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BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 14, no. 3, 2020

Ecology

Some Ecological Aspects for Sustainable Development of Agriculture in Georgia

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Georgia, being in normal ecological situation, is looking for the ecologically friendly technologies and processes corresponding to its natural and environmental situation. As a result of deep analysis of the existing ecological situation in the country, phytoremediation technologies, the most corresponding to Georgia have been selected. In the presented paper, the advantages and possibilities of application of phytoremediation technologies namely "Green filter" technology, in Georgia are discussed. *© 2020 Bull. Georg. Natl. Acad. Sci.*

Phytoremediation, urbanization, toxicants, heavy metals

Annually, a result of urbanization, unpredictable growth of industry, transport, production of chemicals, military action and so on, annually, billions of tons of anthropogenic toxic compounds are naturally concentrated, greatly damaging nature and agriculture in particular (soil, water reservoirs, air). Over 900 billion of tons of chemicals are annually produced in the world per year. Large amounts of these stable, hazardous compounds or their incomplete metabolic transformations, still having high toxicity, are accumulated in the biosphere, significantly affecting the agricultural sector. Great majority of chemically synthesized stable compounds of different structure hardly undergo extracellular or intracellular enzymatic transformations and are vitally dangerous for all kinds of organisms.

Nevertheless, the members of the plant kingdom (microorganisms and plants) can assimilate environmental contaminants, and are successfully directed to remove toxic compounds from the environment, providing long-term protection against their environmental dispersal [1]. These technologies are effectively used to clean the soil, water reservoirs and are known as phytoremediation and bioremediation technologies. Lately, the number of new innovative ecological technologies have been elaborated, targeted to minimize the flow of toxic compounds to the biosphere or to control their level or state [2]. Despite the definite positive effect from the realization of these technologies, the intensive flow of toxic compounds to the biosphere is still increasing.

Undoubtedly, the great majority of chemically synthesized compounds such as plant protection and pest control agents (pesticides), paints and varnishes, solvents and emulsifiers, petroleum products, products of applied chemistry, chemicals, products of the pharmaceutical industry, surfactants, refrigerants, aerosols, explosives, according to their nature are toxic. Examples of exceptions (highly toxic compounds of natural origin) are cyanogenic glycosides, glycoalkaloids, lectins, phenols, coumarins and some other secondary metabolites of plants. Toxins of micro-organisms, poisons elaborated by both prokaryotic and eukaryotic microorganisms. These toxins are often polypeptides varying in molecular mass and contain up to one hundred thousand of amino acids [3]. Low molecular mass organic compounds are also encountered as microbial toxins. In spite of their high toxicity, these compounds exist in nature at such low concentrations in comparison with toxic compounds of anthropogenic nature that they cannot be considered as contaminants (Springer).

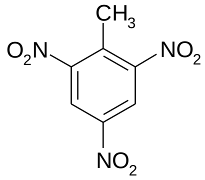
What is the real ecological situation in Georgia, a country located on the Eastern side of the Black Sea occupying 69 700 km^2 This area seems to be the most Eastern part of Mediterranean climate and culture, having great similarities with sub-tropical agriculture (grapes, cereals, vegetables, fruits, citruses, etc.). From the north Georgia shares a border with the big Caucasus (average altitude 4 000 m), from the south – small Caucasus (2 800 m), and from the west – the Black Sea. In the middle, the country is divided by mountains (up to 2 000 m). The existence of almost 30 different soil-climatic zones in the country is the main reason for some unique features such as extreme biodiversity in the country, where over 1 000 endemic plants are grown; all kinds of climates are registered (the only exception being the tundra climate). The same diversity is detected in Caucasian animals and birds. Historically, Georgia is known as the homeland of wine, having above 500 varieties of endemic grape plants. Today in Georgia, the northernmost tea plantations are cultivated. Great number of Mediterranean fruits are also cultivated. The country is crossed by about 20 000 different rivers of various sizes. Both parts of Georgia (western, eastern) has a reasonable amount of precipitation, but in western Georgia, the amount of precipitation is much higher. The most south-westernmost parts of Georgia (Adjara, Guria regions) are the rainiest places in Europe. On the whole, it seems that Georgia is one of the richest countries in terms of drinking water, including great varieties of mineral water. Among the 16 officially recognized varieties of wheat, four of them have Georgian roots. This line of natural uniqueness of the biodiversity of the country can be continued but it is also extremely important to indicate the ecological situation, which determines the efficiencies of application of all these unique features. A country of agriculture, a country of tourism, a country of great orthodox history and so on, this is the way Georgia is mentioned in the majority of foreign publications. Ecological situation in absence of big factories pollution can be considered acceptable. The existing small and average factories do not create ecological problems. Future development of the industry is under special ecological control. The main attention is paid to the creation of modern agriculture with number of innovative technologies.

Central area in development of agriculture in Georgia is soil. Georgians call it “Mother-Earth”, due to the great respect. Historically, full value and purity of soil was the main problem of the whole nation. Soil is a highly developed biological system, minimally containing physically differing organic and inorganic compounds, microorganisms, water and air. In some places of Georgia, erosion and pollution of soils takes place. Today, the most dangerous seems to be the multinational highway crossing the whole country from west to east (over 500 km in length). It is believed that this highway, which is still under construction, connecting Europe with eastern countries will be very busy, overcrowded by big tracks and other transportation. That is why it requires special attention.

Among modern technologies, one variety of phytoremediation – the so called “Green filter” technology should be mentioned. It is based on plants potential to clean soil from all kinds of pollutants including technogenic pollutants and heavy metals. Uncontrolled discharge of all kinds of wastes always creates functioning biological source of contamination. The elimination of contaminants from the environment by their mineralization is the main tool of nature to battle the annually increasing concentration of contaminants. In the frame of this publication, only some of the most widely distributed and dangerous contaminants can be discussed.

Pesticides, compounds for plant protection and pest control, are the most widely distributed chemical contaminants of the environment in the twentieth century. According to data gathered by the United States Environmental Protection Agency (EPA) and the World Health Organization (WHO), over 1 000 compounds are used as pesticides, representing compounds of many different chemical classes: carbamates, thiocarbamates, dipyridyls, triazines, phenoxyacetates, coumarins, nitrophenols, pyrazoles, pyrethroids, and organic compounds containing chlorine, phosphorus, mercury, arsenic, copper, etc. In agriculture millions of tons of pesticides are produced and used annually.

The group of polychlorinated dibenzodioxins and dibenzofurans called dioxins are distinguished by especially high toxicity [4]. Polychlorinated biphenyls, a family of over two hundred compounds, are characterized by extremely high toxicity among polychlorinated aromatic compounds. A very toxic contaminant, 2,4,6-Trinitrotoulene (TNT) is used as an explosive by all militaries in the world.



2,4,6-Trinitrotoluene

Benzene and its homologues are extremely toxic. Nowadays over 90% of the benzene produced is connected with the petrochemical industry, the rest with the coal industry and natural gas. UK, the major exporter of benzene, annually produces one million tons of this substance. Since 1980 the production and use of benzene has been limited in the countries of the EU, UK and USA because of its extremely high toxicity.

Heavy elements are defined as chemical elements where density is at least five times heavier than that of water. Among 35 widely occurring metals, 23 are heavy elements or heavy metals: Ag, As, Au, Bi, Cd, Ce, Cr, Co, Cu, Fe, Ga, Hg, Mn, Ni, Pb, Pt, Te, Th, Sb, Sn, U, V and Zn [5]. In small amounts, most of these elements are indispensable for the plants and all other kinds of organisms, but their enhanced doses induce acute or chronic poisoning. The toxicity of heavy metals is revealed via suppression of growth and development of microorganisms and plants, and seriously harming the health of animals and humans.

Among the gases playing special role in the contamination of the air, carbon monoxide formed by the incomplete burning of carbon-containing substrates should be considered as one of the most poisonous. The annual global emissions of carbon monoxide into the atmosphere have been estimated to be as high as 2 600 million tons, of which about 60% are from human activities and about 40% from natural processes [6].

The constantly increasing level of toxic compounds has a rather negative effect on nature, especially on such vitally important biological processes as respiration, photosynthesis, fixation of molecular nitrogen, reproduction, etc. High concentrations of environmental contaminants may lead to the destruction of some particular living species via mutagenesis and the creation of new ones, which often degenerate and weaken. Contamination of soil is more diverse and prolonged than that of water or air. The main factor controlling this phenomenon is high adsorption capacity of soil, as well as the physical-chemical characteristics of the contaminants and particularly their solubility and resistance in the natural environment. The binding of toxicants is accomplished by the inorganic part and organic matter of soils. Environmental contaminants enter plant cells from air, soil and water. Plants absorb contaminants primarily through their roots and leaves. Contaminants get into leaves as a result of the direct spraying of plants with agrochemicals and by absorption of gaseous contaminants existing in the air. Below ground, foreign compounds penetrate in plants together with water and nutrients penetrate in plants by the roots. Chemical compounds are absorbed by roots less selectively than by leaves. Environmental contaminants absorbed by roots and leaves are translocated into different organs of the plants as a result of the physiological processes transporting nutrient substances. The plant's potential to absorb, deposit and deeply degrade, mineralize organic and accumulate inorganic pollutants within its cells determines the ecological potential of the plant. These abilities are the main technological parameters determining the application of plants, as technological agents, in novel phytoremediation technologies. Thus, it is evident that after environmental contaminants penetration into the plant cell, the plants function decreases take place as a result of contaminant toxicity. This is the main problem created of any kind of pollution and all existing ecological technologies are directed to maximally decrease or eliminate this phenomenon.

One of the most desirable ecological features of plants is their potential to carry out by different mechanisms mainly oxidative degradation of environmental organic contaminants performed by different groups of enzymes (oxidases, reductases, esterases, transferases). Such transformations lead to the complete or partial decomposition of the carbon skeletons of toxic molecules, to regular cell metabolites, or in best to mineralize them to CO_2, for further participation of carbon atoms in characteristic for plants natural cycles (regular plant cell processes). Heavy metals are accumulated into plant cell space and partially transported to the above ground parts of annual and perennial plants. Such action allows to clean the soil from heavy metals and other undesirable compounds.

Since the remote past, plants, in combination with microorganisms, through photosynthesis, fixation of molecular nitrogen and metabolic transformations in the extant water and air environment have been fashioning the organic world for over a billion of years. Human beings from the earliest times also started to participate in the distribution of organic substances. Later, due to increased human activities, the composition of undesirable organic and inorganic compounds in the air, soil and water reservoirs increased. The creation and distribution of these technogenic chemicals became especially obvious in the 19^{th}-21^{st} centuries, as a result of military action, relentlessly increasing manufactures, increased oil production, transportation, use of pesticides, etc. In order to properly understand the ecological power of plants and evaluate their detoxification potentials, the anatomical-morphological and physiological-biochemical particularities of plants responsible for establishing the basis for their action as environmental protectors and remediators should be emphasized:

– Higher plants contact with soil and water through roots and with the air by leaves, so they interact simultaneously with two different environments (Table 1);
– Highly developed root systems allow plants to control large areas of soil at different depths and create micro conditions convenient for the multiplication of microorganisms in the rhizosphere with the help of exudates;
– The large surface of plant leaves permits absorption of pollutants from the air via the cuticle (lipophilic compounds) and stomata (gases);

– A well-developed internal transportation system for nutrients works in both directions, allowing environmental contaminants to be distributed throughout the entire plant.

The main disadvantage of plant-based cleaning technologies is their strong dependence on climate. Climate is a very important factor for growth, development and metabolic activity of plants; climate is the main limiting factor in the distribution and survival of plants.

Generally, the planting of almost any kind of vegetation, including agricultural flora, is beneficial for the human environment. In order to make the most of the ecological potential of each particular plant, selection should be carried out according to the above-indicated criteria. Undoubtedly, technologically the most important part of plants are the roots, which take up contaminants from the soil and perform the initial stages of their transformation or accumulation within them. Therefore, it is clear that the type of roots and their depth, distribution and type and degree of ramification are extremely significant components for the successful realization of any phytoremediation technology. A fibrous root system has numerous fine roots providing maximum contact with soil due to the high surface area of the roots.

Table 1. The depth of the roots of different plants used in phytoremediation technologies [7]

Plant	Root depth/m
Indian Mustard	0.30
Grasses	0.60–1.20
Alfalfa	1.20–1.80
Poplar trees	4.50

Some plants are able to accumulate high amount of metals in their inner parts, but the typically low growth rates of these plants limit the total biomass and indicate that the total mass of accumulated metals will be low. Better extraction of toxic compounds from soil may be achieved by the use of mixed plant cultures, but at present, there is very little data on their effectiveness.

Effective monitoring of the phytoremediation process requires quite a lot of information to be gathered, because many factors influence it apart from the plant species: availability of nutrients, daily maximum, minimum and average temperatures, illumination level (spectral characteristics and irradiance), humidity and its variations, etc. All these parameters should ideally be monitored.

Phytoremediation is a concept constructed from an emerging, natural set of technologies to support a number of recently developed clean-up strategies. This term is relatively new [26] and means plant-based action (*phyto* – plant, *remediation* – to recover). According to the most modern understanding in phytoremediation technologies, microorganisms also participate as very important technological accessory agents. Phytoremediation has received special attention just in the last decade as an innovative, cost-effective and alternative combination of technological approaches. The main objective of scientists, agronomists and engineers dealing with phytoremediation is to exploit in the most rational way possible the potential of this natural process in the most rational way possible. From the technological point of view phytoremediation is the use of vegetation to decontaminate soils, air and water from heavy metals and toxic organics (Table 2). Very often, phytoremediation assumes the joint action of both plants and microorganisms.

One of the known strategies for remediation is planting of the contaminated area by plants specially selected for having a high potential to uptake the targeted contaminant. Another strategy of remediation is to surround an underground area of contaminated soil by specially selected plants, to prevent the further distribution of contaminants through the hydrostatic barrier of roots [27].

Table 2. Promising plant species for the remediation of sites polluted by organic contaminants

Organic contaminant	**Plant Species**	**Comments**	**Ref**
1	**2**	**3**	**4**
Aromatic hydrocarbons (benzene, toluene)	Maple (*Acer campestre*) Oleaster (*Elaeagnus angustifolia*) Locust (*Robinia pseudoacacia*) Caucasian pear (*Pyrus caucasica*) Walnut *(Juglans regia)* Almond (*Amigdalus communis*) Cherry (*Cerasus avium*) Cherry (*Cerasus vulgaris*) Amorpha (*Amorpha fructicosa*) Chestnut (*Castanea sativa*) Apple (*Malus domestica*) Zelkova (*Zelkova caprinifolia*) Poplar (*Populus canadensis*) Ryegrass (*Lolium perenne*) Lilac (*Syringa vulgaris*	Plants capable of absorbing 1-10 mg of benzene and toluene per kg fresh leaves per day from air	[8 - 10]
	Alfalfa (Medicago sativa L.)	Can remove benzene from soil	[11]
		Can enhance biodegradation of toluene by associated microorganisms	[12]
	Tea (*Thea sinensis*) Vine (*Vitis vinifera*) Poplar (*Populus canadensis*) Walnut *(Juglans regia)* Maple (*Acer campestre*) Ryegrass (*Lolium multiflorum*) Maize *(Zea mays)* Kidney bean (*Phaseolus vulgaris*)	Plants capable of absorbing 0.1-10 mg of gaseous alkanes per kg fresh leaves per day from air	[13]
Petroleum hydrocarbons (PHC)	Pine (*Pinus silvestris* L.)	Plant roots enhance rhizospheric degradation of PHC in soil	[14]
	Alfalfa (*Medicago sativa* L.)	Can remediate crude oil-contaminated	[15]
	Spartina alterniflora (salt marsh sp.) *Juncus roemerianus* (salt marsh sp.) *Spartina patens* (brackish marsh sp.) *Sagittaria lancifolia* (fresh marsh sp.) *Clover (Trifolium sp.)*	Can remediate oil spills in marches	[16]
	Tall fescue (*Festuca arundinacea* Schreber)		[17]
	Bermuda grass (Cynodon dactylon)		
	Ryegrass (*Lolium perenne*)	Can remember PHC-contaminated soil and dredged material	[18, 19]
PAHs	*Ryegrass* (*Lolium multiflorum*) *Hybrid poplar (Populus sp.)*		[20]
	Sorghum (*Sorghum bicolor)* Switch grass (*Panicum virgatum*)	Entrance rhizospheric degradation of PAHs in soil	[21]
	Big bluestem (*Andropogon gerardii)* *Little bluestem (Schizachyrium scoparius)* Indian grass (*Sorghastrum nutans)* Switch-grass (*Panicum virgatum)* Canadian wild rye (*Elymus canadensis*)		[22]
	Tall fescue (*Festuca arundinacea* Schreber)		[17]
	Prairie buffalo grass (*Buchloe dactyloides)*		[23]
Nitrobenzene	Soybean (*Glycine max* L. Merr. cv. Fiskby v)		[24]
Phenols	Soybean (*Glycine max* L. Merr. Cv. Fiskby v)		
	Cane (*Scirpus lacustris* L.)		[25]

Plants can very effectively hinder the emission of environmental contaminants of the exhaust gases of motorcars: carbon monoxide, nitrogen and sulphur oxides, aromatic hydrocarbons, etc. “Green filter” 30 m wide and consisting of five layers (four lines of shrubs, mulberry and fustic, 70 cm high, and a fifth line of maple, birch and elm 6-8 m high, plant age 12 years) planted along a highway reduces carbon monoxide concentrations in the air by 60-70%, in comparison with the concentration of this aerial contaminants elsewhere along the highway [28]. Plants are very promising detoxifiers allowing the creation of safe technologies around or along hotbeds of contamination (Green filter, Vegetation cap, Phytoremediation cover, Hydrologic control, Evapotranspiration cover or any other plant-based technology) – ecologically friendly, and definitely positive. It should be firmly grasped that nowadays technologies for enabling the maximum potential of plants in combination with microorganisms for accumulating and degrading organic contaminants of different structures are definitely within reach, and allow to widen our understanding of phytoremediation potential and realize its use on a scale significantly exceeding any existing local or even national level.

Based on the material presented above and the ecological situation in Georgia, the author strongly believes that the phytoremediation technology seems to be the best solution for the remediation of slightly polluted soils in Georgia and preserve building hay highway. Special attention should be paid to the “Green filter” technology developed in Georgia and is now getting international recognition for wider practical realization.

ეკოლოგია

ზოგიერთი ეკოლოგიური ასპექტი საქართველოში სოფლის მეურნეობის მდგრადი განვითარებისთვის

ს. პავლიაშვილი

საქართველოს გარემოს დაცვისა და სოფლის მეურნეობის სამინისტრო, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის გ. კვესიტაძის მიერ)

ბუნებაში არსებული ქიმიური დაბინძურების წყარო ორ განსხვავებულ ჯგუფად არის წარმოდგენილი, ბუნებრივი და ანთროპოგენული. ბუნებრივს მიეკუთვნება ყველა, რაც ბუნების მიერ არის წარმოქმნილი: მიწისძვრები და ამოფრქვევები, მომწამლავი გაზების მიკრობიოლოგიური წარმოქმნა, ჭაობებისთვის დამახასიათებელი მომწამლავი გაზები და პათოგენური მიკროფლორის წარმოქმნა და სხვა. მეორე ჯგუფს წარმოადგენს ადამიანის მოქმედების მიერ წარმოქმნილი ტოქსიკური ნაერთების რაოდენობა და მრავალფეროვნება, რომელიც გაცილებით უფრო შთამბეჭდავია. რომლის ძირითადი მიზეზებია ურბანიზაცია, მრეწველობა, ტრანსპორტი, ქიმიკატების წარმოება და გამოყენება, საომარი მოქმედებები და

ბევრი სხვა, რამაც მნიშვნელოვნად დაამძიმა სამყაროს ეკოლოგია. საქართველოში გიგანტი ქარხნების არარსებობის პირობებში მდგომარეობა გაცილებით უკეთესად გამოიყურება. სწორედ ამიტომ ქვეყნის სამომავლო ეკოლოგიური პრობლემების გადასაწყვეტად მრავალ-მხრივი ანალიზის შედეგად შერჩეულ იქნა ეკოლოგიურად მეგობრული ტექნოლოგია-ფიტო-რემედიაცია, რომელიც კარგად შეესაბამება ქვეყანაში არსებულ მდგომარეობას. ნაშრომში განხილულია აღნიშნული ტექნოლოგიის უპირატესობები და, კერძოდ, ე.წ. „მწვანე ფილტრის“ ტექნოლოგიის გამოყენების მიზანშეწონილობა.

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Received July, 2020