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Agriculture and Environment

Anthropogenically disturbed soils and methods for thier reclamation

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Abstract. *The present article summarizes the problematic issues, scientific quests and achievements related with lands reclamation during the past 40 (forty) years. The anthropogenic activities that alter natural landscapes and form a new anthropogenic relief are indicated here, as well as the consequences of those activities on the environment and the measures that apply to its recovery. We have outlined the classic and new leading technologies for reclamation of damaged areas. The characteristics of some specific objects for reclamation and the difficulties in their recovery are also described. We have reflected the advantages of interdisciplinary studies on damaged ecosystems and have presented the methods for their field and laboratory analyses and subsequent monitoring. Classifications and methodologies for agro-environmental assessment of the suitability of the various geological materials for reclamation are specified. We have also included a taxonomic list of some of thoroughly studied reclaimed lands in Bulgaria according to the World Reference Base for Soil Resources (WRB, 2007).*

Keywords: soils, reclamation, mineral resources, geological materials, classification.

Introduction

Sustained decrease of land fund has established in recent years all over the world. Agricultural lands have often used by more aggressive technologies of heavy and mine industries and urban-planning. Only in developed countries over the past 10 years, more than 3 million ha of productive agricultural lands was granted for settlement, roads, infrastructure and others. Worldwide, this figure is about 6-8 million ha. Some statistical data indicate that since man is began to till the land, the agricultural fund decreased by about 2 billion ha. Mining activities along with other negative factors (erosion, salinization, acidifying, etc.) have a great contribution to the loss of arable lands. Nowadays, each inhabitant of the World accrues 0.3 ha arable lands. If lands disturbing continue, the amount of arable lands will soon decrease to 0.1-0.2 ha per person.

The uninterruptedly intensive extraction of minerals from the Earth leads to ever more distinct change the physical condition of the lithosphere's upper layer. Mining activities infringe soils' cover, deteriorate hydrological conditions and form new relief that violate ecological balance and radically alter the landscape. Such large-scale disturbances are caused by the open and underground coal mining, extraction and processing of ferrous metals and inert materials, building linear construction and engineering facilities, urban agglomerations, and so on.

The main task at restoring the environment disturbed by mining and construction activities is to create an ecologically balanced system representing the economic and aesthetic value. Reclamation is the most fundamental method for restoration and improvement of soils' fertility that is aimed to retrieve disturbed lands to arable landed fund. Generally, the reclamation represents a system of engineering, ecological, ameliorative, agrotechnical, forestry and other activities orientated to restore destroyed territories, soil's cover and fertility, as well as the re-creation of landscape or formation of lands with different intention - agricultural, sanitary, forest, etc.

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In Bulgaria, the area of reclaimed lands has significantly increased in recent years, resulting from the increased production of certain minerals. To this trend it should add the lagging pace of reclamation, which additionally damages the ecological status in mining areas. According to data of EEA (1999) by the end of 1999 the total area of damaged lands was 23 794,7 ha but reclaimed areas to the same period were only 8 048,79 ha.

The European Union enforces more stringent requirements for protection, restoration and improvement of environmental components, basic and integral part of which are soils. The main part of the European standards are transposed into Bulgarian legislation with the exception of two particularly important directives for the mining industry:

- Directive 2004/35/EC of 21 April 2004 on environmental liability, prevention and remedying of environmental damages;
- Proposed draft for management waste of mine industry, equipments for disposal of mining waste and determination of the regime and order of their exploitation.

The draft for management waste of mine industry defines the scope, terminology, types and characteristics of the waste, the type and classification of depots servicing the waste of mining. Currently, the areas occupied by the existing depots for extraction and primary processing of mineral resources in Bulgaria amount to approximately 6 000 ha. According to preliminary estimations the necessary resources for closing and reclamation of depots will exceed 1.2 billion BGN. The cost for remediation of industrial sites and open pits is estimated of about 0.5 billion BGN. In addition, it will require substantial funds for construction and operation of treatment plants for mine waste water, monitoring, etc.

Material and methods

Reclaimed soils (Technosols) are found wherever human activity has led to the construction of artificial soil, sealing of natural soils or mining. Thus, spoils (near roads and mining), refuse dumps, oil spills, coal fly ash deposits and similar sites are designated as reclaimed lands. Soils built in the extraction of ore minerals and natural materials occupy a larger area in Bulgaria. They are situated in the closest vicinity of the mining and manufacturing enterprises and have lots of specific characteristics related to the kind, composition and properties of the composing them materials and their organization.

Industrial activities as a result of which were built reclaimed soils are:

1.1. Mine industry – by following major methods:

- Classical open-cast method – it is realized by the construction of terraces for discovering ore minerals (left of Figure 1) (Stoyanov, 1979).

- Classical underground method – it function by the vertical or horizontal mine tunnels (shafts) which reach the ore's level and then the ore is digging out and transport by underground horizontal galleries (in the middle of Figure 1) (Arnaudov et al., 1992).

- Geotehnological method - extraction is realized by the passage of acidifying drilling to the ore body through which a sulfuric acid solution is inserted. Conversely draw out of enriched solutions implements by drawing drilling (right of Figure 1).

Figure 1. Pictures of the open-cast mine (pit), the vertical mine tunnels (shafts) and the land disturbed by geotechnical extraction method

1.2. Manufacturing Industry

Processing (enrichment) of ore minerals produces great amount of waste that accumulate in landfills - tailing-ponds, ash dams, etc. As a rule they are build in naturally lower places and occupy large areas - 100 and more ha (Figure 2) .

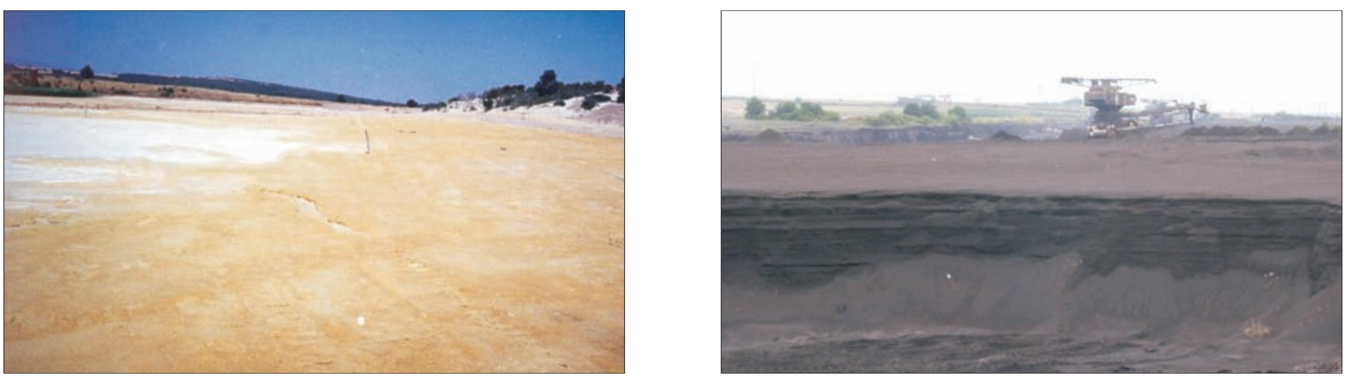


Figure 2. Pictures of the field from saturation lime (left), fly ash deposit and lands destroyed by the road construction works

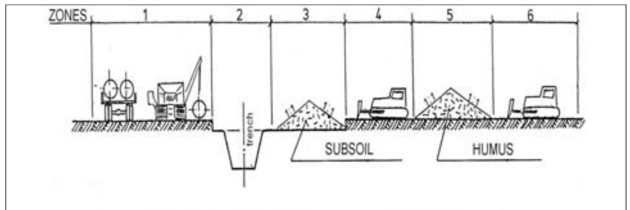
1.3. Construction of linear objects

Lots of lands throughout the country are harmed or destroyed by the road construction works (highways, roads, railways, pipelines - gas, oil, water, etc, lines, lifts). Increasingly areas have been separated recently for the construction of pipeline and especially of gas pipelines. The total length of existing transit gas pipelines to Macedonia, Yugoslavia, Greece and Turkey is around 890 km (this figure does not include national and local pipeline infrastructure). Area, affected in the pipeline construction varies according to the tube size, cultivar, through which the gas pipeline passing, the system of collection and storage of the humus and underlying horizons, used machinery and others (Figure 3). The average width of the disturbed strip is about 30-35 m, which mean length of 2,670 ha to 3,115 ha to be recovered (reclaimed).

2. Methodology for study of destroyed ecosystems

In order to achieve successful reclamation of damaged areas it is necessary to carry out a number of detailed preliminary studies of all environmental components in mining areas, including: prior geoecological study including determination of soil varieties that will be destroyed, characterization of stratigraphic profile overlie the ore body, climatic features of the region and geobotanical studies.

2. 1. Field and laboratory determination of soil varieties



PIPE DIAMETER (mm)	WORKING AREAS WIDTH (m)						TOTAL (m)	
	1	2	3	4	5	6	ZONES 1 - 4	ZONES 1 - 6
up to 426	10,0	3,5	3,5	3,0	4,0	4,0	20,0	28,0
up to 720	12,0	4,0	4,0	3,0	5,0	5,0	23,0	33,0
up to 1020	12,0	5,0	5,5	5,5	6,0	5,0	28,0	39,0
up to 1220	12,5	6,0	6,0	5,5	6,0	6,0	30,0	42,0
up to 1420	13,0	6,0	7,0	6,0	7,0	6,0	32,0	45,0

Figure 3. Pictures of lands destroyed by the road construction works and a scheme for building the pipeline's route

Field study of soils' cover must be carried out in M 1:10 000 for large areas and flat terrain and in M 1:5 000 or M 1:2 000 at smaller areas and rugged terrain. The study aims to determine the major genetic-morphological features of soils, quality of humus horizon and possibilities for its collection, disposal and utilization. For field soil mapping bases on the topographic information for undisturbed area in the appropriate scale. Soils varieties are characterized according to the existing Bulgarian system for soils classification and diagnosis - width of humus horizon, color, texture, density, structure, presence of soil diagnostic horizons and others. It is necessary to make a conclusion about the suitability of humus horizon for bio-remediation, according to analytical data obtained. Humus horizon should be collected selectively, according to its width and lands category - I, II and III. It is important to collect topsoil separately according to soils' different types and subtypes, since soils varieties have individual fertility. After field and laboratory studies of soil varieties the soils are also classified according to the suitability of their humus horizons for collection and use.

2. 2. Climatic characteristics of the studied territory

The vegetation cover has created during the biological stage of reclamation in accordance with the planned use of anthropogenic soils - agricultural, forestry, etc. Therefore, it is necessary to describe the more important climatic characteristics for plants growth (average monthly and annual temperature, middle and latest dates of last spring and first autumn frost and the average frost-free time, average monthly and annual amount of precipitation, etc.) in the researched area. These studies ensure the correct choice of suitable plant species for reclamation.

2. 3. Study of biodiversity

The study of biodiversity facilitates selection of adaptive to local conditions species and the rapid restoration of ecological balance in the mining areas. Biological diversity or biodiversity is the term defining the diversity of life on Earth and the various patterns formed by it. Bulgaria is one of the richest in bio-diversity countries in Europe.

2.4. Characterization of geological materials from the stratigraphic profile for the reclamation purposes.

Assessing the suitability for reclamation of geological materials that are discovered in the extraction of ore minerals is among the current major problems of disturbed lands' reclamation. Suitability of various stratigrafic materials is estimated by detailed geochemical study aimed at determining the most appropriate of them which can be use for bio-remediation (Hristov, 1989).

3. Monitoring of damaged lands and reclaimed soils

Reclamation activities go along with the function of mining and processing plants and end with the final cessation of their activities. This stage is characterized by implementation of already developed technologies for reclamation and enhanced control functions of their performance. The period after the biological reclamation of lands allows to take into account the success of the implemented reclamation and should be actively used for periodic monitoring. Monitoring of these areas usually involves studying both the general status (development) of the reclaimed area and the monitoring of critical parameters of created new systems: catchment, drainage, soil - plant, etc. Therefore, the reclaimed land monitoring scheme is strictly specific to each region.

Results and discussion

The open-cast mining provokes the most noticeable disruptions of the surface, which is largely determined by the fact that the volume of earthly materials is usually 3 to 5 times greater than that of the extracted ores. On the other hand, the application of this method injures vast territories. There are quarries, occupying area up to 3 000 ha and 800 m in depth. The negative impact of open mining on the environment evinces in alteration of hydrogeology of mines and adjoining areas. Deflection of water fluxes from disclosed water horizons leads to the formation of major depression curves, within which the vegetation is changed and even degraded in consequence of significant dehydration. This evokes both the degradation of soil texture and the acceleration of the erosion processes causing further changes of landscape away from the mine boundaries. Further pollution of drained groundwater makes them residual.

The underground mining implements on significantly smaller area and does not lead to such significant changes of landscape and infrastructure, as open mining. Changes in the environment accompanying this activity are mostly associated with the relocation of overlying rocks. Transference of differently fragmented rock changes the environment in the same way as open mine - deform soils' cover, occupy large areas suitable for agriculture, change the groundwater hydrogeology and form huge rocks massifs, overgrown with no grass.

Geotehnological method for extraction of raw materials produces very large distortions of landscape and soil cover - first the integrity of soils is mechanically destroyed in the course of drilling and blasting, construction of the sorption system, the arrangement of drilling pipes and other technological equipment, and secondly - the soils are chemically affected by working solutions that leads to complete destruction of the topsoil and its pollution with radionuclides. Apart from purely extractive activities additional destruction of fertile agricultural lands provokes the construction of acidifying farm, sorption system, administrative and technological complexes (mining yards), auxiliary roads and other equipment, which are necessary for the entire process of production.

Deposits for waste from processing (enrichment) of ore minerals also create ecological and agronomical imbalance. Under Bulgarian law, these objects can not be used for agriculture and therefore, they are not liable to reclamation in terms of restoration of soil fertility. In this case should only provide their integration with the surrounding landscape and the common natural view by conducting specific reclamation activities aimed at recovering the surface and slopes part of the wall (dike), thus only partially restores the disturbed soils' cover (Banov et al., 2007). The waste deposits are one of the major pollutants of the environment. Wind erosion facilitates the diffusion of waste products on neighboring areas affecting all existing ecosystems. Like previous mine's activities and these also fulfill on large fertile areas for a long time.

During road construction works the impact on environmental components and particularly on soils may vary depending on the technology of construction and the intended use. Usually, these anthropogenic activities permanently destroy soil cover, which imperatively imposes the collection and utilization of humus horizon for land reclamation or for improving the fertility of low-productive lands, located near roads.

1. Technologies for reclamation

Classical methods for reclamation of destroyed or technogenic (reclaimed) lands are two in Bulgaria. By the first method is constructed a specific lands' profile as the surface is formed by geological or waste materials with appropriate physical and chemical properties and then is overlaid with a humus layer, till the second method is realized by direct biological reclamation of lands built by geological materials (Banov, 1989; Hristov, 1989; Regulation 26/1996; Hadjyanakiev and Banov, 1997, etc.).

The first method of reclamation has higher implementation costs, but greater efficiency, since rapidly and sustainably increases fertility of the reclaimed lands. The second method for reclamation is necessary to implement in the absence of sufficient humus amount (Banov, 1989). In this case it is particularly important to undertake a preliminary detailed study of geological materials piled up. It is also necessary to take into account geographical conditions in the area such as: climate and its impact on the growth of various types of vegetation, topography, determining the risk of erosion, soils, mainly their physico-chemical characteristics and of course interactions between individual components.

In recent years, numbers of new, effective and rational technologis for restoration the fertility of anthropogenic soils were developed (Figure 4). This is necessitated by the fact that amount of available humus materials is depleted, but also large amounts of waste materials of different origins are accumulate. For these and other reasons, recently, various organic sludge are widely used in reclamation of lands disturbed by mining. The high content of basic nutritious macro- and microelements in the sludge, especially of carbon available to plants, provide high ameliorative effect, especially valuable in imbalance of organic matter. Still, these sediments create a risk of heavy metal pollution.

Figure 4. Pictures of reclamation activities

Increasingly topical relevance to the rapid restoration of disturbed lands acquires the use of microbiological methods for reclamation. Microbial communities play important role for plant growth in technogenic soils in view of many functions which they enact in nutritious circle, plant symbiosis and remnant decomposing. Soil microorganisms may modify the soil structure and water regime and thus to influence plant growth. For these reasons, microbial diversity in reclaimed soils is often used as an indicator for their fertility (Banov, 1989, Hristov et al., 1996; Marinkina, 1999). Symbiosis of various perennial grass species with mycorrhizal fungi is among the wide used methods for reclamation in mining areas. The possibilities for agricultural usage of technosols considerably increase through inoculation of legumes and cereals with nitrogen fixing bacteria (Okon and Itzigsohn, 1995; Simon et al., 2006). This method shows very good results in our country and has significantly increased the productivity of clayey reclamation materials from the region of Maritsa-Iztok mine (Dimitrova, 1998, 2001, 2003; Dimitrova and Taleva, 1998).

Effectiveness of reclamation activities significantly increased after preliminary selection and estimation of plants suitable for phytoreclamation. Various classifications and estimates have been developed in accordance with the ability of plants to use available vital resources as well as their compatibility in delicate and long-lasting ecosystems. Essentially suitable method for biological reclamation is the introduction of plants that naturally grow in similar habitats.

It should be noted that there are many and varied methods for chemical amelioration and detoxication of reclaimed lands, which significantly increases the possibilities for sustainable management of mining areas (Misheva et al, 2007). As a result of a long research work few classifications were elaborated that ensure quick and precise expert assessment of soils resources in destroyed areas.

2. Soil's classification according to the suitability of their humus horizon for collection and use

Classification scheme is divided into three levels - suitable soils, poorly suitable soils and unsuitable soils. Storage of humus material, however changes its properties and qualities (Petrova, 1989), indicating that new chemical studies should be carried out prior to its use (Banov, 2000).

- Suitable soils

To this group belong soils, which are characterized with mighty humus horizon - above 20 cm, mostly 40-70 cm. The content of physical clay fraction may vary from 20 to 75%, the medium reaction (pH in water) from 5,5 to 7,5 and humus content exceeding 1.0%. Soils that fall within this group are: typical, slightly leached and calcic clay sandy chernozems (Calcic and Haplic Chernozems, WRBSR, 2002); leached and strongly leached heavy loam chernozems, non eroded and slightly eroded heavy loam chernozems; dark gray forest soils (Luvic Phaeozems), leached and clay smolnici, none eroded aand slightly eroded (Haplic (Pelic) Vertisols) and others.

- Poorly suitable soils

This group brings together soils that have shallow humus horizon below 20 cm, highly varied texture - to 60 - 75% physical clay content, pH in water ranged from 4.0 to 7.5 and the humus content goes not beyond the scope of 1.5%. As an example for this soil group might be listed: gray forest soils, moderately and heavy loam (Haplic Luvisols), light gray forest soil, slightly and moderately loam (Planosols); strong leached to weak podzoled cinnamonic forest soils, none eroded (Albic Luvisols) and slightly eroded (Eutric or Gleyic (Distric) Regosols); alluvial-meadow soils, sandy and sandy loam (Eutric Fluvisols).

- Unsuitable soils

These are soils whose humus horizon should not be collected. Under Regulation 26 for reclamation of damaged lands, improvement of slightly-productive lands, bereaving and utilization of the humus layer (Promulgate in Gazette 89/1996, amended in Gazette 30/2002) the humus layer does not collected if its width is lower than 10 cm and/or humus content is below 1.0% and/or it is moderate to high stony. In this group of soils is observed intensive processes of erosion, soil profile development on nearby bedrock, or marshy and saline soils, and also very acidic soils. Such soils are: brown forest soils (Leptic Cambisols), meadow-swamp (Eutric Glaysols), peat-swamp (Fibric Histosols), saline alkali soils, eroded carbonate and typical chernozems (Calcaric-aric Regosols), eroded gray forest soils and eroded cinnamonic forest soils (Eutric or Distric Regosols) and others.

3. Classification of geological materials from the stratigraphic profile concerning their suitability for reclamation

The vast variety of geological materials is presented by the soft (loose) rock and semi-rock formations, and their complexes. Soft (loose) geological materials adopting those that have fine-earth components. The rest are represent by large, hard none weathered rock fragments or their heterogeneous mixture with soft geological materials. In chemical respect they are also very diverse, which imposes to develop a classification of geological materials according to their suitability for biological reclamation (Table 1):

Table 1. Classification of geological materials for biological reclamation (Treykyashki and Hristov, 1982)

Group of suitability	Parameters					
	pH (H_2O)	Total salt content (%)	$CaCO_3$ (%)	Total sulphur content (%)	Physical clay content (%)	Rock content (%)
First	6,0 – 8,0	Down to 0,3	Down to 20	Down to 0,3	20 – 75	0 – 10
Second	6,0 – 8,0	Down to 0,3	Down to 10	Down to 0,3	Down to 10 up 75	0 – 10 , 10 – 20
Third	6,0 – 8,0	0,3 – 0,8	Down to 40	0,3 – 0,5	10 – 75	0 – 10
Fourth	Do not determine					
Fifth	2,0 – 9,0	up 0,8	Down to 40	up 0,5	any	Do not determine

- First group – suitable, pertinent to both the physical and chemical properties - it is used for agriculture and forestry reclamation that is not excepted the implementation of appropriate farming practices and fertilization.
- Second group – poorly suitable, pertinent to physical properties – it is used as well as the materials of the first group when the texture amended components (heavy/light materials in mechanical composition) are added.
- Third group - poorly suitable, pertinent to chemical properties – it is used as well as the materials of the first group after chemical reclamation (flushing of salts, adding of gypsum, etc.).
- Fourth group - unsuitable at physical properties - big, hard, none weathered rocks, unfit for biological reclamation.
- Fifth group - unsuitable at chemical properties - geological materials with toxic properties unsuitable for biological reclamation.

Based on the fundamental and experimental data (Marinkina 1999; Banov 2000) appraised that the listed below indexes are very important for assessment of agro-ecological characteristics of various geological materials isolated from the stratigraphic profile of exploited field. Authors consider that in some particular cases these indexes can be successfully used for estimation of suitability of geological materials for reclamation.

3.1. Reaction medium (pH) can be used as a universal criterion providing the limiting or favorable properties of tested materials.

3.2. Sorption capacity and exchangeable cations.

This indicator is highly informative for estimation of the buffer capacity of geological materials to acidification - by the magnitude of the degree of saturation with bases and for determining the level of harmful acidity and toxicity assessment - by value of the exchange Al.

3.3. Determination of potentially hazardous elements.

It might be determined by the total chemical and mineral composition or by determination of mobile and bioavailable concentrations of elements sensitive to geochemical changes (Fe, S, Zn, Cd, Co, Mn, Ni and others).

4. Classification of reclaimed soils

Although the area of reclaimed lands is small, the actual presence of such anthropogenically built soils necessitates their classification and must be taken into consideration for the current account of the available soil resources in the country. Reclaimed soils in Bulgaria are composed of various geological materials exposed to the surface by mining activities. This is one of the reasons for offering the specific local taxonomic systems for classification of reclaimed lands in each region. Such classification of reclaimed lands from the region of Maritsa-Iztok mines was developed by Banov and Hristov (1996). The proposed soil classification is divided into two types – no humus reclaimed lands (established technical areas) and biologically reclaimed lands, which are divided in the lower taxonomic level "kind" depending on the type of land use, affecting the morphological characteristics (width of new-formed humus horizon) and chemical properties of reclaimed soils (carbonates content, pH, humus content). This level is filled out by Ivanov and Banov (2008), but as well as the taxonomic level "genus", which classifies reclaimed soils depending on the geological materials that formed the pedon it can be additionally extended.

The described above classification is a national system, but designation of reclaimed lands as a well-known soil unit needs juxtaposing with the internationally accepted systems such as the World Reference Base for Soil Resources (WRB, 2007). The last contains a Reference Group Technosols which is intended to include soils, whose properties and pedogenesis is strongly affected by materials and their organization. These are soils of technical origin, containing material of any nature, made or exposed by human activity and would not otherwise occur at the Earth's surface (sludge, cinders, natural earth materials - mining dumps, landfills, ash dams, middling slimes, etc.). Technosols are often referred to as *urban* or *mine* soils (IUSS Working Group WRB, 2007). WRB edition in 2006 resolve the issue for classification of reclaimed lands, but since Technosols are relatively new reference soil group, listed specific qualifiers (suffixes) is still incomplete. This sometimes requires replication of classifiers from other reference groups for detailed classification of technogenic soils. A similar case was described by Ivanov, et al., (2009) who classified reclaimed soils from mine areas of the Pernik town (district Moshino), mines Maritsa-Iztok ("Haldi" spoil) and Chukurovo mine. In order to describe all characteristics of the studied soils authors replicated suffixes *Thionic* and *Eutric* and proposed to be added to the identifiers list of technogenic soils.

Conclusion

Strong disturbance of ecological balance was established in industrial areas of the country recently. Anthropogenic impact there has many dimensions but most significantly affects the land fund. The greatest contribution for reducing and destroying the soils' resources have mining and processing industries. By mining activities are destroying the soils' cover, hydrological conditions are changing and new relief is forming that radically changed the natural landscape. Moreover, extractive work extends to large fertile area for an extended period of time. Simultaneously, the reclamation of destroyed and new-formed lands progresses with a slower pace that additionally damages the ecological balance and moves it into an outfield.

Deposits for mining industry's waste also create environmental and agronomic imbalances since they are liable to partial reclamation and can not be used for agricultural purposes. Reclamation is one of the most radical methods for restoration of soil resources, but its effectiveness is often dependent on cares, which are taken of reclaimed lands.

Although the more stringent requirements for compensation of environmental damage has introduced in the country still anthropogenic activities have not ceased to negatively affect the environment.

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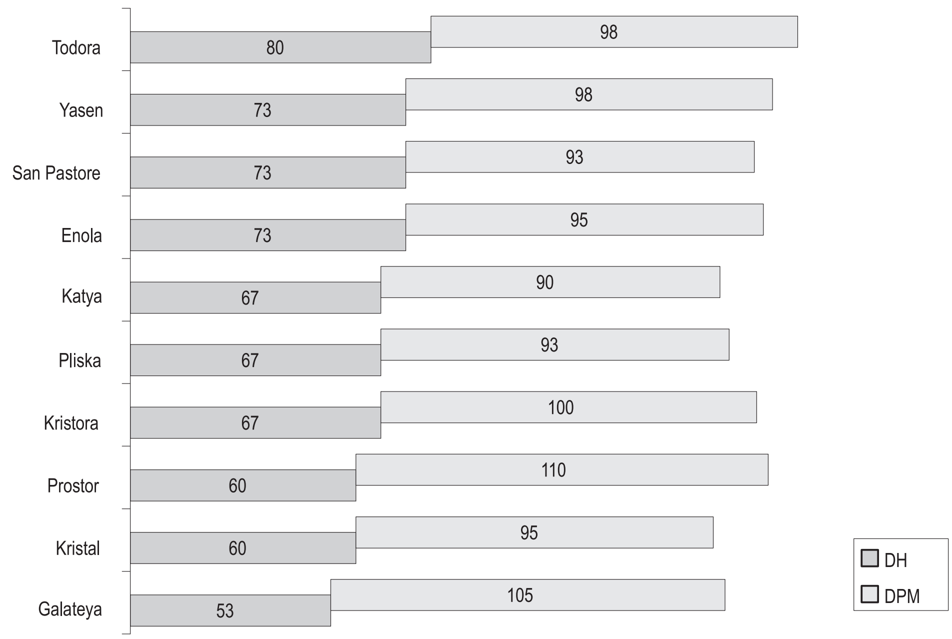
Figure 4 is:



and have to be:

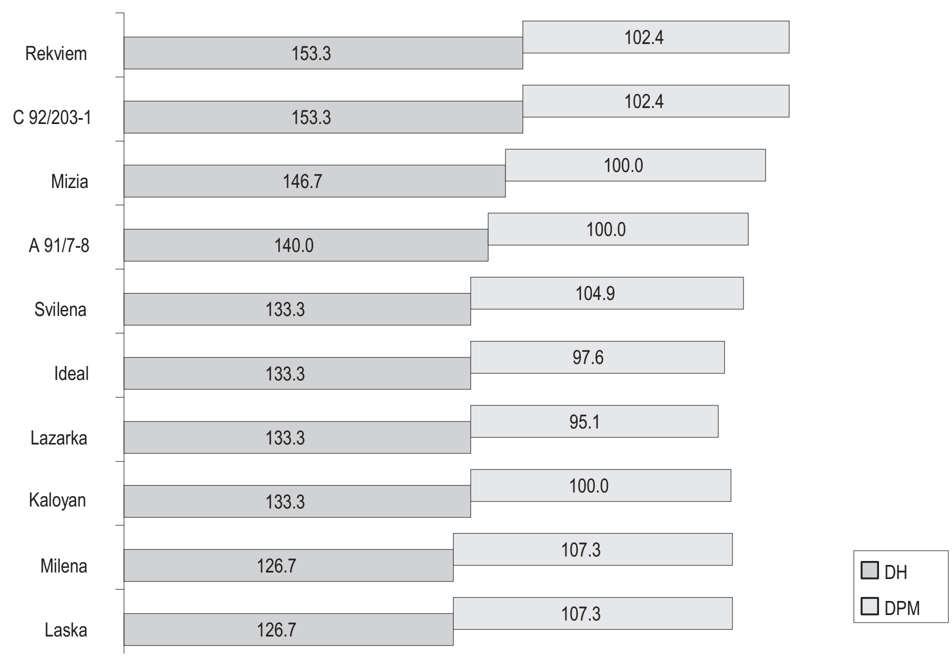


Figure 4. Duration of the period to heading and maturity in the group of late varieties expressed as relative value from the standard

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