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Distribution characteristics of available trace elements in soil from a reclaimed land in a mining area of north Shaanxi, China*

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Abstract

Through field and laboratory tests we studied the temporal and spatial variation in the soil content of four available trace elements: copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), to analyze their distribution characteristics in reclaimed mining land under different reclamation conditions. The available trace elements content varied considerably with different land reclamation patterns. Extended reclamation time was helpful for the recovery of the available trace element content in the soil, and after more than eight years of soil reclamation, the content of available trace elements was closer to or greater than that in soil under natural conditions. Various treatment measures significantly influenced the content and distribution of available trace elements in the soil, and reasonable artificial treatments, including covering the soil and growing shrubs and herbaceous plants, increased the content of available trace elements.

Key Words: Available trace element, Reclaimed land, Reclamation time, Treatment measure, Mining area

1 Introduction

Trace elements in soil are one of the most important environmental factors in plant ecology (Zhang et al., 2006; Jiang et al., 2009; Zhu et al., 2009). Influenced by soil parent material, climate, and vegetation, the content of trace elements in soil directly relates to the growth and development of vegetation and reflects the supply of mineral nutrition to plants by soil. Soil tests and plant tissue analyses have demonstrated that trace elements are an important limiting factor in crop growth. If any trace element is found to be excessive or deficient in soil, plant growth is affected and human and animal health are consequently impacted. It has been reported that worldwide millions of hectares of farmland soil lack sufficient trace elements (White et al., 2009). Therefore, studies on the circulation and balance of trace elements in ecosystems have attracted increasing scientific interest (Brady et al., 1999; Rengel et al., 2007; Ballard et al., 2000).

Research has demonstrated that the effective components of a nutrient are those that can be absorbed by a plant, and that the bioavailability of an element is related to its chemical state in the soil (Thornton et al., 1996; Ge et al., 2000; Jeffrey et al., 1996; Maiz et al., 2000; Ge et al., 2000). Accordingly, research on element availability has focused on the circulation of trace elements and its main influencing factors in forests (Jiang et al., 2009) and farmland ecosystems (Zhu et al., 2009), as well as ecological succession processes, through bioavailability analysis of trace elements in soil ecosystems (Zhang et al., 2006). Element bioavailability is influenced by many factors, such as pH value, redox conditions, texture, organic matter, soil mineral composition, and temperature

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(Chlopecka et al. ,1996; Kabata-Pendias et al. ,2004). Kabata-Pendias (2004) summarized the availability of some elements under different soil conditions and stated that in oxidizing acid soils, many trace elements, especially Cd and Zn, are very active and have strong bioavailability, whereas in reducing neutral or alkaline soils, element bioavailability is lower. Therefore, the bioavailability of trace elements, be they beneficial or harmful, is not only dependent upon their total content but also upon their soil state and their ability to transfer from the solid phase of a soil into the soil solution (Zhao et al. ,2010).

A few studies of trace elements in the arid and semi-arid regions of northwest China have been conducted, including research on the distribution characteristics of trace elements in Xinjiang Uygur Autonomous Region (Li et al. ,1985) and Gansu Province (Zhao et al. ,2010) which indicated that although average levels of local trace elements were equivalent to those of trace elements nationwide, their spatial distribution differed greatly among regions. In terms of the spatial distribution of available trace elements, the content of trace elements in cultivated oasis soil was slightly higher (Ma et al. ,2006) and both altitude and grass land type influenced the content of available trace elements (Wu et al. ,2008).

We studied the impact of the energy resources and heavy chemical industry in Shaanxi Province, within an ecologically vulnerable zone, and adopted mutual substitution between time series and space series, and selected areas representing different reclamation times and different reclamation treatments during coal mine exploitation, to analyze the main soil environment indices (pH value, organic matter content) and the available state of copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). The aim of this research was to determine the relationship between the soil environment and available trace elements in soil during land reclamation within a mining area, to provide a reference for land remediation, utilization, and management for development and construction projects.

2 Materials and methods

2.1 *Overview of the study area*

The study area was located in the Ulan Moron River Basin, within the boundary of Daliuta Town, Shenmu County, Shaanxi Province, P. R. China. The mean annual temperature is 8.4 ℃, the mean annual rainfall is 434.2 mm, and the frost-free period is 130 days. Rainfall is uneven throughout the year, with 288.4 mm falling from July to September accounting for 66.4% of total annual rainfall.

The first and second phases of the Shenfu-Dongsheng Coalfield Project were based in the Ulan Moron River Basin, where the underground coal resources are very rich but the surface ecological environment is quite vulnerable; the soil is poor, the vegetation is sparse, the climate dry, the Aeolian sand is damaging, and soil and water loss is severe.

2.2 *Sample collection and analysis*

The Shenfu mining area was studied with reclamation time (hereinafter referred to as Reclamation Mode Ⅰ) and reclamation treatment (hereinafter referred to as Reclamation Mode Ⅱ) as key variables. The mining area was divided into four plot types including a mining zone, an Aeolian sand site type zone, reforesting and beautifying zones, and a coal gangue dumping site. From each plot, soil samples were taken from all quadrats using the "S" shaped multi-point mixing sampling method. During sampling, a spade was used to excavate the profile and a wooden spatula was used to trim the profile and take the sample layer by layer. The soil samples were taken to the laboratory, air dried naturally, sieved soil particles (< 2 mm), and then used for analysis and determination. The contents of available trace elements in the soil samples were determined by DTPA extraction and the extract was then analyzed with an atomic absorption spectrophotometer. An overview of the plots is shown in Table 1.

Table 1 **Plot overview**

Plot name	Reclamation mode	Reclamation time	Vegetation
Reforesting zone of Bulianta Mine	Reclamation Mode Ⅰ	1 year AF1	*Pinus tabuliformis*, height 160 cm, plant spacing 2 m. *Hippophae rhamnoides* Linn. ,250 cm, community 2 m × 1 m. *Artemisia desertorum* Spreng 30 cm × 10 cm

Continue

Plot name	Reclamation mode	Reclamation time	Vegetation
Halagou Coal Mine	Reclamation Mode Ⅰ	3 years AF3	*Artemisia annua* L. ,height 60 cm,5 plants/cm^2 ; *Pyrus* spp. ,row spacing 1. 5 m;*Hippophae rhamnoides* Linn. ,community 30 cm × 40 cm
West Mountain at Daliuta		8 years AF8	Main communities: *Pinus tabuliformis*, *Populus* spp. , *Hippophae rhamnoides* Linn. ,height 70 cm,12 plants/cm^2 ,*Artemisia desertorum* Spreng,9 plants/cm^2
Coal gangue field at initial stage of Shangwan Coal Mine construction		13 years AF13	*Hippophae rhamnoides* Linn. ,1 plant,height 89 cm,community 40 cm × 18 cm; *Artemisia desertorum* Spreng,7 plants,height 23 cm; *Medicago sativa* Linn. ,4 plants,height 5 cm,community 10 cm × 5 cm,with coal gangue seen at depth 30 cm,40 cm and 50 cm
Coal Gangue Dumping Site #1 at Shigetai	Reclamation Mode Ⅱ	Artificial treatment TS100	*Medicago sativa* Linn. ,dominant community,length 48 cm,community 30 cm × 40 cm. *Artemisia desertorum* Spreng,16 plants/cm^2 ; with coal gangue seen in soil samples taken at a depth of 50 cm. Coal gangue and soil layers were mixed and stacked,with cover soil layer having a thickness of about 50 cm – 1 m
Coal Gangue Dumping Site #2 at Shigetai		Closure treatment TS50	*Medicago sativa* Linn. ,5 plants,height 3cm,community 20 cm × 20 cm. *Trifolium repens* 1 cluster,height 8 cm,community 8 cm × 10 cm. *Artemisia capillaries* 2 plants,height 5 cm; *Artemisia desertorum* Spreng,52 plants, height 27 cm; with coal gangue seen in soil samples taken at a depth of 50 cm
		No-treatment/ Burning TF	The vegetation was mostly burnt to death. Plot #5 was not completely closed for treatment,and there was coal gangue dumped,with coal gangue seen in soil samples taken at a depth of 10 cm
Majiata Open-Pit Mine		No-measure TN	This was a spoilt area after mining,without vegetation covering
Natural land		Natural form for reference CK	*Hippophae rhamnoides* Linn. ,dominant community height 38 cm,community 20 cm × 30 cm;*Artemisia desertorum* Spreng

3 Results and discussion

3. 1 *Distribution characteristics of available trace elements in soils with different reclamation times*

3. 1. 1 Distribution of soil available trace elements for different reclamations

The variability of soil properties was classified according to the coefficients of variation: if the coefficient of variation was within 0 – 15% ,then variation was low; if the coefficient of variation was 16% – 35% ,then variation was moderate; and if the coefficient of variation was > 36% , then variation was high (Kabata-Pendias et al. , 2004). Table 2 shows that within the 0 – 10 cm soil layer,the contents of iron,zinc and copper exhibited medium variation and the content of manganese exhibited low variation. Within the 10 – 20 cm soil layer,the degrees of variation increased so that the content of iron showed high variation and the contents of copper,manganese and zinc displayed moderate variation. Within the 20 – 30 cm soil layer,the contents of iron and zinc showed high variation and copper and manganese showed moderate variation. Within the 30 – 40 cm soil layer,the contents of iron and manganese exhibited high variation and copper and zinc showed moderate variation; and within the 40 – 50 cm soil layer,the contents of copper and iron displayed high variation and manganese and zinc showed moderate variation. With regards to the distribution characteristics for the entire profile,copper,manganese,and zinc showed a fluctuating decreasing trend,with the highest available content of the elements found in the surface soil layer. This indicated that these three elements had a gradual migrating trend to the surface soil layer during land reclamation in the mining area. Previous research on the distribution characteristics of trace elements during fly-ash land reclamation by Hu et al. (2003) showed that elements such as copper and zinc move slowly and gradually upwards in the soil as water evaporates, which is consistent with the results of the present study. There was no evident trend in the content of available iron, except that the iron content of a relatively deep soil layer (30 – 40 cm) was obviously higher than that of other soil layers, and an enrichment of the available-state of iron may have been due to such processes as rainfall and eluviation.

Table 2 **Distribution characteristics of available trace elements for different reclamations**

Soil layer depth (cm)	Statistic characteristics	Trace Element			
		Copper (mg · kg^{-1})	Iron (mg · kg^{-1})	Manganese (mg · kg^{-1})	Zinc (mg · kg^{-1})
0 – 10	Mean	0.108	2.215	2.423	0.367
	Standard deviation	0.021	0.783	0.355	0.129
	Coefficient of variation (%)	19.444	35.350	14.651	35.150
10 – 20	Mean	0.087	2.225	2.113	0.238
	Standard deviation	0.030	0.915	0.742	0.053
	Coefficient of variation (%)	34.483	41.124	35.116	22.269
20 – 30	Mean	0.094	2.185	2.001	0.175
	Standard deviation	0.016	0.970	0.592	0.074
	Coefficient of variation (%)	17.021	44.394	29.585	42.286
30 – 40	Mean	0.100	2.400	2.197	0.226
	Standard deviation	0.025	1.186	0.791	0.057
	Coefficient of variation (%)	25.000	49.417	36.004	25.221
40 – 50	Mean	0.083	2.197	1.909	0.218
	Standard deviation	0.030	1.102	0.565	0.051
	Coefficient of variation (%)	36.145	50.159	29.597	23.395

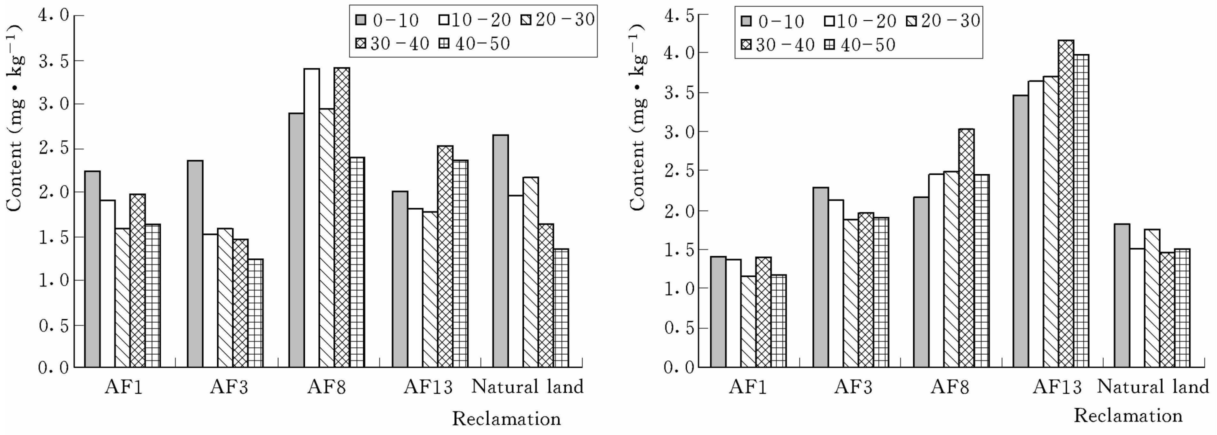
3.1.2 Profile distribution of available trace elements in soil at different reclamation times

Fig. 1 shows the profile distribution characteristics of available trace elements in soils with different reclamation times. The results showed that available manganese content [Fig. 1 (a)] exhibited a fluctuating increasing trend with an increase in reclamation time, especially during the 8-year reclamation stage when it rose to a relatively high level. Under natural conditions, the content of available manganese in soil displayed clear profile distribution characteristics, i. e., decreasing gradually with the increase in depth. Compared with the distribution characteristics of available manganese in soil under natural conditions, the content of available manganese in soil at the initial stage of reclamation was slightly lower. As the soil structure in the mining area was greatly changed by strong artificial disturbance, the original profile structure was destroyed and a new profile was formed through the mixing of the soils from different depths. With the increase in reclamation time, however, the available manganese in soil tended to move upwards gradually due to evaporation.

With an increase in reclamation time, the content of available iron in soil [Fig. 1 (b)] shows a clear increasing trend and soon (after 3 years' reclamation) exceeded the content level of available iron in soil under natural conditions. As seen from the profile distribution characteristics, the content of available iron in soil differed little among the various layers in the soil profile, whether under natural conditions or under different reclamation time conditions. However, when the reclamation time was over 8 years, the content of available iron in the deep soil layers was higher than that in the surface layer, indicating an enrichment of available iron in the deep soil layers due to eluviation of available iron mobilized by weathering from the surface layer.

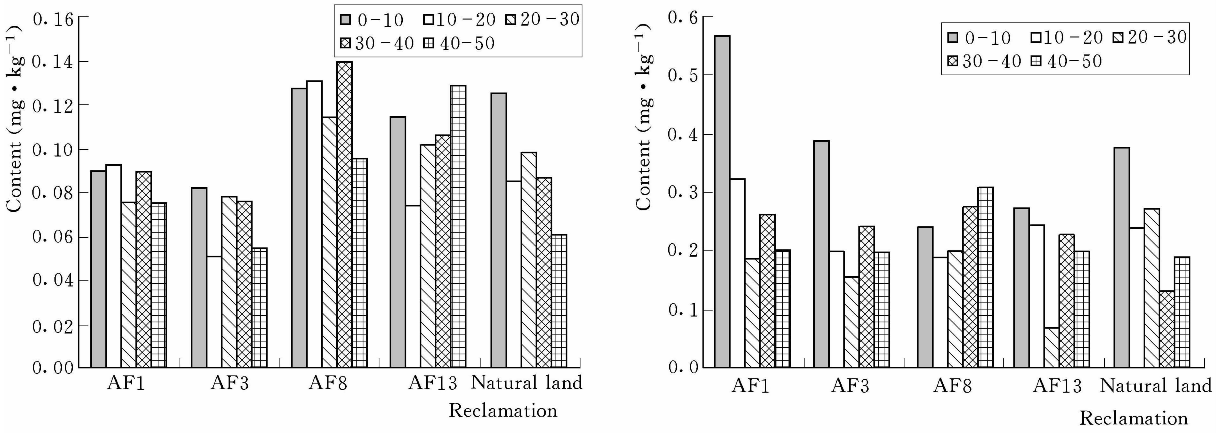
Analysis of the distribution of available copper in the soil under different reclamation time conditions [Fig. 1 (c)] revealed an increasing trend with the increase in reclamation time. Under natural conditions, the content of available copper in the soil decreased with increasing depth. For different reclamation times, the content of available copper in soil also showed a fluctuating decreasing trend with depth. In general, the content of available copper in the soil was lower at the initial stage of reclamation (1 year reclamation and 3 years' reclamation) than that under natural conditions, but higher when the reclamation time was over eight years.

Analysis of available zinc in the soil [Fig. 1 (d)] showed a decreasing trend with increasing depth and



(a) Manganese element

(b) Iron element



(c) Copper element

(d) Zinc element

Fig. 1 Profile distribution of available trace elements in soil at different reclamation time

a slight decrease with the increase in reclamation time. The profile distribution characteristics showed that with the increase in reclamation time, the content of available zinc in deep soil layers evidenced an increasing trend. However, the content in the surface layer was still high, which indicates that the available zinc was mobilized quickly by weathering after disturbance, and that its transport and distribution in the soil might be influenced by both rainfall eluviation and evaporation simultaneously. The content of available zinc in soil after 8 years' reclamation was relatively close to that in soil under natural conditions.

Reclamation time had a major influence on the content of available trace elements in the soil, and an extended reclamation time was generally helpful for restoration and an increase in the content of available trace elements in the soil. Analysis of the results for the four trace elements showed that after more than 8-years of soil reclamation, the content of available trace elements in the soil were close to or greater than those under natural conditions, which is consistent with the relevant conclusions for the evolution of the surface and underground soil environment of an ecosystem during ecosystem reclamation (Hou et al., 2002; Zou et al., 1998). In light of the distribution trends, available copper and manganese in soil were obviously enriched towards the surface soil layer; available zinc was enriched due to the simultaneous effects of eluviation by rainfall and evaporation; and available iron was evidently enriched in the deep soil layers.

3.2 *Distribution characteristics of available trace elements in soil on gangue dumping sites under different reclamation measures*

3.2.1 The distribution of available trace elements in soil subject to different reclamation measures

Gangue is a typical solid waste generated during coal mining, and is generally stored by establishing a dumping site. The ecological remediation of gangue dumping sites in coal mining areas has always been a key area of interest. Table 3 shows that within the 0 – 10 cm and 10 – 20 cm soil layers, the content of iron and manganese exhibited high variation, while zinc and copper exhibited low variation. Within the 20 – 30 cm soil layer, the content of manganese showed high variation and the other three elements showed low variation. Within the 30 – 40 cm soil layer, the content of manganese displayed high variation, copper and iron moderate variation, and zinc, low variation. Within the 40 – 50 cm soil layer, the content of copper, iron and manganese showed high variation and zinc, low variation. Of these four trace elements, manganese had the highest degree of variation and zinc the lowest.

Table 3 **Distribution characteristics of available trace elements on gangue dumping sites subject to different reclamation measures**

Soil layer depth (cm)	Statistical characteristics	Trace Element			
		Copper (mg · kg^{-1})	Iron (mg · kg^{-1})	Manganese (mg · kg^{-1})	Zinc (mg · kg^{-1})
0 – 10	Mean	0.109	2.236	2.649	0.231
	Standard deviation	0.039	1.140	0.983	0.083
	Coefficient of variation(%)	35.780	50.984	37.108	35.931
10 – 20	Mean	0.095	1.697	2.209	0.193
	Standard deviation	0.036	0.495	0.925	0.031
	Coefficient of variation(%)	37.895	29.169	41.874	16.062
20 – 30	Mean	0.096	1.886	2.265	0.184
	Standard deviation	0.034	0.648	0.891	0.051
	Coefficient of variation(%)	35.417	34.358	39.338	27.717
30 – 40	Mean	0.091	1.640	2.156	0.139
	Standard deviation	0.028	0.331	0.814	0.014
	Coefficient of variation(%)	30.769	20.183	37.755	10.072
40 – 50	Mean	0.095	1.887	2.105	0.206
	Standard deviation	0.045	0.950	1.438	0.064
	Coefficient of variation(%)	47.368	50.344	68.314	31.068

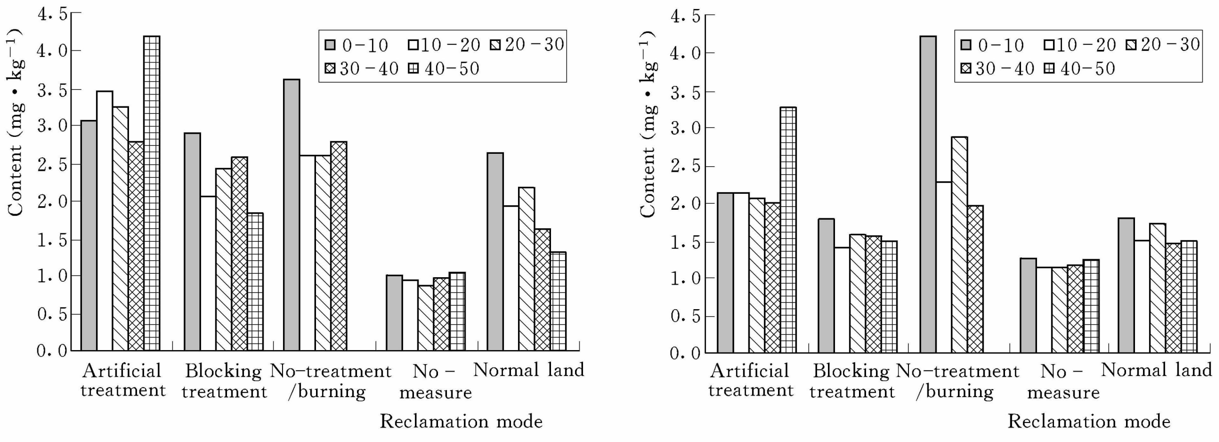
With regards to the distribution characteristics of the elements in the overall soil profile, the mean element content showed a decreasing trend with increasing depth within the 0 – 40 cm soil layer, which indicates that available copper, iron, manganese, and zinc have moved slowly upwards as water evaporated within this soil depth range. The content of some available trace elements increased in the 40 – 50 cm soil layer. According to the on-site survey (Table 1), the gangue dumping sites were mostly covered with soil to a depth of 50 cm and the enrichment of trace elements at the boundary between the cover soil and the gangue might reflect exchange of trace elements between the cover soil and the gangue.

In addition, most of the coefficients of variation for the trace elements showed a decreasing trend with increasing depth within the 0 – 40 cm soil layer, indicating that the available trace elements in soil tended to be more spatially evenly distributed at increased soil depths, although the coefficient of variation increased greatly at a depth of 40 – 50 cm, indicating that the variation of available trace element concentrations in the soil at that depth increased under various restoration measures. This further indicates that there was some exchange between cover soil and trace elements present in the gangue at that depth, leading to an elevated content of available trace elements in this layer of soil.

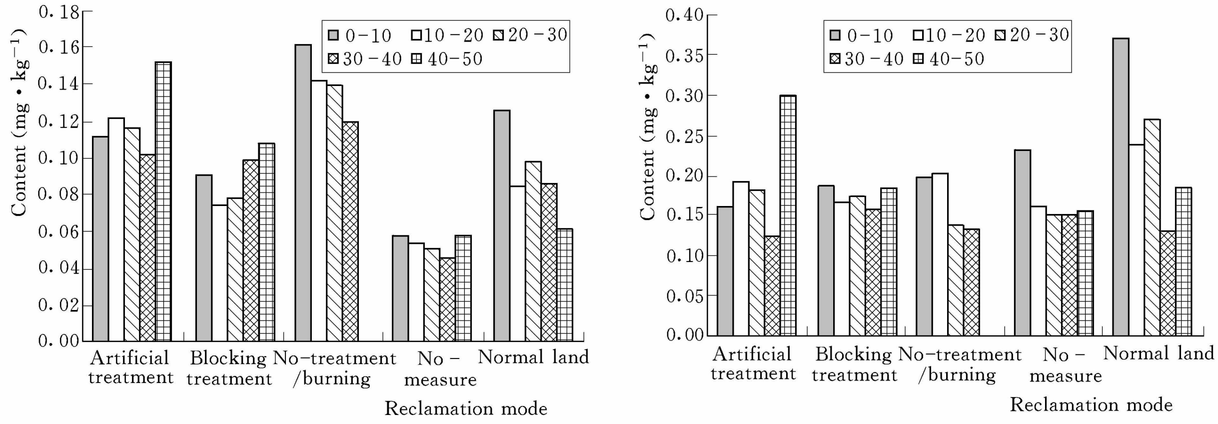
3.2.2 Profile distribution of available trace elements in soil under different reclamation measures

Fig. 2 shows the depth distribution characteristics of available trace elements in the soil on the gangue dumping sites under different treatments. The profile distribution characteristic of available manganese in soil varied greatly with treatment [Fig. 2(a)]. Compared with that under natural conditions, the content of available manganese in soil under artificial treatment, blocking treatment and no-treatment/burning was obviously increased, whereas it decreased under no-treatment.

Treatment measures had a large influence on the content of available iron in the soil [Fig. 2(b)]. Under artificial treatment and no-treatment/burning, available iron was higher than that under natural conditions, but was



(a) Manganese element (b) Iron element



(c) Copper element (d) Zinc element

Fig. 2 Profile distribution of available trace elements in soil under different reclamation modes

lower under blocking treatment and no-measure. With regards to the profile distribution, the content of available iron in the soil under blocking treatment, no-treatment, and natural conditions differed little among the different soil layers, but showed more differentiation under artificial treatment and no-treatment/burning conditions.

The content of available copper in soil under artificial treatment and no-treatment/burning [Fig. 2 (c)] was higher than that under natural conditions, but was lower under the blocking treatment and no-treatment conditions. With regards to the profile distribution characteristics, the variation of available copper content with depth was smaller under all four treatments than under natural conditions.

The content of available zinc in soil under all four treatments was lower than that under natural conditions [Fig. 2(d)]. With regards to the profile distribution characteristics, the content of available zinc in the surface soil layer was higher than in the deep soil layers, except for that under artificial conditions.

Different treatment measures greatly influenced the content of available trace elements in the soil; artificial treatment increased the content of available trace elements in the soil as a whole. The closure treatment, as a primary measure of ecological remediation, did not have a clear effect on the levels of available trace elements in the soil. No-treatment/burning, a common situation on coal gangue dumping sites, effectively increased the content of available trace elements in the soil, and, if used together with the natural closure treatment, significantly increased the available trace element content of the soil, resulting in improved restoration and soil fertility for gangue dumping sites.

3.3 *Distribution of available trace elements in soil under different reclamation conditions*

Analysis of the distribution of available trace elements in soil under two kinds of reclamation conditions (Table 4) showed that, in the case of Reclamation Mode Ⅰ, the content of iron had high variation, while copper, manganese, and zinc had moderate variation. In the case of Reclamation Mode Ⅱ, the content of manganese had high variation, while copper and iron had moderate variation and zinc had low variation. In terms of the abundance of available trace elements in the soil, their content in the soils of the mining area soil was very low and could be further increased. This indirectly indicates that the trace elements in the reclaimed soils of the mining area were at safe levels and had not harmed the environment.

Table 4 **Statistical analysis of available trace elements in soil for different reclamation time and modes in the mining area**

Reclamation condition	Statistical indexes	Element type			
		Copper ($mg \cdot kg^{-1}$)	Iron ($mg \cdot kg^{-1}$)	Manganese ($mg \cdot kg^{-1}$)	Zinc ($mg \cdot kg^{-1}$)
Different reclamation times	Mean	0.094	2.244	2.105	0.246
	Standard deviation	0.020	0.980	0.536	0.045
	Coefficient of variation(%)	21.277	43.672	25.463	18.293
Different reclamation modes on gangue dumping sites	Mean	0.099	1.907	2.309	0.189
	Standard deviation	0.033	0.657	0.923	0.030
	Coefficient of variation(%)	33.333	34.452	39.974	15.873

Through comparison of the content of the available trace elements, their degree of variation and the different trends between the two reclamation conditions, we found that the influence of different treatment measures on the content of available copper, iron, and manganese was obviously greater than that of different reclamation times. The coefficient of variation can express the degree of influence of human activities on the content of trace elements in soil and thus it can be said that during the initial stage of land reclamation, the treatment measures had a much larger influence on the content of available trace elements in the soil compared with reclamation time. Therefore, in terms of land reclamation and treatment in mining areas, greater attention should be paid to selecting appropriate treatment measures during the initial stage of land reclamation to speed up the restoration and reconstruction of the soil environment. Based on our results, covering gangue with soil, supported by restoring shrub and herb vegetation to a reasonable level, can improve the content of available trace elements in the soil. In the case of limited conditions, closure and proper artificial interference (burning or soil covering) these measures can also be adopted to greatly improve the content of available trace elements in the soil.

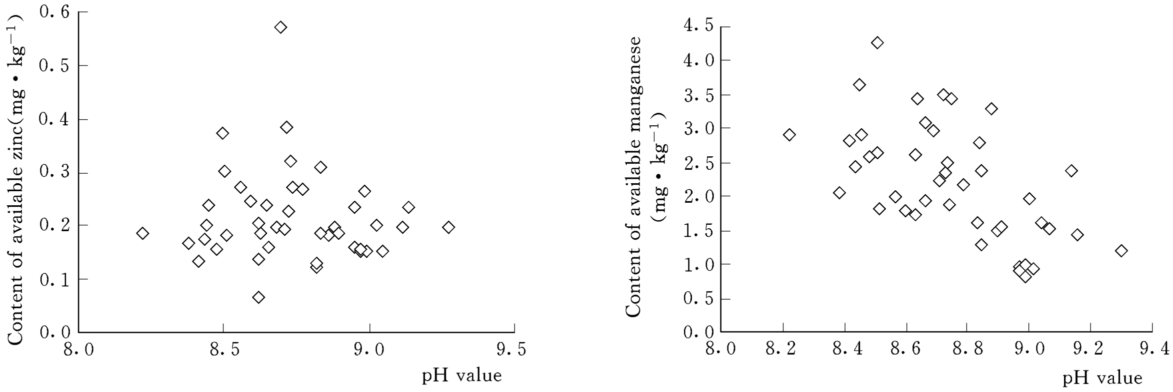
3.4 *Relationship between soil environment and available trace elements in soil*

3.4.1 Relationship between pH value of soil and available trace elements in soil

Fig. 3 shows the relationships between soil pH and the concentration of available trace elements in the soil. We found that pH values were, in general, negatively correlated with all four trace elements, so that the content of available elements decreased with rising pH levels. This may relate to the fact that at a higher pH value, the OH^- content in soil is high with strong attracting and fixing effects on metal elements. The trace metal elements will react with OH^- to form hydroxide precipitates, and the metal content, in the form of precipitate and mineral residue, will account for a large fraction of the total metal content. Accordingly, the content of available trace elements in soil will decrease, and the migrational mobility of available trace elements will become lower. Analysis of the strength of the correlations between the four available trace element concentrations and the pH value of the soil (Table 5) showed that none of the four trace elements had a very high correlation with soil pH. This may reflect that there are many factors influencing the availability of trace elements and the different properties of different elements. Available manganese and copper had higher correlations with soil pH than the two other elements. Previous research in arid regions (Zhao et al., 2010) has revealed that soil pH has a higher correlation with available copper and manganese, which is consistent with the results of the present study.

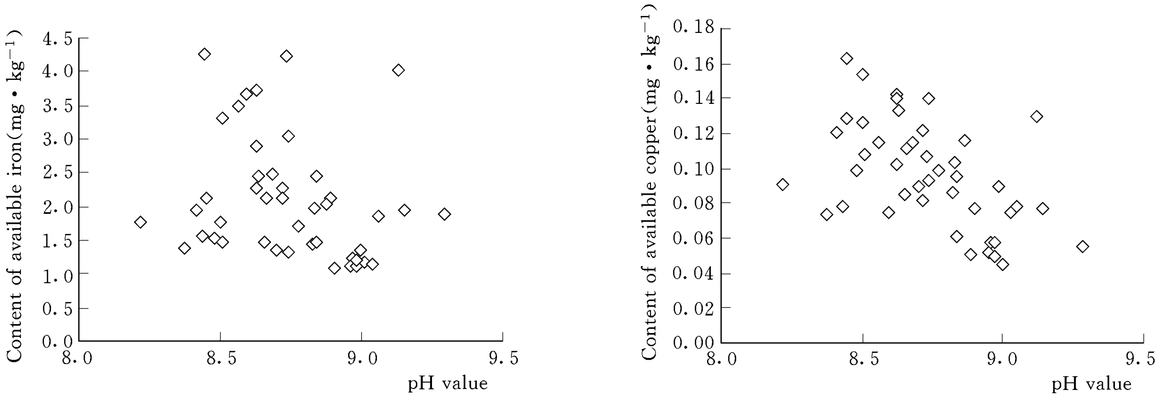
Table 5 **Correlation coefficients for the relationships the content of available trace elements and selected soil properties**

	Cu	Fe	Mn	Zn
TOC	0.331	0.219	0.298	0.390
pH	0.549	0.294	0.626	0.155



(a) Zinc element

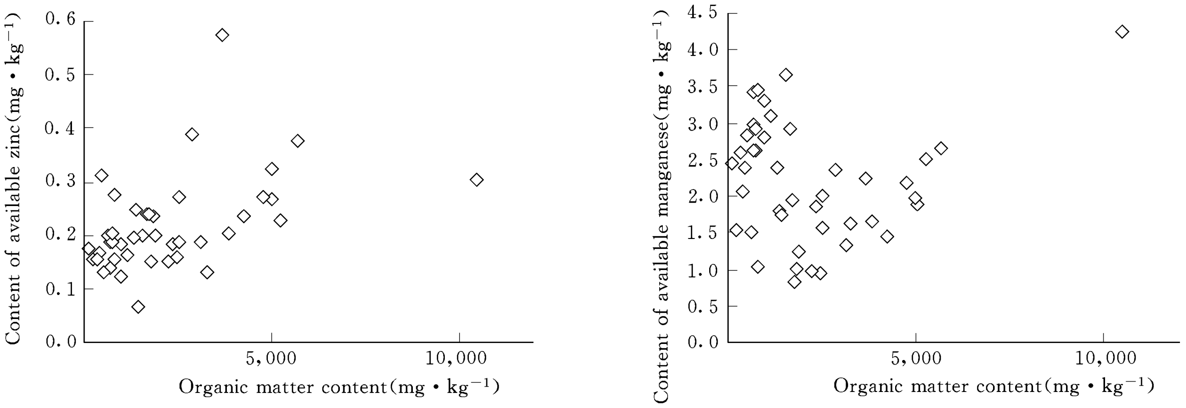
(b) Manganese element



(c) Iron element

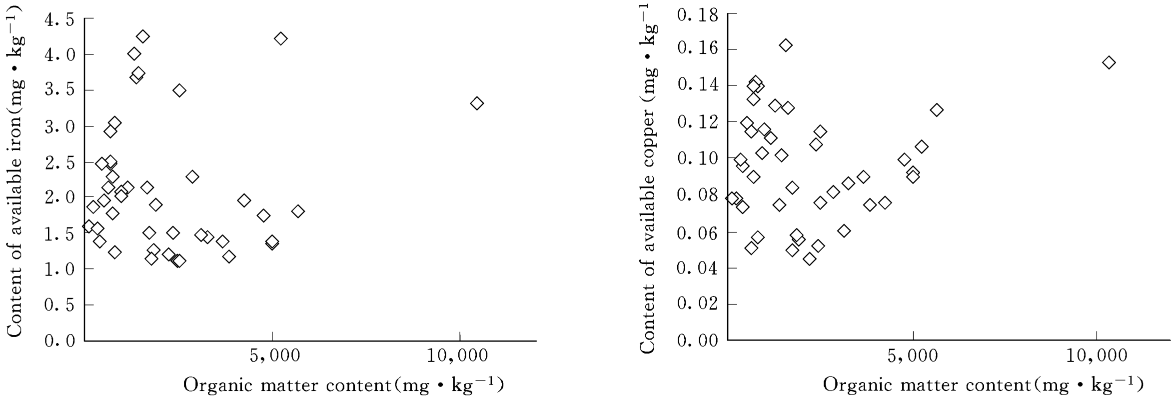
(d) Copper element

Fig. 3 Relationships between available trace elements and soil pH



(a) Zinc element

(b) Manganese element



(c) Iron element

(d) Copper element

Fig. 4 Relationships between available trace elements and soil total organic carbon (TOC) content

3.4.2 Relationship between soil organic matter content and available trace elements in soil

Soil organic carbon is an important component of soil, and has strong influences on its various physical, chemical, and ecological properties and on soil fertility. Soil organic matter can easily generate chelates with metal elements that become trapped in the surface soil. Table 3 shows that the content of all four trace elements had a positive correlation with organic matter content. In this case, the correlations for available zinc and copper were the strongest (Table 4). Past research (Zhu et al., 2009) has shown that the influence of organic matter on the availability of trace elements relates to the influence of organic matter itself and the adjustment of soil pH by its decomposition, and that the content of available trace elements, such as Fe, B and Cu, in soil has obvious positive relationships with organic matter content. These results are consistent with the findings of the present study. Therefore, as soil pH in the study area was predominantly alkaline, increasing soil organic matter content could be used to adjust the pH value of soil to increase the content of available trace elements and improve soil quality.

4 Conclusions

(1) The content of the available trace elements in the study soil were low. For different reclamation times, the content of iron showed high variation while copper, manganese, and zinc showed moderate variation. Under different reclamation modes on gangue dumping sites, the content of manganese showed high variation, copper and iron showed moderate variation, and zinc showed low variation.

(2) Different reclamation and treatment methods exerted an important influence on the content and distribution of available trace elements in the soil. The active artificial treatment activities improved the content of available trace elements in the soil as a whole, and the natural closure reclamation measure had a relatively weak effect.

Reclamation time exerted a large influence on the content and distribution of available trace elements in the soil, and an extended reclamation time was helpful for recovery and increasing the content of available trace elements in the soil. After soil reclamation of more than eight years, the content of available trace elements in the soil was close to or greater than that under natural conditions.

Under different treatment measures on gangue dumping sites, the mean content of trace elements showed a decreasing trend with increasing depth within the 0 – 40 cm zone, which indicates that the available copper, iron, manganese, and zinc moved slowly upwards as water evaporated from this soil layer depth range. Therefore, appropriate treatment measures should be selected during the initial stage of land reclamation to speed up the restoration and reconstruction of the soil environment. Covering gangue with soil, supported by suitable shrub and herb vegetation, could be used to effectively improve the content of available trace elements in the soil.

(3) The soil environment had a large influence on the available trace elements. The available trace elements in soil were negatively correlated with soil pH, and available copper and manganese demonstrated the strongest correlations. Soil organic matter content was positively correlated with the content of the trace elements in soil, and positively correlated with soil organic matter content; with available zinc and copper showing the strongest correlations.

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