Energy-saving technologies for soil purification from chromium (III) ions using higher plants

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Abstract. This work presents investigation of IR-irradiation influence on seeds of beans (Phaseolus), its' growth and development affection during soil purification from chromium (III) ions by energy-saving reagentless phytoremediation technique.

Introduction

The territory of the Russian Federation, which is polluted by heavy metals (HM) is now more than 70 mln. hectares, 1 mln hectares of which are of extremely dangerous level of pollution. Soil and water pollution is a global problem and might lead to irreparable consequences [1–8]. Damage of the fertile layer inexorably leads to destruction of natural balance, metabolic processes in nature, which might result in destruction of other ecosystems [9–11]. In our country there arises a strong demand for urgent actions aimed at reduction of soil pollution by heavy metals. In recent years in many countries intensive works for polluted soil purification by higher plants are carried out. The advantages of this method, known as phytoremediation (from Ancient Greek φυτό (phyto), meaning 'plant', and Latin remedium, meaning 'restoring balance') are possibilities of soil purification from heavy metals, organic compounds, oils and petroleum products, etc. [12]. At this, harmful bacteria are destroyed by this phytomass, soil is enriched by oxygen, obtained during phytosynthesis process. At this the major part of toxic substances is decomposed by components. In plants there is no excessive accumulation of harmful substances and the grown green mass after harvest might be used as a feed for livestock, birds, for production of paper and biofertilizers, recycling for gas and liquid fuel [13,14]. Soil purification by phytoremediation may be considered as the most efficient and cheap method, as special estimations show that today's expenses for it usually do not exceed 20% from alternative technologies expenses [15]. For implementation of this method one need only solar energy.

In the recent decades numerous facts have been discovered, which stated for high sensitivity of plants to impact of external physical fields (EPF) of various nature: ultraviolet (UV), infrared (IR) radiations, which create additional electrical currents at biological objects. These exposures vary the membrane potential of the plant cell and can govern the organism growth and evolution processes having both stimulative and inhibitory impacts. This impact depends on external exposure characteristics: wavelength, oscillation frequency of electromagnetic radiation, intensity and time [16]. Such seed treatment is a progressive way of its preprocessing to planting, which allows one not only to...
remove them from dormant state, but to activate functioning of various biological catalytic agents - ferment, which provide rapid growth and development of plants, and, consequently, speed-up of phytoremediation processes. The cell wall contains proteins, pectins, phospholipides and others containing fixed charged groups (primarily carboxyl ones). They denote cation-exchange ability and affect HM cation accumulation in a cell from soil solution by higher plants.

This work presents investigation of IR-irradiation influence on seeds of beans (Phaseolus) higher plants, its growth and development affection during soil purification from chromium (III) ions by phytoremediation technique.

**Materials and Methods**

Test culture grain bean (*Phaseolus vulgaris*), breed Ruby was selected as a highly productive culture, which might be used for phytoremediation purposes. As pollutants we have chosen model solutions of \( \text{Cr}_2\left(\text{SO}_4\right)_3 \) of 1, 5 and 10 maximum permissible concentrations (MPC) [17] (general sanitary maximum permissible concentration for Cr\(^{3+}\) ions is 6 mg per 1 kg of soil). We took moving form of metal in soil. As a source of IR-irradiation for bean seeds we used blue "Minin" lamp with \( \lambda = 780-1400 \) nm. Seeds treatment was performed at a selected time for 6 hours [18].

**Results and discussion**

The conducted investigations on influence of nature and concentration of Cr\(^{3+}\) ions on plant height and development of Phaseolus lamina (Table 1, Figs.1-3) have shown that after 14-21 days the plants haven't shown any evidence of growth depression and leaves dying away.

It is known, that chromium presence positively affects plant growth. Concentration of this element in seed nucleotides is approximately 100 times higher than in total mass of the plant cell [19], which might be caused by its functional role. Chromium increases chlorophyll content and productivity of photosynthesis in leaves. Positive impact of this element on corn photosynthesis productivity was shown by A.T. Scheglov. The productivity of grown plants has increased for 24-40%, chlorophyll concentration for 16-29%, weights of green and dry mass for 34-65% [20].

| Phaseolus Plant height, mm | Phaseolus Leaf length, mm | Phaseolus Leaf width, mm |
|---------------------------|--------------------------|--------------------------|
| Days          | K*     | 1 MPC | 5 MPC | 10 MPC | K*     | 1 MPC | 5 MPC | 10 MPC | K*     | 1 MPC | 5 MPC | 10 MPC |
| 7            | 130    | 0     | 0     | 20     | 0      | 0     | 0     | 0      | 0      | 0      | 0     |
| 14           | 210    | 80    | 80    | 210    | 70     | 40    | 10    | 53     | 65     | 20     | 10    | 60     |
| 21           | 290    | 260   | 260   | 265    | 70     | 60    | 60    | 54     | 65     | 60     | 60    | 57     |
| 28           | 300    | 270   | 280   | 284    | 60     | 63    | 50    | 55     | 60     | 63     | 52    | 60     |

Note: K* is control without IR-irradiation and HM

Chemical properties make it possible to suppose that chromium, being in the organisms, is not an indifferent metal, but plays an important role in plant lifecycle[21]. It is referred to metals with alternating valence, which are especially active at complex-formation processes.

In 28 days after adding of Cr\(^{3+}\) in soil the Phaseolus plants were took out of soil, then dried out and weighted. Roots were separated, as the previous histochemical investigations had shown, that metal accumulation generally took place in roots of plants-excluders, to which the Phaseolus belongs [22,23]. Complexes are formed in roots which are partially immobilized with donor-ligands. According to [24] a significant amount of chromium also moves to leaves and stems.
In order to estimate influence of chromium ion concentration and its combined impact with IR-irradiation on soil phytoremediation processes we carried out determination of residual concentration of Cr$^{3+}$ ions in soils according to Russian State Standard GOST 17.4.3.01-83 "Protection of soil nature. Basic requirements for sampling".

Fig. 1 Combined influence of Cr$^{3+}$ ion concentration and IR-irradiation of seeds ($\tau_{irrad}=6$ h) on height of Phaseolus plants

Fig. 2 Phaseolus leaf length change in time depending on Cr$^{3+}$ ion concentration and IR-irradiation of seeds ($\tau_{irrad}=6$ h)
We prepared soil extractions and analyzed content of residual metal concentration by photometric technique.

Data on efficiency (Epur, %) of soil purification from chromium ions by phytomeliorant plants seeds of which were treated by IR-radiation and without treatment are presented in Table 2.

It was established that at the lowest Cr^{3+} concentrations (1 MPC) the efficiency of soil purification by Phaseolus plants decreased. Phaseolus showed higher purification efficiency at chromium concentration in soil of 10 MPC and IR-irradiation.

Table 2 - Impact of Cr^{3+} ion concentration with and without IR-exposure on efficiency (E, %) of soil purification by Phaseolus and adsorption capacity of plants (Ai, µkg/kg) after 28-days incubation.

| Cr^{3+} concentration | E, %  | Ai, µkg/kg |
|-----------------------|-------|-----------|
| Without IR            |       |           |
| 1 MPC                 | 71.1  | 92.7      |
| 5 MPC                 | 90.6  | 70.6      |
| 10 MPC                | 74.1  | 99.3      |
| IR                    |       |           |
| 1 MPC                 | 73.4  | 94.9      |
| 5 MPC                 | 97.3  | 91.2      |
| 10 MPC                | 79.1  | 86.4      |

Adsorption capacity (Ai, µkg/kg of soil) of plants (Table 2) was established according to the amount of metal absorbed by Phaseolus after drying-out and wet-ashing of phytomass (in terms of absolutely dry weight of plants). The highest adsorption capacity of Phaseolus appeared to be at chromium concentration of 5 MPC and at IR-exposure of seeds.

**Conclusions**
1. We have studied impact of chromium (III) nature and content on processes of growth and development of Phaseolus plants, as well as its properties for soil phytoremediation. The highest toxical impact on the plants is seen at increase of HM concentration in the soil.
2. It was shown that efficiency for purification of soils polluted by Cr^{3+} ions was 73-97% for Phaseolus and increased with metal concentration growth. This might be caused by functional role of metal. According to literature data, chromium increases chlorophyll content and photosynthesis productivity in leaves which, as a consequence results in completeness of pollutant removal.
3. At definition of plant adsorption capacity in relation to chromium, we have discovered extreme dependence: maximum was observed at Cr$^{3+}$ ion concentration equal to 5 MPC. Adsorption capacities of Phaseolus with respect to chromium were ≈ 74 - 99 µm/kg of dry phytomass.

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