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CERTAN CORINA

THE PECULIARITIES OF THE RESTORATION OF THE PETROPHYTE ECOSYSTEM (ON THE EXAMPLE OF „LAFARGE CIMENT" (MOLDOVA) S.A. LIMESTONE QUARRY)

166.01 – Ecology

Summary of the doctoral thesis in biological sciences

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Doctoral adviser:
BULIMAGA Constantin, habilitated doctor of biological sciences, research associate professor.

Composition of the Committee for public defense of the doctoral thesis:

CRIVOI Aurelia,	habilitated doctor of biological sciences, university professor, USM - chairman
CUZA Petru,	habilitated doctor of biological sciences, university professor, USM - reviewer
POSTOLACHE Gheorghe,	habilitated doctor of biological sciences, university professor, GBNI - reviewer
NAGACEVSCHI Tatiana,	phD in biological sciences, associate professor, USM - reviewer
BULIMAGA Constantin,	habilitated doctor of biological sciences, research associate professor, IEG - member

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Doctoral adviser: **BULIMAGA Constantin**
habilitated doctor of biological sciences, research associate professor

Author: **CERTAN Corina**

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CONCEPTUAL FRAMEWORK OF THE RESEARCH

The actuality of the research topic. During the stage of industrial development of human society, an important role in meeting the needs of people belongs to the mineral resources of the planet. Useful mineral substances are of great importance for the national economy, being used in various fields: as energy sources, as raw material in the metallurgical and chemical industry, as building material [21].

The Republic of Moldova (RM) has a relatively low potential of mineral resources. The main types of useful minerals are building rocks and raw materials for the construction materials, cement, glass industries, chemical industry and other resources. In the 20th century, as a result of the increasing needs of the population and the national economy, a special extent was reached by the exploration and capitalization of mineral resources through the development of constructions, industries, communication networks, etc. Currently, the industry of construction materials is represented by over 40 large enterprises and several dozens of small enterprises. Among the deposits intensively exploited in the last period, can be highlighted limestone and clay, the raw material for the manufacture of cement, from the quarry "Lafarge Ciment" (Moldova) S.A., located in Rezina district. Most of the mineral resources from the RM are exploited through quarries and only some varieties of limestone through galleries [21]. Currently, there are 153 mines and quarries in the RM, and the total area of the mining perimeter is 9672 ha. The total exploited area in the RM is 1423 ha, and the total recultivated area is 240 ha [2]. The mining activity produces an impact that affects, to a greater or lesser extent, all environmental factors, and requires high costs both for their restoration and the reintegration of occupied and degraded areas in the economic and agricultural circuit. In order to diminish the negative impact of the mining activity on the territory of the RM, an important role belongs to the restoration of these ecosystems through different measures: ecological reconstruction through forest recultivation, agricultural recultivation, landscape redevelopment, etc.

Moldova is one of the European countries with the lowest afforestation rate. At the beginning of the last century, the forest cover index reached a minimum of 6%, after which the deforestation trend was slowly reversed. Currently, the forested area of the RM is about 11%, which remains under high pressure due to anthropogenic activities, as well as biotic and abiotic factors. Therefore, there are increased processes of soil erosion, landslides, changes in the hydrological regime, continuous aridization of environmental conditions. Forests are the main element that ensures the ecological balance in this geographical area. Therefore, the issue of conservation and sustainable development of existing forests, as well as the expansion of forests through afforestation of new areas is a matter of national interest [1].

Conservation and restoration of biodiversity, habitats and ecosystems, protection of rare and endangered species is stipulated in the international environmental treaties, which are promoting the global legal framework for actions regarding biodiversity, in particular, in the Convention on Biological Diversity, signed at Rio de Janeiro (1992). Currently, the forest fund of the RM comprises a total area of 446,4 thousand ha and constitutes 13,2% of the country's territory. Forest recultivation is one of the most effective measures for the ecological reconstruction of ecosystems degraded as a result of mining activities.

At the beginning of the third millennium, ecological reconstruction (ER), the restoration of degraded ecosystems, continues to be a major problem for mankind, that is well known and highlighted in numerous documents worldwide and in Europe. [29].

The EU's priority goal for 2020 is to halt biodiversity loss, degrade ecosystem services and restore them as much as possible, while increasing the EU's contribution to tackling global biodiversity loss. Thus, by 2020, in the RM is foreseen the ER of „at least 15% of the degraded ecosystems" by planting 150 thousand ha of forests, including on degraded lands, as well as by creating 30 thousand ha of riparian forest curtains. [29].

Based on the above problem, the **aim** of the research is to evaluate the peculiarities of restoring the petrophyte ecosystem in the limestone quarry of the factory „Lafarge Ciment" (Moldova) S.A.

To achieve this goal, the following **objectives** have been outlined:

1. estimation of the initiation stage and natural restoration of biodiversity on the overburden dumps surface (lower Pleistocene earthy material) in the limestone quarry „Lafarge Ciment" (Moldova) S.A.;
2. assessment of the state and dynamics of biodiversity on the overburden dumps surface depending on their age;
3. estimation of the dependence of the evolution degree of regosols, formed on the surface of overburden dumps in the process of the restoring the petrophyte ecosystems;
4. ecological reconstruction through forestry recultivation of the dumps recently stored in the quarry.

Scientific novelty and originality. For the first time in the RM, it was effectuated the study of the natural restoration of the petrophyte ecosystems and established the rule of the regosols formation on the overburden dumps surface. This rule demonstrates that the degree of regosols formation, represents a process of soil evolution depending on the age of the dumps, the number of species that grow on their surface, the content of nutrients and the humus formed in regosol, assured by the mass of the developed species on the overburden dumps (OD) surface, as

a results of the biogeochemical process (phytocenotic). It was developed and implemented the experimental method of forest recultivation of the petrophyte ecosystem from the quarry „Lafarge Ciment" (Moldova) S.A.

The originality of the results consists in the complex study of the dynamics of natural processes of biodiversity initiation and restoration, of soil formation, nutrients (N_{total}, P_2O_5, K_2O) and humus accumulation in the newly formed soil layers on the overburden dumps surface (soil layer 0–20 cm) and conditions that ensure the restoration of the petrophyte ecosystem in the quarry.

Solved scientific problem consists in establishing the stages of natural restructuring of the petrophyte ecosystem, based on the diversity of the phenomena being explained. This process represents the consecutiveness and reciprocal interaction of the natural stages of biodiversity development, of soil formation, nutrients accumulation and humus formation in regosols, that take place simultaneously, without human intervention, and assures natural restoration of petrophyte ecosystem.

The theoretical importance. The research is a first experience, at national level, on elucidating the stages of biodiversity restoration and establishing the regularity of the soil formation process on the surface of overburden dumps. The results indicate that the process of biodiversity restoration and regosols formation on the overburden dumps surface are interdependent.

The practical value. For the first time, the method of ER through forest recultivation on recently stored land, without organic fertilizers, was used, and an ecosystem with a high index of development of plant biological diversity was obtained. The results of the complex study will serve as a basis for restoration of degraded ecosystems after mining activities in limestone quarries.

Implementation of scientific results. The research results are implemented by the Sustainable Development Department of the factory „Lafarge Ciment" (Moldova) S.A. in order to achieve ER by forest recultivation of overburden dumps and by the Moldova State University in the process of training master and doctoral students.

Publications on research topic. Based on the scientific material presented in thesis, 27 scientific papers were published.

KEY WORDS

Petrophyte ecosystem, biodiversity, ecological reconstruction, natural restoration, biogeochemical process, regosol, overburden dump, quarry.

METHODOLOGY OF SCIENTIFIC RESEARCH

The research of the floristic diversity from the „Lafarge Ciment" limestone quarry was carried out according to the methodology of Cristea V., Gafta D., Pedrotti, F., (2004). [15]. The spectra of biomorphs, biological groups, ecological categories and phytogeographic elements were elaborated according to the methods described in the ecological and geobotanical study of the vegetation in Romania [13]. The soil formation process was studied according to Ursu A. [31]. Ecological reconstruction related to forest recultivation was carried out according to the technical guide on afforestation of degraded lands [18].

SYNTHESIS OF CHAPTERS

1. ECOLOGICAL RECONSTRUCTION OF DEGRADED LAND RESULTING FROM SURFACE MINING

Data from national and international literature on the problem of degradation of natural ecosystems through surface mining, the impact of mining activities on biodiversity and ER of degraded land using agricultural and forest species were collected. Following the analysis of bibliographic resources, we can say with certainty that the surface of degraded land resulting from surface mining is constantly growing, leading to pollution of water, air, soil, destruction of ecosystems, changing landscapes and affecting the health of the population.

2. RESEARCH MATERIALS AND METHODS

Chapter 2 presents the scheme of the location of the study area, description of the physico-geographical, edaphic and biological conditions. The collection, determination, storage and chemical analysis of the samples was performed according to the classical methodology and methods of analysis. Laboratory determination of flora and fauna species was performed using determination keys [13, 23, 24, 38, 39]. Analysis of soil chemical parameters: pH, humus, mobile phosphorus (P_2O_5) and mobile potassium (K_2O), N_{total}, Ca^{2+} and Mg^{2+}, heavy metals: Cu, Zn, Cd, Ni, Pb were performed according to the standardized methods of the State Hydrometeorological Service laboratory [20, 36, 42, 43]. Chemical indices of water: pH, SO_4^{2-}, NO_3^-, NO_2^-, Cl^-, HCO_3^-, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, heavy metals: Cu, Zn, Cr, Ni, Pb, total hardness and the fixed residue were performed in the „Ecourbanistic" laboratory of the IEG [27, 28].

3. STUDY ON THE ECOLOGICAL STATE OF THE LIMESTONE QUARRY „LAFARGE CEMENT" (MOLDOVA) S.A

3.1. Geological and geomorphological conditions

Limestone quarry „Lafarge Ciment" (Moldova) S.A., Rezina, is part of the Dniester river basin, located in the Region of the Forest-Steppes Plateaus and Plains of Northern Moldova, the

physical-geographical subregion The Dniester Forest-Steppe Plateau. This subregion has a moderate relief, fragmented by a system of narrow valleys and ravines, sometimes in the form of gorges (fragmentation density 1,9–2,1 km/km^2). Erosion, landslides and karst processes are widely developed [4].

The geological rocks, which appear on the surface, belong to the Sarmatian deposits, being represented by different limestones, clays, fine sands covered with altered layers, mainly loam-clay or clay-loam. Loessoid clays (over 30% of the surface) are distributed on terraces and lower parts of slightly inclined slopes. Sandy clays and fine sands are spread on some hilltops (over 6%). More than 10% of the surface is occupied by recent sedimentary rocks - deluvial and alluvial - deposited in valleys and meadows [3].

Geomorphological conditions. In different geomorphological regions the district is highlighted under the name „Pre-Dniester Hills" [41], „Codrii from the Rezina", [46], „Dniester Plateau", [3], cit. [30]). This geomorphological region is characterized by a fragmented relief. The peaks of the hills exceed the altitude of 300 m (maximum - 338 m), but the heights of 160–240 m are predominant. The eastern part of the district is crossed by the valleys of the Cuşnirca, Ciorna, Rezina streams, most of them in the form of canyons with steep, calcareous banks. [30]). The bank of the Dniester is also steep, intersected by ravines and short valleys. The average length of the slopes of the Rezina hills is about 1000 m, some with a length of 2000 m and even 2800 m. The relatively flat surfaces (0–2 °) occupy only 30% of the district's territory. Surfaces with an inclination of 2–6 ° predominate (45%), 10% occupy steep slopes > 10 ° (cit. [30]).

3.2. Soil conditions in the study area

According to the pedo-geographic regionalization (cit. [30]) of the RM, the researched area, being situated on the territory of Rezina district, is located in District no. 5 of leached chernozems, alluvial clays and gray soils of the forest-steppe hills from Rezina.

The district is well determined, being framed between the Raut and Dniester rivers to the south and the hills of the Soroca. The territory represents a relief excavated in limestone, being observed the rocky limestone massifs with a rocky appearance.

Climate characteristics: amount of t° >10°= 3000–3150°; P = 550–600 mm; E = 800–820 mm; K = 0,7–0,8. The fertility of the district's soils is medium and low; it is recommended for use primarily in vineyards and orchards, meadows and forests. The soil of the study area before the beginning of the limestone extraction is reflected in figure 3.1.

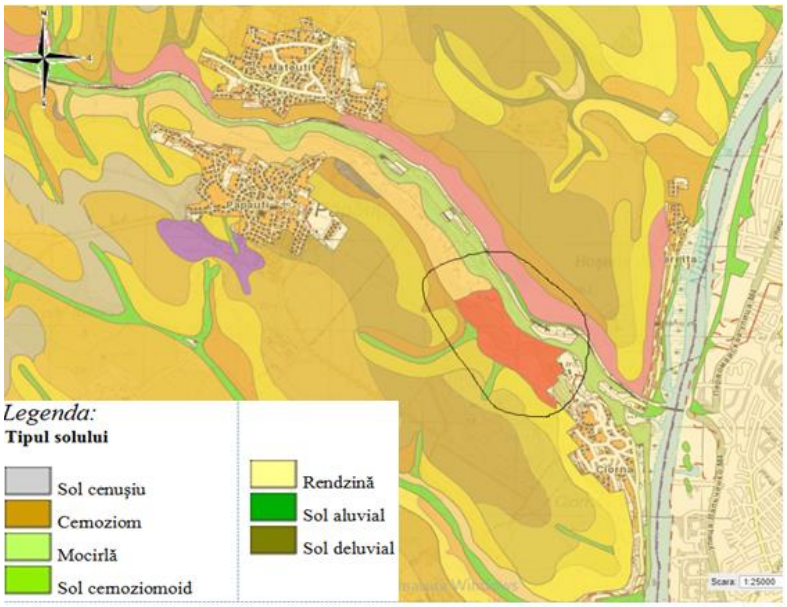

Fig. 3.1. Fragment of the vectorized map (2013) of the soils in the studied area [17]

The quarry soil is complicated and mosaic. On the territory of the district are found almost all types and subtypes of soil, spread throughout the country, except for brown and peat soils. The peaks of the hills, in the altitude range of 348–240 m, are occupied by gray soils (whitish, typical and soft), which are bordered by clay-illuviated chernozems, formed under grassy forests [47]. In the meadow of the valleys of Ciorna and Rezina rivers are spread the soft alluvial soils, and at their confluence with river Dniester - marshy alluvial soils. The following types of soil are located on the studied territory: gray soils, chernozems, silts, chernozomoid soils, rendzines, deluvial soils, alluvial soils. The texture of the soils is clayey. Soft alluvial soils on the researched territory, according to the humus content in the surface horizon, can be characterized as weakly humiferous. The reaction of the soils within the profile is neutral - weakly alkaline.

Fig. 3.2. Fragment of the soil map from the „Lafarge Cement" limestone quarry [17]

Based on pedological investigations carried out in the researched area, a map was drawn up (figure 3.2), on which 5 areas were delimited: *1) clayey leached chernozems; 2) lands affected by earthworks by excavations and stripping; 3) the explored territory of the quarry; 4) dumps with earthy material consisting of fossil soils of the Early Pleistocene age* (foto 3.1); *5) the quarry pond with the adjacent wetland.*

The researched arable leached chernozem is characterized by the following profile type: *Ahp1–Ahp2–Ah–Bh1–Bh2–BCk1–BCk2–Ck* (figure 3.3). Effervescence - from a depth of 96 cm. Carbonates in the form of pseudomycelia - beginning below 100 cm, meet up to 200 cm. Accumulations of limestone points are rarely found deeper than 150 cm.

Foto 3.1. Outcrop of earthen material dumps consisting of fossil soils from the reference area of the „Lafarge Ciment" limestone quarry

Fig. 3.3. Profile of leached chernozem (cambic) in the reference area and the underlying rocky outcrop in the limestone quarry „Lafarge Ciment" (Moldova) S.A.

3.3. The characterization of the petrophyte ecosystem until commissioning the limestone quarry

The petrophyte (rocky) ecosystems on the studied territory are conditioned both by the substrate (limestone rocks), relief and climate, as well as by the eco-preferences of the respective populations. Petrophytic calcareous slopes are distinguished by specific ecological conditions, because the zonal climatic factors in these ecotopes are changing significantly.

The study of floristic diversity before exploitation. According to data from the Atlas of MSSR (1978), [37] in these ecosystems the following types of vegetation can be highlighted: hornbeam and oak forest ecosystems, hornbeam and sessile oak forest ecosystems, forest ecosystems with predominant sessile oak associated with smoke bush, forest ecosystems of linden and ash. The shrub layer usually consists of smoke bush, European cornel, wild ash, hazelnut, common dogwood, European bladdernut, etc. In the 80s of the XXth century, in the natural calcareous ecosystems, were identified about 310 species from 175 genera grouped in 43 families [40].

The study of faunal diversity up to exploitation. The rocks are populated by 38 species of terrestrial vertebrates, mostly mammals and birds. Here, vulnerable and endangered species find refuge, such as the European ground squirrel, the Egyptian vulture, the peregrine falcon, the owl, the stock dove, the Aesculapian snake, the yellow-bellied snake and the smooth snake. Among the common vertebrate animals in the rocks live the stone marten, the black redstart, the rock

pigeon, the blackbird, the wheatear, etc. [22]. According to the research of Derjanschi V. (1989) [44], it was established that out of 173 species of heteroptera, 19 xerothermophilic species, exclusively, inhabit calcareous slopes.

3.4. The taxonomic structure and distribution of flora depending on the age of the dumps and the diversity of the fauna in the quarry

As the result of the extraction of the limestone on the territory of the „Lafarge Cement" quarry, were formed overburden dumps (OD) with ages of 25, 20, 10, 5 and 0 years (figure 3.4). The vascular flora from the „Lafarge Ciment" quarry, Rezina city, is represented by 125 species from 108 genera, grouped into 42 families [35]. The investigated flora, compared to the floristic diversity identified by different authors up to the exploitation of the quarry, is reduced. The lake located in the quarry, slightly to the northwest of its center with an area of about 75 ares, the perimeter - 365 m and a depth of 4 m, serves as a reservoir for the accumulation of the groundwater and rainwater in the perimeter of the quarry. In the plankton of the water basin, can be found the species from the following fila: Cyanophyta (*Gloeocapsa sp.*); Chlorophyta (*Oocystis sp. Naegheli* in A. Braun., *Ankistrodesmus angustus* (Bern.) Korschik., *Ankistrodesmus minutissimus* Korschik., *Scenedesmus oblicus* (Turb.) Kuetz.); Bacillariophyta (*Synedra acus* Kutz., *Synedra ulna* (Nitzch.) Her., *Campylodiscus clypeus* Ehr., *Achnanthes lanceolata* (Breb.) Grunow., *Navicula rhynchocephala* Kutzing, *N. cryptocephala* Kutz. *Var. cryptocephala*, *Caloneis amphisbaena* (Bory.) Cl., *Cymbella prostrata* (Berkeley) Grunow., *Rhoicosphenia curvata* Grun.) [10]. Most algae species detected in the lake refer to the range of α-, β-mesosaprobe saprobity, which indicates a low and medium degree of pollution of the water.

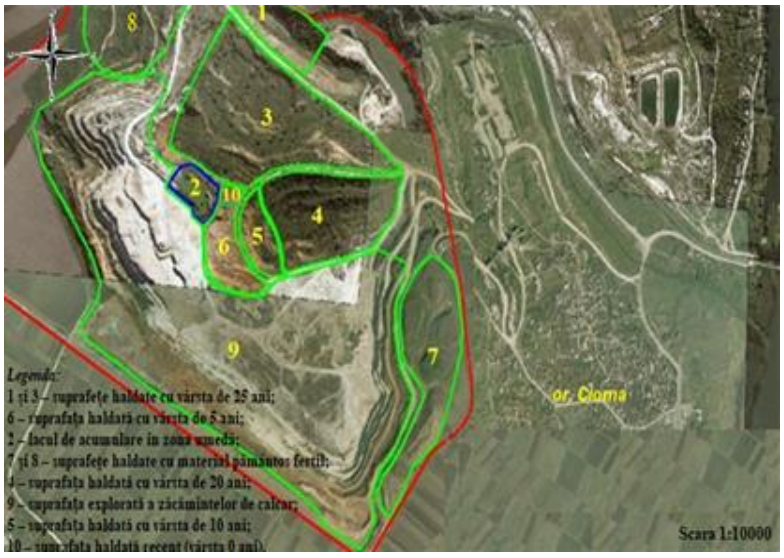

Fig. 3.4. Location scheme of the sectors of „Lafarge Ciment" (Moldova) S.A. quarry [33]

The 25-years-old dump is characterized by the maximum floristic diversity where 73 species vegetate, whose contribution in the formation of the vegetal carpet is different. A large part of the site surface is covered by woody plants of different ages [9, 11, 12]. The dominant position is occupied by invasive species: *Elaeagnus argentea* Pursh, *Elaeagnus angustifolia* L., *Acer negundo* L., *Robinia pseudoacacia* L. Among dominant species, fruit tree species have

been also detected, for example: *Juglans regia* L., *Armeniaca vulgaris* Lam., *Cerasus avium* (L.) Moench, *Malus domestica* Borkh., *Malus sylvestris* Mill. Quite rich is the vegetal carpet of the slope of this site, where the species *Knautia arvensis* (L.) Coult. vegetates abundantly. A high degree of grass cover has been found at the base of the slope where the soil is much wetter, and the vegetation consists here of a larger number of species, including *Poaceae*: *Festuca pratensis* Huds., *Elytrigia repens* (L.) Nevski etc. Quite common in this site are also invasive herbaceous species, such as: *Sonchus arvensis* L., *Arctium lappa* L., *Xanthium strumarium* L., *Knautia arvensis* (L.) Coult., *Crepis rhoeadifolia* Bieb., *Urtica dioica* L., *Cirsium arvense* (L.) Scop. etc. In this sector, some species of medicinal plants are also found sporadically, for example: *Lotus corniculatus* L., *Inula helenium* L., *Potentilla argentea* L., *Agrimonia eupatoria* L., *Onopordum acanthium* L., *Achillea millefolium* L., *Valeriana officinalis* L., *Cichorium intybus* L. etc. Some plant species have been found exclusively only on this dump, such as: *Carthamus lanatus* L., *Inula helenium* L. and *Solanum dulcamara* L.

It should be mentioned that in the fall of 2018 on the 25-year-old dump was identified the rare species included in the Red Book (RB) of RM - *Vitis sylvestris* C. C. Gmel., which so far has not been registered in the limestone quarry (foto 3.2).

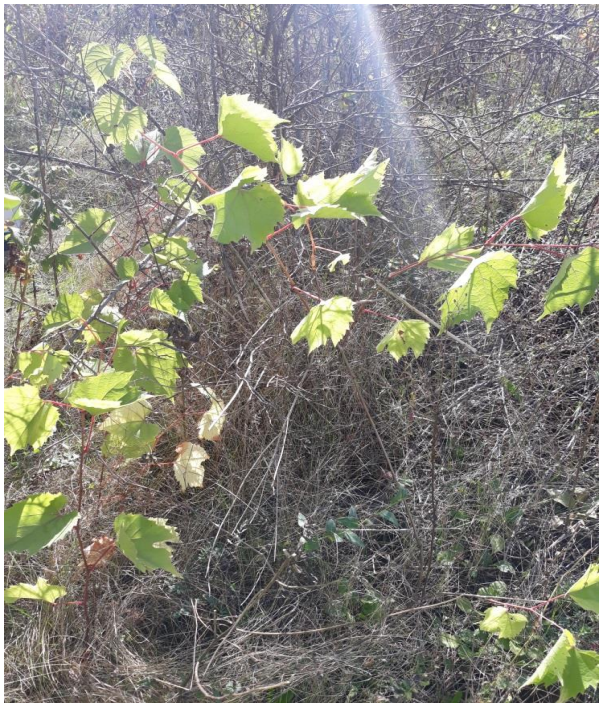

Foto 3.2. *Vitis sylvestris* C. C. Gmel. (viță-de-pădure)

The 20-years-old dump is characterized by a relatively high diversity, a total of 68 species of woody and herbaceous plants. The vegetation of this site is also dominated by woody species *Elaeagnus argentea* Pursh, *E. angustifolia* L., which is accompanied by *Acer negundo* L., *Robinia pseudacacia* L. and shrub species, being more common *Crataegus monogyna* Jacq. and *Rosa canina* L. Although the abundance of herbaceous species on the slopes of this dump is lower compared to that of the previous one, the soil is covered by 60–70%, and the base of the slope is covered almost entirely by herbaceous plants, quite abundant are invasive plant species like: *Grindelia squarrosa* (Pursh.), *Lactuca tatarica* (L.) C. A. Mey., but also species like: *Melilotus officinalis* (L.) Pall., *Xeranthemum annuum* L., *Verbascum nigrum* L., *Echium vulgare* L., *Tanacetum vulgare* L. etc. As on the previous site, on the slopes of this sector of the quarry,

specimens of *Cerasus avium* (L.) Moench and *Juglans regia* L were found. The species *Knautia arvensis* (L.) Coult., grows more moderately on this site.

The floristic diversity of the 10-year-old dump is much lower than that of previous sites and is represented by 30 species of plants, including the one woody species - *Elaeagnus argentea* Pursh., which has a more moderate development, reaches 2,5–3 m height and is evenly distributed over the surface of the site. The species of herbaceous plants that vegetate in this site form a compact carpet, where the main weight belongs to the invasive species *Grindelia squarrosa* (Pursh.), but also quite common species are: *Melilotus albus* Medik., *Echium vulgare* L., *Erigeron annuus* (L.) Pers., *Cirsium arvense* (L.) Scop. şi *Polygonum aviculare* L. The overall coverage on this site is quite high and is about 80-90%.

The 5-year-old dump is represented by 26 species of herbaceous plants, saplings and young trees of woody plants. The degree of surface coverage is low and can be estimated to about 20–30%. In this site there is an intense increase both in the length of the plant stem, which can sometimes exceed 1,5–2 m, and in the thickness of the stem. For example, the stem length of the *Coronilla varia* L. reached 1,0–1,3 m. An intense growth on this site has also been observed within following species: *Lotus corniculatus* L, *Linaria vulgaris* Mill., *Echium vulgare* L., *Rumex conglomeratus* Murr., *Polygonum aviculare* L., *Erigeron annuus* (L.) Pers., *Crepis rhoeadifolia* Bieb, *Cirsium arvense* (L.) Scop. etc. The virgin territory of this site, which is not very favourable for plant development, has nevertheless become the living environment for woody species like *Elaeagnus argentea* Pursh, *Populus sp*., *Acer negundo* L. and, also, saplings of *Juglans regia* L.

During floristic study of the overburden dumps in the quarry, the process of initiating and restoring the following plant associations was observed: fescue (*Festuca pratensis* Huds.) with other herbs, which grow abundantly at the base of the 25-years-old dump and at the level of the terraces on the 20-years-old dump; yellow sweet clover (*Melilotus officinalis* (L.) Pall.), which develops abundantly on the plateau of the 20-years-old dump; of wild olive (*Elaeagnus argentea* Pursh and *Elaeagnus angustifolia* L.), which grows abundantly on all overburdens dumps.

On the freshly stored overburden dump, 30 species of herbaceous plants were identified as a result of the spread of fruits and seeds by zoochoric, anemochoric, hydrocoric, anthropocoric ways of dispersion. A more intense development possess the species unpretentious to soil nutrients like: *Coronilla varia* L., *Melilotus officinalis* (L.) Pall., *Sonchus arvensis* L., *Medicago lupulina* L., *Trifolium fragiferum* L., *Grindelia squarrosa* (Pursh.) [11].

Study of faunal diversity in the „Lafarge Ciment" limestone quarry area. The quarry ornithofauna is represented by 12 species [7]. The species *Larus argentatus* Pont and *Larus*

ridibundus L. are trophic invasive species. The species *Buteo rufinus* Cretzsch. nests only on the territory of the quarry, where it has found favourable conditions, in some places, there are also nests of *Hirundo rustica* L., *Phoenicurus ochruros* Gmel., *Motacilla alba* L., *Oenanthe oenanthe* L. Also, it was confirmed the presence of a colony of the bank swallow (*Riparia riparia* L.) consisting of about 120 burrows, built in the sandy shore wall. Along with the swallow, here are nesting a few more pairs of European bee-eater (*Merops apiaster* L.). Among the species of snakes are found *Natrix natrix* L. and *Natrix tessellata* Laurenti., that feed in the lake with the single species of frog - *Rana lessonae* Camer., because its population is quite large. Among the mammals, *Lepus europaeus* Pallas, *Capreolus capreolus* L. and *Sus scrofa* L. are more common. The soil is not yet well enough formed to ensure the habitat of small rodents. There are not enough common resources for a successful development of reptiles. Only the autonomous restoration of habitats through the application of various protection measures will ensure the enrichment of the biodiversity of ecosystems in the quarry area.

In total, 13 species of diurnal butterflies have been recorded during entomological research, including the species *Zerynthia polyxena* Den. & Schiff. included in the RB of the Republic of Moldova, several species of beetles *Lethrus apterus* Laxm., *Amphimallon solstitiale* L., etc. from the Scarabaeidae family. Different species of the order Orthoptera were recorded on the herbaceous plants - *Acrida hungarica* Herbst, *Gryllus campestris* L., *Tettigonia viridissima* L. and 6 species of the genus *Chorthippus*.

In the wetland area are present the dragonflies (ord. Odonata) like *Ischnura elegans* Vand. Lind., *Aeshna affinis* Vand. Lind., *Orthetrum albistylum* Selys, *Sympetrum striolatum* Charp., which during larval stage develop in the aquatic environment etc. Among the aquatic beetles, 5 species were registered: *Haliplus ruficollis* De G., *Hygrotus inaequalis* F., *Gyrinus natator* L., *Sphaeridium scarabaeoides* L. and *S. bipustulatum* F. – belonging to fam. Haliplidae, Dytiscidae, Gyrinidae and Hydrophilidae. Knowing the specific composition of this taxonomic group is important, given that some species are used as bioindicators of water purity.

4. THE STAGES OF THE NATURAL RESTORATION PROCESS OF THE PETROPHYTIC ECOSYSTEM IN THE „LAFARGE CEMENT" QUARRY (MOLDOVA) S.A

4.1. The stage of formation of overburden dumps and the process of initiating the restoration of plant diversity on their surface

The background soils before the opening of the quarry are made up of leached chernozems (cambic) with a high potential fertility. Soft alluvial soils were spread sporadically before the

period of quarrying on this territory and, according to the humus content in the surface horizon, can be characterized as weakly humiferous.

The stages used for limestone extraction are: the stripping stage, which consists in stripping the fertile layer (> 1% humus), represented by the chernozem and placing it on the edge of the quarry for later use and the actual limestone extraction [11]. The stages of restoration of the petrophyte ecosystem are: *the stage of OD formation and the stage of restoration of plant biodiversity on the surface of the dumps*.

The results obtained regarding the natural restoration of the flora showed that a slow process of its development takes place. The number of species, the degree of development and the abundance of species is determined by several factors, such as: the period of formation of the vegetal carpet on the surface of the dump (number of years), the place on the surface of the dump (on the coast, on flat ground or at the foot of the dump). On flat ground and at the foot of the dump, the abundance of species is much higher compared to coastal places. This fact is possibly explained by the amount of moisture that ensures the development of herbaceous species. These dependencies have been established for the 25-, 20-, 10- and 5-years old dumps. The results obtained indicate the following relationship between the age of the dump (years) / the number of species (units) = 25:20:10:5:0/73:68:30:26:0. Based on these results, it can be concluded that the process of initiation and restoration of biodiversity is due to the surface soil material, formed by earthworks, consisting of a mixture of clays and fossil soils of the Early Pleistocene. This earthy material, serving as a biotope, ensures the initiation of the process of development of plant diversity and the formation of the primary horizon of humus accumulation, precursor of horizon A. This process also takes place under the influence of natural conditions. Thus, the surfaces on the stored dumps formed by earthworks, ensure a high level of productivity of the newly formed biocenoses on the quarry territory [5].

Based on the results obtained, it is necessary to mention that the number and abundance of species and the place on the surface of the dump are decisive for the formation of the soil layer, and the soil, in turn, ensures a wider development of all plant species. These are confirmed by the results of the analyses obtained from the soil samples taken from these dumps [5].

4.2. The regosol formation stage and morphological description of soil profiles of overburden dumps of different ages located in the quarry

The process of formation of the new soil. According to Ursu A., the soil is an organo-mineral body with a vertical profile divided into genetic horizons, formed on the land surface as a result of the long interaction of parent rocks with organisms and their residues, under certain conditions of relief and climate. Soil formation - pedogenesis - occurs simultaneously with the

natural evolution of plant and animal associations and is in a permanent balance with the respective biocenoses. The soil is a background, a base and at the same time, an objective mirror of the biocenosis, the landscape and the ecosystem [31].

The results obtained on the restoration of biodiversity are also closely related to the process of new soil formation. This process is interdependent with the process of restoring biodiversity. Both processes (sol formation and restoration of biodiversity) are dependent on the age of the dumps. Depending on the period of exposure of the dump to the soil formation process, the content of the organic matter (humus) in the newly formed soil increases, the structure of soil aggregates improves, the thickness of the profile increases, the biomass increases and the vegetation becomes richer in species.

Studies have established the dependence of the process of restoring plant diversity on the surface of dumps according to their age. The number of herbaceous plant species is determined by the age of the dumps, the older the dump, the higher the number of species that grow on them. As a result, it can be concluded that this process of restoring biodiversity on the surface of OD *takes place simultaneously with the process of formation of new soil on the surface of the studied dumps and they are interdependent and represent a reciprocal process*.

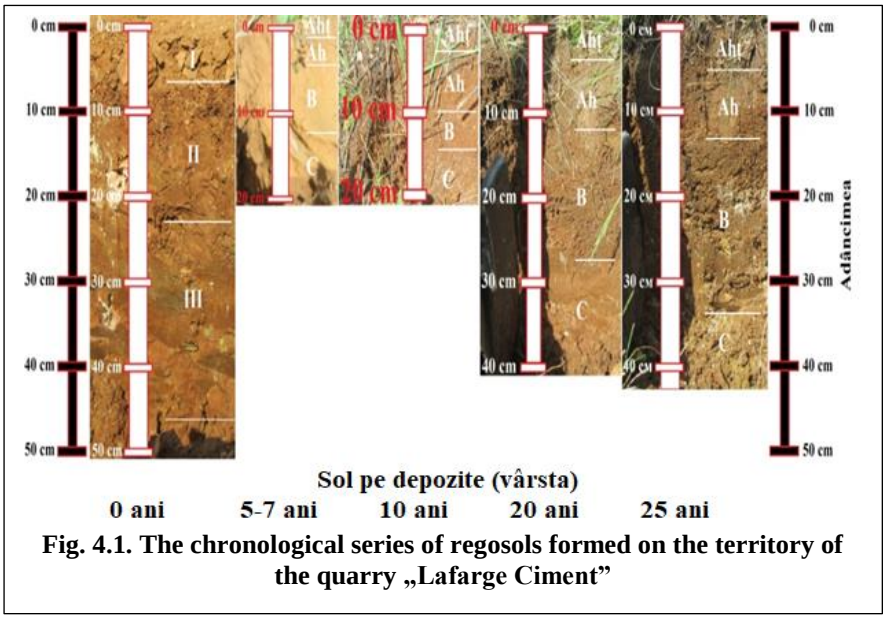

Fig. 4.1. The chronological series of regosols formed on the territory of the quarry „Lafarge Ciment"

Should be mentioned that the process of regosol formation [8], which represents soils in an incipient stage of evolution, the formation of which is conditioned by the presence of unconsolidated parent material (loess, loessoid deposits, clays, etc.) in the RM is described for the first time in this paper (figure 4.1).

4.3. Study on the content of humus (organic matter) and nutrients in the soil layers on the surface of overburden dumps of various ages

Soil samples were taken on horizons from newly formed primary soils: I - humus accumulation horizon precursor of horizon *A*, II - transition horizon to parent rock precursor of horizon *B* and III - parent rock *C*.

Study on the content of humus (organic matter)

Analysis of the humus content for dumps of various ages in the 0–20 cm soil layer indicates that the highest humus content is contained in the soil layer on the surface of the 25-year-old dump (0–20 cm) and constitutes 2,22% of humus, followed by the 20-year-old dump with a content of 1,72% humus, the 10-year-old dump with a humus content of 0,62% and for the 5-year-old dump the humus content is 0,45% , and for freshly stored OD the humus content is 0,34% for the 0–20 cm layer and 0,28% for the 20–40 cm layer (figure 4.2).

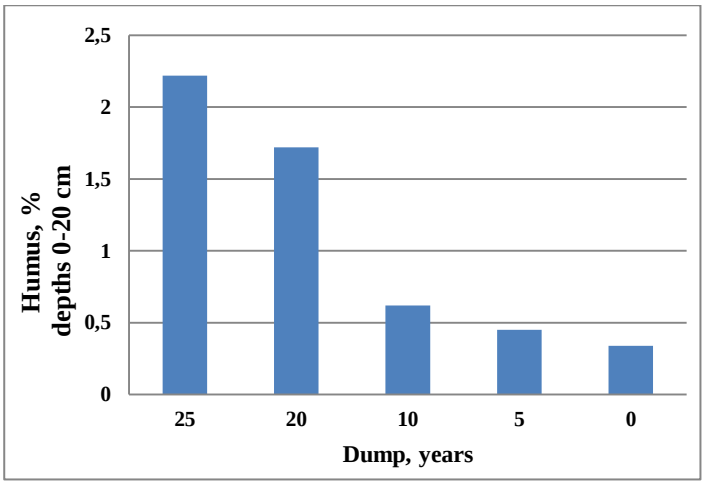

Fig. 4.2. The humus content in the layer of the researched regosols (0–20 cm) from the limestone quarry „Lafarge Ciment" (Moldova) S.A.

The results obtained on the dynamics of humus formation (organic matter) in the regosol layer of 0–20 cm (figure 4.2) indicate the following relationship *between, age of the dump, (years)/number of species (units)/humus content (organic matter), (%) 25:20:10:5:0/73:68:30:26:0/2,22:1,72:0,62:0,45:0,34*. The data indicate that the largest number of species corresponds to the 25-years-old dump, followed by the 20-, 10- and 5-years-old dumps. The same trend is observed in the humus content: the highest humus content corresponds to the 25-years-old dump, followed by the 20-years-old, 10-years-old, 5-years-old dump and the newly stored dump.

The data in figure 4.3 indicate that the largest difference in the content of humus (organic matter) is established between the dump of 25 and 0 years, which is possibly explained by the very slow dynamics of the humus formation process in the layer of 20–40 cm.

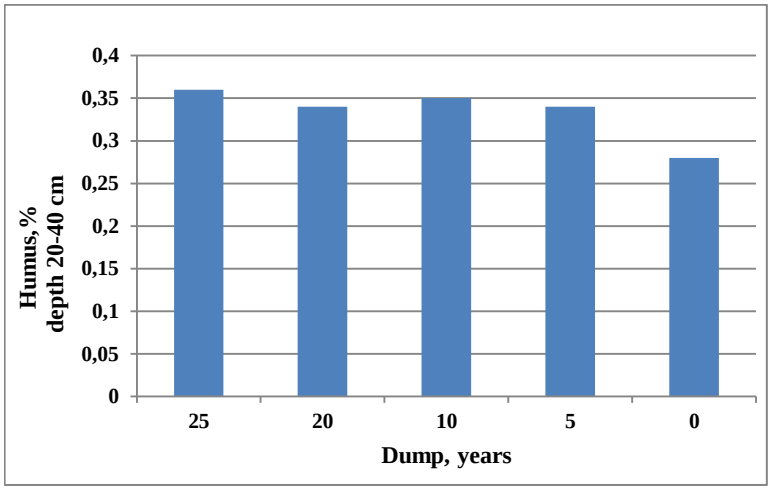

Fig. 4.3. The humus content in the layer of the researched regosols (20-40 cm) from the limestone quarry „Lafarge Ciment" (Moldova) S.A.

The obtained results indicate that the natural restoration of the quarry petrophyte ecosystem *is ensured by the processes of restoration of plant diversity, formation of regosol and*

humus. It should be noted that these processes are interdependent (they depend on each other and influence each other) [6].

Heavy metal content. The results regarding the HM content in the newly formed soils on the OD surface depending on their age and the depth of sampling (0–20) and (20–40) cm do not exceed the alert and intervention threshold for any of the analysed metals.

Nutrient content. Content results regarding N_{total}, P_{mobil}, K_{mobil} indicates the dynamics of these nutrients and humus over time, in which the growth and development of plant species and the process of new soil formation in the layers on the surface of the dumps takes place. *These processes: variation in the content of nitrogen, phosphorus, potassium, humus and new soils formation are interdependent processes and underlie the natural restoration of the petrophyte ecosystem.*

4.4. Rules and dependencies (peculiarities) established in the process of natural restructuring of the petrophyte ecosystem from the „Lafarge Ciment" quarry

Has been determined [6], *the rule of the soil formation process on the OD surface which is expressed by the fact that the formation of regosols is a process of soil evolution determined by the age of the dumps, the number of species growing on the surface of the dumps and the content of humus (organic matter) formed by the mass of the species developed on the surface of the dumps*, which in this case is expressed by the following relation: *(age of the dump), (years)/ number of species (units)/ humus content (organic matter), (%) = 25:20:10:5:0/73:68:30:26:0/2,22:1,72:0,62:0,33:0,28.*

The process of natural restoration of the petrophyte ecosystem is ensured by:

1. The initiation of the process of restoration of plant biodiversity on the surface of OD is ensured by the soil material at the surface of the dump, consisting of layers of unconsolidated rocks and fossil soils of the Early Pleistocene. This soil material has the necessary potential and as a biotope, ensures the initiation of the process of development of biodiversity and the formation of the primary horizon of humus accumulation, precursor of horizon A.

2. Finding the dependence of the biodiversity restoration process on the surface of the dumps depending on the age of these dumps. The number of herbaceous plant species is determined by the age of the dumps, the older they are, the greater the number of species that grow on them, expressed by the following relation: *dump age (restoration period of the species' carpet), (years) / number of species (units) = 25:20:10:5:0/73:68:30:26:0.* As a result of the research, it was established the *dependence of the evolution degree of the regosols, formed on the surface of the dumps*. The evolution degree of regosols depends on the age of OD. The highest

degree of evolution of the new soil process formation is characteristic to the regosol on the surface of the 25-years-old dump

5. ECOLOGICAL RECONSTRUCTION OF THE PETROPHYTE ECOSYSTEM FROM THE „LAFARGE CIMENT" (MOLDOVA) S.A LIMESTONE QUARRY

5.1. Proposed technical solutions for the ecological reconstruction of the petrophyte ecosystem from the „Lafarge Ciment" limestone quarry

The surface exploitation of the limestone from the „Lafarge Cement" quarry results in enormous quantities of overburdens deposited in dumps whose ER is inevitable.

The overburden resulting from limestone extraction are deposited in the form of dumps. The dumps consist of an inhomogeneous mixture of topsoil, sand, gravel, clay and loam, which has an uneven distribution in the body of the dump. The excavated material is deposited in dumps. The dumps in the quarry have the shape of mounds with the appearance of a pyramid trunk or cone. On the territory of the „Lafarge Ciment" quarry are formed dumps of 25, 20, 10 and 5 years. After the formation of OD, there was noticed a tendency of spontaneous installation of a quite abundant natural vegetation that has an important role in the protection of the dump against erosion and in the beginning of the soil formation process.

The research was carried out during the years 2017–2019 on a freshly deposited OD with an area of 0,12 ha (figure 3.4, sector no. 10) from the limestone quarry „Lafarge Ciment". In the spring of 2017 (March 23) the following species were planted: *Robinia pseudoacacia* L. (acacia), *Elaeagnus argentea* Pursh. (wild olive), *Hippophaë rhamnoides* L. (sea buckthorn), *Ligustrum vulgare* L. (wild privet), *Pinus nigra* J. F. Arnold. (black pine), *Cotinus coggygria* Scop. (smoke bush), *Ulmus glabra* Huds. (mountain elm), *Fraxinus exelsior* L. (common ash), *Acer pseudoplatanus* L. (mountain maple), *Gleditsia triacanthos* L. (honey locust). A total of 771 trees and shrubs were planted on this dump [34].

5.2. Ecological requirements of the forest species planted on overburden dumps

The forest vegetation installed on the surface of the dump leads to the formation of a layer of fertile soil by transforming biomass into humus, contributes to improving the water infiltration capacity, to aeration of the soil after the formation of the root system. Trees and shrubs planted in the dump help stabilize the dumps, stop the erosion and create a pleasant landscape.

Robinia pseudoacacia L. has a wide ecological amplitude, which determines a relatively fast accommodation [14]. *Ulmus glabra* Huds. – mountain elm, is long-living, fast growing, resistant to shading, does not support salinization, soil and air dryness, prefers clay-sand-limestone soils [26]. *Fraxinus exelsior* L. it is resistant to low temperatures, but high winter frosts are harmful to it, causing frostbite. It is also resistant to smoke, gas and dust [26]. *Acer*

pseudoplatanus L. prefers a cool and humid climate, is resistant to drought, is light loving. It requires fertile, loose, wet soils, needs enough moisture. Clay, limestone and sandy soils, to an appropriate extent, are the best [26]. *Gleditsia triacanthos* L. prefers warm climate, with long and late autumn. Due to its deep and rich roots, it is resistant to drought and strong winds. It is a light-loving species. It supports compact soils, dust and smoke [26]. *Pinus nigra* Arnold J. F. prefers sandy-clay soils with calcareous substrate and low humidity. It is a "pioneer" species and is successfully used to capitalize on degraded land [26]. *Hippophaë rhamnoides* L. is a species very resistant to frost, but also to drought. Unpretentious to the soil. It is a species that fixes very well the slopes of the dumps, having a well-developed rooting system, which was also proved on the dump in the quarry. Also, it makes symbiosis with nitrifying bacteria, enriching the soil with nitrogen. The species is very important in the food and pharmaceutical industry, the fruits being rich in vitamins A and C. [14]. Sea buckthorn flowers are honey plants. *Elaeagnus argentea* Pursh., grows on sandy, dry soils, is resistant to frost and drought, enriches the soil with nitrogen, due to nitrogen-fixing bacteria [14]. *Ligustrum vulgare* L. has a wide ecological amplitude, adapting to the most different soils provided they are loose, aerated [14]. It prefers rich and wet soils but grows even on the poorest and driest. It is resistant to gas and smoke. It protects the soil well as part of forest plantations [26]. *Cotinus coggygria* Scop. is a drought resistant species able to withstand frost. Requires a large amount of light, but also resists shading. Unpretentious to the soil, it grows on sands, on steppe salt marshes, rocks. It tolerates smoke, dust, gases, soot. Valuable plant in industry, contains tannins (15–42%) [26].

5.3. Rooting, survival and growth of the wood species on the overburden dump from the „Lafarge Cement" limestone quarry

Ecological reconstruction is a widely used method to ameliorate land degraded by anthropogenic factor by the fact that being applied it creates favourable conditions for restoring the structure and functions of the damaged ecosystem. The forests newly created on degraded lands ensure the maintenance of forest plant diversity and serve as a refuge for the spontaneous animal world, which exists sporadically in the conditions of agrocenoses subjected to anthropogenic pressure. [19].

The tree species (acacia, mountain elm, common ash, mountain maple, honey locust, black pine) were characterized by different attachment to the soil. In the first year after planting, the highest degree of rooting of seedlings was recorded for acacia (99,5%), followed by mountain elm (97,5%) and honey locust (92,9%). On the dump the mountain maple ensured a good rooting (88,6%), and the lowest was recorded for common ash (78,8%) and black pine (68,8%). The rooting of acacia, mountain elm, honey locust, common ash and mountain maple tree seedlings

was high enough (78,8–99,5%) exceeding the provisions of the Technical Norms on technical reception and annual control of regeneration, afforestation and growth of forest reproductive material [25] according to which the success of afforestation in the first year of growth constitutes 75,0% of the total number of seedlings planted. A lower rooting than the one shown above was recorded for black pine seedlings (68,8%), which suggests that the given species requires increased attention and care.

Three years after planting, acacia (98,9%), mountain elm (97,5%) and honey locust (92,8%) showed high survival, on freshly stored OD, and good survival was recorded for common ash (76,3%) and mountain maple (75,7%). A low survival was recorded for black pine (56,3%). The average value of the rooting index for the common ash was equal to 78,8%, and in the next two years only 2,5% of seedlings were eliminated from various causes (survival being 76,3%), which shows that in the first vegetation season after planting, the fragile seedlings show a high degree of sensitivity to the action of unfavourable local environmental factors.

From the research regarding the comparison of experimental crops in the first years after planting has been observed that in the conditions of the dump ecotope containing freshly stored earthy material, acacia recorded the most active increase in height, starting with the first year after planting. The increase in height remained active throughout the three years of the study. We mention that, in the extreme environmental conditions of the dump space, after the 3rd vegetation season the acacia has achieved an accelerated average annual increase in height, which was located at over one meter (Z_h = 3,3 m – 2,2 m = 1,1 m).

The other species introduced into the culture were characterized by much lower growth rates compared to those of acacia. The mountain elm, used as the main species, in association with the dogwood and the smoke bush, showed an average growth rate in height and diameter.

As for the common ash, which was used as the main basic species and the mountain maple - as the main species for associations, both are relatively fast-growing species [14, 16]. These species, during the 3 years of analysis, were characterized by a relatively slow rate of growth in height.

The honey locust and black pine recorded a slow growth rate in height, and, also, a relatively slow growth rate in diameter was recorded in the first year after planting, but which has increased somehow in the following years (especially for black pine). Compared to the studied species, the black pine was on the third place in the ranking, in terms of growth rate of seedlings by diameter, and the increase in height was low, so that the species occupied the last position after the average value of that index.

The growth rate of seedlings of shrub species: wild olive, smoke bush, sea buckthorn and dogwood was analysed according to the classification of wood species developed by Криворотов С. and Карпун Ю. [45], which provides for the following gradations: 1) wood species with very fast growth - annual growth of up to 2 m and more; 2) fast growing wood species - annual growth of up to 1 m; 3) wood species with moderate growth - annual growth of 0,5–0,6 m; 4) slow-growing woody species - annual growth of 0,2–0,3 m; 5) wood species with very slow growth - annual growth of up to 0,2 m.

Following the studies carried out on the growth and development of forest crops in the conditions of a freshly stored dump with earthy material, it was established that after the first year of planting a good rooting was recorded for dogwood (88,3%) and sea buckthorn (95,5 %). A very low rooting was recorded for smoke bush (37,5%) and wild olive (49,3%). Results different from those obtained by us were attested on very heavily degraded lands where sea buckthorn achieved a rooting of 75,7% and wild olive of 83,8% of the total planted seedlings [32], which suggests that the rooting of seedlings is influenced by the species, the environmental conditions of the place of cultivation and the quality of the afforestation works.

After three years after planting, the species that ensured a high degree of survival were the dogwood (83,3%) and the sea buckthorn (90,9%), the lowest degree of survival was recorded for smoke bush (35,4%).

The minimum height values are close for the seedlings of the investigated species after the first year of planting, varying in the range of 4–11 cm, except for the wild olive at which the respective index is higher (20 cm). The maximum values of height differ significantly from one species to another (from 46 cm for the sea buckthorn to 138 cm for the smoke bush). The differences between the minimum and maximum values of seedling height in the analysed species increased in the following years, which indicates that the rate of growth in height (either slow or on the contrary fast) is specific for any species of shrubs. It can be concluded that shrub species are characterized by a certain genetically determined growth rate.

The data obtained indicate that the wild olive was characterized by rapid growth throughout the observation period, increasing its growth rate from one year to another. For example, the wild olive after the first year of life achieved an average annual height of Z_h = 42,9 cm, after second year – de Z_h = 96,7 cm, after third year – de Z_h = 131,7 cm, which clearly demonstrates that the growth rate of seedlings increases with age. In this respect, the wild olive, giving the classification of woody species according to their rate of growth in height [45], is a very fast-growing species.

Studies show a moderate increase in the height of smoke bush seedlings in the first year of life, when the average height of the seedlings was $\overline{X}$ =71,0 cm, until the third year, when the average height of the seedlings was at the level of $\overline{X}$ =102,5 cm. It turns out that in the ecological conditions of a dump made of earthy material from the „Lafarge Cement" quarry, the smoke bush, according to the classification shown above, manifests itself as a species with rapid growth in height.

Under the conditions of the dump ecotope, sea buckthorn exhibits an ascending growth, which means that after the 3rd year of life compared to the 2nd year, the average height of the seedlings increased by 1,8 times, and compared to the first year of life – 3,2 times. Sea buckthorn by the way it grows and develops, is characterized by rapid growth in height.

At the end of the first year after planting the average height of dogwood seedlings ($\overline{X}$ =25,7 cm) was practically identical to that of sea buckthorn seedlings ($\overline{X}$ =25,6 cm). In the years that followed, the other species investigated began to grow significantly faster than dogwood. For example, after the 2nd year after planting, the average height of sea buckthorn seedlings was 11,4 cm higher, and after the 3rd year after planting, 35,3 cm higher than that of dogwood seedlings. Thus, according to the growth rate in the conditions of the dump ecotope, the dogwood seedlings are characterized by a moderate increase in height.

On the basis of the results, can be stated that according to the height growth rate, the studied shrub species are distributed as follows: wild olive species with very fast growth, smoke bush and sea buckthorn - with fast growth, dogwood - with moderate growth. Other authors, cited above, highlighted different biological features compared to those presented by us regarding the height growth rate of respective shrub species, which suggests that in some phytogeographic areas the growth and viability of seedlings undergo changes depending on the specific environmental conditions. The experimental results obtained showed that the method of forest recultivation can be used successfully in the accelerated restoration of the quarry petrophyte ecosystem.

5.4. Possibilities for ecological and economic integration of the studied dumps

Plant and animal resources represent natural sources in this ecosystem for its ecological and economic use. Although, the ecosystem, in terms of extracting useful mineral resources, is radically changed, the quarry still has the capacity to regenerate. During the study of the floristic and faunal components of OD of different ages, a self-regulation of this ecosystem at a satisfactory level was observed. The number of, typical for calcareous ecosystems, species detected by us is lower compared to the number of species from bibliographic sources. In the

exploited quarry ecosystem, there are species of fruit, honey, nut, hetero-oily, medicinal, fodder, spice, tannin-containing, insecticidal, dye-containing plants, toxic plants used in various fields of the economy. From an ecological point of view, an important feature is the rare species included in the RB of the RM, which have found favourable conditions for development in this ecosystem: *Vitis sylvestris* C.C. Gmel. and *Zerynthia polyxena* Den. & Schiff.

Possibilities for ecological integration has the wetland area of the quarry, where migratory birds, using this habitat for resting, have been observed. Hundreds of wild ducks were observed on the surface of the quarry lake during their resting. The population of this lake with fish and amphibian species will attract aquatic bird species, which can contribute to the development of a new ecosystem in the area, superior in quality to the existing one. Also, the afforestation of the adjacent areas will contribute to the repopulation of the area with characteristic faunal species, ensuring to a greater extent the improvement of biodiversity.

Another possibility of economic integration is the placement of the beehives on dumps, because here grow in abundance honey species like: *Elaeagnus argentea* Pursh, *Elaeagnus angustifolia* L., *Robinia pseudoacacia* L., *Melilotus officinalis* (L.) Pall. etc. The capitalization of the dumps in the quarry through the rapeseed culture, from which the biofuel is obtained, is also a possibility of economic reintegration.

After the cessation of the career activity, the territory is a suitable place for ecotourism, leisure area, rest, recreation, sports, arranging tracks for bicycles, motorcycles, building a racecourse.

In conclusion, it can be considered that these proposals can lead both to reduce the environmental pollution hazards in the analysed area and to restore environmental factors to a level as close as possible to the situation before mining activities, in the context of sustainable development. We can say that from an ecological point of view OD of different ages are self-established, due to both tree species: wild olive, buckthorn, sea buckthorn, etc., and grass species: crownvetch, yellow sweet clover, clover, birdsfoot deervetch, etc. Tree species stop the process of landslides and erosion, and nitrogen-fixing species provide the source of nitrogen in the soil.

GENERAL CONCLUSIONS

The researched ecosystem is part of the group of petrophyte ecosystems, but with a pronounced anthropogenic impact, determined by the activity of useful mineral substances extraction.

1. The initiation of the process of restoring plant biodiversity on the surface of overburden dumps is ensured by the earthy material on the surface of the dump, consisting of layers of

unconsolidated rocks and fossil soils of the Early Pleistocene. This soil material has the necessary potential and as a biotope ensures the initiation of the process of biodiversity establishment and the formation of the primary horizon of humus accumulation, precursor of horizon A.

2. Research has shown the dependence of the process of restoring biodiversity on the surface of overburden dumps of different ages. The taxonomic spectrum of the vascular flora from the „Lafarge Ciment" quarry highlights the presence of 125 species from 108 genera, grouped in 42 families. The faunal diversity is represented by 41 species of insects, 1 species of amphibians, 2 species of reptiles, 12 species of birds and 6 species of mammals. On the territory of the quarry were identified the rare species included in the RM of the RM: *Vitis sylvestris* C.C. Gmel. (wild grape) and *Zerynthia polyxena* Den. & Schiff. (southern festoon).
3. The process of nutrient accumulation (N_{total}, P_2O_5, K_2O) and humus formation takes place in the newly formed soil layers on the surface of the overburden dumps (soil layer 0–20 cm). The highest degree of accumulation of nutrients and humus has been determined for the 25-year-old dump. This is ensured by the biogeochemical process.
4. The *Rule* on the process of soil formation on the surface of overburden dumps has been established. It shows that the degree of regosol formation is a process of soil evolution depending on the age of the dumps, the number of species that grow on the surface of the dumps, the nutrient content and humus formed in the regosol, provided by the mass of species developed on the surface of the overburden dumps as a result of the biogeochemical (phytocenotic) process. All restructuring stages take place simultaneously and ensure the natural restoration of the petrophyte ecosystem on the surface of overburden dumps.
5. Experimental forest recultivation on the overburden dump showed that the rooting of seedlings of tree species was relatively good (between 69 and 99%), and shrub species are characterized by a good rooting (between 49 and 96%).
6. The survival of tree species varies between 56 - 99%, and of shrub species between 35 - 91%. Three years after planting, acacia (98,9%), mountain elm (97,5%) and honey locust (92,8%) ensured high survival, and for shrub species sea buckthorn (90,9%) and dogwood (83,3%).

PRACTICAL RECOMMENDATIONS

As a result of studying the peculiarities of the restoration of the petrophyte ecosystem (on example: the limestone quarry „Lafarge Ciment" (Moldova) S.A., we propose:

1. The recultivation of the lands within the limestone quarry, simultaneously with their reintegration in the economic circuit, can be achieved, in most cases by afforestation, associated with some auxiliary works of consolidation and arrangement.
2. The results obtained experimentally showed that the method of forest cultivation can be used successfully in the accelerated restoration (3 years) of the petrophyte ecosystem from the quarry „Lafarge Ciment" (Moldova) S.A.
3. For the forest recultivation of overburden dumps from limestone quarries, the following species are proposed: acacia, which is an unpretentious species to soil trophicity, nitrogen-fixing, with a high viability and rapid growth on the soil material of the dump, wild olive, sea buckthorn, which are very fast-growing, viable species with nitrogen-enhancing properties in the soil.
4. In order to ensure a high degree of rooting and survival of tree and shrub seedlings, proper maintenance of forest crops is necessary. To ensure the favourable growth and development of trees and shrubs, it is recommended to make three hoeings in the first year and two in the next two years in the case of crops of all species studied.
5. To ensure the stability of the quarry ecosystem, it is necessary to expand the wetland by increasing the surface area and water storage capacity, which will contribute to the development and enhancement of biodiversity.

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ADNOTARE

Certan Corina „Particularităţile restabilirii ecosistemului petrofit (pe exemplul carierei de calcar „Lafarge Ciment” (Moldova) S.A.)”, teză de doctor în biologie, or. Chişinău, 2020. Introducere, cinci capitole, concluzii generale şi recomandări, bibliografie din 245 titluri, 129 pagini text de bază, 20 figuri, 11 tabele, 10 anexe. Rezultatele obţinute sunt publicate în 27 lucrări ştiinţifice.

Cuvintele – cheie: ecosistem petrofit, biodiversitate, reconstrucție ecologică, restabilire naturală, proces biogeochimic, regosol, haldă de steril, carieră.

Domeniul de studiu: Ecologie. **Scopul:** evaluarea particularităților de restabilire a ecosistemului petrofit în cariera de calcar a uzinei „Lafarge Ciment” (Moldova) S.A.

Obiective: estimarea etapei de inițiere și restabilire naturală a biodiversităţii pe suprafața haldelor de steril din cariera de calcar „Lafarge Ciment” (Moldova) S.A.; evaluarea stării și dinamicii biodiversităţii pe suprafața haldelor de steril în dependență de vârsta lor; aprecierea dependenței gradului de evoluare a regosolurilor, formate pe suprafața haldelor de steril cu vârstă diferită în procesul de restabilire a ecosistemului petrofit; reconstrucția ecologică prin recultivarea silvică a haldelor proaspăt depozitate în carieră.

Noutatea și originalitatea ştiinţifică. Pentru prima dată, în Republica Moldova, a fost efectuat studiul restabilirii naturale a ecosistemului petrofit și stabilită legitatea formării regosolurilor pe suprafața haldelor de steril. Legitatea demonstrează, că gradul de formare a regosolurilor reprezintă un proces de evoluare a solului dependent de vârsta haldelor, numărul de specii care se dezvoltă pe suprafața lor, conținutul de nutrienți și humusul format în regosol, asigurat de masa speciilor dezvoltate pe suprafața haldelor de steril, în rezultatul procesului biogeochimic (fitocenotic). A fost elaborată și implementată metoda experimentală de recultivare silvică a ecosistemului petrofit din cariera „Lafarge Ciment” (Moldova) S.A.

Originalitatea rezultatelor constă în studiul complex al dinamicii procesului natural de inițiere și restabilire a biodiversității, de formare a solului, de acumulare a nutrienților (N_{total}, P_2O_5, K_2O), a humusului în straturile de sol nou-formate pe suprafața haldelor de steril (stratul de sol 0-20 cm) și condițiile care asigură restabilirea ecosistemului petrofit.

Problema ştiinţifică soluționată constă în fundamentarea procesului de restructurare naturală a ecosistemului petrofit, bazat pe diversitatea fenomenelor pe care le explică. Procesul dat reprezintă consecutivitatea și interacțiunea reciprocă a etapelor naturale de dezvoltare a biodiversității, solificare, acumulare a nutrienților și formare a humusului în regosoluri, care au loc simultan, fără intervenția omului și asigură restabilirea naturală a ecosistemului petrofit.

Importanţa teoretică. Cercetarea constituie o primă experiență, pe plan național, privind elucidarea etapelor de restabilire a biodiversităţii și stabilirea legității procesului de formare a solului pe suprafața haldelor de steril. Rezultatele indică faptul, că procesul de restabilire a biodiversității și de formare a regosolurilor pe suprafața haldelor de steril sunt interdependente.

Valoarea aplicativă. Pentru prima dată a fost utilizată metoda de reconstrucție ecologică prin recultivarea silvică pe terenuri proaspăt depozitate, fără adaosuri suplimentare și a fost obținut un ecosistem cu un indice înalt de dezvoltare a diversității biologice vegetale. Rezultatele studiului complex vor servi ca bază pentru restabilirea ecosistemelor degradate în urma activităților miniere la zi în carierele de calcar.

Implementarea rezultatelor ştiinţifice. Rezultatele cercetărilor sunt implementate de către Departamentul Dezvoltare Durabilă a uzinei „Lafarge Ciment” (Moldova) S.A. în scopul realizării reconstrucției ecologice prin recultivarea silvică a haldelor de steril și de Universitatea de Stat din Moldova în procesul de instruire a masteranzilor și doctoranzilor.

ANNOTATION

Certan Corina „**The peculiarities of the restoration of petrophyte ecosystem (on the example of „Lafarge Ciment" (Moldova) S.A. limestone quarry)**", PhD thesis in biology, Chisinau, 2020. Introduction, 5 chapters, conclusions and recommendations, bibliography of 245 titles, 129 pages of text, 20 figures, 11 tables, 10 annexes. The obtained results are published in 27 scientific papers.

Keywords: petrophyte ecosystem, biodiversity, ecological reconstruction, natural restoration, biogeochemical process, regosol, overburden dump, quarry.

Field of study: Ecology. **The aim:** evaluation the peculiarities of restoration the petrophyte ecosystem in the limestone quarry of the factory „Lafarge Ciment" (Moldova) S.A.

Objectives: estimation of the initiation stage and natural restoration of biodiversity on the overburden dumps surface in the limestone quarry „Lafarge Ciment" (Moldova) S.A.; assessment of the state and dynamics of biodiversity on the overburden dumps surface depending on their age; estimation of the dependence of the evolution degree of regosols, formed on the surface of overburden dumps in the process of the restoring the petrophyte ecosystems; ecological reconstruction through forestry recultivation of the recently stored dumps in the quarry.

Scientific novelty and originality. For the first time in the Republic of Moldova, it was effectuated the study of the natural restoration of the petrophyte ecosystems and established the regularity of the regosols formation on the overburden dumps surface. This regularity demonstrates that the degree of regosols forming, represents a process of soil evolution depending on the age of the dumps, the number of species that grow on their surface, the content of nutrients and the humus formed in regosol, assured by the mass of the developed species on the overburden dumps surface, as the results of the biogeochemical process (phytocenotic). It was developed and implemented the experimental method of forest recultivation of the petrophyte ecosystem from the quarry „Lafarge Ciment" (Moldova) S.A.

The originality of the results consists in the complex study of the dynamics of natural process of biodiversity initiation and restoration, of soil formation, nutrients accumulation (N_{total}, P_2O_5, K_2O), of humus in the newly formed soil layers on the overburden dumps surface (soil layer 0–20 cm) and conditions that ensure the restoration of the quarry petrophyte ecosystem.

Solved scientific problem consists in establishing the stages of natural restructuring of the petrophyte ecosystem, based on the diversity of the phenomena being explained. This process represents consecutiveness and reciprocal interaction of the natural stages of biodiversity development, of soil formation, nutrients accumulation and humus formation in regosols, that take place simultaneously, without human intervention, and assures natural restoration of petrophyte ecosystem.

The theoretical importance. The research is a first experience, at national level, on elucidating the stages of biodiversity restoration and establishing the regularity of the soil formation process on the surface of overburden dumps. The results indicate that the process of biodiversity restoring and regosols formation on the overburden dumps surface are interdependent.

The practical value. For the first time, the method of ecological reconstruction through forest recultivation on recently stored land, without organic fertilizers was used, and an ecosystem with a high index of development of plant biological diversity was obtained. The results of the complex study will serve as a basis for restoration of degraded ecosystems after mining activities in limestone quarries.

Implementation of scientific results. The research results are implemented by the Sustainable Development Department of the factory „Lafarge Ciment" (Moldova) S.A. in order to achieve ecological reconstruction by forestry recultivation of overburden dumps and by the State University of Moldova in the process of training master's and doctoral students.

CERTAN CORINA

THE PECULIARITIES OF THE RESTORATION OF THE PETROPHYTE ECOSYSTEM (ON THE EXAMPLE OF „LAFARGE CIMENT" (MOLDOVA) S.A. LIMESTONE QUARRY)

166.01 – Ecology

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