Quantitative Assessment on Spatial Suitability for Tobacco Planting in Bozhou in Northern Anhui Province, China

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Abstract

While Qiaocheng district currently is the main tobacco planting region in Northern Anhui Province, China, the quantitative assessment on spatial suitability for tobacco planting is necessary for the scientific instruction in the adjustment of planting regionalization and fertilization. In this paper, soil samples of the plough layers were collected from 1224 typical farmlands in 2008, and 18 types of soil properties, pH, clay, silt, sand, organic matter, total nitrogen, available phosphorus, slowly available potassium, rapidly available potassium, exchangeable Ca²⁺ and Mg²⁺, Cl⁻, HCO₃⁻, SO₄²⁻, available Fe, Mn, Cu and Zn were measured. Meanwhile irrigation water samples of 90 typical pumping wells were collected, and Cl⁻, HCO₃⁻, SO₄²⁻, K⁺, Ca²⁺ and Mg²⁺ were measured. The above measured properties were used as the assessing indexes for spatial suitability for tobacco planting, in which the weights were generated by the method of principal component analysis and the fuzzy membership functions were produced based on the practical experiences with the related literatures. The soil suitabilities were quantitatively assessed using the ArcGIS 10.0 platform. The experimental results showed that: (1) areas of the highest, higher, middle, lower and lowest levels of suitability are 4.28×10⁴, 4.36×10⁴, 4.82×10⁴, 4.47×10⁴ and 4.81×10⁴ hm², respectively, constituted of 18.84%, 19.16%, 21.20%, 19.66% and 21.14% of the total area of the farmland, respectively; (2) in general, the Northeast, Northwest, Southeast and Southwest regions are the most suitable areas, and (3) for tobacco farmland in the North region, more potassium fertilizers should be applied due to the low available potassium content in soil, and the flood irrigation should be prevented due to the high content of Cl⁻ in irrigation water. Chengfu in the Southeast, Shihe and Feihe in the Southwest, and Longyang and Gucheng in the South could be regarded as the new potential tobacco planting regions.

Keywords: farmland, suitability for tobacco planting, quantitative assessment, qiaocheng district

1. Introduction

Soil properties can decide or influence the quality of tobacco (H. Liu et al., 2011; Huang, Zhang, Li, Wang, & Li, 2007). Quantitatively understanding of the spatial variations of soil properties in a
region is one of the most important steps to disclose and solve the problems in soil or find the suitable farmlands for harvesting high quality tobacco. In recent years, lots of studies have been utilized in quantitatively assessment of tobacco planting in China (Guo et al., 2011; F. Wang, 2010; X. Wang, Xu, Lv, Wei, & Xie, 2012; Li et al., 2008; K. Wu, Yang, Lv, Chen, & Yang, 2007), and the differences in these studies are mainly focusing on the composition of assessing indexes, weighting the parameters and the membership function of the assessing indexes, calculating and classifying the comprehensive scores of soil suitability. Generally speaking, these methods have achieved a series of success.

Bozhou city once was the main tobacco planting region in Anhui province, where the area of the tobacco planting was about $1.6\times10^4$ hm$^2$ in 1980s with an annual yield of about $4.0\times10^4$ t. However, the low tobacco quality particularly due to low K$^+$ content but high Cl$^-$ content hinders the industrial purchase and use of tobacco (S. Wang et al., 1999b; Song, 2003), which results in the significant decreasing of tobacco planting in Bozhou. In recent years tobacco planting has been shrunk only within Qiaocheng district of Bozhou city with a planting area of $0.34\times10^4$ hm$^2$ and an annual tobacco yield of about $0.4\times10^4$ t. Some preliminary studies were conducted on tobacco planting soil and tobacco production of Bozhou (S. Wang et al., 1999b; S. Wang et al., 1999a; Song, 2003), but no information is available on the systematical quantitative assessment soil and irrigation water suitability for tobacco planting. Hence it is necessary to conduct an overall quantitative assessment on soil suitability for tobacco planting in Qiaocheng district aiming to ensure the planting of tobacco with high quality. Because the assessment procedure on soil fertility, quality or suitability is proved effective and practical enough with respect to the 3S techniques and various mathematic statistic softwares (H. Wang, Liao, & Liao, 2014; Fang, 2013; Xu, Zhang, Xie, & Lv, 2010; Yue, Ge, & Wang, 2010), so in this paper, it is unnecessary for us to describe again the assessment procedure in detail, and we will only focus on the assessment results and their useful instructions to the current tobacco planting region and to the future adjustment in tobacco planting.

2. Materials and Methods

2.1. Information of Qiaocheng District

Qiaocheng district is located in $115^\circ30′$–$116^\circ05′$E and $33^\circ25′$–$34^\circ05′$N with a total area of 222600 hm$^2$, in the Northern part of Huaiabei plain of Anhui province. The altitude ranges from 32 to 42 m, the annual sunshine hours are 2508 h, the annual temperature average is 14.5°C, the annual precipitation average is 805 mm, the annual evaporation average is 1748 mm, and frost-free period is 209 d.

The area of the farmland in Qiaocheng is about $12.6\times10^4$ hm$^2$, and the main soil types include fluvo aquic soil (calcric ochi-aquic cambosols (Cooperative Research Group on Chinese Soil Taxonomy, 2001), about $8.4\times10^4$ hm$^2$) and Shajiang black soil (shanjiang-aquic cambosols or calciaquic vertosols, about $4.2\times10^4$ hm$^2$). All the farmlands in Qiaocheng are dryland. The planting system of the farmland in Qiaocheng is usually wheat rotated with maize/cotton/soybean, or tobacco interplanting with sweet potato. All the agricultural water is irrigated from the pumping wells where the current underground water level is about 20-30 m. The main ions in the water are Cl$^-$, HCO$_3^-$, SO$_4^{2-}$, Mg$^{2+}$, Ca$^{2+}$, K$^+$ and Na$^+$. During the growing season each field usually receives 3-5 irrigations of 20-40 mm each (source: personal interview with farmers). Each irrigation event covers an area of a few hectares.

2.2. Sampling and Measurement of Soil and Irrigation Water

In 2008, 1224 typical farmlands (about one sampling typical farmland per 110 hm$^2$ of farmland) in Qiaocheng district were selected uniformly in spatial distribution due to the flat topography in this area (Figure 1). In each typical farmland 5-8 points of plough layer soil samples were collected and
mix uniformly, then 2 kg of soil of each typical farmland were kept left by using quartering and kept in the cloth bag. In the lab soil samples were air dried, and the impurities of roots and gravels were removed. Then they were grinded to pass 1.7 mm, 0.25 mm and 0.149 mm sieves respectively. The measurement methods of soil properties were as follows: pH, potentiometry; particle composition, pipette method; organic matter, potassium bichromate-sulfuric acid digestion; total nitrogen, potassium bichromate-sulfuric acid digestion- distillation; available phosphorus, sodium bicarbonate extraction-Mo-Sb spectrophotometer; slowly available potassium, nitric acid digestion-flamephotometer; rapidly available potassium, acetamide extraction- flamephotometer; exchangeable Ca$^{2+}$ and Mg$^{2+}$, EDTA compleximetry; HCO$_3^-$, SO$_4^{2-}$, phenolphthalein- methyl orange-titrimetry; Cl$^-$, silver nitrate-titrimetry; and available Fe, Mn, Cu and Zn, DTPA extraction-atomic absorption spectrophotometer. All detailed processes of the above measurements could be found in the reference literature (Cooperative Research Group on Chinese Soil Taxonomy, 2001).

Figure 1. Soil and irrigation water sampling sites of Qiaocheng district

Meanwhile fresh irrigation water samples were collected in 1 L PVC bottles from 90 pumping wells, then stored in at 2℃- 5℃ in the deepfreeze and taken back to the lab within 7 days. The contents of K$^+$, Ca$^{2+}$, Mg$^{2+}$, Cl$^-$, HCO$_3^-$ and SO$_4^{2-}$ were measured. The measurement methods of the above ions were as follows: K$^+$, flamephotometer; Cl$^-$, silver nitrate-titrimetry; Ca$^{2+}$, Mg$^{2+}$ and SO$_4^{2-}$, EDTA compleximetry; and HCO$_3^-$, phenolphthalein- methyl orange-titrimetry. All detailed processes of the above measurements could be found in the reference literature (Zhang & Gong, 2012).
2.3. Assessment Methods

The above measured properties of soil and water samples were all taken as the assessing indexes. The outliers were identified by a global threshold (mean ± 3standard deviation) of the assessing indexes and replaced by the maximum or minimum value of each index.

Both the weights of assessing indexes of soil and water samples (see Table 1 and Table 2) were decided by the current common method - principal component analysis (PCA), and the weight ratio between soil and water was decided as 0.8:0.2 as soil plays more important role than water in deciding or influencing tobacco quality. The ratio is an empirical parameter based on the long-term cultivation of local fertilizers. The biological fertilizer was not utilized due the limitation of soil survey. The membership functions of the assessing indexes (see Tables 3 and 4) were generated by fuzzy mathematics method based on the effect curves of tobacco growth and comprehensive consideration of the related information in available literatures (Guo et al., 2011; F. Wang, 2010; X. Wang et al., 2012; Li et al., 2008; K. Wu et al., 2007). Some studies have proposed the parabola-shape relation of soil pH, organic matter and total nitrogen with tobacco quality and S-shape relation of soil available phosphorus with tobacco quality (M. Chen et al., 2015; S. Wu, Xing, & Zhou, 2014; X. Chen, Li, & Chen, 2013). However the actual relation of soil other properties with tobacco quality is still vague with a certain uncertainty although both parabola-shape and S-shape relation are based on the experiences of soil fertility assessment. It is well known that the higher of K+ or the lower of Cl- content is, the higher quality of tobacco will be. Low potassium content and high chloride content are the two fatal factors limiting tobacco quality in Northern Anhui Province. Consequently we defined that positive linear relation of slowly available potassium and available potassium with suitability, negative linear relation of Cl- with suitability since their antagonism with K+, negative linear relation of exchangeable Ca2+ and Mg2+ with suitability since their antagonism with K+, positive linear relation of HCO3- and SO42- with suitability since their antagonism with Cl-, positive linear relation of available Fe, Mn, Cu and Zn with suitability since soil pH is high in Qiaocheng district which can reduce the bio-availability of these trace elements. Likewise, negative linear relation was defined for Cl-, Ca2+ and Mg2+ while positive linear relation for K+, HCO3- and SO42- with considerable suitability. The values of indexes of the linear relation were normalized by $x_i/x_{\text{max}}$ ($x_i$ is the measured value of the index i, $x_{\text{max}}$ is the measured maximum value of index i), while the values of indexes of the parabola-shape and S-shape relation were normalized according to the following Equation (1) and (2) respectively.

Table 1. Weights of the soil assessing indexes

| Texture | pH  | OM  | TN  | SAK | RAK | AP  | Cl- |
|---------|-----|-----|-----|-----|-----|-----|-----|
|         | 0.100 | 0.056 | 0.075 | 0.066 | 0.065 | 0.079 | 0.057 | 0.065 |
| ECa2+   | E Mg2+ | HCO3- | SO42- | A Fe | A Mn | A Cu | A Zn |
|         | 0.055 | 0.055 | 0.055 | 0.055 | 0.055 | 0.055 | 0.055 | 0.100 |
|         | OM, organic matter; TN, total nitrogen; SAK, slowly available potassium; APK, available potassium; AP, available phosphorus; ECa2+ and Ca2+; exchangeable Ca2+ and Mg2+; A Fe, Mn, Cu and Zn, available Fe, Mn, Cu and Zn. |

Table 2. Weights of the water assessing indexes

| Cl-  | K+  | HCO3- | SO42- | Ca2+ | Mg2+ |
|------|-----|-------|-------|------|------|
| 0.213 | 0.211 | 0.144 | 0.141 | 0.145 | 0.145 |
Parabola-shape:

\[
 f(x) = \begin{cases} 
 0.1 & (x < x_1; x > x_2) \\
 0.9 \times \frac{(x - x_1)}{(x_2 - x_1)} + 0.1 & (x_1 < x < x_2) \\
 1.0 & (x_1 \leq x \leq x_2) \\
 1.0 - 0.9 \times \frac{(x - x_1)}{(x_2 - x_1)} & (x < x \leq x_1) 
\end{cases}
\]  \quad (1)

S-shape:

\[
 f(x) = \begin{cases} 
 1.0 & (x \geq x_2) \\
 0.9 \times \frac{(x - x_1)}{(x_2 - x_1)} + 0.1 & (x_1 < x \leq x_2) \\
 0.1 & (x \leq x_1) 
\end{cases}
\]  \quad (2)

The integrated suitability score (ISS) of each sample was calculated according to the following Equation (3):

\[
 ISS = \sum_{i=1}^{n} W_i N_i
\]  \quad (3)

where \( N_i \) and \( W_i \) is the membership value and weight of index \( i \) respectively. The higher of ISS is, the higher spatial suitability will be for tobacco planting.

**Table 3. Membership functions of the assessing indexes of soil and water**

| Sample | Assessing index | Membership function type* |
|--------|-----------------|--------------------------|
| Soil   | pH, organic matter, total N | Parabola-shape |
|        | available phosphorus | S-shape |
|        | exchangeable Ca\(^{2+}\) and Mg\(^{2+}\), Cl\(^-\) | Negative linear |
|        | slowly available K, rapid available K, HCO\(_3^-\), SO\(_4^{2-}\), available Fe, Mn, Cu and Zn | Positive linear |
| Water  | Ca\(^{2+}\), Mg\(^{2+}\), Cl\(^-\) | Negative linear |
|        | HCO\(_3^-\), SO\(_4^{2-}\), K\(^+\) | Positive linear |

* note: 1) linear type means the higher of the index value, the higher or lower of tobacco quality; 2) Ca and Mg antagonistic with K, HCO\(_3^-\) and SO\(_4^{2-}\) antagonistic with Cl\(^-\). 3) for soil texture, 1, 0.8, 0.6, 0.4, 0.2 and 0 were defined for sandy loam, loam, clayey loam, silty clay, loam clay and clay (6 textures in studied soil samples) respectively.

**Table 4. Classification of membership function of soil assessing indexes**

| Membership function | Soil index      | Low limit | \(x_1\) | \(x_2\) | Upper limit |
|---------------------|-----------------|-----------|---------|---------|-------------|
| Parabola-shape      | pH              | 5         | 5.5     | 7       | 7.5         |
|                     | Organic matter (g kg\(^{-1}\)) | 15        | 25      | 35      | 45          |
|                     | Total nitrogen (g kg\(^{-1}\)) | 0.9       | 1.4     | 2.5     | 3.5         |
| S-shape             | Available phosphorous (mg kg\(^{-1}\)) | 100       | 1.4     | 2.5     | 3.5         |
|                     | Available phosphorous (mg kg\(^{-1}\)) | 150       |         |         |             |
2.4. Platforms for Data Processing and Mapping
IBM SPSS 20 software and ArcGIS 10.0 were used for the data processing and mapping in this study.

3. Results and Discussions
3.1. Value Spatial Distribution Characteristics of Soil Assessing Indexes
Figure 2 shows the spatial distribution of the soil assessing indexes. As low potassium content and high chloride content are the two fatal factors limiting tobacco quality, here we focus on the contents of soil available potassium and Cl⁻.
Figure 2. Value spatial distribution of soil assessing indexes in Qiaocheng district
As can be seen from Figures 2 and 3, it can be found that slow available potassium ranged from 632.77 to 1121.87 mg kg$^{-1}$ spatially higher in the Northwest. Rapid available potassium ranged from 92.38 to 299.85 mg kg$^{-1}$ spatially lower in the Northwest. Cl$^{-}$ ranged from 3.52 to 5.15 m mol kg$^{-1}$ spatially higher in the South and East. Among of total 1224 soil samples, 6.0%, 18.8% and 75.2% are insufficient (<100 mg kg$^{-1}$), middle (100-150 mg kg$^{-1}$) and plentiful (>150 mg kg$^{-1}$) in the content of rapid available potassium, respectively. About 4.5% and 95.5% of the content of slowly available potassium are middle (300-400 mg kg$^{-1}$) and plentiful (>400 mg kg$^{-1}$) respectively. The above data show that there are high current available potassium contents in farmland soil. As for contents of Cl$^{-}$, all the soil samples are lower than unsuitable critical values (30 mg kg$^{-1}$, i.e., 8.45 m mol kg$^{-1}$) (J. Liu, Liu, & Chen, 2009), and 3.4%, 89.8% and 6.8% of the Cl$^{-}$ contents of the samples are smaller than 10 g kg$^{-1}$, between 10 and 20 g kg$^{-1}$ and larger than 20 g kg$^{-1}$ respectively.

3.2. Value Spatial Distribution Characteristics of Water Assessing Indexes
The spatial distribution of the water assessing indexes is given in Figure 4. It can be found that $K^+$ ranged from 1.00 to 1.75 mg L$^{-1}$, and spatially higher in the Northwest. $Ca^{2+}$ and $Mg^{2+}$ ranged from 0.047 to 0.093 mg L$^{-1}$ and 240.83 to 742.91 mg L$^{-1}$, respectively, and spatially higher in the Northwest and Southeast. $Cl^{-}$ ranged from 4.12 to 11.99 mg L$^{-1}$, and spatially higher in the North. $SO_4^{2-}$ ranged from 114.83 to 295.31 mg L$^{-1}$, and spatially higher in the North and Northeast. $HCO_3^-$ ranged from 32.74 to 73.11 mg L$^{-1}$, and spatially higher in the North.

### 3.3. Spatial Suitability for Tobacco Planting

Figure 5 (a), (b) and (c) showed the spatial distribution of soil, water and integrated suitability for tobacco planting in Qiaocheng district.

From Figure 5 (a) and (c) it can be seen that Lumiao, Huatuo, Qiaodong, Shijiuli, Guantang, Shatu and Zhaoqiao in the middle-North are the regions with lower, lower soil and integrated
suitability, while Shihe, Shuanggou, Feihe, Chengfu, Niuji and Zhangdian are the regions with higher soil and integrated suitability. From Figure 5 (b) it can be seen that Gujing, Lumiao, Yanji, Qiaodong, Zhangdian, Guantang, Shibali and Shihe in the North and West are the regions with higher water suitability, while Zhaoqiao, Dayang, Gucheng, Chengfu and Lide in the middle and South are the regions with lower water suitability.

Table 5 shows that the total area of the highest and higher integrated suitability is $8.64 \times 10^4$ hm$^2$, constituting of 38.0% of the total area of the farmland in Qiaocheng district, mainly distributed in Shihe, Shuanggou, Feihe, Gucheng, Chengfu, Niuji, Zhangdian, Lide and Longyang as pointed above (see Figure 5 (c)). Meanwhile the total area of the lowest and lower integrated suitability is $9.28 \times 10^4$ hm$^2$, constituting of 40.8% of the total area of the farmland in Qiaocheng district.

| Grade  | Integrated score | Area ($\times 10^4$ hm$^2$) | Area percentage (%) |
|--------|------------------|-----------------------------|---------------------|
| Highest| $> 0.375$        | 4.28                        | 18.8                |
| Higher | 0.358 - 0.375    | 4.36                        | 19.2                |
| Middle | 0.340 - 0.357    | 4.82                        | 21.2                |
| Lower  | 0.323 - 0.339    | 4.47                        | 19.7                |
| Lowest | $< 0.323$        | 4.81                        | 21.1                |

3.4. Proposals for Tobacco Planting

Current main tobacco planting in Qiaocheng district can be divided into four regions: 1) Niuji, Weigang, Gujin, Lumiao in Northwest and North, 2) Zhangdian in the Northeast, 3) Shuanggou in the Southwest, and 4) Dayang in the Southeast.

| Index               | Northwest and North | Northeast | Southwest | Southeast |
|---------------------|---------------------|-----------|-----------|-----------|
| available potassium | - (lowest)          | + (high)  | + (high)  | ++ (highest) |
| exchangeable Ca$^{2+}$ and Mg$^{2+}$ | -- (highest)        | ++ (lowest) | ++ (lowest) | ++ (lowest) |
| Cl$^-$               | ++ (lowest)         | - (high)  | -- (highest) | - (high)  |
| HCO$_3^-$            | ++ (highest)        | ++ (highest) | - (low)   | - (low)   |
| SO$_4^{2-}$          | ++ (highest)        | --(low)   | + (high)  | + (low)   |
| K$^+$                | ++ (high)           | --(lowest) | --(lowest) | --(lowest) |
| Ca$^{2+}$, Mg$^{2+}$ | -- (highest)        | + (low)   | + (low)   | -- (high) |
| Cl$^-$               | -- (highest)        | - (high)  | -- (highest) | - (high)  |
| SO$_4^{2-}$          | + (high)            | + (high)  | ++ (highest) | - (low)   |
| HCO$_3^-$            | ++ (highest)        | + (high)  | - (low)   | -- (lowest) |

* ++, +, – and – – mean content are very unsuitable, suitable, unsuitable and very unsuitable for tobacco planting.
Table 6 shows the overall evaluation of these regions. Aiming to increase K⁺ content and decrease Cl⁻ content in tobacco, it can be found from Table 6 that for tobacco planting region of Northwest and North, more potassium fertilizer should be used due to the low content of soil available potassium. According to our field survey, for tobacco planting farmland under the rotation of tobacco and sweet-potato in Qiaocheng, in total about 13.7 kg/667 m² K₂O is used by fertilization annually for, but about 13.3-16.0 kg K₂O is taken away annually by the tobacco and sweet-potato. Hence available potassium in soil decreases gradually. It is necessary to apply more potassium fertilizer so as to maintain potassium. It is also very important that all the tobacco planting regions should not adopt the fertilizers containing Ca, Mg and Cl, and also should employ the drop-irrigation mode to avoid more Ca, Mg and Cl brought into soil.

For the adjustment of tobacco planting region in terms of the integrated suitability, among of the current tobacco planting regions, Lumiao should be abandoned because its lowest suitability, while Shihe and Feihe in the Southwest, Chengfu in the South, Longyang and Gucheng in the South could be considered as the new potential tobacco planting regions.

4. Conclusion

We quantitatively assessed the integrated suitability for tobacco planting in Qiaocheng district by using indexes of soil and irrigation water, the current main tobacco planting region in Northern Anhui province, and found that about 38% of the farmland is suitable for tobacco planting. For current tobacco planting farmland, more potassium fertilizer should be used to maintain or increase potassium in soil. Meanwhile, the fertilizers containing Ca, Mg and Cl should not be employed, and the drop-irrigation mode should be adopted so that little Ca, Mg and Cl will be brought into the soil. Chengfu in the South, Shihe and Feihe in the Southwest, and Longyang and Gucheng in the South could be regarded as the new potential tobacco planting regions.

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