Soil CEC Predicting Model of Tobacco-Planting Fields in Chenzhou, South Hunan Province

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Abstract. [Background] Cation exchange capacity (CEC) is a basic but important soil property of soil fertility or quality. CEC predicting model is often derived from other soil properties measured more easily because the traditional method determining CEC is time-consuming and laborious. It is necessary to establish a new CEC prediction model for a new region because CEC predicting model usually is dependent on the study region. [Objective] Chenzhou City is the most important and typical tobacco-planting region with tobacco-rice rotation in Hunan province and China, this study was conducted to establish CEC predicting model for the tobacco-planting fields in Chenzhou because so far no CEC predicting model is available for tobacco-planting fields in Chenzhou and in China. [Method] In total 1055 topsoil samples (0–20 cm) were collected in 2015 from the tobacco-planting fields in Chenzhou, soil properties included the particle size composition, pH, soil organic matter and various nutrients were determined, the status of CEC were assessed, and then CEC predicting models were setup in different regions in Chenzhou. [Result] The results showed that CEC in Chenzhou was ranged from 3.50 to 48.50 cmol (+) kg⁻¹ with a mean of 22.05 cmol (+) kg⁻¹, averagely belonged to the very high grade (>20 cmol(+) kg⁻¹). There were significant differences in CECs in different regions in Chenzhou, which was the highest in Jiahe (23.83 cmol(+) kg⁻¹) but the lowest in Anren (15.78 cmol(+) kg⁻¹). CEC was significantly correlated with different soil properties in different regions, which was significantly correlated with coarse sands, fine sands, clays, pH and total P in Chenzhou (R²= 0.312**–0.445**), significantly correlated with coarse sands, silts, clays, pH, total P, available B and Cu in Yongxing (R²=0.321**–0.605**), significantly correlated with coarse sands, fine sands and clays and total P in Guiyang (R²=0.330**–0.477**), significantly correlated with coarse sands, silts and total K in Yizhang (R²=0.326**–0.466**), and only significantly correlated with fine sands in Jiahe (R²=0.350**). The accuracy of CEC predicting model usually was lower when less properties involved. Based on the comparison of the R² and RMSE of the established CEC predicting models, it is recommended that the total model for Chenzhou could be used for Guiyang, Jiahe and Yizhang, while the regional models should be selected for Yongxing, Anren and Suxian. [Conclusion] This study proves further that different soil properties were most important for CEC predicting models in different regions, new CEC predicting models must be setup for a new study region, and soil organic matter is

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not a variable in soil CEC predicting models for tobacco-planting fields in
Chenzhou, which are different from some previous studies.

**Keywords.** soil CEC, statistic information, correlation, predicting model

1. Introduction

Cation exchange capacity (CEC) is a basic soil property often used as an index of soil fertility or quality, understanding CEC plays important roles in guiding reasonable fertilization and soil improvement [1-2]. Meanwhile, CEC is also an index for soil classification or taxonomy [3-4]. Because the traditional methods determining CEC are time-consuming and laborious, more studies were conducted to setup CEC predicting model from soil properties measured more easily [5-14], and the results showed that for different regions or soils, the variables used in predicting soil CEC are different, for examples, Rahal and Alhumairi [5] predicted soil CEC in mid-Mesopotamian plain by using texture class, bulk density, total available water content, soil color, sodium adsorption ratio, electrical conductivity and Ca2+. Khaledian et al. [6] proved that soil CEC was affected by different variables in different situations, clay (positively correlated) and sand (negatively correlated) were the most influential variables for predicting CEC, CEC was significantly and negatively correlated with pH in agricultural land uses in Spain, significant positive relationship between CEC and OC in Spain, the USA, Iraq, and pasture. Shiri et al. [7] used the contents of silts, clays, sands, organic carbon and pH in modeling soil CEC in Iran. Seyedmohammadi et al. [8] proved soil organic carbon and clay could be used as input variables (positively correlated) for predicting CEC of paddy soils in Guilan province, northern Iran. Liao et al. [9] modeled soil CEC with organic matter, silt, clay and pH (positively correlated) as well as sand (negatively correlated) in Qingdao in China. Obalum et al. [10] found that CEC of coarse-textured soils in southeastern Nigeria increased with decreasing coarse sand but with increasing fine sand, silt correlated negatively with the CEC, clay and organic matter generally impacted positively on the CEC, and the best-fitting linear CEC function was attained with fine sand, clay, and organic matter. Yuksel and Kaya [11] predicted soil CEC in Hawaii by using organic matter and clay fraction (positively correlated) with other variables (specific surface area, activity, Atterberg limits, plastic, shrinkage, and modified free swell index). Seybold et al. [12] used organic matter and clay content (positively correlated) and pH (positively or negatively correlated) as the main variables to model soil CEC in USA. Krogh et al. [13] found that CEC of Danish soils could be modelled with clay and organic matter content (positively correlated), while silt and pH (positively correlated) might also contribute as predictor variables. Manrique et al. [14] found that clay, organic carbon (positively correlated) and pH (negatively correlated) could be used in predicting CECs for all soils, while clay and organic carbon used in predicting CECs of Alfisols, Inceptisols, Mollisols, Vertisols, Entisols, Spodosols, Spodosols.

For tobacco-planting soils in China, CEC is often measured and used as an index of soil fertility [15-23], and the relationship between CEC and other properties were also discussed in some studies [24-27]. Furthermore, some studies found that CEC is closely related to the chemical components of tobacco leaves (total sugar, reducing sugar, salt and nicotine etc.) [28-29], and high CEC is conducive to reducing the occurrence and harm of bacterial wilt and red weed diseases of tobacco [30-31].
Chenzhou City of south Hunan Province, with a long history of tobacco-planting as early as in 1593 and where most paddy fields are under tobacco-rice rotation [32], is the most important and typical planting region of flue-cured tobacco with burnt-pure sweet aroma in China [33]. The area of tobacco-planting in Chenzhou is about $2.67 \times 10^3 \text{ hm}^2$ in recent years, which plays an important role in ensuring the supply of high-quality tobacco leaves and the sustainable development of regional society and economy. Some literatures were published about tobacco-planting soil characteristics in Chenzhou [34-37]. Nowadays, a new round of tobacco-planting soil improvement is underway in Chenzhou and in other regions of China, it is helpful to understand further soil CEC in tobacco-planting fields in providing scientific instruction for this work. However, so far little information is available on soil CEC predicting model for tobacco-planting fields in Chenzhou and China, thus, in this study, the status of soil CEC in tobacco-planting fields in Chenzhou were studied and CEC predicting models were setup based on other soil properties.

2. Methods and Materials

2.1. Sources of Soil Data

The data of soil properties used in this study came from the tobacco-planting soil surveys conducted in 2015, which included 1055 topsoil samples (0~20 cm) collected from the typical tobacco-planting fields in different regions of Chenzhou. The typical field was decided according to the spatial distribution uniformity of the tobacco-planting field, in each typical field the topsoil sample was collected randomly at 5~8 points with stainless steel drill and then were mixed completely. The measured soil properties were included particle composition, pH (H$_2$O), organic matter (OM), total nitrogen (TN), phosphorous (TP) and potassium (TK), available nitrogen (AN), phosphorous (AP) and potassium (AK), exchangeable calcium (Ca$^{2+}$) and magnesium (Mg$^{2+}$), available sulfur (S), water-soluble chlorine (Cl$^-$), and available boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo). The detailed determination methods for soil properties could be found in related literatures [38-41].

2.2. Grading Standard of Soil CEC

No information was available in China on the grading standard of soil CEC for tobacco-planting fields, in this study, soil CEC in Chenzhou was divided into 5 grades as shown in Table 1 which was based on soil CEC classification of the 2nd national soil survey [42-43].

| Grade   | Very low | Low      | Middle   | High     | Very high |
|---------|----------|----------|----------|----------|-----------|
| Value cmol(+) kg$^{-1}$ | <6.2     | 6.2–10.5 | 10.5–15.4| 15.5–20  | ≥20       |
2.3. Data Processing and Statistics

Microsoft Excel 2016 and IBM Statistics SPSS 22.0 software were used for statistical analysis of the data, and Duncan test method (2-tailed) was used for variance analyses and multiple comparisons [43-44].

3. Results

3.1. Statistics and Comparison of CEC

Table 2 shows the statistical results of CEC. CEC was ranged from 3.50 to 48.50 cmol(+) kg\(^{-1}\) with a mean of 22.05 cmol(+) kg\(^{-1}\), which covered the whole 5 grades, but averagely belonged to the very high grade (>20 cmol(+) kg\(^{-1}\)). Meanwhile, for total samples, CEC was in the moderate middle variation (C.V. =61.08% < 100%), very positive skewness distribution (Skewness>0.3) and flat peak distribution (Kurtosis=0) [44-45].

CEC was the highest in Yongxing (24.11 cmol(+) kg\(^{-1}\)) but the lowest in Anren (15.31 cmol(+) kg\(^{-1}\)). CEC of Yongxing was not significantly higher than those of Jiahe and Guiyang, but significantly higher than those of other regions. CEC of Jiahe was not significantly higher than those of Guiyang and Beihu, but significantly higher than those of Yizhang, Suxian, Linwu and Anren. CEC of Guiyang was not significantly higher than that of Beihu, but significantly higher than those of Yizhang, Suxian, Linwu and Anren. CEC of Beihu was not significantly higher than that of Yizhang, but significantly higher than those of Suxian, Linwu and Anren, CEC of Yizhang was significantly higher than those of Suxian, Linwu and Anren, while no significant difference was found among Suxian, Linwu and Anren.

Table 2. Statistic information of tobacco-planting soil CECs in Chenzhou.

| Region  | Sample no. | Minimum CEC cmol(+) kg\(^{-1}\) | Maximum CEC cmol(+) kg\(^{-1}\) | Mean±S.D. CEC cmol(+) kg\(^{-1}\) | C.V. (%) | Skewness | Kurtosis |
|---------|------------|-------------------------------|-------------------------------|--------------------------------|---------|----------|----------|
| Total   | 1055       | 3.5                           | 48.5                          | 22.05±7.70                     | 34.9    | 0.45     | 0.01     |
| Guiyang | 560        | 3.5                           | 48.5                          | 23.80±7.62ace                  | 32.02   | 0.42     | 0.01     |
| Yongxing| 115        | 6.3                           | 45                            | 24.11±8.17a                    | 33.88   | -0.01    | -0.15    |
| Jiahe   | 110        | 9.3                           | 40.4                          | 23.83±6.32ac                   | 26.51   | 0.41     | 0        |
| Anren   | 100        | 5.8                           | 30.7                          | 15.31±5.15k                    | 33.62   | 0.4      | -0.17    |
| Yizhang | 96         | 6.2                           | 37.6                          | 18.10±5.77dfgi                 | 31.86   | 0.8      | 0.53     |
| Suxian  | 45         | 6.2                           | 27.6                          | 16.30±4.92hjk                  | 30.2    | -0.05    | -0.16    |
| Beihu   | 17         | 14.7                          | 29.1                          | 20.88±3.94beceg                | 18.88   | 0.44     | 0.18     |
| Linwu   | 12         | 8.8                           | 28.6                          | 15.78±5.70k                    | 36.16   | 1.22     | 1.24     |

Note: values in the same column followed by different lowercase letters are significantly different at the 0.05 level.

3.2. Statistics and Comparison of Soil CEC in Each Grade

Table 3 shows the statistical results of the numbers and proportions of tobacco-planting fields in different grades of CEC. For all the samples in Chenzhou and the samples in Guiyang, Yongxing, Jiahe and Beihu, the sample proportions were all in the order of
the very high grade > the high grade > the middle grade > the low grade > very low
grade, and the sample proportion of the very high grade was 57.25%~74.78%.
However, for the samples in Anren, the sample proportion was in the order of the
middle grade (32.00%) > the high grade (29.00%) > the low grade (20.00%) > the very
high grade (18.00%) > the very low grade (1.00%), while for the samples in Yizhang
and Suxian, the sample proportions were both in the order of the high grade (34.38% and
35.56%) > the middle grade (32.29% and 28.89%) > the very high grade (29.17% and
24.44%) > the low grade (4.17% and 11.11%), and no sample in the very low grade.

Table 3. Sample numbers and proportions in different grades of CEC.

| Region    | Very high (≥20) | High (15.4–20) | Middle (10.5–15.4) | Low (6.2–10.5) | Very low (<6.2) |
|-----------|-----------------|----------------|--------------------|----------------|-----------------|
|           | Sample no.     | %              | Sample no.         | %              | Sample no.      | %              |
| Total     | 604            | 57.25          | 239                | 22.66          | 160             | 15.17          |
| Guiyang   | 367            | 65.54          | 122                | 21.79          | 60              | 10.71          |
| Yongxing  | 86             | 74.78          | 10                 | 8.70           | 10              | 8.70           |
| Jiahe     | 81             | 73.64          | 23                 | 19.09          | 7               | 6.36           |
| Anren     | 18             | 18.00          | 29                 | 29.00          | 32              | 32.00          |
| Yizhang   | 28             | 29.17          | 33                 | 34.38          | 31              | 32.29          |
| Suxian    | 11             | 24.44          | 16                 | 35.56          | 13              | 28.89          |
| Beihu     | 11             | 64.71          | 4                  | 23.53          | 2               | 11.76          |
| Linwu     | 2              | 16.67          | 4                  | 33.33          | 5               | 41.67          |

3.3. Correlation between CEC and Other Properties

Table 4 shows the statistical results of other soil properties while Table 5 shows the
Pearson correlation coefficients between CEC and other properties. It can be seen from
Table 5 that CEC was significantly correlated with different properties in different
regions, for examples, CEC was significantly correlated with coarse sands, fine sands,
clays and TP for all samples in Chenzhou (R= 0.312**~0.445**), in this paper only soil
properties with R ≥ 0.3** was used to setup CEC predicting model, because this value
usually means significant correlation existed [44-45]), significantly correlated with
coarse sands, fine sands, silts, clays, pH, TP, Ca²⁺, Mg²⁺ and Zn for samples in Suxian
(R= 0.430**~0.684**), significantly correlated with coarse sands, fine sands, silts, clays
and pH, TP, B and Cu for samples in Yongxing (R=0.321**~ 0.605**), significantly
correlated with coarse sands, fine sands and clays and TP for samples in Guiyang
(R=0.330**~0.477**), and only significantly correlated with fine sands for samples in
Jiahe (R=0.350**).

According to the significant correlation existed between CEC and other properties,
the optimal regression models of CEC were established for Chenzhou and for different
regions in Chenzhou (see Table 6). If judged from R² and RMSE/S.D., the accuracy
was higher for soil CEC predicting models in Suxian, Anren and Yongxing (R²=0.795**, 0.602** and 0.489**, and RMSE/S.D=0.57, 0.66 and 0.74, respectively), but the
accuracy was lower for soil CEC predicting models in Jiahe, Guiyang and Yizhang
(R²=0.123, 0.288 and 0.231 and RMSE/S.D=0.94, 0.85 and 0.89, respectively). Thus, it
is recommended that for Yongxing, Anren and Suxian, their own regional models
should be used to predict soil CEC, but for Guiyang, Jiahe and Yizhang, the total model could be considered to predict soil CEC.

Table 4. Statistic information of other soil properties in Chenzhou (n=1055).

| Soil property | Minimum | Maximum | Mean±S.D. | C.V. | Skewness | Kurtosis |
|---------------|---------|---------|-----------|------|----------|----------|
| Coarse sands  | 0       | 56      | 8±5       | 61.08| 2.89     | 15.51    |
| Fine sands    | 4       | 64      | 25±8      | 31.87| 1.10     | 2.18     |
| Silts         | 10      | 56      | 38±7      | 17.76| -0.64    | 0.73     |
| Clays         | 10      | 66      | 29±8      | 27.54| 0.37     | 0.10     |
| pH            | 4.47    | 8.14    | 7.00±0.93 | 13.35| -0.97    | -0.34    |
| OM            | 0.90    | 132.30  | 48.00±14.38 | 29.95| 0.56     | 1.14     |
| TN            | 1.06    | 5.26    | 2.66±0.71 | 26.76| 0.41     | 0.10     |
| AN            | 64.70   | 447.40  | 202.98±54.07 | 26.64| 0.46     | 0.51     |
| TP            | 0.27    | 2.84    | 0.92±0.28 | 30.28| 0.32     | 1.78     |
| AP            | 1.66    | 118.80  | 36.48±17.74 | 48.62| 0.89     | 1.40     |
| TK            | 18.60   | 725.70  | 205.71±87.51 | 42.54| 0.68     | 1.25     |
| AK            | 6.22    | 40.10   | 12.74±3.83 | 30.05| 2.33     | 10.16    |
| Ca²⁺          | 2.11    | 83.77   | 33.27±23.35 | 70.19| 0.62     | -1.00    |
| Mg²⁺          | 0.08    | 7.55    | 1.65±1.04 | 63.21| 1.25     | 2.02     |
| S             | 7.40    | 594.57  | 39.42±35.83 | 90.89| 8.26     | 107.76   |
| Cl             | 0.00    | 98.09   | 6.30±9.84 | 156.19| 2.72     | 11.96    |
| B             | 0.19    | 1.36    | 0.55±0.18 | 32.59| 1.05     | 1.88     |
| Fe            | 10.80   | 502.10  | 142.86±89.59 | 62.71| 1.23     | 1.23     |
| Mn            | 0.81    | 294.20  | 33.24±31.53 | 94.87| 2.94     | 12.37    |
| Cu            | 0.27    | 96.30   | 4.70±5.31 | 113.05| 12.66    | 190.18   |
| Zn            | 0.42    | 233.00  | 4.44±9.77 | 220.12| 15.65    | 318.23   |
| Mo            | 0.00    | 4.40    | 0.16±0.23 | 143.79| 8.18     | 124.05   |

Note: Coarse sands, Fine sands, Silts and Clays, %; OM, TN, TP and TK, g kg⁻¹; AN, AP, AK, S, Cl⁻, B, Fe, Mn, Cu, Zn and Mo, mg kg⁻¹; Ca²⁺; coml(1/2Ca²⁺) kg⁻¹; Mg²⁺ coml(1/2Mg²⁺) kg⁻¹.

Table 5. Pearson correlation coefficients between CEC and other properties.

| Soil property | CS | FS | Silt | Clay | pH | OM | TN | AN | TP | AP | TK |
|---------------|----|----|------|------|----|----|----|----|----|----|----|
| Total 1055    | R  | -0.358** | -0.445** | -0.277** | -0.437** | -0.327** | 0.041 | 0.049 | -0.010 | -0.312** | -0.106** | 0.253** |
|               | S  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GY 560        | R  | -0.330** | -0.375** | 0.046 | -0.477** | 0.076 | -0.042 | -0.009 | -0.051 | -0.102* | -0.028 | 0.190** |
|               | S  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| YX 115        | R  | -0.605** | -0.339** | 0.416** | -0.321** | -0.371** | 0.095 | 0.154 | 0.080 | 0.384** | 0.219* | 0.224* |
|               | S  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| JH 110        | R  | -0.052 | -0.350** | 0.029 | -0.236* | 0.151 | -0.040 | -0.045 | -0.174 | 0.198* | 0.175 | 0.285** |
|               | S  | 0.592 | 0.00 | 0.764 | 0.013 | 0.116 | 0.677 | 0.638 | 0.069 | 0.038 | 0.068 | 0.003 |
| SX 45         | R  | -0.590** | -0.398** | 0.591** | -0.513** | -0.438** | 0.231 | 0.239 | 0.259 | -0.361* | -0.222 | 0.130 |
|               | S  | 0.007 | 0.00 | 0.00 | 0.00 | 0.003 | 0.127 | 0.113 | 0.086 | 0.015 | 0.143 | 0.395 |
| AR 100        | R  | -0.361** | -0.412** | 0.514** | -0.524** | -0.603** | 0.317** | 0.358** | 0.175 | 0.407** | -0.266** | 0.045 |
|               | S  | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.001 | 0.000 | 0.081 | 0.000 | 0.007 | 0.660 |
| YZ 96         | R  | -0.446** | -0.215* | 0.367** | 0.170 | 0.067 | 0.098 | 0.139 | 0.133 | 0.326** | 0.201* | 0.398** |
|               | S  | 0.000 | 0.035 | 0.000 | 0.098 | 0.517 | 0.343 | 0.175 | 0.197 | 0.001 | 0.049 | 0.000 |
Table 5. Pearson correlation coefficients between CEC and other properties (Continued)

| Soil property | AK | Ca²⁺ | Mg²⁺ | S | Cl⁻ | B | Fe | Mn | Cu | Zn | Mo |
|---------------|----|------|------|---|-----|---|----|----|----|----|----|
| Total 1055    | R  | -.123** | .183** | -.203** | -.026 | -.134** | .136** | -.268** | .162** | .040 | -.051 | .071* |
|               | S  | .000 | .000 | .395 | .000 | .000 | .000 | .189 | .096 | .021 |
| GY 560        | R  | -.004 | -.027 | .041 | -.078 | -.094* | .017 | -.122** | .123** | -.043 | -.087* | .047 |
|               | S  | .925 | .516 | .332 | .066 | .026 | .691 | .004 | .003 | .308 | .040 | .270 |
| YX 115        | R  | .081 | .260** | .253** | .042 | -.176 | .321** | -.213* | -.097 | .335** | -.122 | .068 |
|               | S  | .392 | .005 | .006 | .656 | .060 | .000 | .022 | .304 | .000 | .196 | .469 |
| JH 110        | R  | .182 | .046 | -.060 | .246** | -.139 | .258** | -.141 | -.111 | .076 | -.103 | -.121 |
|               | S  | .057 | .633 | .530 | .010 | .147 | .007 | .141 | .250 | .433 | .283 | .207 |
| SX 45         | R  | -.072 | .528** | .640** | .201 | .277 | .671** | -.295* | .046 | -.226 | -.351* | -.217 |
|               | S  | .641 | .000 | .000 | .185 | .066 | .000 | .049 | .764 | .136 | .018 | .152 |
| AR 100        | R  | .140 | .603** | .446** | .227* | .192 | .231* | -.486** | .093 | .253* | -.018 | .072 |
|               | S  | .165 | .000 | .000 | .023 | .055 | .021 | .000 | .358 | .011 | .863 | .479 |
| YZ 96         | R  | -.029 | .119 | .098 | -.097 | -.050 | .274** | .074 | -.198 | .281** | -.136 | -.058 |
|               | S  | .777 | .249 | .344 | .347 | .629 | .007 | .473 | .054 | .006 | .188 | .576 |

Note: in the first line, CS means coarse sands, FS means fine sands; In the first column, the number following the region means the number of soil samples; In the second column, R, Pearson coefficient; S, sig.(2-tailed).

Table 6. Optimal regression equation between CEC and other properties in Chenzhou

| Region       | Optimal regression model                                             | R²  | RSME | RMSE/S.D. |
|--------------|----------------------------------------------------------------------|-----|------|-----------|
| Total        | CEC=-0.606-0.357CS-0.133FS+0.336Clay+2.627pH+0.864TP                 | 0.407 | 5.94 | 0.77 |
| Guiyang      | CEC=-20.048-0.420CS+0.134FS+0.341Clay                                | 0.288 | 6.45 | 0.85 |
| Yongxing     | CEC=-30.655-0.593CS-0.335FS-0.342Silt+2.367pH+2.863TP-0.608B+0.977Cu | 0.489 | 6.02 | 0.74 |
| Jiahe        | CEC=-33.250-0.395FS                                                 | 0.123 | 5.94 | 0.94 |
| Anren        | CEC=-1.484-0.222CS+0.110Silt+0.257Clay+0.545pH+0.023OM+1.216TN-2.110TP+0.202Ca²⁺+1.070Mg²⁺+0.05Fe | 0.602 | 3.42 | 0.66 |
| Yizhang      | CEC=-14.153-0.348CS+0.153Silt+0.112TK                                 | 0.231 | 5.14 | 0.89 |
| Suxian       | CEC=-5.821-0.350CS+0.288Silt+0.240Clay+0.936pH-5.630TP+0.099Ca²⁺+2.352Mg²⁺+0.020Zn | 0.795 | 2.46 | 0.57 |

Note: CS, coarse sands; FS, fine sands; CEC model was setup for Beihu and Linwu due to their less samples (< 20).

4. Discussion

4.1. High CEC in tobacco-planting fields in Chenzhou

CEC was high in tobacco-planting fields in Chenzhou, the mean value of CEC was 22.05 cmol(+) kg⁻¹, higher than the very high grade of CEC (≥20 cmol(+) kg⁻¹). The high CEC could be attributed to the high values of fine particles, pH and OM of the
samples, because many studies have proved well that CEC usually is positively correlated with clays, pH and OM, while negatively correlated with sands [5-14, 46-53], and Zhang and Zhu (1993) found that the positive contribution of silts to soil CEC could not be ignored [54]. From Table 4 it could be seen that both the contents of silts and clays were high, which were ranged from 10%–56% and 10%–66% with a mean of 38% and 29%, respectively, in total constituted of 2/3 of the particle composition. The high content of silts and clays could be attributed to that about 75% of the soil samples in Chenzhou were derived from the clayey parent materials of limestone and Quaternary red clay [42-43, 55]. pH value was also high in Chenzhou, ranged from 4.47 to 8.14 with a mean of 7.00, 89.18% or 62.37% of the soil samples were ≥ 5.5 or ≥ 7.0 in pH. High pH in Chenzhou could be attributed to the samples came from the paddy-planting and to high contents of Ca²⁺, ranged from 2.11–83.77 cmol(Ca²⁺) kg⁻¹ with a mean of 33.27 cmol(Ca²⁺) kg⁻¹, 85.12% of the samples were higher in Ca²⁺(≥10 cmol(Ca²⁺) kg⁻¹). High Ca²⁺ was mostly due to superphosphate fertilizer applied for tobacco-rice, fired soil used to improve soil quality [56-57], and possibly Ca²⁺ was dissolved out of the limestone for most tobacco-planting fields in Chenzhou are located in the limestone hill and mountainous area [32]. Meanwhile, OM was also high in Chenzhou, ranged from 0.90 g kg⁻¹ to 132.30 g kg⁻¹ with a mean of 48.00 g kg⁻¹, and 86.06% and 90.33% of the samples were ≥ 30 g kg⁻¹ in OM (high grade of OM). High OM in tobacco-planting fields in Chenzhou was decided by tobacco-rice rotation, straw returning to the field and organic fertilizer application [58-60].

4.2. Necessity for New Transfer function of CEC

Previous studies found that the application of the existing pedotransfer function models was usually limited in a new region due to the different backgrounds of study regions [61-62]. For example, OM is an indispensable parameter in most existing CEC models because OM is usually significantly correlated with CEC [5-14]. However, in this study no significant correlation was found between OM and CEC in most regions of Chenzhou (R=0.040–0.231, Sig.= 0.127–6.77) except Anren (R=0.317**, Sig.= 0.001), thus OM was not involved in CEC models established in this study except CEC model in Anren, which not only showed the particularity of the influencing factors of soil CEC in tobacco-planting fields in Chenzhou, but also proved again the necessity for establishing a new model for a new study region. The disappearance of OM from the CEC predicting model could also be attributed to narrower variation but high value of OM, the C.V. of OM was 61.86% of that of CEC, meanwhile, high OM more easily covers up the interchange points of cations in the process of organic-inorganic recombination [2, 63-64], both may weaken the positive contribution of OM to CEC.

4.3. Scale Effects of CEC Predicting Model

Most soil properties have the scale effects, and usually the larger the study area, the more influencing factors, the greater the variability of the study object, and then the lower the universality of the model established [61-62], but sometimes the real situation is not always the case [65]. In our study, it could be found that scale down (from whole Chenzhou City to six regions in Chenzhou City) caused the accuracy of CEC model increased in Yongxing, Anren and Suxian (mainly located in northeast and central of Chenzhou) while decreased in Guiyang, Jiahe and Yizhang (mainly located
in west, southwest and south of Chenzhou), and usually the accuracy was low when less properties were significantly correlated with CEC, for examples, ≤3 properties (coarse sands and clays in Guiyang, fine sands in Jiahe, coarse sands, silts and total K in Yizhang) were significantly correlated with CEC, so the accuracies of their CEC models (R²=0.795**, 0.602** and 0.489**, and RMSE/S.D=0.57, 0.66 and 0.74, respectively) were lower than those of Yongxing, Anren and Suxian (R²=0.795**, 0.602** and 0.489**, and RMSE/S.D=0.57, 0.66 and 0.74, respectively), where ≥5 properties were significantly correlated with CEC, which not only reflected the spatial complexity and differences between different regions in Chenzhou, but also proves further that it would be better to setup the optimal CEC models for different regions.

4.4. Influences of Climate Parameters and Parent Materials on Soil CEC

Bai et al. [66] found that climate parameters and parent materials had great influences on soil CEC, soil CEC had significant negative correlation with mean annual temperature (MAT, P<0.01) and quadratic function with mean annual precipitation (MAP, P<0.01), and CEC of soils derived from glacial drifts were higher than those of soils from alluvial sediments and purple siltstone (P<0.05).

In this study there is only one meteorological station in each region of Chenzhou, thus, it is unreliable to use the climate data of the 8 stations to extract the information of climate parameters of each typical field through the method of spatial interpolation. However, the relationship between mean soil CEC with MAP and MAT in the eight regions was analyzed (see Table 7), and the results showed that Pearson correlation coefficients of soil CEC with MAP and MAT were -0.290 and -0.260 with Sig.(2-tailed) of 0.486 and 0.534, respectively, which indicated no significant correlation between soil CEC and MAP and MAT, so in this study, the two climate parameters were not used in soil CEC predicating models.

Table 7. Mean values of soil CEC, annual precipitation (MAP) and air temperature (MAT).

| Region | CEC cmol(+) kg⁻¹ | MAP Mm | MAT ℃ |
|--------|-----------------|--------|--------|
| Guiyang | 23.80 | 1385 | 17.2 |
| Yongxing | 24.11 | 1417 | 17.6 |
| Jiahe | 23.83 | 1409 | 18.3 |
| Anren | 15.31 | 1404 | 17.7 |
| Yizhang | 18.10 | 1453 | 18.7 |
| Suxian | 16.30 | 1487 | 18.2 |
| Beihu | 20.88 | 1504 | 18.4 |
| Linwu | 15.78 | 1422 | 17.9 |

The parent material could affect soil CEC mainly through particle size distribution and clay mineral composition of the derived soil [1, 4]. The 1055 typical fields in this study are all under tobacco and rice rotation, and all located in the flat terrains along the rivers and valleys, thus, their soil parent materials all are the alluvial materials, but the material sources of these alluvial materials might be different, which could be roughly divided into three types: limestone (limestone, dolomite, slate, etc., 883 typical fields), Quaternary red clays (41 typical fields) and sandstones (sandstone, conglomerate, granite, etc., 130 typical fields). Table 8 shows that soil CECs of
limestone and Quaternary red clay were significantly higher than that of sandstone (P<0.01 and P<0.05, respectively), which could be attributed to that clay contents were significantly higher while sand contents were significantly lower in the former two than that of the latter (see Table 9), because as shown in Table 5 that soil CEC was significantly positively correlated with clay content but negatively correlated with sand contents (coarse and fine sands).

| Parent material     | Sample no. | Minimum | Maximum | Mean±S.D.      | Skewness | Kurtosis |
|---------------------|------------|---------|---------|----------------|----------|----------|
| Limestone           | 884        | 3.50    | 48.50   | 23.95±7.48 A   | 0.46     | 0.03     |
| Quaternary red clay| 41         | 7.10    | 37.20   | 20.90±7.31 a   | 0.06     | -0.30    |
| Sandstones          | 130        | 5.80    | 42.40   | 16.35±6.78 b   | 1.11     | 1.98     |

| Parent material     | Minimum | Maximum | Mean±S.D. | Skewness | Kurtosis |
|---------------------|---------|---------|-----------|----------|----------|
| Clays               | Limestone | 9.64    | 66.05     | 28.86±8.66 a | 0.37 | 0.09     |
|                     | Quaternary red clay | 19.48    | 46.98     | 32.21±6.88 A | 0.23 | -0.45    |
| Sands               | Limestone | 12.57    | 78.56     | 32.08±8.35 C | 12.57 | 78.56    |
|                     | Quaternary red clay | 19.00    | 61.45     | 32.16±8.33 b | 19.00 | 61.45    |
|                     | Sandstone | 7.48     | 68.09     | 41.81±12.23 a | 7.48 | 68.09    |

5. Conclusion

This study disclosed that soil CEC averagely was high in tobacco-planting fields in Chenzhou, more than half of the tobacco fields in Chenzhou were in the very high grade of soil CEC, there were significant differences in soil CEC among different regions in Chenzhou. Different soil properties were most important for CEC predicting models in different regions, and the optimal soil CEC predicting models were different in different regions, the sampling and study region must be considered in establishing or applying the optimal soil CEC models. Soil organic matter is not a variable in soil CEC predicting models for tobacco-planting fields in Chenzhou.

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