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RESEARCH ARTICLE

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Bio-absorption coefficients and relationships between elements in chestnut leaves and their fractions in chestnut forest soil

Abstract The Ca, Mg, Fe, Zn, Cu, and Mn concentration in the 0–20 cm and 20–40 cm soil layers of chestnut forest in the Yanshan mountainous area were determined by the available form and BCR three-step sequential chemical extraction methods. The bioabsorption coefficients and the relationships between elements in chestnut leaves and their fractions in soils were analyzed. Results showed that chestnut's bioabsorption coefficients of Ca and Mn were higher than those of other elements. There was a negative correlation between the concentrations of Fe, Mn, and Cu in chestnut leaves and each of their fractions in soils, except for the deoxidized fraction Fe, and a positive correlation between fractions of Zn in soils and in chestnut leaves. The element fractions in soils could better reveal the biogeochemical characteristics of nutrient elements in chestnut forest soils. The nutrient status of chestnut leaves could be estimated by the acetic acid extractable fractions of Mn in the 0–20 cm soil layer and Fe and Zn in the 20–40 cm soil layer.

Keywords chestnut leaf, soil, nutrient element, element fraction, bio-absorption coefficient

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1 Introduction

Soil and plant are two key factors of the environment circulation system constituted by geochemical elements. It is realized that agriculture geology and geochemistry background is one of the most important factors that impact the quality and yield of the famous, special, and high-quality produce (Gong et al., 1998; Zhao et al., 2004; Gong et al., 2006). In particular, the geochemical behavior of nutrient elements in soil is affected by their speciation in a large degree (Sutherland et al., 2000; Liu et al., 2002), and the bioavailability of plant can be influenced directly by the element speciation (Liu and Wang, 2006). The content level, presence pattern, migration, and transformation of nutrient elements have great significance on environment quality and biology process (Weng et al., 2003). Chestnut (*Castanea mollissima* Blume) is a traditional economic species with better economic, social, and ecological benefits. Yanshan mountainous area is rich in chestnut trees and boasts a famous brand "Jingdong Chestnut." In the past, the researches on chestnuts used to focus on the cultivation and management, breeding, pests and diseases control, soil properties, and the relationship between soil mineral elements and chestnut yield, rather than on the biogeochemical characteristics of nutrient elements in chestnut forest soil (Liu, 1999). Specially, few studies referred to the relationship between the element speciation in chestnut forest soil and the leaf nutrition. Therefore, our study determined the medium and trace nutrient element forms in chestnut forest soils in the Yanshan mountainous area using the methods of available form and BCR three-step extraction. The correlations between the chestnut leaf nutrition and soil nutrient elements were observed, and also, the indexes used to estimate the nutrition of chestnut leaf were sought for, which provides a theoretical basis for monitoring the chestnut growth and rational fertilization, raising chestnut yield and quality, and maintaining the ecological environment.

2 Materials and methods

2.1 Materials

2.1.1 Soil sampling

Soil samples were collected from the 0–20 cm and 20–40 cm soil layers of chestnut soil at Qianxi and Kuancheng Counties, Hebei Province, China, in the end of July, 2007 (It was rocks below 40 cm at most soil sampling sites). In all the selected areas, five soil samplings were done from each of five sites designed in S-shape, using stainless drill, which were mixed as one sample at the same layer. Twelve mixed samples from layers at 0–20 cm and 20–40 cm depths were gathered, respectively. One kilogram soil samples were collected by quartering method at each site. After removing gravels, visible plant roots, and other impurities, those soil samples were air-dried and mixed thoroughly and finally passed through a 0.1 mm and 0.25 mm sieves, respectively. The physical and chemical properties of the soil samples are shown in Table 1, in which Number 1, 5, and 6 samples were collected from Kuancheng County and others from Qianxi County.

2.1.2 Chestnut leaf sampling

There were 100 mature leaves from the middle part of branches of 30 chestnut trees, which grew well and were around 10 years old under similar managements, collected in the research area. After washing three times with tap water, distilled water, and deionized water, respectively, the chestnut leaves were dried under 60°C–70°C, milled with a stainless steel pulverizer, and grinded in a porcelain mortar and then mixed and reserved.

2.2 Method

Soil pH was determined by potentiometry under 1:2.5 soil-water ratio. Soil organic matter (SOM) was determined by using $K_2Cr_2O_7$ heating method. The total concentrations of Ca, Mg, Fe, Mn, Cu, and Zn in the soil samples were determined after HNO_3-H_2SO_4-$HClO_4$ acid digestion. Elements available form was abstracted using 0.1 $mol \cdot L^{-1}$ HCl. Elemental chemical forms were determined by BCR three-step extraction method improved by Rauret (Rauret et al., 1999). Chestnut leaves were digested by HNO_3-$HClO_4$. Mensuration of each sample was repeated three

Table 1 Physical and chemical characters of soil samples

No.	sampling site	depth/cm	pH	OM±SD/%	available P±SD /($mg \cdot kg^{-1}$)	available K±SD /($mg \cdot kg^{-1}$)
1	Wanzi village	a	7.98	1.86±0.01	2.14±0.01	139.30±23.97
		b	7.99	1.50±0.00	6.40±0.13	87.50±0.05
2	Daoguyu village	a	6.85	1.32±0.01	3.74±0.04	106.88±7.95
		b	6.95	0.78±0.00	3.52±0.05	69.38±0.88
3	Xiaolongwan village	a	6.94	1.10±0.01	5.55±0.08	50.00±2.83
		b	7.28	0.96±0.01	20.24±1.20	41.88±1.20
4	Linhe village	a	6.51	1.20±0.02	3.52±0.07	84.38±11.05
		b	6.87	0.85±0.01	12.10±1.02	75.00±1.41
5	Wanzi village	a	7.47	1.84±0.03	2.40±0.06	109.38±13.26
		b	8.17	1.59±0.02	5.90±0.09	85.94±11.05
6	Beichang village	a	7.13	1.45±0.00	3.62±0.03	142.19±11.05
		b	7.34	1.06±0.01	9.41±0.48	84.40±0.67
7	Yangjiayu village	a	5.98	0.86±0.04	9.69±0.55	45.31±2.21
		b	6.25	0.49±0.02	8.20±0.84	42.50±3.54
8	Yangjiayu village	a	6.45	1.06±0.02	4.51±0.06	43.76±4.44
		b	6.53	0.87±0.01	10.49±0.89	35.63±23.86
9	Yangjiayu village	a	5.61	0.93±0.00	9.03±0.05	65.63±4.42
		b	6.03	0.76±0.00	23.54±6.41	36.56±8.40
10	Haner village	a	7.15	1.03±0.04	4.95±0.02	62.50±17.68
		b	7.25	0.87±0.03	16.46±3.21	50.63±0.11
11	Beiguan village	a	7.27	0.89±0.01	3.57±0.17	90.63±2.21
		b	7.29	0.48±0.01	10.64±0.27	50.00±11.05
12	Houzhuang village	a	6.23	0.55±0.03	6.46±0.98	55.00±11.05
		b	6.27	0.34±0.02	13.26±0.05	31.25±0.03

Note: a and b represents 0–20 cm and 20–40 cm soil layers, respectively. SD is standard deviation.

times. Element concentration was mensurated by the model of atomic absorption spectrophotometry. There were 20 chestnut leaves selected from each chestnut leaf sample randomly, and their chlorophyll content was determined by using chlorophyll meter SPAD-502.

2.3 Calculation

Biological absorption coefficient (BAC) can be used to figure the relationship between elements in both plants and soils (Fortescue, 1980), which was calculated by using the following formula:

$$\mathrm{BAC} = L_x/N_x,$$

where L_x is the element concentration in plant, and N_x is the element concentration in rhizosphere.

2.4 Data analysis

The analysis of all the data and the figures were performed by using the Excel 2003. The statistical package SPSS (version 13.0 for Windows) was used for the correlation analysis and the stepwise regression equation.

3 Results

3.1 Biological absorption coefficients of nutrient elements in chestnut forest soil

BAC indicates the transfer extent of elements from soil to plant and helps estimate the effect of soil on plants. It showed that the largest BAC was Ca, followed by Mn, and the smallest BAC is Fe in Figs. 1 and 2. The chestnut absorption abilities of Ca, Fe, and Mn varied greatly, but the absorption abilities of Cu, Zn, and Mg had no significant differences in all the samples.

It was also showed that elements had large BAC possibly without a high concentration in the soil (Figs. 1 and 2). For example, the BAC of Cu and Zn was 10–100 times higher than that of Fe, but the concentrations of Cu and Zn were far less than that of Fe in the soil.

3.2 Analysis of correlation between nutrient elements in chestnut leaves and soils

The correlations between each element content in chestnut leaves and the total and available contents in soils were

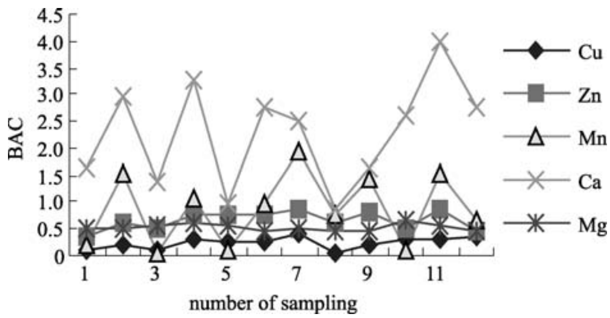

Fig. 1 BAC of Cu, Zn, Mn, Ca, and Mg

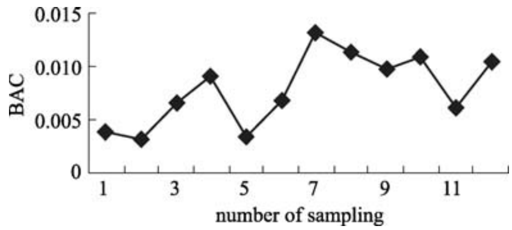

Fig. 2 BAC of Fe

analyzed (Table 2). The results showed a negative correlation between nutrition elements in chestnut leaves and total concentration of Ca, Fe, and Cu in two soil layers and Mn in the 0–20 cm soil layer, and a positive correlation between those in leaves and total concentration of Mg and Zn, but no significances were discovered. However, there was a significant negative correlation between those in leaves and total concentration of Mn in the 20–40 cm soil layer. A negative correlation between elements in chestnut leaves and available contents of Ca, Mn, and Cu in soils and a positive correlation between Fe, Zn, and Mg in chestnut leaves and available Fe, Zn, and Mg in two soil layers were found. Nevertheless, there only existed a significant positive correlation between available Mg in the 0–20 cm soil layer and Mg in chestnut leaves.

The analysis of correlation between elements in chestnut leaves and their BCR (Community Bureau of Reference) forms concentration in soils showed that each form of Fe, Mn, and Cu in soils had a negative correlation with those in chestnut leaves, except for deoxidized Fe and oxidized Fe, but each form of Zn in soils had a positive correlation with Zn in chestnut leaves (Table 3). This result was similar with the correlation between element available forms in soils and chestnut leaves. Significant negative correlations between Fe in leaves and acetic acid extractable Fe in the

Table 2 Correlation between elements concentration in chestnut leaves and content in soils

element	Ca		Mg		Fe		Mn		Cu		Zn	
soil layer	a	b	a	b	a	b	a	b	a	b	a	b
total	–0.219	–0.167	0.208	0.073	–0.336	–0.346	–0.559	–0.695*	–0.071	–0.046	0.431	0.329
available	–0.448	–0.193	0.667*	0.518	0.435	0.396	–0.427	–0.483	–0.082	0.019	0.331	0.205

Note: * represents significance at the 0.05 level. a and b represent 0–20 cm and 20–40 cm soil layers, respectively.

Table 3 Correlation between elements concentration in chestnut leaves and each fraction of them in soils

element	Fe		Mn		Cu		Zn	
soil layer	a	b	a	b	a	b	a	b
acetic acid extractable	−0.148	−0.581 *	−0.623*	−0.246	−0.165	−0.152	0.481	0.710*
deoxidized	0.260	0.161	−0.137	−0.586*	−0.083	−0.029	0.620*	0.194
oxidized	0.322	0.121	−0.254	−0.621*	−0.360	−0.536	0.360	0.202

Note: * represents significance at the 0.05 level. a and b represent 0–20 cm and 20–40 cm soil layers, respectively.

20–40 cm soil layer, Mn in leaves and acetic acid extractable Mn in the 0–20 cm soil layer, deoxidized and oxidized Mn in the 20–40 cm soil were observed. However, significant positive correlations between Zn in leaves and deoxidized Zn in the 0–20 cm soil and acetic acid Zn in 20–40 cm soil were found.

3.3 Analysis of relationship between chlorophyll in chestnut leaves and nutrient elements in soils

The correlation analysis between chlorophyll in chestnut leaves and concentration of element available form and BCR form in soils revealed that chlorophyll content had the most significant positive correlation with available Fe in two layers and a significant negative correlation with available Mn in the 20–40 cm soil layer. A significant positive correlation between the chlorophyll content and the acetic acid extractable Fe in the 20–40 cm soil layer, and the most significant negative correlation between the chlorophyll content and the acetic acid extractable Mn in 0–20 cm soil layer were found (Table 4).

A stepwise regression analysis was applied for further determining the relationship between the chlorophyll in chestnut leaves and the element fractions in soils (Table 5). The result showed that the content of chlorophyll increased with the increase of available Fe in the 20–40 cm soil layer and decreased with the increase in acetic acid extractable Mn in the 0–20 cm soil layer, suggesting that available Fe in the 20–40 cm soil layer and acetic acid extractable Mn in the 0–20 cm soil layer had the most positive and negative contribution to chlorophyll, respectively.

4 Discussion

Chestnut is fond of Ca and Mn. Some researches indicated that chestnut trees had a strong enrichment ability to Mn, and their bioaccumulation and biotransfer coefficient were more than 1 (Luo et al., 2005). The absorption coefficient of Ca was larger than that of Mg (Liu et al., 2003). Therefore, the chestnut biological absorption coefficient of Ca and Mn was higher than that of other elements in soils, which is in accordance with the previous studies. The chestnut absorption coefficient of Fe in soil was the smallest, but the available Fe concentration was higher than that of Cu and Zn. This result suggested that the biological absorption ability of elements in soils should be improved according to the rules of biogeochemistry. The plant enrichment ability of trace elements from soil was not only decided by the particular element concentration in soils (Miao et al., 2008) but also related to the element fractions in soil. A slight change of total or fraction content of particular elements in soil may directly affect the normal growth of trees and nevertheless changes of some element content had little influence on tree growth.

The total concentration of elements in soils should not be viewed as a full standard to assess their influences on life-form (Ramos et al., 1994). Hence, it is necessary to

Table 4 Correlation between chlorophyll of chestnut leaves and each fraction of elements in soils

element	Fe		Mn		Cu		Zn	
soil layer	a	b	a	b	a	b	a	b
available	0.752**	0.802**	−0.481	−0.576*	0.476	0.579*	0.206	0.060
acetic acid extractable	0.362	0.581*	−0.746**	−0.491	0.070	0.156	0.215	0.420
deoxidized	−0.052	−0.090	−0.078	−0.575	0.107	0.127	−0.162	0.129
oxidized	−0.076	−0.196	−0.067	−0.368	−0.074	−0.179	0.117	0.225

Note: ** represents significance at the 0.01 level. a and b represent 0–20 cm and 20–40 cm soil layers, respectively.

Table 5 Stepwise regression equation between chlorophyll of chestnut leaves and each fraction of elements in soils

stepwise regression equation	R	R^2	P
$Y = 40.906 + 0.118 \times (\text{Fe } A_b)$	0.643	0.413	0.002
$Y = 55.928 - 0.109 \times (\text{Mn } I_a)$	0.557	0.310	0.005

Note: A represents available Fe; I represents the acetic acid extractable Mn. a and b represent the 0–20 cm and 20–40 cm soil layers, respectively.

make further study on their fractions. Available form method may lead to a more ambiguous or less correlation with chestnut bioavailability. Hereby, using BCR method to make more research on element speciation was necessary. Elements geochemistry fractions extracted by sequential extraction method can reflect the distribution of contaminated elements in various geochemistry phases of soil and sediment (He et al., 2005) and the better reproducibility (Mossop and Davidson, 2003; Bacon, 2005). Compared with Tessier method (Tessier et al., 1979), the BCR method proved that the acetic acid extractable form, the deoxidized form, and the oxidized form were equivalent to the carbonate form, Fe-Mn oxide form and organic form, respectively (Wang et al., 2005). The analysis showed that the available form from $0.1\ mol \cdot L^{-1}$ HCl extraction was equivalent to the acetic acid extractable form. The chestnut leaf nutrition had little correlation with the trace nutrient element available form in soils. Elements forms in soils obtained by BCR extraction method had a better correlation with elements in chestnut plants than the available form.

Two analysis methods indicated that forms of Mn and Cu extracted whatever by the available method or BCR method in chestnut forest soil had a negative correlation with elements in chestnut leaves. However, any form of Zn in soils had a positive correlation with Zn in chestnut leaves. The reason may be the competition of cations on the surface of root. The complexation that the cations (Cu, Mn, and Fe) has a strong binding with DOM leads to the weak binding cation (Zn) increasing the absorption. The available Fe and deoxidized Fe in soils had a positive correlation with Fe in chestnut leaves, while the acetic acid extractable Fe and oxidized Fe had a negative correlation with Fe in chestnut leaves, indicating that the deoxidized Fe had potential bioavailability related to Fe absorption mechanism of plants and that Fe^{3+} was deoxidized to Fe^{2+} (Sultan and Ratana, 2006; Wu et al., 2007). In general, there was a complex interaction among elements. Though the bioavailability of plants was related to metal element forms in soils, it is not sufficient to predict the accumulation of metals in plants (Luo et al., 2008). Therefore, further study is needed in the future.

Fe is one of the main components in chlorophyll, and generally, the available form or the acetic acid extractable element in the surface layer of soil is regarded as the fraction absorbed and utilized by plants. Hence, the content of chlorophyll increases with the increase of available Fe in soils. Mn takes part in the photosynthesis, but excessive Mn will be poisonous to plants. Mn poison is more ordinary than its scarcity in many sour soils (Ren and Liu, 2007). Chestnut trees were found to grow well at sour soil sites (pH 5–7) and with a higher accumulation of Mn, which often causes too much Mn in chestnut leaves. This is the possible reason that the content of chlorophyll decreases with the increase of Mn content in soils.

5 Conclusion

Elements biogeochemical characteristics in the chestnut forest soil can be better revealed through the nutrient elements speciation analysis. Chestnut leaf nutrition can be judged by the content of acetic acid extractable Mn in the 0–20 cm soil layer and Fe and Zn in the 20–40 cm soil layer. The chlorophyll content in chestnut leaves could be judged by the concentration of available Fe and acetic acid extractable Mn in surface layer soil. Therefore, balanced fertilization will be feasible.

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