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STUDY ON SOIL QUALITY CHARACTERISTICS AND SPATIAL DIFFERENCE OF THE WALNUT PRODUCING AREA IN HUBEI PROVINCE OF CHINA

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ABSTRACT

To study the soil pH value, quality characteristics of organic matter, and available elements in intensive cultivation of walnut orchards in different areas of Hubei Province, and to provide the scientific basis for the soil management of walnut orchards in different areas, the distribution frequency and correlation of the pH value, organic matter and alkalescence N, available P, available K, available Ca, available Mg, available S,available Fe, available Zn, andavailable B in 135 walnut orchards from 6 walnut production areas in Hubei Province were analyzed by a typical sampling method. The differences and main sources of comprehensive fertility coefficients in different production areas were also analyzed. The distribution frequency of organic matter and available elements in walnut orchards were unbalanced. Available P was the most skewed with 55.67%. The soil organic matter content was significantly correlated with the contents of alkalescence N, available P, available K, available Mg, available Fe, available Zn and available B. The comprehensive soil fertility coefficient ranged from 1.21 to 1.84, with an average of 1.52, which was the general fertility level. The maximum limiting factor of soil fertility was available S, followed by alkalescence N and available P. There were significant differences in comprehensive soil fertility among different walnut production areas. 92.67% of the differences came from within the production areas, and 7.33% from between production areas. The highest differentiation coefficients were available K and available P, which were 26.20% and 10.79%, respectively. The contents of alkalescence N and P were elements that affect the soil fertility of walnut production areas in Hubei Province. And the skew amounts and differentiation coefficients of P were larger than other elements. In view of the significant positive correlation between organic matter content and most soil elements, in order to improve the comprehensive soil fertility, it is suggested that soil management should focus on increasing soil organic matter, the application of phosphorus fertilizer and improving the availability of phosphorus.

Keywords: Walnut, Soil, Comprehensive fertility coefficient, Spatial difference.

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INTRODUCTION

The forest industry is important for the implementation of the strategic adjustment of the rural industrial structure and key forestry projects in China. Walnut (*Juglans regia* L.) is the most economically important member of the Juglandaceae family (Milatovi *et al*., 2020). It is widely cultivated in the temperate and subtropical regions of the Northern Hemisphere, for its edible nuts and high-quality wood. It is one of the four main nuts consumed worldwide with abundant nutrients, such as fats, proteins, carbohydrates, vitamins, and minerals (Fang *et al*., 2019, 2021). As one of the most important traditional economic forest tree species in China, walnut is cultivated in 1046 counties and cities of 27 provinces (regions and cities) in China, and its cultivated area has annually increased by 10% in recent years (Wu *et al*., 2009; Leslie *et al*., 2015).

The soil nutrient content has an important effect on tree biomass accumulation (Gauthier and Jacobs, 2011). More and more attention has been paid to research on soil quality and soil fertility of forests (Rosati *et al*., 2006). The nutrient demand of walnut trees are tall high. Ensuring a nutrient supply is key to obtaining high quality, high yield, and higher economic value. As a rapidly growing tree species in China, it is very important to study the soil quality characteristics and nutrient status of walnut orchards in walnut production areas for site selection and management. A large number of studies have been carried out on the annual changes of walnut leaves, fruit, tree mineral nutrition, and walnut orchard soil nutrients (Asma, 2012; Cosmulescu and Trandafir, 2014; Ma *et al*., 2019; Ozdemir *et al*., 2019). However, the scale of walnut cultivation has rapidly expanded, and many walnut cultivation areas have not carried out an adaptability evaluation, resulting in poor walnut growth, low yield, serious diseases and insect pests, and other problems (Gharibzahedi *et al*., 2014; Culumber *et al*., 2019; Mora *et al*., 2019; Qiao *et al*., 2020). Therefore, it is very important to carry out regional evaluations of walnut soil nutrient quality, which is rarely reported at present.

Hubei Province is located at the intersection of the first-grade plane lowlands in eastern China and the second-grade plateau mountains in western China, and is the watershed of the north-south climate and the cross zone of the natural environment (Ponder, 2004). As China's traditional walnut producing area and poverty-alleviation development zone is in Qinling and Daba Mountains, the scale of intensive walnut cultivation has rapidly developed, from less than 10,000 hm^2 in 1996 to about 170,000 hm^2 at present, mainly concentrated in the mountainous area of western Hubei Province (Yang *et al*., 2014; Lu *et al*., 2016). With the rapid expansion of the scale of cultivation, the site selection of many walnut orchards were not scientific enough. And the backward soil management resulted backward, with serious diseases and insect pests, low yield and low efficiency being common. This research studied the soil quality characteristics and spatial soil fertility differences of typical walnut orchards in Shiyan City, Enshi Autonomous Prefecture, Yichang City, Xiangyang City, Suizhou City, and Jingmen City in Hubei Province, where intensive walnut cultivation is concentrated, in order to provide a scientific basis for the selection of walnut orchard sites and soil management in this and its surrounding areas. This should give walnut orchards high-yield and high-efficiency in order to promote the realization of the walnut poverty alleviation role.

MATERIALS AND METHODS

Overview of the study area: Hubei Province is located in the center of China, at 29°05'~ 33°20' north latitude, 108°21'~ 116°07' East longitude. Most of the province has a humid subtropical monsoon climate, with an annual average temperature of 15-17℃, average precipitation of 800-1600 mm, and annual average sunshine duration of 1100-2150 h. The walnut scale in the province is about 170,000 hm^2, with 98,000 t yield. The sampling area of this study is shown in Table 1.

Table 1. Survey of sample plots.

Areas	Soil profile number	Altitude/m	Proportion of gravel (>5mm) /%	Annual temperature/℃	Annual rainfall/mm	Annual sunshine hours/h
Shiyan	63	541.31±49.57c	5.75±0.55d	15.4	833.1	1989.3
Xiangyang	39	822.10±78.54a	2.42±0.25e	15.3	845.6	1825.1
Suizhou	11	140.00±19.00d	10.53±1.32c	15.6	962.6	2082.0
Enshi	6	880.00±92.35a	29.22±1.50a	16.3	1439.4	1295.3
Yichang	11	653.73±22.97b	2.06±0.10e	16.8	1031.0	1696.7
Jingmen	5	110.00±10.00d	22.94±1.86b	15.9	993.7	2035.5

Note: Data (means ± SD, n = 4) followed by different letters in the column indicate significant differences (P≤ 0.05) between treatments.

Sample collection and processing: 135 representative walnut orchards were selected from 16 counties (districts) of the 6 main walnut production areas in Hubei Province, with each walnut orchard being more than 3.3 hm^2. Soil samples were collected from 10 to 15 points in 5 directions in each walnut orchard, with a depth from 0 to 40cm, and then fully mixed. 1kg of soil was taken by the quartering method as soil samples to be tested. Refer to Lu *et al*. (2016) for the soil sample treatment methods.

Measurement indexes and methods: The determination of organic matter content was according to the LY/T1237-1999 method, alkalescence N, available P and available K were according to the LY/T1228-2015 method, the pH value was according to the LY/T1239-199 method, the available Ca and available Mg were according to the LY/T1245-1999 method. The available S was according to the LY/T1265-1999 method, the available Fe was according to the LY/T1262-1999 method, the available Zn was according to the LY/T1261-1999 method, and the available B was according to the LY/T1258-1999 method.

The data analysis: According to the results of the second national soil census, the soil nutrient classification standards of this study were established (Table 2). X was the measured value of the soil attribute, and Xa, Xc, and Xp were the classification standards of soil attributes. In this study, the method of the fertility coefficient was used to standardize the data. The formula of fertility coefficient was based on Su and Zhu (2012) (Table 3).

$$IFI = \frac{\sqrt{\frac{IFI_f^2 - IFI^2_{fmin}}{2}}}{n}(n-1)$$

Where IFI is the comprehensive soil fertility coefficient, IFI_f is the average value of the soil fertility coefficient of each attribute, IFI_{fmin} is the minimum value of the soil fertility coefficient, and (n- 1)/n is the modified term.

IFI_f=X/Xa when X≤Xa;

When Xa≤X≤Xc, IFI_f=1+(X-Xa)/(Xc-Xa);

When Xc≤X≤Xp, IFI_f=2+(X-Xc)/(Xp-Xc)

When X≥Xp, IFI_f=3

The method of Su and Zhu (2012) was used to calculate the nutrient skew (P), and EXCEL and SAS8.1 were used for multiple data comparison and nested analysis of variance.

Table 2. Classification standard values of soil nutrients.

Soil properties	Xa	Xc	Xp
pH value	4.5/9	5.5/8	6.5/7
Organic matter / $g{\cdot}kg^{-1}$	10	20	30
Alkalescence N / $mg{\cdot}kg^{-1}$	60	120	180
Available P / $mg{\cdot}kg^{-1}$	5	10	20
Available K / $mg{\cdot}kg^{-1}$	50	100	200
Available Ca / $mg{\cdot}kg^{-1}$	300	500	700
Available Mg / $mg{\cdot}kg^{-1}$	50	100	200
Available S $mg{\cdot}kg^{-1}$	0	16	30
Available Fe / $mg{\cdot}kg^{-1}$	2.5	4.5	10
Available Zn / $mg{\cdot}kg^{-1}$	0.3	0.5	1
Available B / $mg{\cdot}kg^{-1}$	0.2	0.5	1

Table 3. Classification of soil fertility.

Items	Fertility level			
	First	Second	Third	Fourth
Fertility comprehensive coefficient range	≥2.7	2.7~1.8	1.8~0.9	≤0.9
Fertility evaluation	Very fertile	Fertile	General	Poor

RESULTS

Distribution of soil pH, organic matter, and available elements in walnut production areas: Fig. 1 shows the distribution frequency of pH, organic matter and available elements in the soil of walnut orchards in the province. According to the $\chi 2$ test of distribution function, except for the pH value, the distribution frequency of organic matter and available elements in walnut orchards in the province were non-normal, indicating that there was a large amount of human interference in the process of site selection and soil management. The maximum deviation degree of available P in walnut orchard soil was 55.67%, which because of that P is easily adsorbed and fixed in the soil (Su and Zhu, 2012). At the same time, soil available P content in more than 60% of orchards were low, indicating that the application of P fertilizer will effectively improve the overall forest fertility.

Relationships among soil pH, organic matter, and available elements in walnut production areas: The correlation analysis of soil pH, organic matter, and available elements in 135 walnut orchards showed that there were extensive correlations among soil pH, organic matter, and available elements. And the organic matter content was significantly correlated with all factors except pH, available Ca, and available S (Table 4). The results showed that increasing the soil organic matter content had a significant effect on improving soil fertility. In addition, there were significant correlations between N, P, and K, as well as between medium and trace elements, indicating that the nutrient balance should be considered in walnut orchard fertilization to improve the comprehensive fertility.

Comprehensive evaluation of fertility in different walnut production areas:

Comprehensive fertility of walnut producing areas in the whole province: The comprehensive fertility coefficient IFI (Table 5) of walnut production areas in the province ranged from 1.21 to 1.84, with an average of 1.52, indicating a general fertility level. The maximum limiting factor that affected the improvement of the comprehensive fertility coefficient was available S, and the partial fertility coefficient was only 0.9, followed by available P, available B, and alkalescence N. The fertility coefficients of available Fe, available Ca, and available Zn were 2.99, 2.93 and 2.90, respectively, which were non-limiting factors. Therefore, in future production management, in addition to increasing the application of large amounts of elements N and P, the application of medium element S and trace element B should also be considered in order to improve soil productivity.

Soil fertility varies in different walnut production areas: As shown in Table 5, there were extremely significant differences in soil available P, available K and available Mg, and significant differences in soil available B, and the comprehensive fertility coefficient in different walnut production areas, indicating that there was a certain spatial specificity in soil fertility in different walnut production areas.

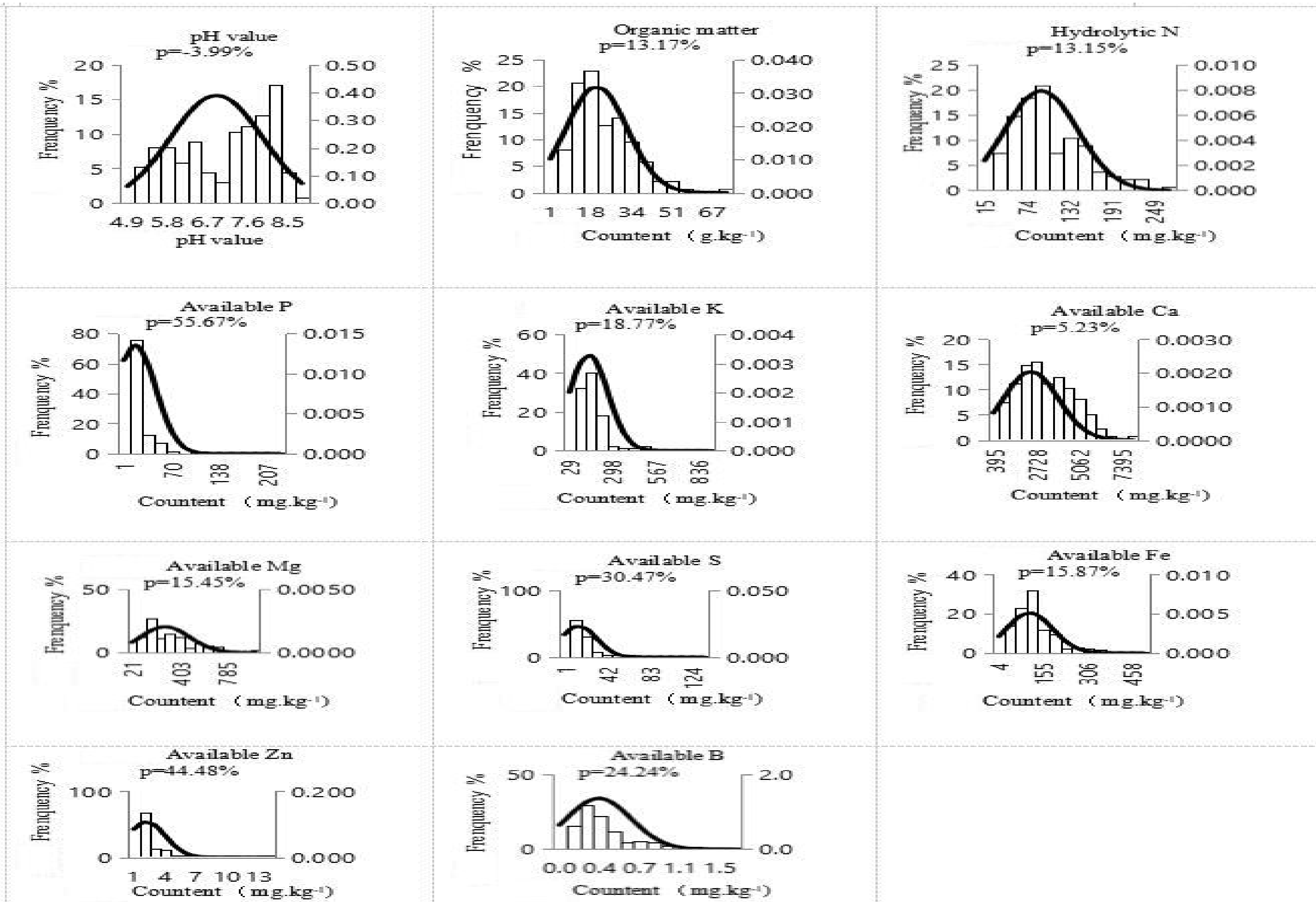

Fig. 1. Distribution of values of walnut orchard soil nutrients content.

Table 4. Correlation coefficients between Ph value, Organic matter, and soil nutrient elements (n=135).

	pH value	Organic matter	Alkalescence N	Available P	Available K	Available Ca	Available Mg	Available S	Available Fe	Available Zn	Available B
pH value	1										
Organic matter	0.06188	1									
Alkalescence N	-0.11605	0.7928**	1								
Available P	-0.02208	0.22744**	0.35048**	1							
Available K	0.25176**	0.24180**	0.27825**	0.69507**	1						
Available Ca	0.79189**	0.00903	-0.17702*	0.09236	0.15855	1					
Available Mg	-0.04563	-0.29662*	-0.19771*	0.02459	0.10051	-0.06526	1				
Available S	-0.01787	-0.05403	0.02595	0.50909**	0.32876**	0.07141	-0.02856	1			
Available Fe	-0.10263	0.46784**	0.54495**	0.60633**	0.50732**	-0.26351**	-0.03556	-0.02187	1		
Available Zn	0.28445**	0.42593**	0.41786**	0.51851**	0.49629**	0.13289	-0.03753	0.15958	0.52567**	1	
Available B	0.24765**	0.64267**	0.62284**	0.42531**	0.56843**	0.11977	-0.14916	0.19877*	0.4371**	0.67683**	1

*means significant correlation ($P \le 0.05$), ** means extremely significant correlation ($p \le 0.01$)

Table 5. Comprehensive evaluation of soil fertility in different walnut production areas.

Areas	pH value	Organic matter / g·kg^{-1}	Alkalescence N / mg·kg^{-1}	Available P / mg·kg^{-1}	Available K / mg·kg^{-1}	Available Ca / mg·kg^{-1}	Available Mg / mg·kg^{-1}	Available S / mg·kg^{-1}	Available Fe / mg·kg^{-1}	Available Zn / mg·kg^{-1}	Available B / mg·kg^{-1}	IFI
Shiyan	2.20±0.69 a	1.81±0.99 a	1.51±0.85 a	1.76±1.19 A	2.38±0.57 A	3.00±0 a	2.68±0.50 A	0.87±0.68 a	2.94±0.22 a	2.88±0.33 a	1.48±0.85 a	1.57±0.47 a
Xiangyang	2.46±0.45 a	1.64±0.70 a	1.46±0.62 a	1.05±0.87 B	2.11±0.50 B	2.98±0.13 a	2.63±0.49 A	0.88±0.51 a	3．00±0 a	2.93±0.17 a	1.29±0.56 a	1.53±0.28 a
Suizhou	2.29±0.45 a	1.70±0.81 a	1.33±0.65 a	1.20±0.96 A	1.32±0.70 C	2.86±0.46 a	2.84±0.54 A	0.31±0.19 a	3.00±0 a	2.72±0.59 a	0.83±0.63 b	1.21±0.37 b
Enshi	2.36±0.30 a	2.64±0.57 a	2.07±0.37 a	1.66±1.13 A	1.89±0.48 B	2.81±0.47 a	1.86±1.06 B	1.29±1.34 a	3.00±0 a	2.89±0.27 a	1.91±0.62 a	1.84±0.56 a
Yichang	2.28±0.43 a	2.00±0.67 a	1.43±0.49 a	1.57±1.14 A	2.07±0.33 AB	2.91±0.32 a	2.43±0.69 A	1.02±0.78 a	3.00±0 a	2.98±0.05 a	1.24±0.31 ab	1.58±0.28 a
Jingmen	2.46±0.41 a	2.21±0.97 a	1.94±0.89 a	0.47±0.08 B	1.93±0.87 AB	3.00±0 a	2.92±0.19 A	1.02±1.13 a	3.00±0 a	2.97±0.04 a	1.22±0.48 ab	1.41±0.25 a
Total	2.34±0.45	2.00±0.78	1.62±0.65	1.29±0.9	1.95±0.58	2.93±0.23	2.56±0.58	0.9±0.77	2.99±0.04	2.90±0.24	1.33±0.57	1.52±0.37

Capital letters mean extremely significant differences among different areas ($P \le 0.01$), and lowercase letters mean significant differences among different areas ($P \le 0.05$).

The origin of the soil fertility difference in different walnut production areas: Based on nested variance analysis of soil fertility coefficients of pH, organic matter, and available elements in the six walnut production areas, the proportion of each component to the total variation was calculated (Table 6). The variance component within production areas accounted for 92.67% of the total variation, and the variance component between production areas accounted for 7.33%. The results indicated that the main source of the soil fertility difference in different walnut production areas was come from the difference within production areas. The differentiation coefficients of 11 factors of fertility among production areas ranged from 0.04% to 26.20%, with an average of 7.33%. The highest differentiation coefficient was available K followed by available P, with a distribution of 26.20% and 10.79%, respectively, and the lowest differentiation coefficient was effective Fe, with a differentiation coefficient of 0.04%.

Table 6. Difference of component and differentiation coefficient of soil pH, organic matter, and available elements fertility coefficient in different walnut production areas.

Soil properties	Difference portion		Percentage of difference portion%		Differentiation coefficient
	Among areas	Within areas	Among areas	Within areas	
pH value	0.0019	0.3270	0.5757	99.4243	0.5757
Organic matter	0.0301	0.7444	3.8835	96.1165	3.8835
Alkalescence N	0.0063	0.5405	1.1599	98.8401	1.1599
Available P	0.1367	1.1304	10.7874	89.2126	10.7874
Available K	0.1106	0.3115	26.2046	73.7954	26.2046
Available Ca	0.0023	0.0375	5.7149	94.2851	5.7149
Available Mg	0.0383	0.2945	11.5035	88.4965	11.5035
Available S	0.0286	0.4581	5.8727	94.1273	5.8727
Available Fe	0.0000	0.0241	0.0424	99.9576	0.0424
Available Zn	0.0006	0.0916	0.6068	99.3932	0.6068
Available B	0.0406	0.5012	7.4922	92.5078	7.4922
Means	0.0394	0.4134	7.3268	92.6732	7.3268

DISCUSSION

Available P content of Walnut orchards in Hubei Province: Studies showed that available P in walnut orchard soil of Hubei Province was the soil element with the largest skew degree (Fig. 1) and one of the important limiting factors of walnut soil fertility, and the coefficient of differentiation was large in different regions, which was similar to the research results of soil nutrients in agricultural areas of Hubei Province (George *et al.*, 2015). Hubei Province is not only one of the most abundant phosphate rock provinces in our country, and the content of phosphate rock in the nation (Chi *et al.*, 2005), but due to the presence of large amounts of active aluminum in acidic soil and iron ions (Fig. 1), which may resulting phosphorus aluminum phosphate precipitation formation, when P was applied into the soil. And in the alkaline soil, calcium ion also may resulting calcium phosphate (Ning *et al.*, 2012; Jaisi *et al.*, 2014). So, the content of available phosphorus decreased, which may be the main reason for the lack of phosphorus in walnut orchards soil in Hubei Province.

Phosphorus is one of the most important elements affecting the yield of oil seed crops such as walnut and rape (Yu *et al.*, 2011; Gou *et al.*, 2020). The typical reaction of plant roots suffering from phosphorus deficiency is for roots to distribute more carbohydrates thus increasing the root-shoot ratio in order to improve the ability of plants to obtain more soil phosphorus. However, this will reduce the above ground parts of the plant and reduce photosynthesis and assimilation production. Such a case will not only affect the production of the plant but will also inhibit its root growth (Yuan *et al.*, 2011). In view of the rich content of solid P in Hubei Province walnut orchard soils, measures should be taken to promote the release of available P in the soil. For example, Li *et al.*, (2020) believe that phosphorus solubilizing bacteria have a significant effect on the effective release of solid P in the soil and promoting the growth of walnuts.

Comprehensive fertility of Walnut orchards in Hubei Province: The comprehensive fertility coefficient IFI of walnut production areas in Hubei Province ranged from 1.21 to 1.84, with an average of 1.52, which was the general fertility level (Table 5), and the fertility coefficients of effective N, effective P, effective S, and effective B were all low. In view of the organic matter content and that a variety of nutrition elements are related (Table 4), the soil organic matter can not only enhance the elements of vegetation influence on effective soil transformation, but can also increase the soil microorganism quantity, activity, and microbial diversity, thus improving soil physical and chemical properties, increasing soil permeability, water resistance, and the activity of soil microorganisms. At the same time, it can also reduce the effects of toxic substances such as heavy metals (Marinari *et al*., 2007). Therefore, increasing the soil organic matter content is an important measure to improve comprehensive fertility of walnut orchards. Studies have shown that no-tillage and grass planting in orchards can effectively improve the organic carbon content of orchards, the contents of available nitrogen, phosphorus, and potassium and also increase them to varying degrees (Zhang *et al*., 2019; Bousfield *et al*., 2020; Appelhans *et al*., 2021; Wang *et al*., 2021; Zhang *et al*., 2021). In conclusion, in order to improve the soil organic matter content, in addition to increasing the application amount of organic fertilizer, and in order to manage walnut orchard soil in the future, it is suggested to promote walnut orchard no-tillage or orchard grass.

Conclusions: The distribution frequencies of organic matter and available elements in walnut orchards in Hubei Province were non-normal, and available P was the most skewed with 55.67%. There were correlations among soil pH, organic matter, and available elements, among that soil organic matter content was significantly or extremely significantly correlated with other factors except pH, available Ca, and available S. The comprehensive soil fertility coefficient of walnut orchards in the province ranged from 1.21 to 1.84, with an average of 1.52, which was the general fertility level. The maximum limiting factor of soil fertility was available S, followed by available N and available P. There were L. ELsignificant differences in comprehensive soil fertility among different walnut production areas. 92.67% of the differences came from within the production areas, as well as7.33% from between production areas. The higher differentiation coefficient were available K and available P, with differentiation coefficients of 26.20% and 10.79%, respectively.

In conclusion, the contents of alkalescence N and available P are among a large number of factors affecting soil fertility in walnut producing areas of Hubei Province, and the skew amount and differentiation coefficient of phosphorus are large. In view of the significant positive correlation between organic matter content and most soil elements, and in order to improve the comprehensive soil fertility, it is suggested that soil management should focus on increasing soil organic matter, and paying attention to the application of phosphorus fertilizer to improve the availability of phosphorus.

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