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Biotechnological Approach to the Accelerated Creation of an Artificial, Sustainable Soil-Plant System on Lifeless Land Areas as a Result of Human Activity



Gulevich AA^{1*}, Raldugina GN² and Baranova EN¹

¹Department of Agricultural Biotechnology, All-Russia Research Institute, Russia

²Department of Plant Physiology, K A Timiryazev Institute, Russia

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***Corresponding author:** Gulevich AA, Department of Agricultural Biotechnology, All-Russia Research Institute, Moscow, Russia

Abstract

The article discusses the possibility of overcoming the remediation restrictions in the territories of technogenic and anthropogenically altered landscape using an integrated biotechnological approach that affects modern technologies for optimizing the landscape conditions and creating sustainable plant-soil-microorganism systems. The possibilities of increasing the resistance of plants, microorganisms and actinomycetes for the purposes of biological remediation are analyzed. We are discussing the technological aspects of the organization of the restoration of landscapes with slopes and problematic in terms of the availability of toxic materials.

Keywords: Remediation of anthropogenic and technogenic landscapes; Soil recovery; Soil toxicity; Biotechnology; Modified plants and microorganisms

Introduction

Human livelihoods result in the emergence of vast barren land areas on which it is impossible not only efficient agricultural production, but in general any kind of livelihood that is different from extreme. Even in ancient times, large-scale territories were subjected to degradation and soil erosion, increased salinity due to deforestation, uncontrolled use of pastures, and the use of intensive water and chemical amelioration [1]. "Martian" landscapes are characteristic of the habitats of most ancient civilizations: Mesopotamia, North Africa, etc. The cultivation of agricultural plants over the centuries has allowed human civilization to significantly increase the population of the planet. However, as a result of economic activity, many of its areas turned into lifeless deserts, salt and drying semi-deserts. In addition, open pit mines, waste dumps and waste heaps are a problem. Existing reclamation methods and classical technologies are not capable of effectively solving the problems that have arisen, which are constrained by the physical resources of the regions, the very high cost of projects and the impossibility of financing them at the

expense of the resources of the affected region. The humanistic values of modern Western civilization do not allow us to follow the path of limiting the growth of the population used in India and China in the twentieth century (birth control and attempts to artificially sterilize part of the population) [2], which is enhancing the ecological burden on inhabited areas of the planet. Another problem is the increase in the amount of waste, which grows as the quality of life in areas that were characterized by an almost natural economy, which gave a minimum of waste, increases. Therefore, the development of technologies for the revival of lifeless territories is urgently needed to save human habitat. Such technologies can be of particular importance when creating projected large-scale agglomerations on the Moon and Mars that are promising for future development.

This review examines new approaches that can significantly increase the efficiency of de novo creation of soil-like substrates and restoration of fertility of barren ground (parent material) due to the combinatory application of several biotechnologies: genetic

engineering of plants and microorganisms [2]; recultivation nanotechnologies for the purpose of obtaining of artificial analogues of the soil, using new synthetic geoplastic materials to create and maintain an optimal artificial landscape [3]. The possibility of creating artificial «plant–soil–microorganism» collaborations on the basis of potentially tolerant to pollution species capable of effective interaction is being considered. With the use of non-standard complex approaches, fundamentally new opportunities are opening up for restoring the completely established ecological state of the land territories that have been degraded over thousands of years of the destructive impact of humanity.

Key point

When considering issues related to the restoration or imitation of the natural process of soil formation, as an element related to non-renewable natural resources, it is necessary to systematize the constraints [4] that impede the effectiveness of each component of this complex biosystem. A number of restrictions can now be overcome due to technical progress provided by irrational, at first glance, development to create gardens in the desert or technological solutions to create extraterrestrial greenhouses based on lunar or martian ground, which seem unpromising because of the impossibility of recoupage. At the same time, developed exclusive technologies over time begin to look very commonplace. So, drip irrigation and the use of mineral

substrates today are used everywhere. Thus, passing through a «bottleneck» conditioned by material inexpedience with the financing of “fantastic” ambitious projects leads to grandiose technical breakthroughs. In case of remediation of the territories of the disturbed technogenic or natural landscape, the main limitations are:

- 1) Restriction of water sources and methods of its delivery and discharge;
- 2) The presence of toxic elements in the substrate;
- 3) Unfavorable landscape structure and unsuccessful vertical planning, which limits the possibilities of engineering solutions (unfavorable gradients, lack of effluents, or excessive drainage);
- 4) Unfavorable mechanical composition;
- 5) The high cost of solving each of these issues.

The lack of moisture and the presence of toxic elements leads to toxic soil elements (transparent arrow) causing the death of most microorganisms and plants brought in with dust, water, and wind ((Figure 1), black frames on left). The biotechnological approach allows solving or significantly expanding the possibilities of remediation by removing the toxicity barrier both at the level of plant (Figure 1, light green scheme) and at the level of the soil microflora (Figure 1, cream scheme).

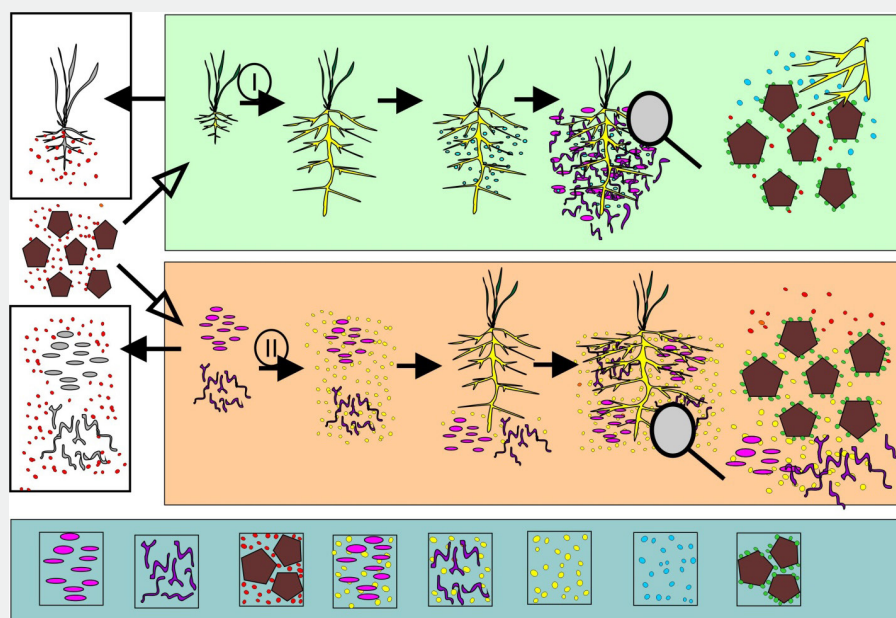


Figure 1: The process of neutralizing the toxic elements of the soil substrate of the barren territories when using modified plants - light green, microorganisms - cream. The death of unmodified plants under the action of toxic elements - a white scheme. Decoding is a blue scheme: bacteria, actinomycetes, soil and toxic elements of the soil, bacteria and their excretions, actinomycetes and their excretions, microorganisms, rhizoplanes, plant excretions, soil detoxification.

The use of genes for plant transgenesis, which increase the resistance to toxic elements of the soil solution and the deficiency

of water, will allow plants to survive in conditions not accessible to unmodified plants and create conditions for the development of

rhizoplane [2,5]. At the same time, modified soil microorganisms, such as fungi, actinomycetes, bacteria and microalgae can exist in conditions of high toxicity of the substrate and lack of moisture due to root plant secretions. Increasing the soil's water retention capacity due to its biomass and increasing the surface sorbing moisture from the environment, assisting to neutralize toxic elements, resistant microorganisms-extremophiles will increase the chances of survival and normal activity of both modified and unmodified plants. Due to recent advances in the elucidation of the functions of many genes associated with the growth, differentiation and development of individual elements of the root system, it was possible to obtain plants with a modified root system architecture using genetic transformation methods [6]. The alfalfa plants transformed by the gene of the transcription factor Alfin1 had significantly greater length (by a factor of 2-3) and weight (by a factor of 2-5) of roots than control plants [7]. Overexpression of the transcription factor NAC of wheat (TaRNAC1) under the control of a root-specific promoter resulted in an increased root length and increased biomass and a noticeable increase (70% more than in control plants) of the root mass [8]. Hypertrophic root growth can significantly increase the flow of root excretions into the soil and thus contribute to the attraction of various soil microorganisms and a significant enhancing of microbiological activity.

Currently, few studies have been conducted with the aim of creating genetically modified bacteria to increase their effectiveness in the formation of collaborations with plants. Thus, the siderophore receptor gene was introduced to the *Pseudomonas fluorescens* strain to make it more competitive in the soil [9]. Overexpression of the trehalose-6-phosphate synthase gene enhanced the ability of rhizobacteria *Rhizobium etli* to form the nodules and increased the efficiency of nitrogen fixation in faba beans (*Phaseolus vulgaris*) [10]. In recent studies, the chitinase gene from *Bacillus subtilis* introduced into cells of the *Burkholderia vietnamiensis* P418 strain has led to significant suppression of phytopathogens that caused such diseases as root rot of wheat, cotton wilt and gray rot of tomato [11]. The *Ensifer medicae* strain, genetically modified to increase tolerance to high concentrations of copper, improved the formation of nodules and the growth of alfalfa plants (*Medicago truncatula*) on copper-polluted soils [12]. Such works have a great creative potential in obtaining microorganisms that can, in interaction with plants, change the biological activity of the surrounding soil, increasing its fertility and accelerating the formation of humus.

Genetically modified microorganisms and plants can also be used for the remediation of contaminated soils. For example, the strain of endophytic bacterium *Burkholderia cepacia* was transformed with a plasmid carrying the genes for toluene degradation, after which this strain inoculated plants of yellow lupine (*Lupinus luteus* L.). Inoculated plants maintained growth at a high concentration (1000 mg/l) of toluene, as opposed to

control plants, which demonstrated the signs of phytotoxicity at levels above 100 mg/l [13]. Expression of cytochrome P450 soybean monooxygenase, which is involved in the metabolism of phenylurea contained in herbicides, was achieved in tobacco plants [14]. Transgenic plants not only were more resistant, but they also easily metabolized all four phenylurea-based herbicides (fluometuron, linuron, chlortoluron, and diuron). An example of using transgenic plants to clean up the environment from man-made pollution are transgenic plants of tobacco, rapeseed, poplar, and arabidopsis that express the *Mer-A* gene from bacterial plasmid, which encodes the mercuric-reductase enzyme that is involved in detoxification of mercury [15,16]. Such plants without inhibiting growth and metabolism can grow intensively on a medium containing mercury ions in toxic concentrations, and to absorb them ten times more efficiently than control non-transgenic plants. Another example is a successful genetic modification: a series of genes that decompose benzene, toluene, and xylene have been introduced into the nitrogen-fixing bacterium *Rhizobium meliloti*, an alfalfa symbiotic. The deeply penetrating root system of alfalfa allows cleaning the soil to a depth of 2.0-2.5m due to the expression of heterologous genes. Modified rhizobia are also used to decontaminate the soil from heavy metals [17]. Thus, the synergistic interaction of plants and microorganisms can significantly enhance the biological cleaning of the environment and contaminated areas [18].

An obligatory component for successful remediation of barren territories, waste heaps, dumps, solid domestic waste landfills, quarries, and other man-made lifeless landscapes (Figure 2, left column) is the creation of a soil infrastructure capable of maintaining an optimal level of vegetation activity. Such infrastructure should prevent erosion of the fertile layer, stabilize the drainage mode and moisture supply, which is terracing and vertical planning, securing the slopes, water supply and drainage (in some cases, gas removal and heat removal for solid waste landfills and waste heaps). It also requires the introduction of the amount of fertile soil necessary for the recultivation, planting resistant woody trees or shrubs to ensure the stability of the substrate fixation, and planting various grasses (Figure 2, central column). Modern methods of phytoremediation of water systems can significantly reduce toxic and hazardous substances entering the water runoff [19]. The functional load of the renewed territories can be different: restoration of lost forests, cultivation of garden plants, cereals, creation of a park zone, cultivation of traditional crops, such as grapes, creation of visual vertical landscape compositions of the urban environment, maintaining conditions for the preservation of natural or historical monuments (Figure 2, right column). At the same time, an important aspect is the problem of the state of control and safety of water systems [20], especially when purification of substrates containing heavy metals and other toxic elements. The possibilities of correction of the landscape organization of territories allow the use of modern

technologies and materials to create a stable self-sustaining viable system that can exist autonomously or require relatively little effort to maintain optimum humidity. When using an integrated approach to the modification of the landscape, substrate,

microflora and plant communities, mankind for the first time has the opportunity to develop and implement full-fledged projects to create de novo the most important for our existence on the planet non-renewable resource - soil.

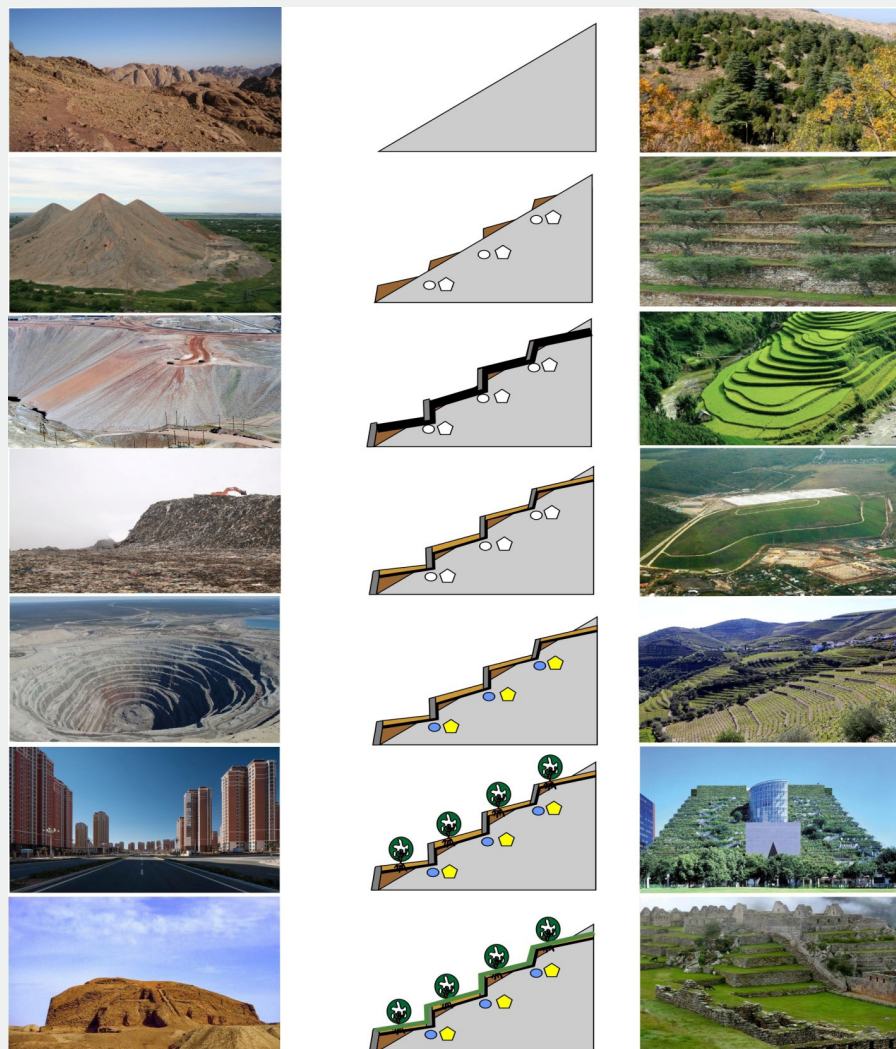


Figure 2: Features of the formation of restored and the creation of viable landscapes in areas affected by desertification and loss of soil cover as a result of man-made, anthropogenic and adverse natural impacts. Examples of lifeless landscapes of the Earth (left column): mountain range, in the region of arid climate and strong wind erosion; waste heaps formed by waste rock in the area of coal mining; pit dump when mining non-ferrous metals; solid waste landfill; deep quarry formed during the mining of precious stones; anthropogenic landscape; The ancient structure of Babylon “Gardens of Babylon”. The central column is a slope remediation scheme. Right column, promising solutions for damaged areas.

Conclusion

Thus, modern technologies for modifying the individual properties of each part of a complex living system «soil-plant-microorganism» can be subjected to a number of structural modifications that increase viability, resistance to the adverse effects of antagonists (for example, toxic elements) and the ability to modify the entire system. New materials, genetic engineering and integrated biotechnology offer great opportunities for bioremediation of «dead» territories with lost biogenicity.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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