北亚热带森林土壤有效微量元素状况研究

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摘要：研究了北亚热带 25a 生栓皮栎林、杉木林、火炬松林、毛竹林和 5 年生 2 代杉木萌芽林土壤中 B、Mo、Cu、Zn、Fe、Mn 的有效含量、在土壤剖面中的分布规律、影响其有效性的土壤因子以及不同林分对土壤微量养分含量的影响。结果表明，在该地区的森林土壤中，有效 B, Mo, Cu 的平均含量均低于各自临界值，有效 Zn 平均含量接近临界值，Fe, Mn 含量丰富；有效微量养分在土壤剖面中的分布因林分和元素种类而异；影响微量元素有效性的主要土壤因子为有机质和有效磷含量；不同林分对土壤有效微量元素含量有显著影响，栓皮栎林土壤中有效微量养分含量最高，2 代杉木萌芽林最低，其余林分居中且基本接近。

关键词：北亚热带；森林土壤；有效微量元素；分布；影响因素

Available Microelements in Soils under Different Stands in Northern Subtropics of China

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Abstract: Contents, distribution and influencing factors of available B, Mo, Cu, Zn, Fe and Mn in soils under the stands of oriental oak, Chinese fir, loblolly pine, moso bamboo and secondary sprouting Chinese fir in northern subtropics of China, and the influences of different stands on soil microelement availability have been studied. The research area was situated in Xiashu Forest Farm, Jurong, Jiangsu Province, where the soil is yellow-brown soil derived from siliceous slope wash of sand stone. The results revealed that the average contents of available B, Mo and Cu in the region were much lower than their respective critical levels, mean content of available Zn was near the critical level and Fe and Mn were rich; microelements distribution in soil profiles varied with elements and stands; soil organic matter and available P were found to be the major factors influencing the availability of micronutrients; the contents of available micronutrients in horizontal soils under different stands varied significantly, with those under the oriental oak almost all the highest, those under the secondary sprouting Chinese fir the lowest and the rest moderate and similar.

Key words: northern subtropics of China; forest soils; available microelements; distribution; affecting factors

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1 Introduction

The effects of different forest stands on soil nutrient status, including both macronutrients and micronutrients, are an important aspect in studying the development of forest soil fertility and also a

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problem deeply concerned in studying the relationship between plantations and soil depletion. With respect to the major forests in northern subtropics of China, a project of systematic research on nutrient cycling and the macronutrient status under different stands has been conducted in the Xiashu Ecological Station of Nanjing Forestry University since late 1980s[1~3]. Yet, studies on the available micronutrients and influences of different stands on the available microelement contents in soils under different forest stands in the northern subtropics of China have not been reported.

Microelements B, Mo, Cu, Zn, Fe and Mn are necessary to tree growth. However, under natural stands, the available contents of microelements except Mn are usually low, rarely exceeding 100 mg/kg. These elements are mainly from soils[4]. And micronutrient deficiency or disorders can seriously affect the normal growth of trees[5~9].

2 Materials and Methods

The research area is situated in the low hills of the Xiashu Ecological Station of Nanjing Forestry University in Jurong County, Jiangsu Province, 31°59′north latitude, 119°14′east longitude, altitude of 100～250 m. It is in subtropical monsoon climatic zone with an average annual precipitation of 1104 mm. The soils are yellow-brown soils derived from siliceous slope wash of sand stone, dominate in yellow-brownish color, loamy texture and acidic to strongly acidic. The background values of the soil inorganic composition under these stands studied were mostly similar, and the difference of soil nutrient status in the sample plots could be attributed to the influence of various stands and management measures[10]. The major stands in the region are loblolly pine(*Pinus taeda* L.), Chinese fir(*Cunninghamia lanceolata* (Lam.) Hook.), oriental oak(*Quercus variabilis* Bl.), mason pine(*Pinus massoniana* Lamb.) and moso bamboo (*Phyllostachys pubescens* Mazel ex. H. de Lehaie). The stands studied included 25-year-old Chinese fir, loblolly pine and oriental oak, moso bamboo, and 5-year-old secondary sprouting Chinese fir(See table 1 for the backgrounds of the research area). Five sample trees were selected in each stand and soil samples were collected from 0～20cm, 20～40cm and 40～60cm at the circumference of 2/3 crown-width from the stems of the trees. Equal quantity of soils of the same layers under the same stand were mixed as soil samples of the stand. After air-dried, soils were sieved for determination.

Table 1 Basic conditions of the soils under the stands

Stand type	Soil layers cm	pH		O.M. g/kg	Total N g/kg	Available P mg/kg	Available K mg/kg
		H_2O	KCl				
25a-oriental oak	0～20	4.69	4.04	55.20	2.26	12.99	109.46
	20～40	4.83	4.30	24.98	0.94	2.97	49.29
	40～60	5.01	4.04	22.95	0.68	2.78	14.62
25a-Chinese fir	0～20	5.48	3.80	33.80	1.27	5.31	71.18
	20～40	4.87	3.50	15.34	0.80	1.55	34.98
	40～60	5.18	3.49	13.30	0.67	1.46	40.77
25a-loblolly pine	0～20	5.25	4.02	28.25	0.79	2.45	30.32
	20～40	5.11	3.86	11.92	0.49	0.75	20.39
moso bamboo	0～20	5.43	4.02	38.66	1.48	4.40	70.43
	20～40	5.00	3.94	15.29	0.83	1.68	34.86
	40～60	5.30	4.29	11.57	0.56	1.24	25.60
5a-secondary sprouting Chinese fir	0～20	4.96	4.01	35.58	1.29	2.12	29.46
	20～40	4.95	3.74	16.03	0.55	1.90	19.45
	40～60	5.30	3.71	12.79	0.53	1.51	21.52

pH value was determined in 1:2.5 soil/water and KCl suspension, respectively; organic matter by the volumetric analysis with heated $K_2Cr_2O_7$ solution; total N by the Kjeldahl method; available P by the colorimetric analysis with 0.03mol/L HCl extraction; available K by the flame photometry with 1mol/L

NH_4AC neutral extraction[11].

Available B was determined by turmetric colorimetric method with boiling water extraction, available Mo, Cu, Zn, Fe and Mn by the atomic absorption spectrometry, Mo with $H_2C_2O_4$-$(NH_4)_2C_2O_4$ extraction, Cu, Zn with 0.1N HCl extraction, Fe with DTPA extraction, Mn with CH_3COONH_4-$C_6H_6O_2$ extraction[11]. Parallel chemical analyses were carried out on each soil sample.

3 Results and Discussion

3.1 Micronutrient contents in the forest soils

In the soils under the stands in the northern subtropics of China, contents of available B were 0.22～0.38 mg/kg (table 2) and the average content was 0.32 mg/kg, far below the critical level of 0.5 mg/kg[12] (As the critical concentrations of available microelements for forest soils are not yet available, the critical levels of the available microelements in cultivated soils are hereby consulted for reference.) However, the content is much higher than that in soils of other forest regions, such as Xishuangbanna Nature Reserve, Yunnan Province where the available B is only 0.05～0.12 mg/kg[13], yet lower than B content in cultivated soils of Shandong Province where the content is 0.48 mg/kg[14]. Contents of available Mo in the soils of the studied region were 0.07～0.18mg/kg, with the average content at 0.111mg/kg, lower than the critical content of 0.15 mg/kg. Available Cu contents, ranging from 0.37 to 2.76mg/kg, averaged at 0.88mg/kg, much lower than the critical level, yet similar to the case of Xishuangbanna Nature Reserve[13] and lower than cultivated soils in Shandong Province where the content is 1.18 mg/kg[14]. Available Zn contents were between 0.84 and 4.39 mg/kg, averaging at 1.92mg/kg, much higher than soils of Xishuangbanna Nature Reserve[13] and higher than that in the cultivated soils of Shandong Province where the amount is 0.54 mg/kg[14]. Contents of available Zn in surface soils were all above the critical level of 2 mg/kg, but much lower in the subsoils. Fe in the region was rich; the contents were between 31 and 60.5 mg/kg, averaging at 44.9 mg/kg, much higher than the critical content of 3 mg/kg, and also higher than the average content of 12.6 mg/kg in cultivated soils of Shandong Province. Mn ranged from 39.0 to 193 mg/kg, with the mean content reaching 117.7 mg/kg, far more than the critical level of 7 mg/kg. The mean content of Mn is about ten times of the Xishuangbanna Nature Reserve and also much higher than available Mn content of cultivated soils in Shandong Province, which is merely 17.1 mg/kg[14].

The order of the available micronutrient contents in the soils of forest stands in the northern subtropics of China was Mn> Fe>Zn>Cu>B>Mo.

3.2 Microelements distribution in soil profiles

B is mobile and cannot be adsorbed by the clay. Soluble B in horizontal soils is usually drenched and gets lost. In the research region, a significant variation of available B contents in the profiles was found. B was richest in the layer of 20～40cm, and in the layer of 0～20cm, due to drenching, was lower than the layer of 40～60cm. In the profiles of farmland, however, B content in the horizontal layer was higher than that in subsoils[14～16].

In the soils under the 25-year-old Chinese fir and moso bamboo, Mo contents increased with soil depth. Under the rest stands, surface soils had higher Mo contents than subsoils.

Cu was rich in horizontal soils, as shown in some research papers[17,18]. The mean content in layer 0～20cm was 1.06mg/kg, 216.3% and 136.0% as high as those in layers of 20～40cm and 40～60cm, respectively. Cu in the soil profile of farming land in Shandong Province is similar[14].

In farmland soils, Zn content decreases with the depth[14～16]. Under the studied forest stands, contents of Zn were highest in surface soil, averaging at 3.18 mg/kg, 2.5 times as high as those in the subsoils, which was probably due to the fact that organic matter is an important source of Zn and organic matter is richest in the surface soils[18].

Table 2 Contents of available microelements in forest soils under different stands (mg/kg)

Stand type	Soil layers (cm)	B	Mo	Cu	Zn	Fe	Mn
25a-oriental	0～20	0.30±0.02	0.181±0.003	2.33±0.05	4.18±0.13	40.5±2.34	220.0±10.6
oak	20～40	0.38±0.05	0.106±0.002	1.71±0.09	1.25±0.06	60.5±3.41	105.3±12.9
	40～60	0.36±0.04	0.099±0.005	1.93±0.03	0.84±0.04	48.0±1.53	155.7±2.99
25a-Chinese	0～20	0.36±0.03	0.085±0.003	0.76±0.07	3.00±0.18	31.0±2.34	118.0±13.5
fir	20～40	0.38±0.03	0.101±0.003	0.50±0.03	1.35±0.07	53.0±3.57	141.2±12.8
	40～60	0.37±0.03	0.119±0.002	0.66±0.04	1.50±0.14	59.0±1.56	193.0±10.0
25a-loblolly	0～20	0.28±0.01	0.138±0.004	0.67±0.04	2.25±0.06	49.0±3.00	172.0±14.6
pine	20～40	0.29±0.04	0.078±0.006	0.41±0.05	1.58±0.13	56.0±2.91	104.0±5.9
moso bamboo	0～20	0.27±0.02	0.070±0.003	0.65±0.03	4.29±0.19	36.0±2.74	119.0±6.7
	20～40	0.30±0.02	0.090±0.002	0.48±0.08	1.38±0.16	36.5±1.89	75.6±5.4
	40～60	0.28±0.01	0.157±0.007	0.53±0.06	1.40±0.05	41.0±3.63	119.4±7.8
5a-secondary	0～20	0.22±0.02	0.100±0.003	0.88±0.01	2.16±0.18	34.5±2.12	39.0±2.7
sprouting	20～40	0.38±0.03	0.090±0.003	0.37±0.04	0.85±0.08	38.5±2.33	40.0±3.5
Chinese fir	40～60	0.37±0.02	0.084±0.004	0.48±0.05	0.85±0.02	44.5±3.51	46.0±3.7
	Average	0.32±0.05	0.111±0.032	0.88±0.63	1.92±1.15	44.9±9.5	117.7±55.9
	Critical levels	0.50	0.15	2.00	2.00	3.0	7.0

Fe contents increased with soil depth. Fe in surface soils was readily oxidized; Fe^{3+} and its complex ions permeated to the subsoil by way of soil water, leading to the accumulation of Fe ion in subsoils. It is similar to the rice soils[14]. Moreover, Fe nodules were found in some subsoils in the region.

In the case of Mn, subsoils had higher contents than surface soils under the Chinese fir stands; under the rest stands, surface soils had higher contents than subsoils, same as the case of Cu, which is similar to the profile distribution of Mn in the cultivated soils of Shandong Province[14].

3.3 Soil factors affecting micronutrient availability

In cultivated soils, many factors, including soil type, topography, land use, parent materials, soil texture, pH values, organic matter and available P affected the availability of microelements and the roles of these factors varied with regions[19～22]. In this research, organic matter and available P were found to be the major factors affecting the availability of microelements in forest soils.

Contents of available B increased with the enrichment of organic matter in the case of acid farmland soils[4]. However, this research reveals that contents of organic matter and available B, Fe was negatively correlated, the correlation coefficients were -0.500^{*} and -0.418^{*}, respectively. One reason for this was that the complex action in organic matter reduced the availability of B and Fe.

In crop soils, organic matter decreased the availability of Cu[18, 21, 22]. In this research, however, a positive correlation existed between Cu and organic matter, the coefficient being 0.63^{*}, which indicated that organic matter contributed greatly to the availability of Cu. One reason is that Cu chelated in natural organic matter was not absolutely unavailable; in some circumstances, chelation of Cu could promote its availability[19].

The correlation coefficient between Zn and organic matter was 0.855^{**}, that is, the richer the organic matter in soils, the higher the availability of Zn. Some researches supported the result[21～23], but it's contrary to the conclusion that soils rich in organic matter were liable to be deficient in Zn[18].

*: $p<0.05$; ** $p<0.01$ $N=14$

Some papers showed that available P in soil decreased the availability of Fe and increased that of Mo[19], but in this research available P had no detectable effects on Fe and Mo. Nevertheless, there existed positive correlations between available P and available Zn, Cu and Mn, and the correlation coefficients were 0.751**, 0.708** and 0.552*, respectively.

As shown above, the chemistry of microelements in forest soils differed that in farmland soils. Therefore research results about microelements in cultivated soils may not necessarily be applicable to forest soils.

3.4 Comparison of available microelements conditions in soils under different stands

There were noticeable differences in available contents of microelements in soils under the stands studied, particularly in surface soils. Generally but not exclusively, contents of microelements in surface soils under 25-year oriental oak stand were the highest, that is, oriental oak had the highest capacity to fertilize soils in terms of micronutrients. The stands of Chinese fir, loblolly pine and moso bamboo, however, showed no significant differences. The secondary sprouting Chinese fir stand, with many of the micronutrients getting lost due to land burning and tillage, had the lowest micronutrient contents. Similar results in terms of macro-nutrients have also been reached by Yu Yuanchun who conducted a research into effects of different forest types on nutrient status of soils in Anhui Province[24]. It's recommended that in the management of forest soils, some traditional practices such as burning and overall tillage which result in soil-water-nutrient losses be abandoned and less tillage or no tillage be adopted, as far as soil fertility maintenance is concerned.

4 Conclusion

4.1 The average contents of available B, Mo and Cu in forest soils in the northern subtropics of China were all lower than their respective critical levels; the average content of Zn was near the critical level; Mn and Fe were rich in this region. Application of microelement fertilizers of B, Mo, Cu and/or Zn might improve forest growth and productivity and further research on the topic is required.

4.2 Distribution of the micronutrients in soil profiles varied with elements and stands. B in surface soils (0～20cm) was the lowest and that in the layer of 20～40cm the highest, on the contrary, Cu was highest in the surface soils and the lowest in the layer of 20～40cm. Contents of Zn decreased with soil depth. The distribution of Fe was just opposite to that of Zn. Mo and Mn varied with stands.

4.3 The soil factors affecting the availability of microelements in the region were mainly organic matter and available P. Organic matter negatively affected the availability of B and Fe while increased that of Cu, Zn and Mn. Available P promoted the availability of Cu, Zn and Mn and had no obvious effects on Fe, Mo and B.

4.4 The surface soils under the oriental oak stand almost had the highest micronutrient contents, while those under the 5-year secondary sprouting Chinese fir almost had the lowest, and the surface soils under the rest stands showed no significant differences.

References

[1] Gao Z Q(高志勤), Luo R Y(罗汝英). Properties of osmotic water in forest soils of Nanjing-Zhenjiang hilly regions. *Journal of Nanjing Forestry University*(in Chinese)(南京林业大学学报), 1994, **18**(2):7～12.

[2] Li W H(厉婉华). Studies on the differences of N and pH in between root-soils and nonroot-soils of Chinese fir and loblolly pine. *Journal of Nanjing Forestry University*(in Chinese)(南京林业大学学报), 1996, **20**(2):49～52.

[3] Ruan H H(阮宏华), Sun D(孙多), Ye J Z(叶镜中). Studies on biological cycling of nutrient elements in the secondary oak in Kongqing hill. In: Jiang Z L(姜志林)ed. *The Proceedings of Forest Ecosystems on Xiashu*

Ecological Station(in Chinese). Beijing: Chinese Forestry Publishing House, 1992. 73～77.

[4] Yuan K N(袁可能). Soil chemistry of nutrient elements for plants (in Chinese). Beijing: Science Press, 1983. 499～500.

[5] Bari P A A and Gupta G N. Effect of foliar spray of macro-and-mciro-nutrients on growth of pine seedlings in nursery. *India Forester*, 1990, **116**(2): 115～120.

[6] Dell B and Bywaters T. Copper deficiency in young Eucalyptus maculata plantations. *Canadian Journal of Forest Research*, 1989, **19**(4): 427～431.

[7] Will G M. Influence of trace-element deficiencies on plantation forestry in New Zealand. *Forest Ecology and Management*, 1990, **37**: 1～6.

[8] Jokela E J and Mcfee W W. Micronutrient deficiency in slash pine: response and persistence of added manganese. *Soil Science Society of America Journal*, 1990, **55**(2): 492～496.

[9] Turvey N V and Grant B R. Copper deficiency in coniferous trees. *Forest Ecology and Management*, 1990, **37**(13): 95～122.

[10] Luo R Y and Gao Z Q. Effects of Chinese fir, loblolly pine and deciduous oak forests on nutrients status of soils in northern subtropics of China. *Pedosphere*, 1994, **4**(1): 1～10.

[11] The State Standard Bureau. *Analysis methods for forest soils* (in Chinese) (book six). Beijing: Science Press, 1987.

[12] Xiong Y(熊毅), Li Q K(李庆逵). *Soils of China*(in Chinese) (2nd edition). Beijing: Science Press, 1987. 517～536.

[13] Wang J Y(汪家育), Yu N Z(于南子), Liu Z Z(刘增芝). Microelements in forest soils of Xishuangbanna Nature Reserve. *Yunnan Forestry Survey and Design*(in Chinese), 1986, (4): 6～12.

[14] Wu J M(吴建明), Gao X B(高贤彪), Gao B M(高弼模). Content and distribution of trace elements in the soils of Shandong Province. *Acta Pedologica Sinica*(in Chinese)(土壤学报), 1990, **27**(1): 87～93.

[15] Li Q C(李庆春), Xu P(徐萍). Evaluation on available trace elements in cultivated soil in Liaoning Province. *Journal of Shenyang Agricultural University*(in Chinese)(沈阳农业大学学报), 1997, **28**(2): 125～129.

[16] Liu Z(刘铮), Zhu Q Q(朱其清). Soils deficient in microelements and their regional distribution in China. *Acta Pedologica Sinica*(in Chinese)(土壤学报), 1982, **19**(3): 209～233.

[17] Zhang G R(张桂荣), Yang L B(杨令宾), Lang H Q(郎惠卿), *et al*. Microelement contents of Larix gmelinii-Sphagnum bog peat and their changing pattern. *Chinese Journal of Applied Ecology*(in Chinese)(应用生态学报), 1995, **6**(supp.): 23～26.

[18] Zhou M Z(周鸣铮). *An introduction to soil fertility*(in Chinese). Hangzhou: Zhejiang Science and Technology Press, 1985. 315～319.

[19] Yuan K N(袁可能). *Soil Chemistry*(in Chinese). Beijing: Science Press, 1990, 159～162.

[20] Huang J H(黄建辉), Chen L Z(陈灵芝), Han X G(韩兴国). Changes of some major and micro-nutrients during the decomposition process of oak twigs. *Acta Ecologica Sinica*(in Chinese)(生态学报), 2000, **20**(20): 229～234.

[21] Gao M R(高美荣), Zhu B(朱波), Jiang M F(蒋明富). Distribution of zinc forms and its influence factors in calcareous purple soils. *Chinese Journal of Applied Ecology*(in Chinese)(应用生态学报), 1999, **10**(4): 415～418.

[22] Liu Q Y(刘全友), Tong Y P(童依平), Li J Y(李继云), *et al*. Factors influencing the availability of nutrients in soil of Duolun County in mixed area of agriculture and pasturing. *Acta Ecologica Sinica*(in Chinese)(生态学报), 2000, **20**(6): 1034～1037.

[23] Lu W L(陆文龙), Cao Y P(曹一平), Zhang F S(张福锁). Role of root-exuded organic acids in the mobilization of soil phosphorus and microelements. *Chinese Journal of Applied Ecology*(in Chinese)(应用生态学报), 1999, **10**(3): 379～382.

[24] Yu Y C and Zhang H C. Effects of different types of Chinese fir stands on nutrient status of soils. *Pedosphere*, 1995, **5**(1): 45～50.