Study on Cation Exchange Capacity of Agricultural Soils

Dai yunan1,2, Qiao xianliang1*, Wang xiaochen1,2

1Dalian University of Technology, School of Environmental Science & Technology.
*Associate professor, E-mail: xqliao@dlut.edu.cn, Chinese.

Abstract: 100 agricultural soil samples from 23 provinces of China were collected, basic physical and chemical properties of soils, including cation exchange capacity (CEC), pH, organic matter (OM) and particle size composition (clay, silt, and sand), were measured. The correlation among these physical and chemical properties was examined and a prediction model of CEC was established. The results showed that silt and sand parts were the main composition, and most of the soils are loam or clay loam. The pH values of soils range from 4.69 to 8.45. The level of OM is 9.75 g/kg to 150 g/kg; and CEC of soils range from 6.63 cmol/kg to 41.65 cmol/kg. Pearson correlation analysis showed that soil CEC, OM and clay, silt parts, have significant positive correlation, and the correlation coefficient are 0.457, 0.459, and 0.363 (P<0.01) respectively. A prediction model of CEC was established with a R² of 0.415, which demonstrated better prediction than the models of previous studies.

1. Introduction

Soil cation exchange capacity (CEC) is an important physical and chemical property of agricultural soils, which reflects not only the surface properties of soil colloids, but also the retention and supply capacity of soil fertilizer. CEC is an important indicator for evaluating soil fertility, crop growth and pollutants partition and transport in soils. For example, Sharma[1] successfully applied soil parameters including CEC as variables in the prediction of the yield of corn and soybean. In addition, CEC is also an important parameter that influences the adsorption of heavy metals and organic pollutants (such as antibiotics) in soils. For example, Dutta[2] studied the effects of soil physical and chemical properties, including pH value, organic carbon (%) and CEC, on the adsorption of lead in soil, and predicted the adsorption and desorption behavior in soils by multiple linear regression equations. Teixido[3] found that CEC was the key parameter that influenced the soil adsorption of tetracycline in acidic environment.

Previous studies showed that physical and chemical properties of soil, such as OM, pH, particle size composition have significant effects on CEC[4,5]. For example, Cai Zucong[6] reported that soil OM is an important factor influencing CEC. Akpa[7] found that clay, sand, pH and soil OM are the important influencing factors to predict topsoil CEC in Nigerian soil. Due to the mutual influence of soil physical and chemical properties, there are significant differences in CEC among different soils. For example, the soil CEC of Sichuan Micang Mountain Nature Reserve reported by Meng Zhen[8] range from 24.75 cmol/kg to 34.79 cmol/kg, While CEC of Xiangyang City, Hubei province, measured by Zhao Xiang[9] is from 9.3 cmol/kg to 24.98 cmol/kg.

The CEC experimental test of a large number of soil samples is time and labor consuming. Therefore, the predictive model of CEC is essential. Currently, most of the researches on CEC were carried out in small and medium-sized areas. The investigation on the change of soil CEC in large areas is relatively scarce. Liao Kaihua[10] predicted CEC of different soils in Qingdao, China by support vector machine, and the prediction results were rather good. Emamgolizadeh[11] used multiple...
adaptive regression method to predict the CEC values of soils from Semnan and Taybad in Iran, which showed good prediction ability ($R^2=0.765$). The prediction results of soils’ CEC in small areas are generally favorable, which are possibly related to similar soil parent materials and soil forming environment, and less differences in soil properties. In this study, 100 soil samples from 23 provinces of China were measured for basic physical and chemical properties. The correlation between CEC and basic physical and chemical properties was analyzed, and a model for CEC prediction was established.

2. Test and analysis methods

2.1. Preliminary treatment of the tested soils
The tested samples were randomly collected from 100 agricultural soils nationwide (Fig 1). The sampling points were set by S-shape, and more than 20 soil samples from 0~20 cm depth soil layer were collected. The soil samples were sieved by mesh number after air-dried.

![Fig. 1 Distribution map of soil sampling points](image)

2.2. Test method of soil physical and chemical properties
After air-drying and grinding, four kinds of physical and chemical properties were determined respectively. The soil particle size ratio was determined by Malvin laser particle analyzer 2000, which was divided into three categories: 0~2 μm-clay, 2~20 μm-silt and 20~200 μm-sand. The soil texture types were determined by the percentages of the three components. The pH value was determined by FE-28 pH meter equipped with FE-438 glass electrode with the water-soil ratio of 2.5:1. OM was determined by potassium dichromate volumetric method-external heating method. The acidic (pH < 6.5) and neutral (6.5 < pH < 7.5) soils were determined by ammonium acetate exchange method, and the alkaline soils (pH > 7.5) were tested by flame photometry method[12].

2.3. Data analysis method
For experimental data analysis, Excel 2013 was used as the data processing tool. SPSS 19.0 was used for correlation analysis of data and establishment of multiple linear regression equations. Origin Pro 9.0 was used as the drawing tool.

3. Results and discussion

3.1. Distribution of main physical and chemical properties of soils
Figures 2-5 list the statistical distribution of four basic physical and chemical properties of the measured soils. In this study, soils were classified by soil texture according to the international classification method. The classification results showed that most soil textures are loam and clay loam. The pH values range from 4.69 to 8.45, and alkaline soil accounts for about 50 % (Fig.3). The range of
OM is 9.75~150 g/kg (fig.4). The CEC of soils range from 6.63 cmol/kg to 41.65 cmol/kg (fig.5). Generally, the soils with CEC > 20 cmol/kg, 10-20 cmol/kg, <10 cmol/kg have relatively high fertility, middle and weak fertility, respectively\textsuperscript{[13]}. The coefficient of variation (CV) for pH, OM and CEC of soils were 14.4 %, 57.06 % and 43.26 % respectively. The variation of soil properties might be related to parent material, forming environment, tillage and utilization, etc.

3.2. Correlation analysis
Based on the Pearson correlation coefficient data analysis, the observed soil CEC showed significant positive correlation with clay, silt and OM, and the correlation coefficients are 0.457, 0.459 and 0.363 in turn (p <0.01). But it showed obvious negative correlation with sand, and the correlation coefficient is -0.518 (p<0.01), which have the greatest influence on CEC. In this study, it was found that the relationship between CEC and pH value was not obviously, which is different from the conclusion that there is a significant negative correlation between CEC and pH in the study of Zhang Shuiqing\textsuperscript{[14]}, which may be related to the regional distribution and variability of studied soil samples.

3.3. CEC prediction model
Based on the correlation between CEC and other soil properties, previous researchers had established some CEC prediction models by using multiple linear regression equations. Using stepwise multiple linear regression of CEC, pH, OM and particle size composition, three prediction equations (1)–(3) are obtained as shown in table 1. Khaledian\textsuperscript{[15]} predicted and analyzed 65 soils CEC in Iran, and five parameters were selected with adjusted $R^2$ of 0.470. Whereas Ghorbani\textsuperscript{[16]} used the same five parameters to predict CEC of 220 soils in Gulistan province of Iran, and the predicted $R^2$ was 0.770. Wang et al.\textsuperscript{[17]} predicted CEC of 18 soils from Shanxi province, and the $R^2$ value was as high as 0.998. The differences of these prediction models’ $R^2$ may be caused by the differences of spatial geography.
The differences of soil physical and chemical properties in small areas such as cities are relatively small, while in large spatial scales, these differences will become more obvious, thus leading to the influence on the prediction results. On the other hand, the quantity of soil samples and the quantity of basic physical and chemical properties parameters of the selected soils are also important factors influencing model $R^2$. Generally speaking, the larger the soil sample number is, the more statistically significant the model is.

| Test area                        | Number | Multiple linear regression equation                                      | $R^2$ | $R^2$ |
|---------------------------------|--------|-------------------------------------------------------------------------|-------|-------|
| Iran                            | 65     | $\text{CEC}=9.471+0.475\text{Clay}-0.236\text{Silt}-0.346\text{Sand}+3.125\text{pH}-0.233 \text{OC}$ (1) | 0.470 | 0.065 |
| Gulistan, Iran                  | 220    | $\text{CEC}=31.59-5.38\text{pH}-2.69\text{OC}+0.17\text{Sand}+0.19\text{Silt}+0.44\text{Clay}$ (2) | 0.770 | 0.311 |
| Polo town, Hengshan county,     | 18     | $\text{CEC}=-43.446+0.508\text{OM}+5.145\text{pH}+0.023\text{Silt}-0.397\text{Clay}$ (3) | 0.998 | 0.219 |
| Yulin city, Shanxi province     |        | $\text{CEC}=14.488+1.458\text{pH}-0.233\text{Sand}+0.121\text{OM}$ (4) | 0.374 | 0.415 |

a, $R^2$ of the training sets of prediction models in previous studies and in our study. 
b, $R^2$ for 25 soils of validation sets using models in previous studies and in our study.

In this study, the previous research prediction model of CEC was used to predict the data of 25 validation sets in this study, and the results are shown in table 2. The prediction results show that using CEC prediction models of small regions or other countries to predict our soil samples’ CEC in China, $R^2$ of these models are very low with 0.065, 0.311 and 0.219 respectively, and these models can’t predict well for soil CEC of large-scale in our study. In this study, 75 soil samples were randomly selected as training sets according to the ratio of 3:1 (in 100 soil samples), and SPSS was used to conduct stepwise multiple linear regression, and the prediction model equation was established as shown in table 2. The $R^2$ value of this model verification set is 0.415 ($p<0.05$), which demonstrated better prediction than the models of previous studies.

4. Conclusion
The pH, OM, particle size composition and CEC levels of the collected 100 soils showed significant differences. The determined pH values of soils range from 4.69 to 8.45. The OM contents range from 9.75 g/kg to 150 g/kg. The CEC values of soils range from 6.63 cmol/kg to 41.65 cmol/kg. Correlation analysis showed that the contents of Clay, Silt and OM in soils are positively correlated with CEC, while the content of sand is negatively correlated with CEC. The prediction model of soil CEC established by this study demonstrated better prediction than the models of previous studies with $R^2=0.415$.

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