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Evaluation of the rare earth elements phytotoxicity on the example of La and Ce

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Abstract. Interest in the study of the toxicity of rare earth elements (REE) naturally increases with an increase in their consumption. The growth of exploration, development and mining of rare earth metals poses a serious threat to the environment, increasing the concentration of REE in air, water and soil. In this work, we assessed the phytotoxicity of cerium and lanthanum, as the most common rare earth lanthanides in the earth's crust, using test systems with oats (*Avena Sativa* L.) and onion (*Allium cepa* L.). For both test objects, the toxic effect of high concentrations of lanthanum and cerium has been proven. In addition to the inhibition of the development of onion roots, a visually determined thickening and yellowing of the root cap, a change in the cells of the root merisystem were noted. For oats at high concentrations of lanthanum and cerium, yellowing of the roots and inhibition of their development, slowing down the growth of seedlings were also noted. At the same time, for oats at low concentrations of the studied substances, the effect of hormesis was noted.

1. Introduction

The rare earth elements (REE) include 15 elements – lanthanides (from La to Lu) – and two elements (Sc and Y), which have similar chemical and toxicological properties [1, 2]. REE, despite their name, are fairly widespread, but rarely concentrated in ore deposits [3].

REE are widely used in the field of high technologies: superconductors and laser technology, catalytic converters in cars, camera and telescope lenses, powerful magnets used in computer technology and the production of wind turbines, in X-ray scanning systems and many other industries [4, 5].

Along with the development of REE deposits, there is a growing interest in assessing the impact of these elements on the state of the environment and the health of the population of nearby settlements.

It is known that developed deposits and tailings and processing of rare metal ores can pose a serious threat to the environment, increasing the concentration of REE in in natural environments [6, 7]. Accordingly, plants growing near mining enterprises are polluted by dusting and by absorption of REE and HMs from soils. It should be noted that toxical action of REE on plants is still insufficiently studied [2]. It is known that REEs of the light group accumulate in the roots of vascular plants [2, 8].

Some REE compounds are widely used in the agricultural industry due to the hormesis effect of low REE concentrations for agricultural crops; however, there is evidence of the inhibitory effect of their high concentrations [9].

The study goal was to evaluate the phytotoxic effect of rare earth elements on the example of La and Ce using different methods of phytotesting.

2. Objects and methods

To assess phytotoxicity, solutions with a given content of La and Ce were prepared. The following reagents were used: $CeCl_3 \cdot 7H_2O$ and $LaCl_3 \cdot 7H_2O$ due to good solubility in water, chemically pure grade. Phytotoxicity was determined by two methods - the standard method "Phytotest" [10] and according to the existing method of the Allium test without preliminary germination of the bulbs [11].

The "Phytotest" method is based on the germination of seeds of a test culture - oat *Avéna satíva* L. - in a native extract and several dilutions of 25 seeds in each of the Petri dishes for 7 days. At the end of the exposure time, two test parameters were measured: root length and sprout length. In this experiment, native solutions were prepared by dissolving 1 g of crystalline hydrate in 1 L of distilled water, which corresponds to a concentration of 374 mg/L La and 376 mg/L Ce. Subsequent solutions were obtained by diluting the previous one five times, the solutions contained: $R=5^1$ 75.2 and 74.8 mg/L, $R=5^2$ 15.04 and 14.96 mg/L, $R=5^3$ 3.008 and 2.992 mg/L, $R=5^4$ 0.6016 and 0.5984 mg/ L, $R=5^5$ 0.1203 and 0.1197 mg/L, $R=5^6$ 0.0241 and 0.0239 mg/L, $R=5^7$ 0.0048 and 0.0047 mg/L, $R=5^8$ 0.00096 and 0.00095 mg/L Ce and La, respectively.

Cerium and lanthanum chloride solutions were tested according to the Allium test method using *Allium cepa* L. bulbs of the "Stuttgarter Riesen" variety calibrated in size (1.5–2 cm in diameter) were placed for germination in containers filled with Ce and La solutions of the following concentrations: 0 (control, distilled water), 376 and 374 mg/L (native solution), 75.2 and 74.8 mg/L (dilution R=51), respectively.

The bulbs were preliminarily cleaned from dry integumentary leaves and germinated for 96 hours. After germination, the obtained material was fixed in a Clark's fixative: the tips of the roots were cut off and placed in the solution for 24 h. The length of several longest roots of each bulb was also measured. To prepare for microscopy, fixed roots were washed in distilled water and stained [12].

We used a microscope: Altami BIO 4 (trinocular) with a UCMOS03100KPA camera (3 MPx) with the visualization program Altami Studio

All solutions were tested for three times, the results were statistically processed using the Statistica 10 software product.

3. Results and discussion

The results of phytotesting carried out according to the "Phytotest" method are shown in figures 1 and 2.

Figure 1. The results of phytotesting. Test culture - *Avéna sativa* L.: on the left - La, 2) on the right - Ce.

In figure 2, the phytoeffect is calculated - an indicator the effect of root growth inhibition compared to control [13].

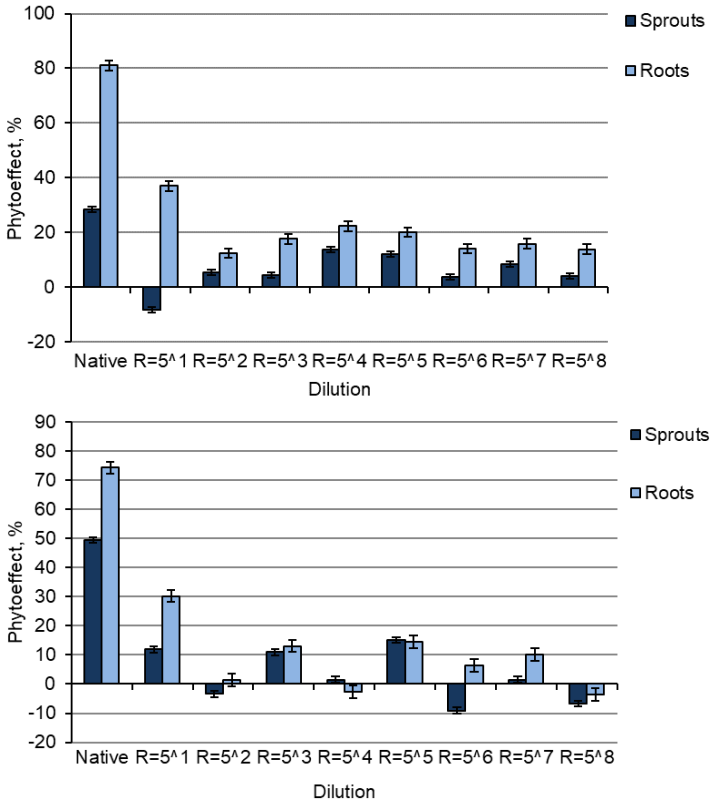

Figure 2. The results of phytotesting, phytoeffect. Test culture - *Avéna satíva* L., test parameters - root length (mm), shoot length (mm): top - La, 2) bottom - Ce.

As can be seen, concentrated solutions of La and Ce (native extract and five-fold dilution), exceeding the phytoeffect threshold established in the method of 20% of the control, have a toxic effect on the higher plants on the example of *Avéna satíva* L. According to the test parameter, the average root length. In the case of La in the first dilution ($R=5^1$), a hormesis effect was noted. In [14], both suppression and stimulation of germination of plants immersed in solutions containing La were reported. Stimulation of the growth of roots and shoots of *Avéna satíva* L. was also noted during seed germination in highly dilute solutions containing Ce.

Bulbs germinated in control and solutions of La and Ce are shown in figure 3.

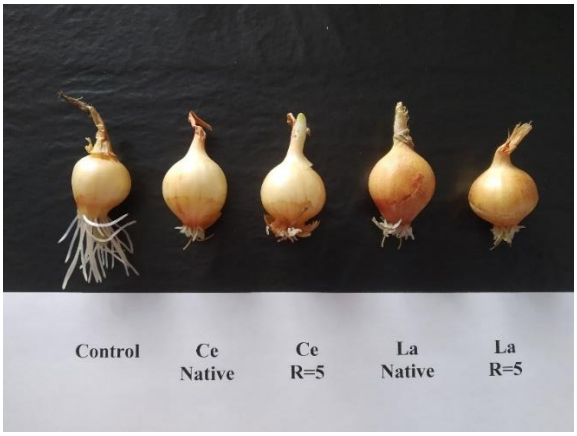

Figure 3. The results of phytotesting. Test culture – *Allium cepa* L.

The standard method of the Allium test does not provide for the calculation of the value of the phytoeffect, however, we recorded changes in the length of the roots of *Allium cepa* L. depending on the concentration of solutions (table 1).

Table 1. The results of phytotesting. Test culture – *Allium cepa* L.

	Control	Ce Native	Ce R=5	La Native	La R=5
Average root length, mm	21.3	4.3	9.7	5.7	6.0

Naturally, more concentrated solutions had a greater effect on the length of germinated roots compared to the control variant. Pictures of root preparations are shown in figure 4.

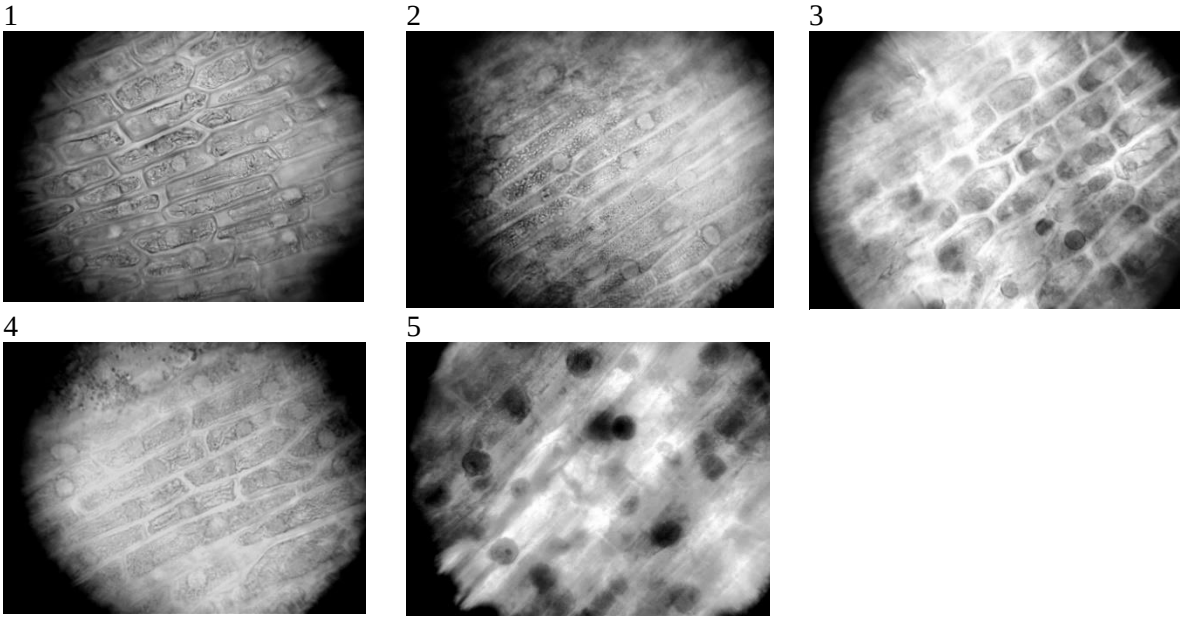

Figure 4. Preparations of *Allium cepa* L. roots grown in: 1 - control, 2 – Ce (Native), 3 – Ce (R=5), 4 – La (Native), 5 – La (R=5).

The photographs of preparations of *Allium cepa* L. roots germinated in La and Ce solutions show changes in comparison with control samples. The cells of the apical meristem of the samples of native solutions are more elongated compared to the control. The samples germinated in native solutions of La and Ce are characterized by thickening (swelling) and yellowing of the root cap. This fact, together with a significant slowdown in root growth according to the results of microscopic and eluate testing, clearly indicates the phytotoxic effect of La and Ce on the development of higher plants.

4. Conclusion

Biotesting carried out by two methods gave well consistent results showing the negative effect of high concentrations of La and Ce on the growth and development of higher plants. The inhibitory effect of solutions of REE chlorides on the length of the roots of test cultures was revealed.

Under the conditions of anthropogenic pollution caused by the development of deposits of rare metal ores, the use of REE-containing phosphate fertilizers, an increased natural geochemical background in a number of territories, as well as the lack of standardization of REE contents in soils and water bodies, studies of the impact of pollutants of this group on biota are of particular relevance.

The purpose of further research will be to assess the effect of REE-contaminated soil on the growth and development of higher plants, to identify the features of REE accumulation in various plant organs used both in agriculture and in carrying out remediation measures on technogenically disturbed lands.

Acknowledgements
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References

[1] *Nomenclature of Inorganic Chemistry IUPAC Recommendations* 2005 (UK, Cambridge, RSC Publishing) p 377
[2] Thomas P J, Carpenter D, Boutin C and Allison J E 2014 *Chemosphere* **96(2)** 57-66
[3] Olmez I, Sholkovitz E R, Hermann D and Eganhouse R P 1991 *Environmental Science and Technology* **25** 310- 6
[4] Rim K T, Koo K H and Park J S 2013 *Safety and Health at Work* **4** 12-26
[5] Goodenough K M, Wall F and Merriman D 2018 *Natural Product Research* **27(2)** 201-6
[6] Schreiber, A, Marx J, Zapp P, Hake J-F, Voßenkaul D and Friedrich B 2016 *Resources* **5** 32
[7] Wang, L, Liang T, Zhang Q and Li K 2014 *Environmental Research* **131** 64-70
[8] Carpenter D, Boutin C, Allison C J, Parsons J and Ellis D 2015 *PloS one* **10** 0129936
[9] Chen Z Y 2004 *Rural Eco-Environment* **20(4)** 1-5
[10] 2007 MP 2.1.7.2297-07 15
[11] Ateeq B, Farah M A, Ali M N and Ahmad W 2002 *Mutation Research/Genetic Toxicology and Environmental Mutagenesis* **514(1)** 105-13
[12] Kotelnikova A D, Fastovets I A, Rogova O B and Stolbova V V 2017 *Byulleten Pochvennogo instituta im. V.V. Dokuchaeva* **89** 54-67
[13] Krasavtseva E A and Maksimova V V 2021 *IOP Conf Ser: Earth Environ Sci* **839** 042051
[14] Hu Z, Richter H, Sparovek G and Schnug E 2004 *Journal of Plant Nutrition* **27(1)** 183-220