potassium exceeds these limits and phosphorus is a little less. Since the soil substrates' organic matter and nitrogen stock values are also much lower than determined limits, these are the main parameters which define the fertility of these substrates.

Vegetation

The distribution of different types of vegetation throughout the study site after biological reclamation is summarized in Table 5. The low percentage of areas covered by black pine plantations highlights the difficulty of reclamation . Observations on this site highlight many potential influential factors, including continued deposition and recovery processes, uneven surface humus and the lack of control on livestock access to pasture.

Table 5. Area distribution of different types of vegetation.

Vegetation	Area, dca	Percent of the territory of the waste bank
Black pine plantation (*Pinus nigra* Ar.)	4.8	24
Grass ecosystems with ~ 90% coverage	10.0	50
Open areas with grass cover between ~ 20–60%	5.2	26
Total	20.0	100

Grass vegetation

These species comprise the composition of grass vegetation on the waste bank; *Plantago lanceolata, Achillea millefolium*, *Hieracium* sp., *Vicia cracca*, *Taraxakum officinale*, *Trifolium pratense* and *Cardus scardicus,* plus also others. These observations showed that grass vegetation has good coverage on areas with a preserved humus layer. In the future, it could rely on natural grass growth, which is of great importance in reducing air dust prior to forest plantation development.

Plantation of Pinus nigra A r.

The main taxing parameters of the forest stand were determined as part of its characterization (Table 6). The created plantation of black pine (*Pinus nigra* A r.) is 10 years old and it has a mean height increase of 0.20m/year, a mean trunk base diameter of 0.10 m and mean increase in diameter of 0.01 m/year.

The variations in stand density depend on the presence of a superficial humus layer and the undertaken digging and/or filling up activities. No traces of additional activities have been detected, in the northwestern part of this site, and here the stand density was the highest at 160 individuals per decare. The southwestern portion has been seriously affected and here stand density decreased up to 40 individuals per decare. The following values for this stand were established; the mean density is 33 individuals per decare, mean growth is 0.20 m and the rooting depth is up to 1.5 m. No diseases or pests were detected in the plantation during this stand's health status assessment. Only about 50% of the black pine trees are seeding, and this indicates a lower vitality of tree vegetation as a result of the deteriorating ecological conditions. Tree mortality percentage is also high at 20%, and this is mainly due to slow growth and dryness.

It is concluded that this forest plantation is currently in a satisfactory state, mainly because of its young age. The plantation is well developed on the waste bank and the quality of soil substrate underlying the humus layer allows for further growth. However, the black pine plantation is vulnerable to additional negative activities and special additional measures are urgently needed.

It should be noted that the soil substrates and plant vegetation on the waste bank are subject to additional air pollution through "dry deposition" of dust and ash from adjacent technological banks. In these cases, the impact on plant vegetation is direct, through leaves

T a b l e 6. Taxation parameters of the black pine forest plantation.

Age (years)	Height (m)	Current growth at height (m)
1	0.10	
		0.12
2	0.22	
		0.19
3	0.41	
		0.21
4	0.62	
		0.25
5	0.87	
		0.27
6	1.14	
		0.21
7	1.35	
		0.21
8	1.56	
		0.24
9	1.80	
		0.28
10	2.08	

and/or needles. Strong sulphate pollution in the Pernik region is an additional factor with negative influence on vegetation (Report for the Environmental Status, 2008). Higher values of SO_2 are measured during the winter period when the coniferous trees on the bank are not at physiological rest like the broadleafed species (Grozeva et al., 1996). This imposes the necessity to introduce more stress tolerant species for afforestation.

Proposal of recommendations to improve the soil substrate for use in biological reclamation

Morphological and analytical studies of soil substrates at this site identified the important role of the surface layers approximately 30 cm deep. The approach required to bring the soil substrates to the required level of fertility to support vigorous forestry on the site involves a stringent management strategy, including the very careful timing and application of imported nutrients. The following strategy is suggested to minimize costs, and to reduce losses from this process.

The amount and concentration of both P and K is of particular importance in the application of additional NPK fertiliser. The alkaline reaction of the soil solution on this site requires careful dosing with soluble N (NH_4NO_3, 30–35% N) fertilisers, and this must be timed to support the growth stage of the trees. Young tree saplings have higher affinity to phosphorus which stimulates the root system formation, encourages faster implantation and supports their growth and development. An important recommendation is to fertilize with super-phosphate in a quantity of 5 kg/dca pure P_2O_5 once in the early stage of reclamation, and not later than mid-summer.

Further reclamation activities should include:

- Additional site preparation including activities to level the terrain, with infilling to the 30 cm layer; comprising 6000 m^3 organic soil.
- Compaction of the superficial 2-metre layer should be avoided in order to provide optimal porosity of the substrate.
- Biological reclamation can be based on afforestation with mixed broadleafed tree species – with *Quercus rubra* L. and *Fraxinus americana* L. The red oak (*Quercus rubra* L.) is recommended as a main tree species. *Fraxinus americana* L. will be planted in 4 groups with an area of 1 decare, randomly located. The density of created plantations for these tree species is 2x1 m. The required plants are; 8000 individuals of 1-year old saplings of red oak and 2000 individuals of 1-year old seed-saplings of ash.
- All forestation should consider climatic conditions and stimulation of natural grass, with the added benefit of dust reduction until development of the forest plantation occurs.
- Other activities ensuring the success of additional reclamation activities include tillage in autumn to the end of October, aiming for the best site preparation and water storage.
- Immediately after tillage 25 kg/dca super-phosphate, or 500 kg for the whole area, could be added. Ammonium nitrate should be added, to 15 kg/dca or a total of 300 kg, before planting. If the survival of planted trees falls below 85%, an additional planting with the same tree species will be made in the autumn.
- Regular trenching of forest plantations in the first three years should be done as follows: 1st year – three times; 2nd year – twice and, 3rd year – once. Fencing the plantation is recommended for the first years after forestation to protect young trees from damage by livestock.

Because of continued rising costs in materials and salaries, and knowing that this biological reclamation will be carried out in two-three years at the earliest, the following summary covers only a quantitative estimation of the planned activities (Table 7).

Financial evaluation of all activities included in biological reclamation should be performed immediately before its commencement.

Conclusion

We established that many soil substrate properties which developed on industrial processing by-products from steel production are quite similar to those of the natural soils in the region. Organic matter and nutrient elements in a substrate with sufficient water for plant growth clearly determine success of further biological reclamation. Overall, the nutrient elements are available for the tree species only in combination with an optimal water regime, which in turn is largely dependent on regional climatic conditions

T a b l e 7. Quantitative account of supposed activities for further biological re-cultivation of studied waste bank.

Code*	Type of activities	quality	Production quota	Monthly shifts/ man months
264	Deep ploughing with tractor type Bolgar TL-45U at depth 20–22 cm	20 dca	20,2	1
2501	Preservation of tree saplings	10000 numbers	16 000	1
2504	Planting tree saplings with Kolesow sword	10000 numbers	450	22
629	Fertilization 25kg/dca	20 dca	12	1,5
627	Fertilization 15kg/dca	20 dca	25	1
	Manual cultivation of created plantation:			
	First year:			
2907	First cultivation	10000 m	457	22
2909	Second cultivation	10000 m	464	22
2909	Third cultivation	10000 m	464	22
	Second year:			
2908	First cultivation	10000 m	425	24
2910	Second cultivation	10000 m	494	20
	Third year:			
2908	First cultivation	10000 m	425	24
		Total		**160,5**

* The utilized production quotas are referred to silvicultural activities in Bulgarian national forestry.

Re-forestation is an appropriate technique for biological reclamation of technological waste materials. However, additional silvicultural activities are urgently needed to improve plant coverage on these waste banks. Recommendations with quantitative assessments will encourage more sustainable biological reclamation of the study area, so that early vegetation growth can establish stronger forest development and increased biomass accumulation in the surface soil horizons.

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