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Predicting Base Saturation Percentage by pH

—A Case Study of Red Soil Series in South China

Anqi Wang[1,2], Bing Ju[1], Decheng Li[1*]

[1]State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China
[2]University of the Chinese Academy of Sciences, Beijing, China
Email: aqwang@issas.ac.cn, *dcli@issas.ac.cn

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Abstract

pH and base saturation percentage (BSP) are two basic indexes in identifying soil types in Chinese Soil Taxonomy. Some studies proved that there is significant correlation between BSP and pH, thus it could save the cost of laboratory work if we can infer BSP directly from pH. In this study, the measured values of BSP and pH of 162 and 232 horizon samples from 48 and 55 red soil series surveyed from 2009 to 2011 in Fujian and Guangdong respectively were adopted from Soil Series Database to set up the optimal correlation model between BSP and pH. The results showed that: 1) BSP ranged from 2.30% to 94.02% with a mean of 25.07%, while pH from 3.42 to 6.91 with a mean of 4.98 for the total soil samples. 2) There were significant differences in pH between different soil types (R^2 were 0.624 for Ferralosols, 0.507 for Ferrosols, 0.515 for Argosols, and 0.456 for Cambosols, $p < 0.01$), in BSP between different parent materials (R^2 were 0.580 for Quaternary red clay, 0.434 for granite, 0.642 for sandstone, and 0.712 for basalt, $p < 0.01$), in pH and BSP between different land use types (R^2 were 0.623 for dryland, and 0.404 for forest land, $p < 0.01$). pH and BSP generally were in moderate variation (10% - 100%), and in positive skew distribution (>0), their probability density curves were mainly in flat or normal curves (<0.67). 3) There is significant positive correlation between BSP and pH, and the optimal correlation models are in quadratic form in most circumstances, but the optimal model and the accuracy are different in different circumstances, changed with different regions, parent materials, soil types and land use types. The accuracy of models established in other studies when predicting our soil samples was lower compared with our models. pH < 5.33 or <5.93 could be used roughly to judge BSP < 35% or <50% based on the model of all red soil series ($y = 6.84x^2 - 45.86x + 81.52$, $R^2 = 0.494$, $p < 0.01$).

Keywords

pH, Base Saturation Percentage (BSP), Correlation Model, Red Soil Series, Fujian, Guangdong, South China

1. Introduction

pH and base saturation percentage (BSP) are two important soil chemical properties which have implications both for soil fertility [1] and taxonomy [2] [3]. For examples in Chinese Soil Taxonomy [2], pH is used in the definitions of Sulfuric horizon (pH < 4.0), Sulfidic materials (pH may < 4.0), "Acidic" soil subgroup (pH < 5.5); BS is used in the definitions of Mollic epipedon (BSP ≥ 50%), Umbric epipedon (BSP < 50%), Agric horizon (BS is higher or much higher than that of underlying layers), L. C. of purplish sandstones and shales (Base saturated), L. C. of carbonate rocks (BSP ≥ 50%), and "Rutrophic" soil subgroups of Ferralosols and Ferrosol (BSP ≥ 35%).

The determination of BSP needs to measure total amount of exchangeable base (Ca^{2+}, Mg^{2+}, K^+, and Na^+) and cation exchange capacity (CEC) of soil samples in the laboratory [4] [5] [6] [7]. It is more laborious and time-consumptive for the measurement of BSP compared with that of pH which is easily and simply determined by potentiometer [4] [5] [6] [7]. Some studies have proved that there is significant correlation between BSP and pH [8] [9], so it is possible to infer BSP directly from pH. Meanwhile and more importantly, nowadays pH can be rapidly measured *in situ* by portable pH meter, so it is helpful for soil survey staffs to preliminarily identify soil types in field more accurately, thus can promote the quality of the description on the formation factors and morphological characteristics of soil profiles. However, BSP is a dynamic soil property, which is affected by climatic, geochemical, and environmental conditions [10]. In soil science it is common that a model established in one scenario often does not work well in other ones, new model has to be set up for higher predication accuracy.

Red soils, as udic Ferrosols, Argosols and Cambosols in Chinese Soil Taxonomy [3], is widely distributed in the hilly area of tropical and subtropical south China, mainly derived from weathered materials of quaternary red clay, tertiary red sandstone, granite, basalt, phyllite and limestone, etc. and under different land use types [11] [12]. Subjected to intensive weathering and leaching, red soil is characterized by high acidity, clayey texture and poor structure, etc. [13] [14]. There are literatures on the relation between BSP and pH for red soil series in county scale [8] [9], but so far little information is available of red soils series in province scale. Therefore, the objective of the current study is to setup the optimal correlation between BSP and pH for red soil series in south China.

2. Methods and Materials

2.1. Data Sources

The values of pH and BSP of red soil series are from Soil Series Database of the

National S & T Special Basic Project of Soil Series Survey and Compilation of Soil Series of China (Nos.2008FY110600 & 2014FY110200). After the comparison of the data completeness of pH and BSP, and the elimination of abnormal data according to method of $\mu \pm 3\sigma$, finally 162 and 232 horizon samples from 48 and 55 red soil series of Fujian and Guangdong were adopted respectively in this study (see Figure 1). As for the method of soil sampling, the genetic horizons of each typical profile (0 - 120 cm or 0 - 150 cm) of the selected soil series were divided according to the morphological characteristics and then soil samples of the partitioned horizons were collected [15].

2.2. Methods to Determine Soil Indexes

pH was determined by the method of potentiometer after water extraction (soil:water = 1:2.5), total amount of exchangeable base (BS) determined by the method of evaporation and neutralization titration after 1 mol/L NH_4OAc (pH7.0) extraction, cation exchange capacity (CEC) determined by 1 mol/L NH_4OAc exchange method [6]. BSP is defined as BS × 100%/CEC [6] [7].

2.3. Data Processing, Modeling and Mapping

Microsoft Excel 2016 and IBM Statistics SPSS 20.0 were used for data processing, modeling and mapping, significance of difference in pH and BSP under different scenarios were tested by LSD method of one-way ANOVA, mean absolute error (MSE) and root mean square error (RMSE) were used to test the prediction accuracy of the established models [16].

3. Results and Discussions

3.1. General Statistics of pH and BSP of Red Soil Series

Table 1 gives the statistical information of pH and BSP under different scenarios. pH ranged from 3.42 to 6.91 with a mean of 4.98 and BSP ranged from

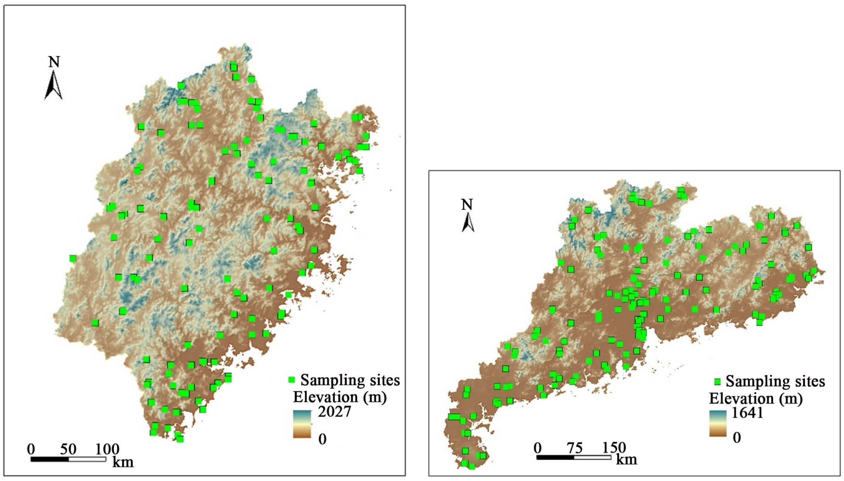

Figure 1. Sites of soil profiles surveyed in Fujian (left) and Guangdong (right) from 2009 to 2011.

Table 1. Statistical information of pH and BSP of red soil series in China.

pH		Mean ± St. D	C. V. (%)	Skewness	Kurtosis
Region	Total	4.98 ± 0.60	11.85	0.64	0.54
	Fujian	5.13 ± 0.63	12.28	0.43	0.41
	Guangdong	4.88 ± 0.55	11.27	0.75	0.75
Soil type	Ferralosols	4.92 ± 0.51	10.37	0.55	−0.97
	Ferrosols	4.83 ± 0.45	9.32	0.56	0.37
	Argosols	5.20 ± 0.69	13.27	0.14	−0.7
	Cambosols	5.04 ± 0.72	14.29	0.62	0.35
Parent material	Q_4 red clay	4.87 ± 0.39	8.01	0.85	−0.39
	Granite	5.02 ± 0.63	12.55	0.4	−0.26
	Sandstone	4.93 ± 0.58	11.76	0.71	1.77
	Basalt	5.36 ± 0.84	15.67	0.16	−0.96
Land use	Dryland	5.3 ± 0.71	13.4	0.53	−0.23
	Forestland	4.9 ± 0.54	11.02	0.44	0.22
BSP		**Mean**	41.26	**Skewness**	**Kurtosis**
Region	Total	25.07 ± 21.26	86.4	1.11	0.25
	Fujian	35.96 ± 23.03	64.04	0.6	-0.7
	Guangdong	17.46 ± 16.95	97.08	1.66	2.03
Soil type	Ferralosols	15.58 ± 11.21	71.95	1.87	3.6
	Ferrosols	22.66 ± 18.65	82.3	1.14	0.38
	Argosols	32.1 ± 23.79	74.11	0.76	−0.49
	Cambosols	23.66 ± 26.81	113.31	1.12	−0.27
Parent material	Q_4 red clay	29.62 ± 19.60	66.17	0.63	−0.66
	Granite	26.19 ± 23.92	91.33	0.92	−0.42
	Sandstone	19.74 ± 19.62	99.39	1.77	2.97
	Basalt	38.68 ± 25.62	13.81	0.18	−1.63
Land use	Dryland	41.26 ± 24.08	58.36	0.37	−0.79
	Forestland	21.26 ± 19.20	90.26	1.34	0.83

2.30% to 94.02% with a mean of 25.07% for total samples, pH of in Fujian were significantly higher than that of Guangdong ($p < 0.01$), while BSP of Fujian were significantly lower than that of Guangdong ($p < 0.01$).

From Table 1 it also could be seen that there were significant differences in pH and BSP between most soil types, but no significant differences in pH between most parent materials, significant differences in BSP between most soil parent materials, and significant differences in pH and BSP between dryland with forest land ($p < 0.01$).

C.V. (%) values of pH and BSP showed that most of these two parameters were in moderate variation (10% - 100%), only pH of Ferrosols series and soil series derived from quaternary red clay were in weak variation (<10%). Skewness values of pH and BSP showed that they were all in positive skew distribution (>0) under all scenarios, while kurtosis values of pH and BSP showed that the probability density curves of them mainly in flat or normal curves (<0.67) [16].

3.2. Optimal Models between pH and BSP of Red Soil Series under Different Scenarios

On regional scale, quadratic model was optimal for describing the correlation between BSP and pH (**Figure 2**), and the accuracy was higher for model of Fujian ($R^2 = 0.565$, $p < 0.01$) than for model of Guangdong ($R^2 = 0.402$, $p < 0.01$). On soil type scale, quadratic model was also optimal for describing the correlation between BSP and pH (**Figure 3**), and the accuracy was highest for model of Ferralosols ($R^2 = 0.624$, $p < 0.01$), followed by model of Argosols ($R^2 = 0.515$, $p < 0.01$) and of Ferrosols ($R^2 = 0.507$, $p < 0.01$), and the accuracy was lowest for model of Cambosols ($R^2 = 0.456$, $p < 0.01$). On parent material scale, quadratic model was also optimal for describing the correlation between BSP and pH (**Figure 4**), and the accuracy from high to low was in order of basalt ($R^2 = 0.712$, $p < 0.01$) > sandstone ($R^2 = 0.642$, $p < 0.01$) > quaternary red clay ($R^2 = 0.580$, $p < 0.01$) > granite ($R^2 = 0.434$, $p < 0.01$). On land use scale, linear and quadratic models were optimal for describing the correlation between BSP and pH of dryland and forest land, respectively (**Figure 5**), and the accuracy was higher for model of dryland ($R^2 = 0.623$, $p < 0.01$) than model of forest land ($R^2 = 0.404$, $p < 0.01$).

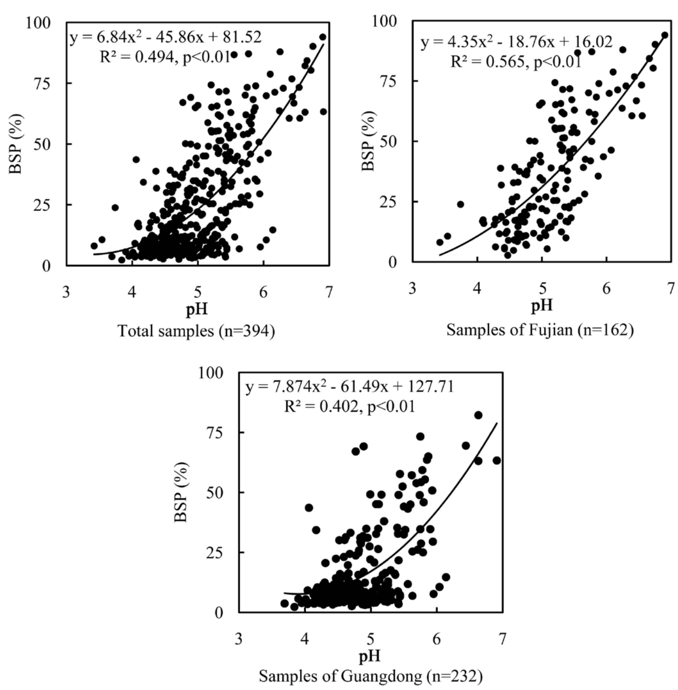

Figure 2. Optimal correlation models between BSP and pH under different regions.

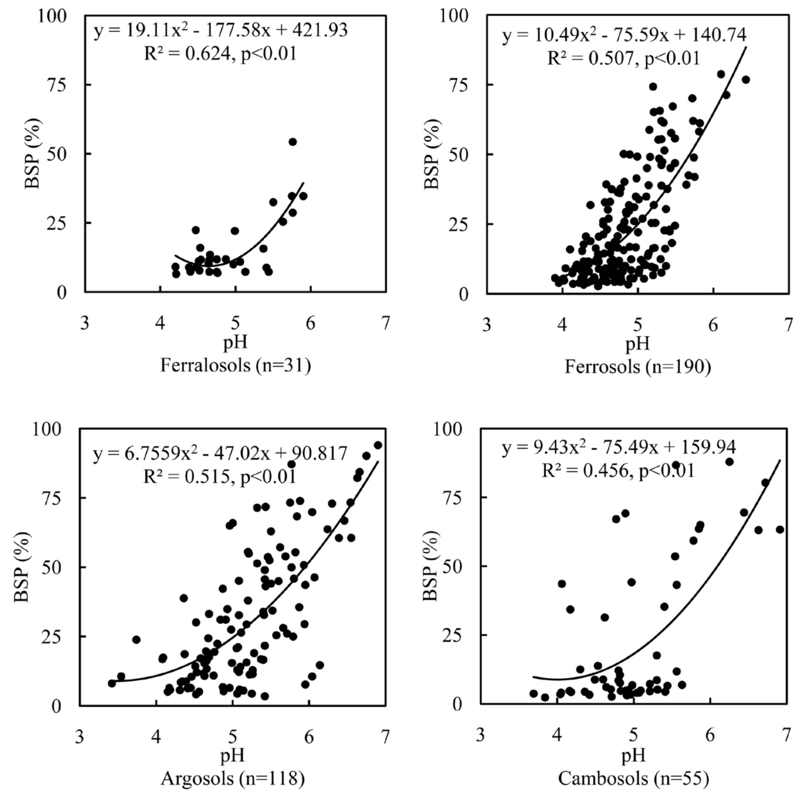

Figure 3. Optimal correlation models between BSP and pH under different soil types.

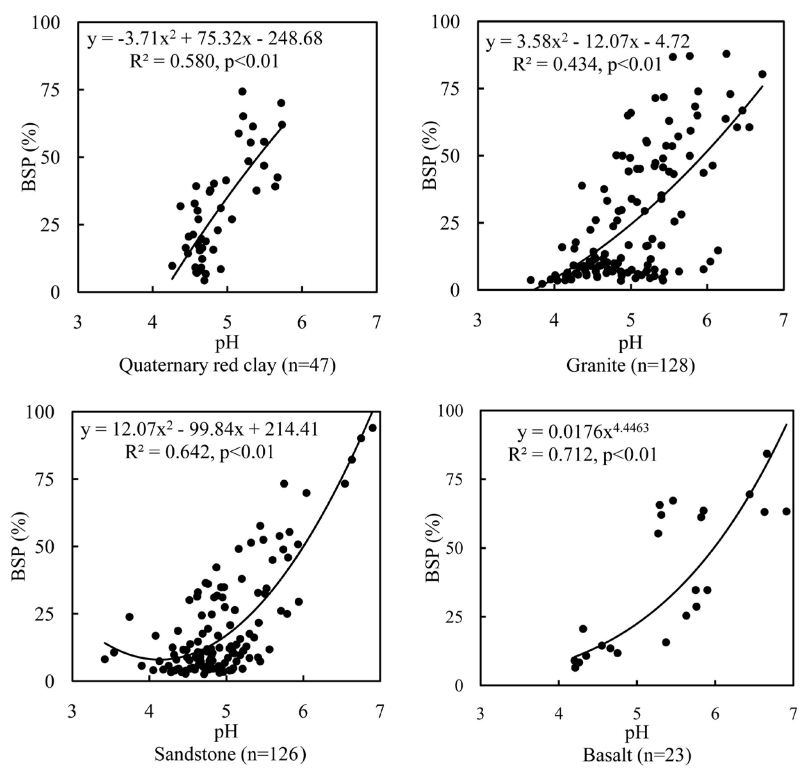

Figure 4. Optimal correlation models between BSP and pH under different parent materials.

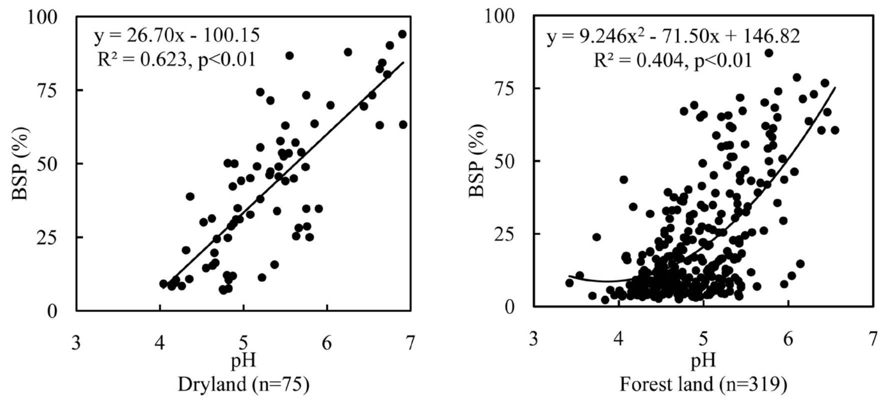

Figure 5. Optimal correlation models between BSP and pH under different land use types.

3.3. Accuracy Comparison of Different Models between pH and BSP

Here, our model of total red soil series samples ($y = 6.84x^2 - 45.86x + 81.52$, $R^2 = 0.494$, $p < 0.01$, n = 394, **Figure 1**, right) and the models established by Mao et al (2005) and by Li *et al.* (2012) were used to compare the predication accuracy (see **Table 2**). MAE and RSME of our model were 11.85 and 15.40, respectively, both were lower than those of others models, which means the accuracy of our model is higher.

4. Discussion

Since significant correlation is existed between pH and BSP, here we only compare pH values in different circumstances. Low pH values of red soil series are normal because red soils in south China are generally acid due to the high precipitation and intense weathered process [11] [12], the leaching losses of K, Na, Ca and Mg in south China could be higher than 80% [17] [18]. Higher pH value (5.13 ± 0.63) of red soil series in Fujian than that of Guangdong (4.88 ± 0.55) could be attributed to the higher annual temperature and precipitation in Fujian (17˚C - 21˚C, 1400 - 2000 mm) than Guangdong (19˚C - 24˚C, 1300 - 2500 mm).

For soil types, pH of Ferralosols (4.92 ± 0.51) and Ferrosols (4.83 ± 0.45) are significantly lower than those of Argosols (5.20 ± 0.69) and Cambosols (5.04 ± 0.72), which may be resulted from the further development of Ferralosols and Ferrosols due to the higher temperature and precipitation than Argosols and Cambosols [17] [18], it could be supported further by the definitions of these four kinds of soil types in Chinese Soil Taxonomy [3] and Chinese Genetic Classification [11] [12]. For land use types, it is common in south China that farmers often used lime or dolomite powders to weaken soil acidity of farmlands [19], thus, it is reasonable for pH of dry land (5.30 ± 0.63) significantly higher than that of forest (4.90 ± 0.63). Meanwhile, soil samples of forests most are from *Pinus massoniana* and *Pinus masoniana*, it is well known that *Pinus massoniana*

Table 2. Accuracy comparison of different models between pH and BSP.

	Model	MAE	RSME
Our model	$y = 6.84x^2 - 45.86x + 81.52$ ($R^2 = 0.494$, $p < 0.01$, $n = 394$)	11.85	15.40
Mao *et al.* (2005) [8]	$y = -8.455x^2 + 115.54x - 305.28$ ($R^2 = 0.854$, $p < 0.01$, $n = 71$)	33.01	36.70
Li *et al.* (2012) [9]	$y = -2.067x^2 + 52.687x - 203.08$ ($R^2 = 0.703$, $p < 0.01$, $n = 30$)	19.99	24.30

could exacerbate soil acidly [20], and more chemical fertilizers are used for rapid growth of *Eucalyptus robusta*, which could also intensify soil acidity [21]. Similarly, pH of basalt (5.36 ± 0.84) is highest could be attributed to its highest ratio of dryland samples (56.5%), the lowest of pH of sandstone (4.93 ± 058) attributed to its highest ratio of forest land samples (81.31%).

Significant correlation between BSP and pH were found in many studies, usually in linear and quadratic models, but the parameters of models are different [8] [9] [22] [23] [24]. Our studies also showed that quadratic model is optimal in most scenarios in describing the correlation between BSP and pH for red soil series of south China.

According to the definition of BSP, it is decided by exchangeable base caions (K^+, Na^+, Ca^{2+} and Mg^{2+}) and the exchangeable H^+ and Al^{3+} simultaneously, because these cations are influenced by temperature, precipitation, parent materials, land use type etc. [1] [11] [12], thus an optimal model should be established according to a specific scenario [25], which is further proved by our studies based on different regions, parent material and land use type or soil types. Because our study is mainly to give out the optimal models between BSP and pH, we will discuss further about the correlation between BSP with the exchangeable cations in red soil series in our next work.

As mentioned above in the introduction, 35% and 50% are two key thresholds of BSP in Chinese Soil Taxonomy [3], based on the model established in our study of total red soil series ($y = 6.84x^2 - 45.86x + 81.52$, $R^2 = 0.494^{**}$, $n = 394$, **Figure 1**, right), the corresponding pH were inferred as 5.33 and 5.93for BSP = 35% and 50%, respectively. But it is should be noted that such inferred pH values are only feasible to identity soil taxonomy type preliminarily in the field, the final soil taxonomy type must be decided by the measured values of BSP in the laboratory.

5. Conclusion

By using the database of soil pH and BSP of red soil series of Fujian and Guangdong provinces, this study discloses that there is significant correlation between BSP and pH, and the optimal models are most in quadratic form, but the optimal model and the accuracy are different with different regions, parent materials, soil types and land use types. For all red soil series, pH < 5.33 or <5.93 could be used roughly to judge BSP < 35% or <50%, respectively.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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