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**Soil-to-Plant Transfer Factors of Rare Earth
Elements in Rice (*Oryza sativa* L.)**
**Factores de transferencia suelo-planta de Elementos Tierras
Raras en arroz (*Oryza sativa* L.)**



<http://opn.to/a/kohOR>

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ABSTRACT. The present study describes the distribution and bioaccumulation of rare earth elements (REEs) in rice plants grown in San Pedro farm, located in San José de las Lajas Municipality, Mayabeque Province, Cuba. The results indicate that accumulation of REEs in different parts of plants follows the order: root>leaf>husk>grain. The transfer factor (TF) values of REEs in rice were determined, confirming that REE content in rice grains, roots, leaves and husks do not attempt on their use for human consumption and animal food, respectively.

Keywords: Rare earth elements (REEs), soils, rice (*Oryza sativa* L.), transfer factors.

RESUMEN. El presente estudio describe la distribución y bioacumulación de Elementos Tierras Raras (ETRs) en plantas de arroz provenientes de la finca San Pedro, ubicada en el municipio de San José de la Lajas, provincia de Mayabeque. Los resultados indican que la acumulación de los ETRs en las diferentes partes de la planta, siguen el comportamiento: raíz>hoja>cáscara>grano. Se determinan los valores del Factor de Transferencia (FT) de ETRs in arroz, confirmando que el contenido de ETRs en los granos de arroz, raíces, horas y cáscaras del grano no atentan contra su empleo como consumo humano y alimento animal, respectivamente.

Palabras claves: Elementos Tierras Raras (ETRs), suelos, arroz (*Oryza sativa* L.), factores de transferencia.

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INTRODUCTION

Rare earth elements (REEs) are a group of 15 elements of which only promethium (Pm) does not naturally exist in the Earth's crust ([Kabata-Pendias, 2001](#)). From a geochemical perspective, REEs are not particularly rare. In fact, they are as abundant as Cu, Pb, and Zn in the average crust sample. Furthermore, they have higher concentrations than Sn, Co, Ag, and Hg ([Wang et al., 2004](#)). REEs are usually divided into two sub-groups: (1) from lanthanum to samarium (with lower atomic numbers and masses), commonly referred to as light rare earth elements (LREEs); and (2) from europium to lutetium (with higher atomic numbers and masses), referred to as heavy rare earth elements (HREEs).

REEs have similar chemical and physical properties and tend to naturally coexist, which explains their similar behaviour in the environment ([Hu et al., 2006](#)). REEs have been characterized neither as essential elements for life nor as strongly toxic elements in the environment ([Hu et al., 2006](#); [Laveuf and Cornu, 2009](#)). Although there is no report on incidents of human poisoning through food chain ([Liu et al., 2013](#)), potential concerns regarding effects of continuous exposure to low levels of REEs on human health have been arising because they are accumulated in blood, brain and bone after entering the human body ([d'Aquino et al., 2009](#)). Previous studies have found that high exposure levels of REEs may be related to health problems such as liver function decline ([Zhu et al., 2005](#)). In addition, occupational and environmental exposure to REEs can pose health risk to human body ([Sabbioni et al., 1982](#)), and little information is so far available about the dose intake and potential health effects of exposure to REEs on human due to food consumption.

Rice is the main garnish and Zinc source in the Cuban diet ([Diaz et al., 2013](#)), with the population consuming, in average, around 200 grams per day. For that reason, rice is cultivated along the country in extensive and small areas. On the other hand, after rice harvest and processing for human consumption, the residual parts of the plant (husk, leaves, roots, etc.) are used for farm animal food. The REE content in rice grain is reported only in a few studies ([Uchida et al., 2007](#); [Rogan et al., 2012](#)). However, information about the REE translocation to other part of the rice plant is scarce. In this context, the main objectives of the present research are: (1) - to estimate the content and distribution patterns of REEs in the soil and rice crops; and (2) - to assess the mobility and bioavailability characteristics of REEs in soil samples.

METHODS

Rice plants (*Oryza sativa* L., IACuba-15 variety) and soil samples were collected in the same journey during harvesting time in 2013 from 10 sampling sites (1 m² each) across San Pedro farm (N 22° 55' 53.62'' y O 82° 2' 56.48''), located in the San José de las Lajas Municipality, Mayabeque Province, Cuba ([Figure 1](#)). All plant samples (n=100) were divided into grain (fruit), leaf and root. Samples were stored in plastic bags and subsequently introduced in cold boxes in order to keep the humidity conditions stable during their transport to the laboratory.

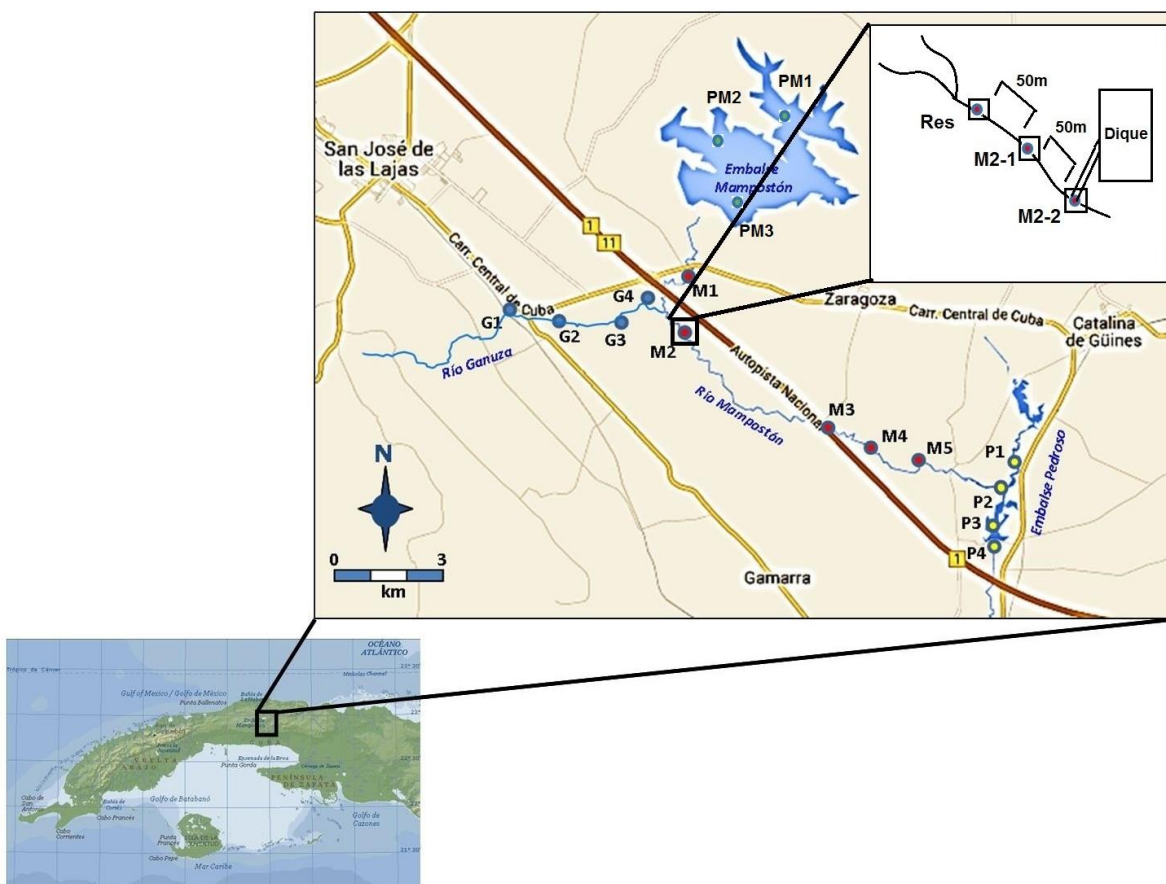


FIGURE 1. Geographical location of San Pedro farm. Source: Woogole Earth (<http://www.googleearth.com>)

In the laboratory, collected plant parts were carefully washed twice with distilled water. The composite samples were dried at 60 °C for 48 h, afterwards, grains were polished and separated in white grain and husk. Grains, husk, leaves and roots were sub-sampled in smaller portions, and macerated within an agate mortar, periodically adding liquid nitrogen to enhance the grinding process.

Soil samples were dried at 60 °C and portioned in three subsamples. Large rock debris; mollusc skeletons and organic debris were removed before sieving. Fraction smaller than 1 mm was sieve to obtain a fine fraction (<63 µm). The subsamples were newly dried at 60 °C before the experiments.

Pseudototal content of REE was extracted by biacid digestion (HNO₃: HCl) in a ratio of 2: 1 and H₂O₂. The temperature during digestion was 55 °C - 80 °C for 3 hours in a Digiprep (Laboratoire d'Ecologie Fonctionnel et Environnemental, Université Toulouse 3. France). Reading was performed by ICPMS Agilent Technologies 7500 CE and HR-ICP-MS Thermo Scientific Element XR at the Observatoire Midi-Pyrénées, Toulouse, France. An ¹¹⁵In/¹⁸⁷Re internal standard of a known concentration (2.0325 µg.L⁻¹) was added to all the samples, and four quality control samples were introduced following every eight samples to correct for any analyser deviation (Aries *et al.*, 2000). All the determined concentration values were within the detection and quantification limits of the equipment (50 pg.g⁻¹).

Interpretation data was done by normalization with average of Upper Continental Crust (UCC) ([Wedepohl, 1995](#)) following the procedure established by [Migaszewski y Gałuszka, \(2015\)](#).

Soil-to-plant transfer is one of the key components of human exposure to REEs that seep into food production. To investigate the transfer values of REEs from soils to crops, the TFs were calculated as follows ([Cui et al., 2004](#)):

$$TF = C_{\text{rice}} / C_{\text{soil}} \quad (1)$$

where C_{rice} and C_{soil} represent REE concentrations in the rice crops and soils, respectively, where the crops are measured on a dry weight basis. In this study, we used the mean concentration values of REEs determined as:

$$C_{\text{rice}} = C_{\text{root}} + C_{\text{leaf}} + C_{\text{grain}} + C_{\text{husk}} \quad (2)$$

RESULTS AND DISCUSSION

The concentrations of REEs in the studied soils are presented in [Table 1](#). For comparison, they are presented alongside the concentrations of REEs in the upper continental crust ([Wedepohl, 1995](#)). The mean REE levels in the soil were slightly higher than the measured mean concentrations of REE in the average upper continental crust. LREEs (La–Sm) accounted for 84.4% of the total REE content in the investigated soils, which is in agreement with the report of [Taylor and McLennan \(1995\)](#), indicating that LREEs are usually more abundant in soils than HREEs, just as they are in the earth's crust.

The upper continental crust normalized patterns show a characteristic pattern of handsaw ([Migaszewski and Gałuszka, 2015](#)) of the studied soil ([Figure 2, left](#)) did not differ appreciably and revealed a similar REE pattern of studied farm soils to REE concentrations in the average upper continental crust ([Wedepohl, 1995](#)) and in soils from different Cuban zones as Piojillo ([Rizo and Herrera, 1997](#)), Cayajabos ([Montero-Cabrera et al., 2000](#)), La Corea ([Blanco-Quintero et al., 2011](#)) and Zaza ([Deschamps et al., 2012](#)). That result is the evidence of a lithological contribution of REE in this area, without anthropogenic intervention in that sense.

REE concentrations in rice organs and transfer factors are also reported in [Table 1](#). The rice grain showed the lowest REE content with very significant correlation ($\rho < 0.01$) with REE concentration in leaves ($r^2 = 0.81$) and husk ($r^2 = 0.80$). Only REE content in roots showed a very significant correlation with REE concentration in soil ($r^2 = 0.99$).

The UCC normalized patterns of REE in roots ([Figure 2, right](#)) are similar to normalized soil patterns, while considerable differ with grain, husk and leaf REE patterns. The concentration of REEs in plants is extremely variable and dependent on the plant species and its corresponding habitat ([Taylor and McLennan, 1995](#); [Laveuf and Cornu, 2009](#)). Different parts of a plant can be ranked in the following order based on their REE content: root > leaf > stem > grain ([Li et al., 1998](#); [Xu et al., 2002](#)). REE concentrations in roots are usually considerably higher than REE concentrations in other plant parts ([Li et al., 1998](#)). Thus, REEs can be accumulated and retained by the roots of rice, with only small portions of the REEs reaching other parts of the plant. This fact helps explaining why the concentrations of REEs in studied rice grain samples were very low.

TABLE 1. Average REE Concentrations (\pm SD) in Soil (mg.kg^{-1}) and *Oryza sativa* L. Organs (mg.kg^{-1}). Soil-to Plant Transfer Factor (TF) for Rice

REE	Soil ^a	UCC	<i>Oryza sativa</i> L.				TF
			Root ^d	Grain ^{bc}	Leaf ^b	Husk ^c	
La	23.1 \pm 0.4	30	11.1 \pm 0.5	0.08 \pm 0.04	0.52 \pm 0.32	0.49 \pm 0.30	0,5
Ce	69.2 \pm 2.4	60	28.6 \pm 0.6	0.05 \pm 0.02	0.54 \pm 0.02	0.16 \pm 0.09	0,4
Pr	6.7 \pm 3.6	6,7	3.2 \pm 0.2	0.07 \pm 0.04	0.46 \pm 0.02	0.20 \pm 0.04	0,5
Nd	30.9 \pm 3.2	27	13.6 \pm 0.1	0.09 \pm 0.05	0.29 \pm 0.02	0.39 \pm 0.05	0,5
Sm	7.0 \pm 5.2	5,3	3.2 \pm 0.1	0.09 \pm 0.05	0.29 \pm 0.06	0.09 \pm 0.05	0,6
Eu	1.9 \pm 2.2	1,3	1.0 \pm 0.1	0.34 \pm 0.04	0.64 \pm 0.02	0.43 \pm 0.13	1,35
Gd	9.5 \pm 1.5	4	4.4 \pm 0.2	0.12 \pm 0.08	0.69 \pm 0.02	0.59 \pm 0.08	0,6
Dy	6.8 \pm 4.7	3,8	3.1 \pm 0.1	0.18 \pm 0.06	0.76 \pm 0.05	0.35 \pm 0.06	0,7
Ho	1.4 \pm 1.9	0,8	0.8 \pm 0.2	0.11 \pm 0.08	0.32 \pm 0.02	0.62 \pm 0.08	1,4
Er	3.8 \pm 1.3	2,1	1.8 \pm 0.1	0.12 \pm 0.07	0.46 \pm 0.04	0.52 \pm 0.07	0,8
Tm	0.5 \pm 1.0	0,3	0.5 \pm 0.1	0.57 \pm 0.16	2.21 \pm 0.52	0.44 \pm 0.06	7,1
Yb	3.1 \pm 1.8	2	1.81 \pm 0.5	0.42 \pm 0.06	1.31 \pm 0.17	0.34 \pm 0.07	1,2
Lu	0.45 \pm 0.30	0,35	0.41 \pm 0.23	1.82 \pm 0.02	1.34 \pm 0.80	1.84 \pm 0.19	12,0
Σ REE	164,4	144	73,3	4,0	10,1	6,7	
Σ LREE	138,7	129	60,6	0,7	2,7	2,0	
Σ HREE	25,6	15	12,7	3,3	7,4	4,7	

a, b, c - Indicates a significant correlation ($\rho < 0.01$).

UCC – Upper continental crust REE concentrations

Source of UCC data taken from [Wedepohl \(1995\)](#).

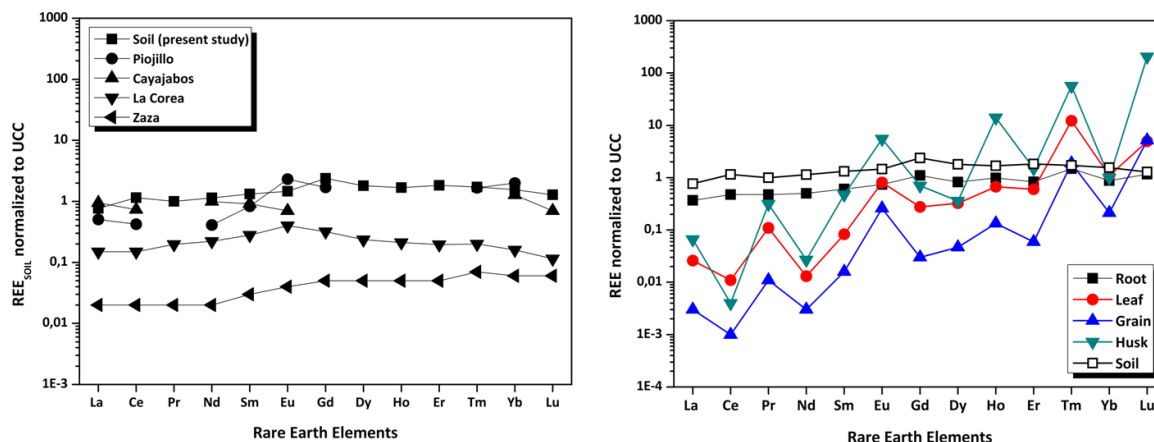


FIGURE 2. UCC normalized patterns of REE content in San Pedro Farm soils and its comparison with REE patterns from other Cuban sites (*left*). UCC normalized patterns of REE in studied rice plant organs and its comparison with soil REE (*right*). Source of UCC data taken from [Wedepohl \(1995\)](#).

The TF values for LREEs in rice were generally very low ([Table 1](#)), and they confirmed the weak accumulation of LREEs (La, Ce, Pr, Nd and Sm) by crops. A similar result was reported for Macedonian rice ([Rogan et al., 2012](#)). The mean values of TF calculations for La, Ce, Pr, Nd, and Sm were very similar: 0.53 (La), 0.42 (Ce), 0.58 (Pr), 0.46 (Nd), and 0.57 (Sm). Such values may indicate similar fractionation events of these elements in the soil–rice system of the farms studied. On the other hand, according to the obtained TF, rice plant is a good HREE accumulator from soil, principally, in roots. However, the HREE content in rice plant is around the 30% of the total REE content present in rice plant. Then, HREE content in rice plant must not be a problem for use in human nutrition (grain) and the normal rice production wastes (plant roots, leaves and grain husk) for animal food.

CONCLUSIONS

The concentrations of REEs in soil samples of San Pedro Farm are associated with the contribution to soil formation of the rocks lithology prevailing in the area. LREEs (La–Sm) accounted for 84.4% of the total REE content in the investigated soils. The absolute concentrations of REEs in polished rice samples of the farm studied were 40 times lower than those detected in the soils. Additionally, REEs could be accumulated and retained by the roots, and only a small portion of the REEs reached the higher parts (grains) of rice plants. The TF values of REEs in rice were also very low, confirming weak accumulation of LREEs (La, Ce, Pr, Nd, and Sm) by rice crops. The REE content in rice roots, leaves, grain and husk do not attempt on their use for human and animal food.

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