Rare Earth Elements and Plants

Rudolf Kastori, Ivana Maksimović, Marina Putnik-Delić

Faculty of Agriculture, University of Novi Sad, 2100 Novi Sad, Trg Dositeja Obradovića 8. Serbia
e-mail: kastori@polj.uns.ac.rs

Abstract

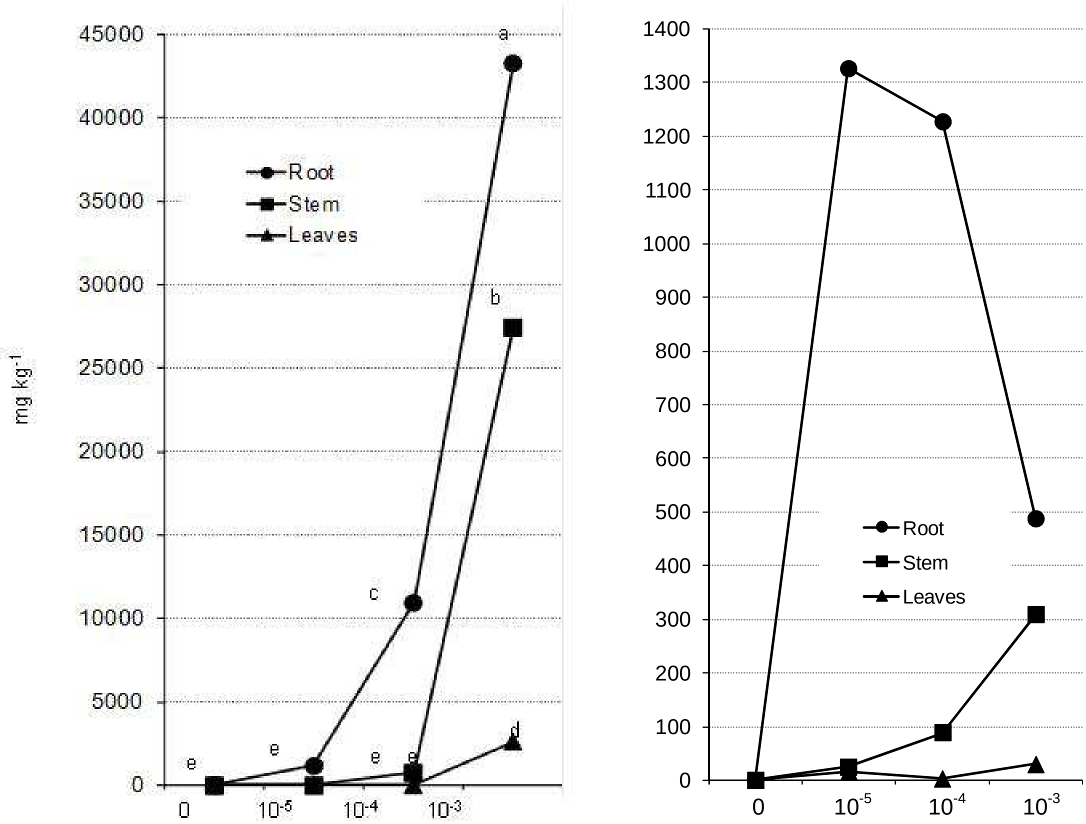
There has been a growing interest in the study of the rare earth elements (REEs) in recent decades of the last century, with the exploitation of REEs resources and applications in modern industry, medicine, agriculture and biotechnology. The main application of REEs is as new materials for recent technologies in the modern industry and agriculture, where low concentrations of REEs-based fertilizers are used to increase yield and quality of crops. Positive, negative or nil effects of RREs on plant growth, chemical composition and yield were observed in experiments done in many countries, but the physiological and biochemical mechanisms are still not well understood. Essentiality of REEs for living organisms or their threat to the environment has not been identified so far.

Introduction

The REEs or rare earth metals include 15 lanthanides. The metals scandium and yttrium are often included in the list of REEs. The REEs possess nearly identical chemical and physical properties and comprise a homogenous group of elements in the periodic system. The REEs are widely distributed and present in all parts of the biosphere, often at the level of the other microelements (Kabata-Pendias, 2001). Numerous investigations showed effects of REEs on physiological and biochemical processes, growth, development and yield of plants (Hu et al., 2004). Essentiality of REEs for living organisms has not been identified so far, but RREs can specifically influence their life processes. Detailed review of REEs in biological systems, their implementation, responses of selected crops, and ecological significance is given in publications Horovitz (2000), Tyler (2004), Kastori et al. (2010) and Maksimović et al. (2014a,b).

Uptake, accumulation and translocation of REEs in plants

Plants can uptake the REEs through the root as well as the aboveground organs. Intensity of uptake of REEs depends of numerous factors (Kastori et al., 2010). There have been determined synergism and antagonism between certain elements of this group during uptake process. The pH value of the environment also affects the REEs uptake. Within the range of pH the uptake efficiency was proportional to the hydrogen ion concentration. Use of EDTA enhances uptake of REEs, since this organic ligand increases desorption of REEs in the soil. It is considered that Casparian strip of the root limits the transport of REEs in the root. Hu et al. (2004) state that the natural translocation rates for REEs from soil to plant are approximately 20%, and for REEs fertilizers this rate was found to be 55-60%. They are mostly accumulated in the root, and less in the stem and reproductive organs (Fig. 1a). The transfer factor of yttrium, in relation to the medium, was much higher in root than in stems and leaves (Maksimović, et al., 2012, 2014b). In general, transfer factor declined with an increase of yttrium concentration in the nutrient medium (Fig. 1b). This is in line with the finding that the uptake rate of REEs from soil to root is much higher than the translocation rate from root to shoot. They are found both inside the cells and in extracellular spaces of plant tissues, where they form chelate compounds with numerous components of metabolism – amino acids, nucleic acids, proteins etc. Uptake of REEs through the leaf is much faster than trough the root. This is not characteristic only for REEs, since the ions of other elements are often much faster taken up through the leaf than through the root and their involvement in the plant metabolism is faster than when taken up through the roots.



Y concentration (M) Y concentration (M)

(a) (b)

Fig. 1. Concentration (a) and transfer factor of yttrium (b) to sunflower organs in the presence of different yttrium concentrations in nutrient medium (Maksimović et al. 2012)

Physiological effects of REEs on plants

REEs are not essential for higher plants or for other live organisms, but can specifically influence life processes, such as: promotion and inhibition of growth of organisms, cell proliferation and apoptosis; antioxidant activity and pro-oxidant activity; stabilization and destabilization of cytoskeleton; enhance or jeopardize of membrane permeability; affect regulation of cell signaling system; promote or inhibit bone growth; increase or decrease oxygen affinity for hemoglobin; inhibit muscle contraction; block transmission of neural signals; enhance mineralization or demineralization.

Impact of REEs on plant physiological and biochemical processes was mainly studied by Chinese researchers and the results were mostly published in Chinese language. Detailed review of these and other papers in the field were given by Hu et al. (2004), who cites results of numerous authors who have described effect of certain REEs on activity of some enzymes, the content of phytohormones, productivity and intensity of photosynthesis, chlorophyll synthesis, translocation of photosynthesis products, water regime of plants and their resistance to water deficiency, symbiotic fixation of atmospheric nitrogen etc. But also, a favorable effect of REEs on seed germination has been described (Bai Bao-Zhang et al., 1988), and effect on morphological characters of plants (Bai Bao-Zhang et al., 1990 a, b). REEs affect the uptake and metabolism of mineral matter in plants. They often stimulate the uptake of certain elements, and decrease the uptake of others.

Research results on the effect of REEs on plant growth are somewhat contradictory. The early findings mostly point to inhibitory effect of these elements on plant growth, first of all lanthanum. The majority of papers published lately point to a stimulating effect of low concentrations of REEs on growth and organic productivity of plants. They were found to affect favorably the yield of many crops such as: rice, sugar cane, sugar beet, soybean, sunflower etc. (Hu et al., 2004). There is far less data in the literature about the single affect of certain REEs elements on life processes in higher plants.

REEs, like all other ions, are toxic when present in excessive concentrations. Mechanisms of their toxicity may include enzyme inhibition, binding to organic ligands, competition for binding sites of some other elements, interactions with proteins, organic acids, carbohydrates and other active molecules, binding cofactors, vitamins, substituting essential metals therefore provoking metal imbalance. They may also be involved in such issues as cation and anion antagonism. In spite of numerous results (Horovitz, 2000), it is not yet clear enough how they affect plant metabolism and human and animal health, which makes is necessary to investigate further on mechanisms of their action.

Conclusions

It has been found that REEs are widely distributed in plants, as well as that certain plants take up REEs to a different extent. RREs accumulate predominantly in roots. Beneficial, toxic or nil effects of REEs on plant metabolism, growth and crop yield were observed in both controlled and field conditions. Identifying appearance of the uptake, accumulation, distribution of REEs in plants and their particular parts and therefore their entrance into the food chain, as well as their non-specific stimulating or toxic effect on plants, can by very significant ecologically too. Systematic research of the environmental biogeochemical behavior of REEs in soil-plant systems is not sufficient at present and information on their involvement in plant metabolism, and impact on human and animal health is still lacking.

References

[1] Z. H. Hu, H. Richter, G. Sparovek, E.Schnug, Physiological and biochemical effects of rare earth elements on plants and their agricultural significance: a review. J. Plant Nutr., 27 (2004) 183-220.

[2] A. Kabata-Pendias, Trace Elements and Plants. Boca Raton, Florida, CRC Press, London, 2001.

[3] R. Kastori, I. Maksimović, T. Zeremski-Škorić, M. Putnik-Delić, Rare earth elements - Yttrium and higher plants. Proc. Nat. Sci. Matica srpska (2010) 118: 87-98.

[4] B. Bai Bao-Zhang, R. Kastori, N. Petrović, Effect of elements from scandium and lanthanid groups on growth and morphological characters of young sunflower plants. Helia, (1990a), 13: 1-9.

[5] B. Bai Bao-Zhang, R. Kastori, N. Petrović, Effect of elements from scandium and lanthanid groups on some morphological and physiological characters of young soybean plants *Glycine max.* (L.) Merill. Agrochimica, 34 (1990b), 467-474.

[6] I. Maksimović, R. Kastori, M. Putnik-Delić, M. Borišev, Effect of yttrium on photosynthesis and water relations in young maize plants. J. Rare Earths., 32 (2014a), 371-378.
[7] I. Maksimović, R. Kastori, M. Putnik-Delić, T. Zeremski, Yttrium – accumulation, translocation and distribution in young sunflower plants (*Helianthus annuus* L). Fresenius Environmental Bulletin, 21 (2012), 11-18.
[8] I. Maksimović, R. Kastori, M. Putnik-Delić, S. Zeljković, Rare earth elements in the environment. Proceedings of XVI International ECO-Conference, Safe Food, Novi Sad, (2014b), 81-89.
[9] C. T. Horovitz, Biochemistry of Scandium and Yttrium. Part. 2. Biochemistry and Application. Kulwer Academic/Plenum Publishers, New York, 2000.
[10] G. Tyler, Rare earth elements in soil and plant systems – A review. Plant Ecology and Systematics, 265 (2004), 191-206.