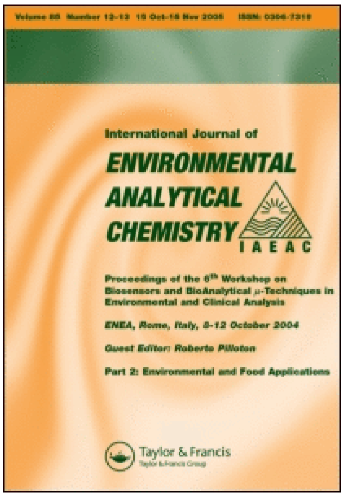

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Determination of Trace Rare Earth Elements in Plant and Soil Samples by Inductively Coupled Plasma-Mass Spectrometry

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DETERMINATION OF TRACE RARE EARTH ELEMENTS IN PLANT AND SOIL SAMPLES BY INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETRY

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Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) was employed to determine the concentration of rare earth elements (REEs) in plants and soils. Sample preparation and analytical conditions were investigated to set up a simple routine procedure for measuring rare earth elements. For prompt sample decomposition, a microwave digestion technique was successfully used with an acid mixture of $HCl+HNO_3+HF$. Detection limits, reproducibility, accuracy and possible interference were also studied. ICP-MS provided extremely low detection limits for REEs (0.6–6ng/l). Precision was typically better than 6% RSD(relative standard deviation) for soil and 10% for plant. The potential of the method was evaluated by analysis of standard reference materials of soils and plants. A good agreement between the experimental results and certified values was observed. The spectroscopic interference of Ba with Eu and light REEs(LREEs, La-Eu) with heavy REEs(HREEs, Gd-Lu) were eliminated by the algebra correction.

The results suggested that REEs in soil samples existed mainly as light REEs, and the same concentration distribution patterns of Oddo-Hakins law were observed, showing negative gradient from La to Lu concentrations. The REE contents in plants were very low, less than 20μg/g and varied with plant species. Apart from rape leaf(*Brassica juncea*), the REE distribution patterns in other plant leaves were consistent with soils, indicating that these plants generally absorbed REEs from soil without selectivity. Rape leaf showed selective absorption for LREEs, especially for La. The REE concentration distribution in parts of hot pepper(*Capsicum annuum*) was characteriaed by root>leaf>stem>fruit. The REEs absorbed by hot pepper concentrated mainly in roots and leaves, very little migrated into fruit. Transfer factors(TFs) of REEs in plants were very low. Although the contents of LREEs were relatively more than those of HREEs, no distinct difference of TFs between LREEs and HREEs was observed, meaning that LREEs and HREEs have the same abilities of transportation. However, for rape leaf, the TFs of LREEs were one or two orders of magnitude higher than those of HREEs.

Keywords: ICP-MS; REEs; plant; soil

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INTRODUCTION

China is abundant in rare earth elements(REEs) resources, occupying 80% of REEs deposit in the world. In addition to their use in industry, REEs are more widely applied to cropland as microelement fertilizer due to their abilities to enhance yields and improve quality of crops[1,2]. With the development of their agricultural application, REEs are increasingly moving into ecosystem. They may accumulate in soils, bioaccumulate in crops, and enter the food chain. This caused a serious environmental problem in China, which has attracted the attention of the environmental scientists in many countries. Although whether REEs are pollutants or not remains unclear, it is important to establish a reliable and sensitive analytical method for the determination of REEs in soils and plants and further to understand how REEs migrate and transfer in the soil-plant environmental system, which could help in the study of the physiological actions of REEs and in the prediction of any possible environmental effects.

Traditionally, X-ray fluorescence(XRF)[3], neutron activation analysis(NAA)[4], and inductively coupled plasma-atomic emission spectrometry(ICP-AES)[5] have been used for REEs analysis. However, these methods were not adequate for some environmental samples with very low levels of REEs in terms of sensitivity, analysis time and data interpretation. The levels of REEs in soils and plants were so low that these methods usually required preconcentration and separation of REE from the matrix prior to analysis, becoming relatively complicated and time-consuming. As a result of its inherent high sensitivity, wide linear dynamic range, relative freedom from interference, very low detection limits and multi-element determination capabilities, ICP-MS has been applied for the determination of REEs. Up to date, the ICP-MS method for the determination of REEs has been mainly applied for geological material analysis after they have been brought into solution[6,7]. A few publications were also available about REEs detection in aqueous samples[8,9]. However, there are very limited reports on the determination of the REE contents in environmental samples, such as soils and plants[10,11]. Moreover, the existing ICP-MS methods adopted the previous separation of REE to suppress the matrix effect. Therefore, the established ICP-MS procedures for REE analysis were still time-consuming and laborious.

The purpose of this study was to establish an effective and simple method for the measurement of REEs in the soil-plant system by ICP-MS. After prompt sample decomposition with microwave digestion, the digested solution was diluted and directly used to determine REE contents by ICP-MS. The potential of the method was evaluated by analysis of standard reference materials of soils and plants. Subsequently, the distribution and migration of REEs in soil-plant environmental system could be discussed on the basis of these analytical results.

EXPERIMENTAL

Instrument

The Plasma Optical Emission Mass Spectrometer(POEMS, Thermo Jarrell Ash Corporation, USA) was used for this work in ICP-MS mode. A IBM586 computer provided overall system control and data acquisition.

A Microwave Laboratory System(MLS 1200, Milestone Company, Italy) was adopted for the decomposition of samples. The maximum power of system was 1200W which could be controlled to change from 1 to 100% by a microcomputer

Materials

Four plow layer soils(S-1, S-2, S-3 and S-4) were collected from 4 different regions of Anhui province, in the east of China, and taken from the surface layer(0–20cm). The soils were air-dried, ground, and passed through a 2mm sieve to remove rock, roots, and other large particles. Sub-samples were further ground and passed through a 0.15mm sieve. The basic characteristics of tested soils were listed in Table I.

TABLE I Some basic characteristics of tested soils

Soil sample No.	*Soil type*	*Sampling location*	*pH*	*CEC (cmol kg^{-1})*	*Organic matter (g kg^{-1})*
S-1	Fer-Udic Luvisols	Fengyang, Anhui	6.82	19.0	16.3
S-2	Haplic Ferralsols	Jixi, Anhui	4.72	24.0	25.2
S-3	Arp-Udic Luvisols	Fuyang, Anhui	5.62	18.5	42.3
S-4	Sha-Aquic Cambisols	huaibei, Anhui	7.22	26.0	36.2

The plant samples of tea-1(*Camelia sinensis*), rape leaf(*Brassica juncea*) and hot pepper(*Capsicum annuum*) were collected from the same soil(S-1). Tea-2 was gathered from another soil (S-2). These plant samples were washed with sub-boiling distillation water, dried, ground and passed through a 0.15mm sieve.

Standard Reference Materials of Bush Twin Leaf(GBW07603: GSV-2) and Tea GBW07605: GSV-4) were issued by China Research Center of Certified

Reference Materials; Standard Reference Materials of soils(GSS-2 and GSS-4) were issued by Institute of Rock and Mineral Analysis of China; REEs standard solution was available from China Research Center of Geoanalysis.

Sample preparation

Soil samples (0.1g) were accurately weighed into Teflon vessels, and $HF+HNO_3+HCl$ were added. The mixtures were exposed to a microwave heating program: 2min at 20% power→2 min at 75% power→2 min at 50% power→5 min at 20% power. After cooling, 6 ml of 0.165% EDTA was added to digestion solution. The program was repeated once. After digestion, the solution was evaporated to near dryness on a hot plate. Then, the residues were dissolved in 2%HNO_3 to yield 50ml of the soil sample solution containing 20ng/ml Rhenium as internal standard.

0.2g of plant samples were accurately weighed into Teflon vessels and $HNO_3+H_2O_2+HClO_4+HF$ were added. The mixtures were subject to a microwave heating program: 2 min at 10% power→2 min at 20% power→2 min at 40% power→5 min at 50%power. The program was repeated once. After digestion, the solutions were evaporated to near dryness. Then, the residues were dissolved in 2%HNO_3 to yield 10ml of the plant sample solution containing 20ng/ml Rhenium as internal standard.

REEs determination

The REEs were measured by POEMS instrument in a ICP-MS mode. The operation parameters were summarized in Table II. In order to obtain lower detection limits, higher abundant isotopes of REEs were chosen along with the consideration of spectroscopic interferences. Under the optimized operation conditions, the maximum yield of singly charged ions for REEs was obtained, and generally, the ratio of MO^+/M^+ was below 1% and that of MOH^+/M^+ below 0.1%. Rhenium was used as internal standard to compensate for any changes in analytical signals and to improve the measurement precision. Scanning range was from 130 ~ 190m/z, covering all Ba and REEs isotopes. Although there exists the difference of two orders among REEs concentrations, ICP-MS has a relative wider linear range for REEs determination, generally up to six orders. Therefore, one standard solution containing 20ng/ml of each individual REE was adopted for making calibration curves. The REEs and Ba were measured on the following masses: ^{135}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{151}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{174}Yb and ^{175}Lu.

TABLE II Operation conditions for POEMS

inductively coupled plasma	
forward power	1350w
reflected	<5w
coolant flow rate(Ar)	15 L min^{-1}
auxiliary flow rate(Ar)	1.5 L min^{-1}
nebulizer flow rate(Ar)	0.77 L min^{-1}
sampling conditions	
sampling conc orifice(Ni)	1.2 mm
skimmer cone orifice(Ni)	1.0 mm
nebulizer	concentric meinhard nebulizer
sample uptake	1.8 ml min^{-1}
data acquisition	
mass range	130–190
acquisition mode	pulse
sweeps	5
numbers of points per peak	5
scan time	2 sec.
run time	32 sec.
washing time	30 sec.
resolution	0.8 amu
replicate	3
calibration strategy	external calibration with ^{185}Re standardization

RESULT AND DISCUSSION

Sample decomposition

The details of plant sample decomposition by microwave digestion were described and discussed elsewhere[12].

For the decomposition and dissolution of geological samples, several methods have been reported, including open wet digestion[13], alkali fusion[14], and microwave digestion[15]. Microwave digestion has some advantages such as rapidity, elimination of cross-contamination, lower analytical blanks and complete decomposition. In the present work, soil samples were decomposed by microwave digestion with a mixture of $HF+HNO_3+HCl$. However, it was occasionally found that a little residue remained after the first digestion. Some investigations[16,17] indicated that EDTA could facilitate the complete decomposition of samples, so a small amount of EDTA was added before the second digestion. After digested twice, a clear solution was obtained.

Detection limits

The concentrations of REEs in soils and plants are usually very low. To obtain lower detection limits, the more abundant isotopes of the REEs were chosen along with the consideration of spectroscopic interferences. Detection limits were defined as 3 times standard deviation of 10 acquisitions of a $2\%HNO_3$ blank solution. Low background counts and the high sensitivity of ICP-MS provided extremely low detection limits for REEs. In this work, detection limits for individual REEs were from 0.6 ng/l to 6ng/l.

Validation of analytical procedure

Several standard reference materials were used to evaluate the analytical procedure. Two soil reference samples(GSS-2, GSS-4) were used for soil analysis. Bush twin leaf (GSV-2) and tea(GSV-4) were used for plant analysis. Good agreements between the certified and measured values were observed for standard reference materials (see Figures 1 and 2). In the case of soil reference samples, errors of measured values were less than 5%of the certified values for light REEs(La ~ Eu), and better than 8% of the certified values for heavy REEs(Gd ~ Lu). Precision calculated using three independent runs were typically less than 2% RSD (relative standard deviation) for light REEs (LREEs)and better than 5% RSD for heavy REEs(HREEs). For the plant reference samples (GSV-2 and GSV-4), several elements were not certified. Errors were less than 5% of the certified or additional information values for LREEs, and less than 10% for HREEs. Precision calculated using three independent runs were less than 5% RSD for LREEs, and less than 10% RSD for HREEs. For most REEs, precision for plant samples were worse than those for soil samples due to the very low concentration of REEs and high concentration of matrix elements in plant samples. Worse precision for HREEs than LREEs might be attributable to very low concentrations of HREEs which were close to their detection limits.

Although ICP-MS shows relative freedom from interference, there exist some interferences from the spectral overlap of the polyatomic ions (MO^+, MOH^+,

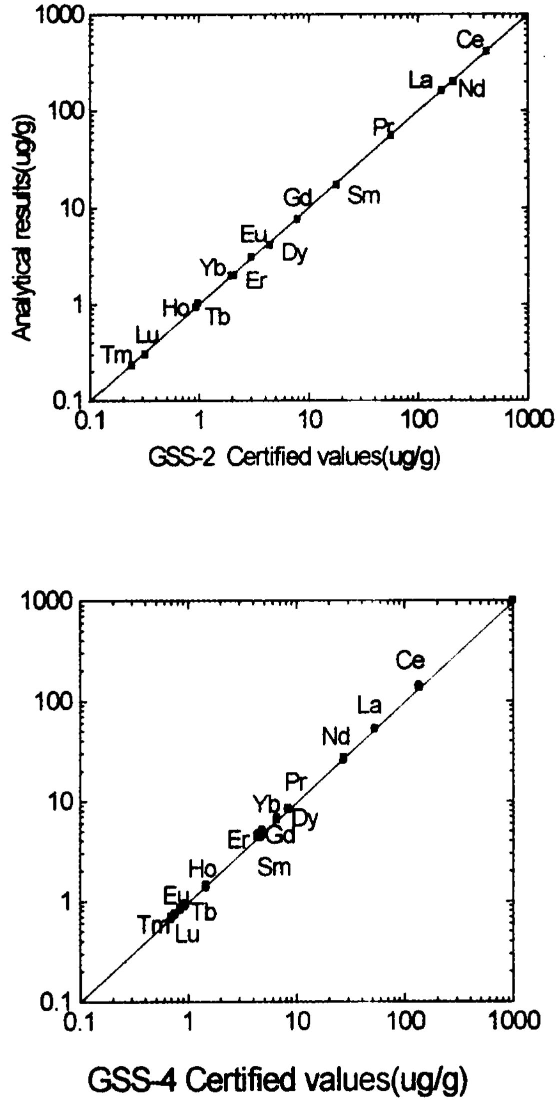

FIGURE 1 Binary plots of analytical results of REEs versus their certified values for GSS-2 and GSS-4 Standard Reference Material. Solid line: slope unity

etc.) of LREEs on HREEs. Under the optimized operational conditions, the ratio of MOH^+/M^+ was generally below 0.1% and that of MO^+/M^+ below 1%. Moreover, the ratio of LREEs/HREEs in soil and plant samples was not high, so this interference is generally minimal and negligible. However, in practical analysis,

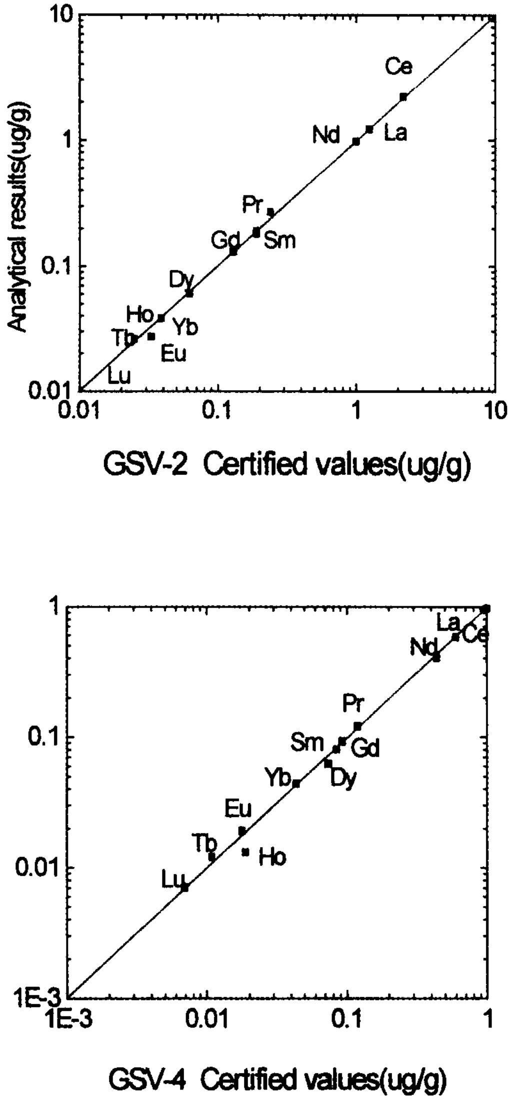

FIGURE 2 Binary plots of analytical results of REEs and their certified and additional information values for GVS-2 and GVS-4 Standard Reference Materials. Solid line: slope unity

the most serious interference results from the spectra overlap of matrix-induced polyatomic ions of BaO^+, $BaOH^+$ on REEs from amu 146 (Nd) through to 155 (Gd), especially the interference of $^{135}Ba^{16}O^+$ on $^{151}Eu^+$ and of $^{137}Ba^{16}O^+$ on $^{153}Eu^+$ when the concentration ratio of Ba/Eu is more than 200[18]. It is, therefore, necessary that measures should be taken to avoid this interference. In this work, a mathematical correction method was applied[19]. Our previous work[20] showed that the satisfactory results could be obtained by this mathematics correction. The correction equation was as follows:

$$C_{\mathrm{F,u}} = \left\{ \frac{I_{151,\mathrm{unk}} - I_{\mathrm{Ba(135),unk}} \left[\left(\frac{\mathrm{Ba(135)O}}{\mathrm{Ba(135)}} \right) \right]}{I_{151,\mathrm{std}}} \right\} C_{\mathrm{Eu,std}}$$

where I meant the total counts(s^{-1} ppb^{-1}) of ions at a certain mass number, *Ba(135)O/Ba(135)* stood for the ratio of Ba(135) oxide yield, *unk* for unknown sample, *std* for standard sample, *C*for concentration.

Another trouble associated with ICP-MS analysis is matrix suppression effect from the considerable amount of matrix elements. High matrix concentrations are known to cause a change in sensitivity[21]. The effects can originate in the aerosol generation and transport processes or in the plasma itself. An accumulation of salts around the hole of the sampling cone and skimmer might cause a signal intensity drift during the measurements. Appropriate dilution can overcome the problem. The experiment results showed that 500 dilution factor for soil and 50 dilution factor for plant sample were satisfactory. In addition, Re as internal standard could compensate for signal drift.

Analytical results of soils

Soil samples from four locations in Anhui Province of China were analysed for REEs. The results are listed in Table III. The REEs concentrations in four soils were more than 200μg/g. In fact, the rare earth group of elements occurs generally at a concentration level of a few hundred μg/g in soils[22]. Meanwhile, it was found that there was no distinct difference of concentration among these four soils of different type. It could also be seen from the results that REEs have almost the same distribution patterns in soils. In the four soils tested, the concentrations of REE with even atomic number were higher than those of two adjacent REEs with odd atomic number, and most of the light REE concentrations were higher than those of heavy REE, i.e. Oddo-Hakins distribution law. These may be attributed to the fact that REEs in the soil mainly came from bed rock or the original material of the soil since REEs distribution in most bed rocks or the original materials of soils also obeys with the Oddo-Hakins distribution law.

Analytical results of plants

Measurement results of plants for REEs are shown in Table IV. In comparison with the element contents of soil, the REE contents in plants were very low, less than 20μg/g and varied with plant species. In fact, Cossa[23] first reported small quantities of REEs in barley, beechwood, rice and in the leaves of tobacco and grape. Although Robinson et al[24] reported on the extraordinary concentration of REEs in the leaves of some hickory trees, amounting to as much as 2300μg/g of the dry weight of the leaves, most plants contain less than 60μg/g of total rare earth elements in their leaves[22]. Generally, metal availability in soils depends not only on soil properties but also on plant species[25]. Although tea-1, rape leaf and hot pepper grew in the same soil(S-1), the highest concentration was found for rape leaf by hot pepper leaf and tea.

TABLE III Results of REEs in soil samples by ICP-MS analysis(μg/g, dry wt)*

	S-1	*S-2*	*S-3*	*S-4*
	mean±sd	*mean±sd*	*mean±sd*	*mean±sd*
La	49.4 ± 2.1	43.8 ± 2.0	41.8 ± 1.9	38 ± 1.7
Ce	100 ± 2.7	99.4 ± 2.1	89 ± 2.0	85 ± 2.3
Pr	11.3 ± 0.1	9.8 ± 0.3	9.7 ± 0.2	8.9 ± 0.4
Nd	41 ± 1.5	35.3 ± 1.6	37 ± 1.5	36.7 ± 1.7
Sm	7.6 ± 0.2	6.3 ± 0.1	7.3 ± 0.3	6.5 ± 0.2
Eu	1.5 ± 0.04	1.1 ± 0.04	1.2 ± 0.03	1.3 ± 0.05
Gd	7.9 ± 0.07	6.3 ± 0.09	5.6 ± 0.07	8.2 ± 0.08
Tb	1.3 ± 0.01	0.97 ± 0.09	0.83 ± 0.04	1.1 ± 0.02
Dy	7.1 ± 0.02	5.1 ± 0.03	5.2 ± 0.03	8.3 ± 0.02
Ho	1.3 ± 0.02	0.91 ± 0.02	0.91 ± 0.03	0.91 ± 0.01
Er	3.9 ± 0.04	3.1 ± 0.04	3.2 ± 0.03	2.1 ± 0.05
Tm	0.47 ± 0.01	0.34 ± 0.02	0.41 ± 0.05	0.31 ± 0.03
Yb	2.8 ± 0.05	2.4 ± 0.04	2.8 ± 0.04	1.9 ± 0.03
Lu	0.46 ± 0.01	0.35 ± 0.02	0.42 ± 0.01	0.31 ± 0.01
ΣREE	236	215	205	200

* The average value of three replicate samples

TABLE IV Results of REEs in plant samples by ICP-MS (μg/g, dry wt)*

	Tea-1	*Tea-2*	*Rape Leaf*	*Hot pepper*			
				root	*stem*	*leaf*	*fruit*
La	0.62	0.66	11.7	1.89	0.77	1.54	0.19
Ce	0.72	0.72	2.36	3.45	1.30	2.27	0.19
Pr	0.12	0.12	1.08	0.46	0.19	0.32	0.031
Nd	0.36	0.38	3.08	1.74	0.60	1.11	0.096
Sm	0.053	0.057	0.17	0.30	0.11	0.21	0.012
Eu	0.014	0.015	0.031	0.06	0.055	0.043	0.003
Gd	0.065	0.070	0.16	0.28	0.13	0.21	0.015

	Tea-1	*Tea-2*	*Rape Leaf*	*Hot pepper*			
				root	*stem*	*leaf*	*fruit*
Tb	0.013	0.020	0.011	0.037	0.019	0.03	0.002
Dy	0.034	0.033	0.012	0.17	0.076	0.10	0.003
Ho	0.007	0.006	0.002	0.036	0.015	0.029	0.002
Er	0.023	0.022	0.010	0.08	0.047	0.073	0.004
Tm	0.003	0.003	0.0004	0.012	0.008	0.011	0.001
Yb	0.019	0.018	0.004	0.079	0.049	0.064	0.003
Lu	0.003	0.003	0.0005	0.011	0.012	0.012	0.001
ΣREEs	2.05	2.13	18.5	8.65	3.35	6.0	0.57

* The average value of three replicate samples

Figure 3 illustrate a comparison of the REE concentrations versus atomic number for some plant leaves and the soil on which the plants grow. It could be found that the concentrations decreased with increasing atomic number, showing a negative gradient from La to Lu. Apart from rape leaf, the other leaves had the same REEs distribution patterns as the soil on which these plants grow, i.e. elements with even atomic numbers were present in higher concentrations than two neighboring elements with odd atomic numbers. Except for rape leaf, similar curve slopes between both leaves and soil were observed. This means that plants generally absorb REEs from soil without selective uptake. However, for rape leaf, the concentration ratio of ΣLREE/ΣHREE was much higher than those of ΣLREE/ΣHREE in other plant leaves. The concentration ratio in rape leaf made up 92, but those in tea1, tea2, hot pepper leaf was 11.8, 10.8 and 10.8, respectively. Rape leaf was rich in LREEs, showing selective absorption for La, resulting a greater fractionation of REEs. Results from analysis of REEs in different parts of hot pepper showed that REEs could be accumulated by root, and a considerable portion reached the above-ground parts. The REE concentration distribution in parts of hot pepper was characterized by root > leaf > stem >fruit. This trend is consistent with that only 10~20% of rare earth element absorbed by the root can be transported to the top parts of plants[26]. However, it was interestingly found that the order of REE concentration in the top parts was leaf > stem >fruit. This slightly higher concentration in leaf might be due to the translocation of REEs with water flow in the plant. Distribution patterns of REEs in every part of hot pepper were similar to that of the soil on which hot pepper grow (Figure 4), and they had similar curve slopes of REE distribution. This suggested that REEs through root absorption migrated into the above-ground parts of hot pepper without selectivity.

In order to estimate the transportation ability of individual REE, transfer factors (TFs) from soil to plants were used. TFs was defined[27] as the ratio of "con-

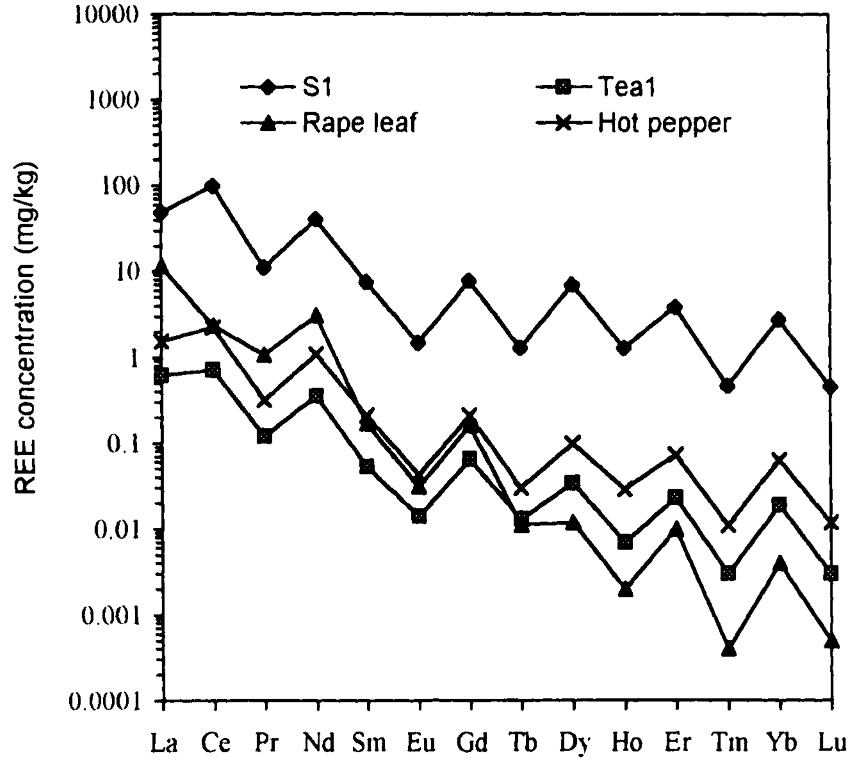

FIGURE 3 Distribution patterns of rare earth elements in some plant leaves

centration in plant on dry weight basis" to "concentration in the surface soil on dry weight basis" and is known to vary with the plant species and elements. S. Yoshida[27] repoted that the TFs in mushrooms and shrubs, were very low for Co, Ba, Pb and Th (0.002–0.1) and, on the other hand, relatively high for Cu, Zn, Cd and Cs (0.02–55). The calculated TFs for 14 individual REEs are summarized in Table V. The TFs of REEs were low(0.001–0.038) for all plants. This result was consistent with the low TFs of REEs in mushroom and shrub reported by other researchers[27]. It implied that REEs showed lower abilities of transportation in the soil-plant system. The order of TFs for plant leaves was found to be rape leaf> hot pepper leaf> tea, the order of TFs for hot pepper organs was root > leaf > stem > fruit. There were no distinct differences between TFs of LREEs and those of HREEs for plants except rape leaf. This indicated that LREEs and HREEs had the same abilities of transportation. However, for rape leaf, the TFs of LREEs were one or two orders of magnitude higher than those of HREEs, an indication of LREEs enrichment in rape leaf. Additionally, Tea-1 and Tea-2 had the same TFs for individual REE, although they grow on two different soils.

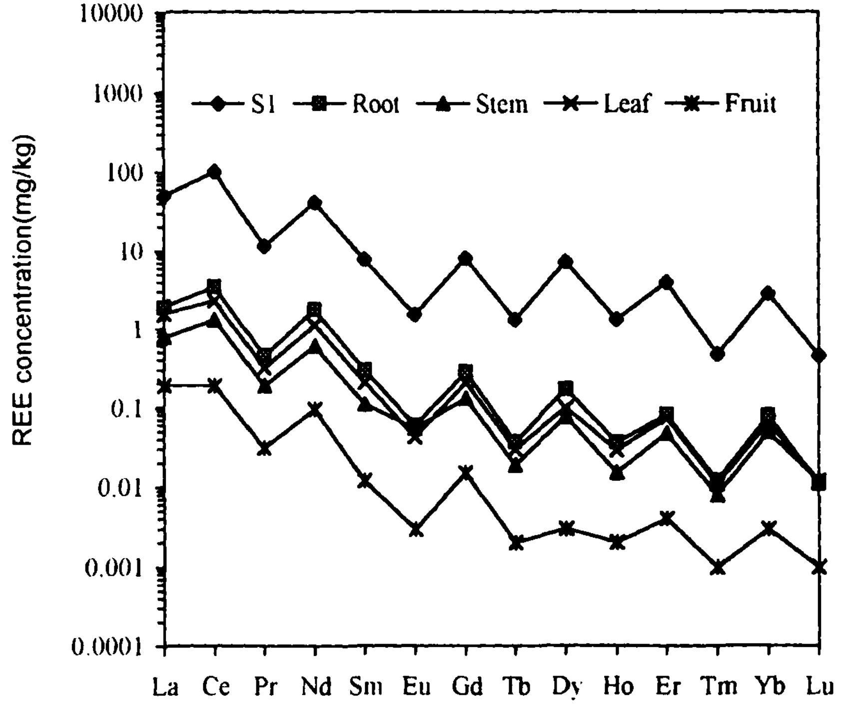

FIGURE 4 Distribution pattern of REEs in hot pepper organs and the soil on which hot pepper grow

TABLE V Transfer factors of trace rare earth elements from soil to plant

	Tea-1	*Tea-2*	*Rape Leaf*	*Hot pepper*			
				root	*stem*	*leaf*	*fruit*
La	0.012	0.013	0.24	0.038	0.016	0.032	0.004
Ce	0.007	0.007	0.024	0.034	0.013	0.023	0.002
Pr	0.011	0.011	0.095	0.041	0.017	0.028	0.003
Nd	0.009	0.009	0.075	0.042	0.015	0.027	0.002
Sm	0.007	0.007	0.022	0.039	0.014	0.028	0.002
Eu	0.009	0.009	0.021	0.040	0.037	0.029	0.002
Gd	0.008	0.008	0.020	0.035	0.016	0.026	0.002
Tb	0.010	0.015	0.008	0.028	0.015	0.023	0.001
Dy	0.005	0.005	0.002	0.024	0.011	0.014	0.001
Ho	0.005	0.005	0.002	0.028	0.011	0.022	0.001

	Tea-1	*Tea-2*	*Rape Leaf*	*Hot pepper*			
				root	*stem*	*leaf*	*fruit*
Er	0.006	0.006	0.003	0.021	0.012	0.019	0.001
Tm	0.006	0.006	0.001	0.025	0.017	0.023	0.002
Yb	0.007	0.006	0.001	0.028	0.017	0.023	0.001
Lu	0.006	0.006	0.001	0.025	0.026	0.023	0.002
ΣREEs	0.009	0.009	0.079	0.037	0.014	0.026	0.002

The location of roots is one of the important factors controlling trace element concentrations in plants in the forests since the element concentrations change with depth in forest soils. However, in case of agricultural soils, this effect might be negligible, the topsoil (plow layer) usually mixed well. In this study, the topsoil(0–20cm) was used for the calculation of TFs, so the calculated TFs could reliably reflect the transportation abilities of REEs in the soil-plant system.

CONCLUSION

A reliable, analytical method was developed to determine REEs in soils and plants by ICP-MS, based on microwave digestion for sample decomposition with a mixture of HCl+HNO_3+HF. Multi-element capability of ICP-MS could provide information on the distribution and transportation of REEs in the soil-plant system. The results indicated that the REEs in soil samples had the same distribution patterns of the concentrations of REEs with even atomic number higher than those of REEs with odd atomic number, and showed a negative gradient from La to Lu concentrations. Meanwhile, apart from rape leaf, the same REE distribution patterns as in soils were observed in the other plant leaves and in every parts of hot pepper. This implies that plants generally absorb REEs from soil without any selectivity. However, rape leaf showed selective absorption for LREEs, especially La. The REEs concentrations in parts of hot pepper were characterized by root>leaf>stem>fruit. The REEs absorbed by the plant concentrated principally in roots and leaves, very little migrating into the fruit. Transfer factors(TFs) could estimate the transportation ability of individual REE. Although plants were rich in LREEs, LREEs and HREEs had the same abilities of transportation. However, for rape leaf, the TFs of LREEs were one or two orders of magnitude higher than those of HREEs. In conclusion, the TFs provided in this study could be used for the estimation of accumulation and plant-availability of REEs

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