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Characters and Influencing Factors of the Distribution of Cultivated Available Soil Fe, Mn, Cu and Zn in Xichang City, Sichuan Province, China

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Abstract

Exploring the spatial distribution of available soil micronutrients can provide a solid foundation for scientifically formulated fertilizer. We investigated the characteristics and influencing factors of available micronutrients in cultivated soil in Xichang City Sichuan Province, China. Soil samples (302) were collected from the cultivated soil, and the contents of available Fe, Mn, Cu and Zn were analyzed respectively. Descriptive statistics and geostatistics were used to analyze the data. The Kriging method was applied to calculate the unobserved points and was used to generate the contour map. The ANOVA was used to study the influencing factors. The mean values of available Fe, Mn, Cu and Zn were 37.62, 2.89, 3.47 and 14.80 $mg \cdot kg^{-1}$ respectively, which were at rich level or at medium level. The available micronutrient contents took on medium spatial correlation, affected by random factors and structural factors. The spatial distribution of the micronutrients was all belt-shaped as a whole and showed significant differences. Topology, parent materials, irrigation water, land use types, pH and organic matter contents had significant effect on the micronutrient availability to different extent.

Keywords: xichang city, soil, micronutrient, GIS, spatial distribution

1. Introduction

Soil is the main source of plant essential micronutrients, and micronutrient availability affects crop growth, yield and quality directly; and the same time, kinds of micronutrients are heavy metals which may cause soil metal pollution if they enter into soil excessively by irrigation, fertilizer or other patterns. Study on spatial distribution of available micronutrients and their influencing factors will provide the theoretical basis for the scientific and effective management of soil micronutrients and soil protection.

Under the case of adequate supplements of N, P and K, lacks one or more kinds of micronutrients will become the main obstacle factor limiting agricultural development. The deficiency of soil Fe, Mn, Cu and Zn was respectively 5.0, 21.3, 6.9 and 51.5 % in Chinese total arable land according to the second Chinese soil survey in the 1980s, and the lack of one or more kinds of soil micronutrient became a common phenomenon in many areas since 1980s (Lu et al., 1998). With the development of agricultural production and the increase of crop yield, the large number of application of chemical fertilizer, organic manure, sewage irrigation, and the rapid development of industrialization and urbanization caused the accumulation of soil micronutrients to different degree (Hu et al., 2008; Cai et al., 2010; Fässler et al., 2010; Li et al., 2010; Rodda et al., 2011; Otero et al., 2012). Farming system and rotation system also affect soil micronutrient availability (Wei et al., 2005). Geostatistics has been proved to be one of the most effective methods of analyzing the spatial variability of soil characteristics, and applied in the study of soil nutrients, including the total amount of soil micronutrients (Huang et al., 2008; Wang et al., 2009; Kheir et al., 2010; Walke et al., 2012).Although only available micronutrients are directly absorbed by plant. In recent years, the study of available micronutrient has attracted more and more attention (Zhang et al., 2005; Bityutskii et al., 2012) .However, there are few available research that has focused on the spatial variability of the available soil micronutrients using geostatistical approaches and their influenced factors, especially in southwest of China.

The objectives of this study were to: (i) investigate the spatial distribution of available soil micronutrients in

Xichang City Sichuan Province, (ii) generate contour maps of available micronutrient contents using geostatistical approaches, and (iii) analyze the relationship between available soil micronutrient contents and topography, parent materials, irrigation water, land use types and organic matter contents.

2. Materials and Methods

2.1 Study Sites Description

Xichang City is located in the Liangpan district of southwestern Sichuan Province of China (27°′32′-28°10′N, 101°46′-102°25′E). The area covers 2650 km^2. The topography consists of plains and middle-sized mountains. The terrain slopes from north to south with elevations ranging between 1160 and 3322 m. The city has a temperate continental monsoon climate. The mean annual mean temperature is 17℃. The annual frost-free period is 270 days. The mean annual precipitation is 1080 mm, most of which is received in summer and about 60% is received at night. The soil types are paddy soil and red soil. The parent materials of the soil are mainly Quaternary yellow-red alluvial, Quaternary purple alluvium, Permian igneous rocks alluvium and river alluvium. The city is a major production base for rice, vegetables, tobacco and fruit.

2.2 Soil Sampling and Soil Analysis

A total of 302 sampling points were chosed in Xichang City according to the program for soil testing and fertilization in China. The study used soil maps of the Chinese nationwide second soil survey (1980) and land-use maps (2005) (choosing only agricultural land, including farmland and garden) to fold and identify the crossed point, then sampled the layered sample in terms of the soil types (Figure 1). All samples were collected within a area of 1 hm^2 surrounding a specific sampling location and then mixed respectively. Every sampling site was located precisely by global positioning system (GPS). We take 1 kg soil sample per sampling site from the mixed samples to analyze available soil micronutrient content by quartile method. All samples were air-dried, and 500 g was taken, ground, and bagged. The available soil micronutrient contents were measured using diethylene triamine pentaacetic acid (DTPA) solution for extraction and atomic absorption spectrophotometry for detection. Soil organic matter (SOM) was analyzed using potassium dichromate-wet combustion method. pH was extracted with the water and soil ration of 2.5:1 and measured by pH equipment. At the same time, we investigated the topography, parent materials, irrigation water, land use type and other aspects in the soil sampling field.

Figure 1. Map of sampling sites in Xichang City

2.3 Data Processing

K-S test of SPSS (v. 16.0) was used to calculate the descriptive statistics of the available soil micronutrients. Analysis of variance (ANOVA) was used to study the effects of different factors on the soil micronutrient content. The correlation of soil organic matter (SOM) or pH with the soil micronutrient content was analyzed by Excel (v. 2003). ArcGIS 9.2 software was used to carry out the geostatistics analysis and to calculate and draw relevant maps. Least significant difference (LSD) was used to compare the average number. The principles and methods of geostatistics refer to the relevant literature (Wang, 1999).

3. Results

3.1 The Descriptive Statistics of the Available Micronutrient Contents in Xichang City

The kurtosis and skewness values in Table 1 showed that the available Fe and Cu in Xichang City were skewed distributed. The available Mn was normally distributed. The available Zn was log normally distributed. The coefficients of variation (CV) of available Zn, Cu and Mn were over 35 % and belong to the strong degree of variability. However, the CV of available Fe was 17.94% and belongs to the middle degree of variation (Lei et al., 1988). The CV of available Zn was the highest in the four micronutrients, and it showed that available Zn was mainly influenced by human activities. In table 1, the mean values of the available Fe, Mn, Cu and Zn were 37.62, 14.80, 2.89 and 3.47 mg kg^{-1} respectively. According to the grading standards of the second Chinese soil survey (Gan et al., 2008), the mean values of the available Fe, Cu and Zn belong to the rich level, and Mn belong to the middle level.

Table 1. The descriptive statistics of the available soil micronutrient contents in Xichang City ($mg \cdot kg^{-1}$)

Variables	Distribution	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	CV (%)
Available Fe	Skewed	6.90	48.13	37.62	6.75	-1.837	3.919	17.94
Available Mn	Normal	2.01	25.68	14.80	7.07	0.028	-1.244	47.77
Available Cu	Skewed	0.10	28.99	2.89	2.45	5.520	49.616	84.78
Available Zn	lgN	0.07	21.62	3.47	3.30	-0.412*	1.260*	95.10

lgN: Log-normal SD: standard deviation CV: coefficient of variation

* represents the number has been converted to a logarithmic

3.2 Spatial Structure Analysis of Available Soil Micronutrient Contents in Xichang City

The selection of theoretical semivariance models and the cross-validation of model parameters can refer to the revant literature (Hou et al., 1998; Hu et al., 1999), and results are shown in Table 2. The errors of prediction (ME) of available micronutrient contents ranged from -0.010 to 0.114. It showed that the theoretical models that were chosen preferably reflected the spatial structure character of soil micronutrients in the city. Available Mn, Cu and Zn were fit with the exponential model, and available Fe was fit with the spherical model.

Table 2. The geostatistical parameters of the available soil micronutrient contents in Xichang City

Variables	Model	Nugget (C_0)	Sill	Co/Sill (%)	Azimuth of axis (°)	Range (km)		Prediction error	
						Axis	Short axis	ME	RMSSE
Available Fe	Spherical	29.49	56.64	52.07	27.1	63.91	32.81	-0.034	1.009
Available Mn	Exponential	28.63	40.26	71.12	36.8	30.76	15.58	0.045	0.969
Available Cu	Exponential	2.87	4.99	36.52	278.7	65.45	60.68	-0.010	1.209
Available Zn	Exponential	0.53	0.79	66.35	68.5	50.30	21.23	0.114	0.622

ME means error of prediction; RMSSE means root error of standardized square mean

In this study, the C_0/sill rations of the micronutrients ranged from 36.52 % in the available Cu to 71.12 % in the available Mn, which showed moderate spatial correlation and affected by structural factors and random factors (Table 2).

The range reflected the autocorrelation range of variables. From Table 2, the range of four kinds of available micronutrients in Xichang City was in the order of available Cu > Fe > Zn > Mn. It was seen that the available Cu, Fe and Zn had spatial correlation in this area, which were affected by the structural factors, such as soil parent material, topography etc. The range of Mn was small. It was seen that the effect of random factors significantly influenced the available Mn, and led to its correlation in a higher distance range.

3.3 Spatial Distribution Features of Available Soil Micronutrients in Xichang City

According to the theoretical semivariance models, the contour maps were generated using Kring-interpolated method (Figure 2).

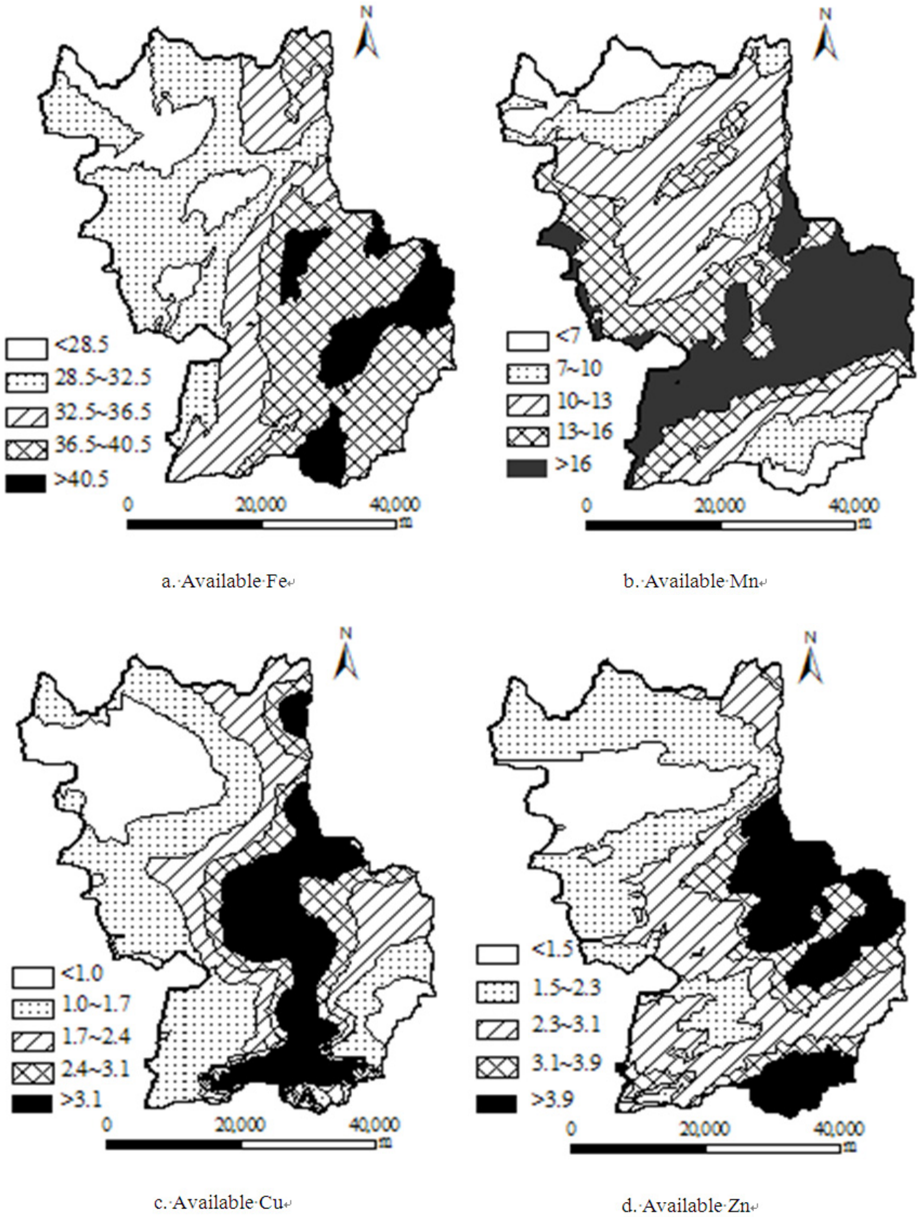

Figure 2. Contour maps of the available soil micronutrient contents in Xichang City (mg·kg^{-1})

It was seen from contour map of the available soil Fe contents in XiChang City (Figure 2 a) that the available soil Fe contents were zonal distribution on the whole, and part of available soil Fe contents were patchy distribution. The available soil Fe contents decreased from southeast to northwest, and were a medium level overall. The highest values (> 40.5 mg kg^{-1}) were mainly in the southeast region such as Chuanxing Town, Daxing Village, Hainan Village, Xixi Village and Huangshui Village. The higher values (36.5-40.5 mg kg^{-1}) were mainly along Anning Town, Gaocao Village and southeastern of Aqi Village. The intermediate values (32.5-36.5 mg kg^{-1}) were mainly along Kaiyuan Village, Mopan Village and Jiedi Village. The lower values (28.5-32.5 mg kg^{-1}) were mainly in Baima Village and Minsheng Village. The lowest value (< 28.5 mg kg^{-1}) were mainly in the northwest region, along Yinchang Village, Minsheng Village and Baima Village.

The available soil Mn contents in Xichang City were very high as a whole, and were zonal distribution on the whole which decreased from the high value areas located in the central region and the southern region to southeast area and northwest area (Figure 2 b). The highest values (> 16 mg kg^{-1}) were mainly along Gaoxian Village, Yulong Village and Mopan Village. The higher values (13-16 mg kg^{-1}) were mainly in the areas surrounding the highest value areas; The intermediate values (10-13 mg kg^{-1}) were mainly in the central region and the northern region such as Xiangshui Village and Baima Village, followed by Huangshui Village lacated in the southern region. The lower values (7-10 mg kg^{-1}) were mainly concentrated in the junction of Langhuan Village, Xiangshui Village and Baru Village. The lowest values (< 7 mg kg^{-1}) were mainly in the northern areas such as Yinchang Village, northern of Minsheng Village and in the southern areas such as south of Huangshui Village.

It was seen from contour map of the available soil Cu contents in XiChang City (Figure 2 c) that the available soil Cu contents were zonal distribution, and decreased from the central high-value areas to the southeast areas and the northwest areas. The highest values (> 3.1 mg kg^{-1}) were mainly along Aning Town, Gaocao Village and Aqi Village. The higher values (2.4-3.1 mg kg^{-1}) were located in the vicinity of the highest values around. The lowest values (<1.0 mg kg^{-1}) were mainly distributed in the northwest Yinchang Village and the southeast Anha Town.

The available soil Zn contents in XiChang City were zonal distribution on the whole, and some parts were patchy distribution (Figure 2 d). The highest values (> 3.9 mg kg^{-1}) were mainly in the eastern areas along Aning Town, Madao Town and Daxing Village, followed by the southern area of Huangshui Village. The higher values (3.1-3.9 mg kg^{-1}) were mainly in the highest value around. Intermediate values were mainly distributed in the middle and the lower part of the city, such as Kaiyuan Village, Mopan Village and Qiaodi Village. The lower values (1.5-2.3 mg kg^{-1}) were mainly distributed in the north area, such as Yinchang Village and Minsheng Village, and the Midwest area, such as Baru Village. The lowest values (<1.5 mg kg^{-1}) areas were mainly located in the northwest area, such as Baima Village.

3.4 Influencing Factors on the Available Soil Micronutrient Contents in Xichang City

3.4.1 Topography

Topography effect the exchange of material and energy between the soil and the environment, which lead to the differences in soil fertility (Zhang, 2002; Pan, 2004). Terrains had a significant effect on the available soil micronutrient contents (Table 3). The available Fe content of the plain soil was 38.39 mg kg^{-1}, which was significantly higher than that of the hills soil ($P < 0.01$) and the mountain soil ($P < 0.01$). The available Mn content decreased in the order hills > plain > mountains, but the effect of topography was not significant. The available Cu content of the plain soil was two times that of the hills soil and the mountains soil, which was significantly higher than that of the both soil ($P < 0.01$). The available Zn of the plain soil was 48 % higher than that of the hills soil, 63% higher than that of the mountains soil; there was a significant difference between the plain soil and the mountains soil ($P < 0.05$).

Table 3. Statistical results of the available soil micronutrient contents under different terrains in Xichang City (mg·kg^{-1})

Terrain	Sample points	Available Fe	Available Mn	Available Cu	Available Zn
Plain	245	38.39aA	14.95aA	3.20aA	3.71aA
Hills	19	33.85 bB	16.04 aA	1.56 bB	2.51abA
Mountains	38	34.52 bB	13.19aA	1.55 bB	2.28bA

Uppercase letter means within a column followed by a different lowercase letter are significantly different at P<0.05 (ANOVA). Lowercase letter means within a column followed by a different uppercase letter are significantly different at P<0.01 (ANOVA).

3.4.2 Parent Material

Parent materials had a significant effect on the available soil micronutrient contents (Table 4). The available Fe content decreased in the order Permian igneous rocks alluvium > Quaternary purple alluvium > Quaternary yellow-red alluvial > river alluvium > Jurassic purple rock slope sediments and residual materials; the former three materials were significantly higher than the last one ($P < 0.01$); there was no significant difference between the former three materials. The available Mn content of the Quaternary purple alluvium soil was 20.51 mg kg^{-1}, which was significantly higher than that of the other soil ($P < 0.01$); the available Mn content of the Permian igneous rocks alluvium soil was the lowest, only 10.19 mg kg^{-1}. The available Cu content decreased in the order Permian igneous rocks alluvium > Quaternary yellow-red alluvial > Quaternary purple alluvium > river alluvium > Jurassic purple rock slope sediments and residual materials; the first material was significantly higher than the last four materials ($P < 0.01$).

Table 4. Statistical results of the available micronutrient contents under different parent materials in Xichang City (mg·kg^{-1})

Parent material	Sample points	Available Fe	Available Mn	Available Cu	Available Zn
Quaternary yellow-red alluvial	148	37.86abcA	14.12bB	3.17bB	3.88aA
Quaternary purple alluvium	39	38.43abA	20.51aA	2.48cB	4.08aA
Permian igneous rocks alluvium	27	39.57aA	10.19cC	4.69aA	3.84abA
River alluvium	58	37.50bcAB	14.71bB	2.21cC	2.44bA
Jurassic purple rock slope sediments and residual materials	30	33.82cB	15.02bB	1.76cC	2.35bA

Uppercase letter means within a column followed by a different lowercase letter are significantly different at $P<0.05$ (ANOVA). Lowercase letter means within a column followed by a different uppercase letter are significantly different at $P<0.01$ (ANOVA).

3.4.3 Irrigation Water

Irrigation water had effect on soil micronutrient contents (Hu et al., 2008; Huang et al., 2008). It was seen that available soil Fe, Mn, Cu and Zn contents showed some differences in the river as irrigation, stream as irrigation, lake / pond / reservoir as irrigation and no irrigation from Table 5. Available Fe contents of lake / pond / reservoir as irrigation (41.66 mg kg^{-1}) and river as irrigation (38.46 mg kg^{-1}) were significantly higher than that of no irrigation at $P < 0.01$, which was only 32.66 mg kg^{-1}. Available Fe content of stream as irrigation was medium, and had no significant difference with the other three kinds of irrigation. Available Mn content of stream as irrigation was the highest, which was 16.39 mg kg^{-1}. Available Mn content of no irrigation was the least, which was only 12.70 mg kg^{-1} and lower significantly than that of stream as irrigation at $P < 0.05$. There were great differences in the four kinds of irrigation on available Cu content. Available Cu content of lake / pond / reservoir as irrigation was the highest, which was 5.76 mg kg^{-1} and was 6.13 times of that of no irrigation. Available Cu contents of river as irrigation and stream as irrigation were in the middle, and there was no significant difference between them, but they were both higher significantly than that of no irrigation. Available Zn content of no irrigation was 2.04 mg kg^{-1}, which was the least and higher significantly than that of river irrigation (3.78 mg kg^{-1}) at $P < 0.01$. Available Zn contents of lake / pond / reservoir as irrigation (2.64 mg kg^{-1}) and stream as irrigation (2.56 mg kg^{-1}) were higher significantly than that of river as irrigation at $P < 0.05$. In general, Available soil Fe, Mn, Cu and Zn contents of lake / pond / reservoir as irrigation water were the highest or higher than other kinds of irrigation, and available soil Fe, Mn, Cu, Zn contents of no irrigation were the least.

Table 5. Statistical results of the available micronutrient contents by different irrigation water in Xichang City (mg·kg^{-1})

Irrigation water	Sample points	Available Fe	Available Mn	Available Cu	Available Zn
River	238	38.46aA	14.80abA	3.13bAB	3.78aA
Stream	32	35.13abAB	16.39aA	2.43bB	2.56bAB
Lake / pond / reservoir	4	41.66 aA	16.32abA	5.76aA	2.64abAB
Unirrigated	28	32.66bB	12.70bA	0.94cC	2.04bB

3.4.4 Land Use Type

Land use type is a comprehensive reflection of natural conditions and human activities. There were some differences in available soil micronutrient contents of different land use types (Table 6). Available Mn and Zn contents had no significant difference in the three kinds of land use types in the studied area, indicating that land use type had less effect on available soil Mn, Zn contents in Xichang city. Available Fe content under dry land-paddy field rotation was 38.81 mg kg^{-1} and was significantly higher than that of dry land use (31.68 mg kg^{-1}) at $P < 0.01$. Available Cu content under paddy field was the highest, which was 4.80 mg kg^{-1} and was significantly higher than that of dry land-paddy field rotation (3.10 mg kg^{-1}) at $P < 0.01$.Moreover, Available Cu content under dry land-paddy field rotation was significantly higher than that of dry land (1.55 mg kg^{-1}) at $P < 0.01$, indicating that available soil Cu content was affected by land use type obviously.

Table 6. Statistical results of the available micronutrient contents under different land use types in Xichang City ($mg{\cdot}kg^{-1}$)

Land use type	Sample points	Available Fe	Available Mn	Available Cu	Available Zn
Dry land	49	31.68bB	13.50aA	1.55Cc	2.73aA
Paddy field	7	37.51aAB	13.30aA	4.80Aa	2.47aA
Dry land-paddy field rotation	246	38.81aA	15.10aA	3.10Bb	3.65aA

3.4.5 pH and Organic Matter Content

Soil organic matter contents were significantly correlated with the available soil Fe, Mn, Cu and Zn contents at $P<0.05$ or $P<0.01$ (Table 7). Soil pH was significantly correlated with available soil Fe, Mn contents ($P<0.01$). These results demonstrate that organic matter and pH affect the availability of soil micronutrients. Our results agree with those of Zhou et al. (2004) and Zhu et al. (2007) who observed that the availability of soil micronutrients increased as the soil organic matter content increased. Yu et al. (2002) and Zhang et al. (2005) reported that the availability of soil micronutrients increased as pH decreased. Similarly, we observed that Fe availability increased as pH decreased. However, we observed that Mn availability decreased and Cu and Zn availability did not change as pH decreased. One explanation is that the availability of micronutrients was induced by human activities.

Table 7. Correlation coefficient of available soil Fe, Mn, Cu, Zn contents and pH or Organic matter contents

Item	Available Fe	Available Mn	Available Cu	Available Zn
pH	-0.370^{**}	0.401^{**}	-0.092	-0.052
Organic matter	0.373^{**}	0.143^{*}	0.150^{**}	0.198^{*}

* means having correlation at $P < 0.05$; ** means having correlation at $P < 0.01$

4. Conclusion

1) Statistical analysis showed that average contents of available cultivated soil Fe, Mn, Cu and Zn were 37.62, 14.80, 2.89 and 3.47 mg kg^{-1} respectively in Xichang City. Available Mn was normal distribution, and available Zn was lognormal distribution, and available Fe and Cu were skewed distribution. Coefficient variation of available Fe contents was 17.97%, which was moderate variability; Coefficient variations of the other three kinds of micronutrient contents were all greater than 35% and were high variability. In addition, available Mn was medium level, and the other three kinds of micronutrient were rich level.

2) Geostatistical analysis showed that the best model of available Fe was spherical model, and the best model of other three kinds of micronutrient was exponential model. The ratios of nugget and sill were 36.52% to 71.12%, which exhibited moderate spatial correlation, indicating that available micronutrient content was affected by structural factors and random factors.

3) Influcing factor analysis showed that topography, soil parent material, irrigation water, land use type, pH and organic matter content could all affect the available soil Fe, Mn and Cu, Zn content.

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