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EFFECTS OF SITE VARIABLES ON SURFACE SOIL ORGANIC CARBON CONCENTRATION IN ZONAL SOILS OF CHINA

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Abstract: An understanding of influences of site variables on surface soil organic carbon (SOC) concentration is important to plan future land use for carbon sequestration and sustaining agricultural production. This study was conducted to clarify the effects of site variables (soil order, texture, altitude, acidity/alkalinity and land use) on surface SOC concentration of zonal soils of China. The results showed that the SOC concentration was generally correlated significantly with the selected site variables ($p<0.001$) and the correlation was stronger in un-cultivated soils than in cultivated soils. The ANOVA factorial model estimated that the contribution of site variables to the variation of SOC concentration was 24.7% in cultivated soils, 48.5% in un-cultivated soils, which was 6.6% and 10.4% higher than that described by univariate multiple regression analysis, respectively. Relatively weak correlations and less explainable variance observed in cultivated soils suggest that actual controlling factors over SOC concentration differ from those in un-cultivated soils.

Key words: site variable; SOC; zonal soil; ANOVA; canonical correlation analysis

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Soil organic carbon is a major component of global carbon cycle. Surface SOC concentration and its turnover rate are known to sensitive to a range of factors, such as climate, topography, vegetation, parent material, and other anthropogenic conditions, and many of which are mutually interactive[1-3]. SOC can act both as a sink and a source of carbon in response to climate, land use changes, and to the rising atmospheric CO_2 levels. Small changes of SOC may influence long-term ecosystem sustainability, the global carbon budget and the atmospheric CO_2 concentration[4]. The relationships between SOC and climate, site variables and land use are important to formulate C cycling process models[5-6] and to evaluate accurately the SOC pools[3].

It is often considered that the climatic variable is the most important factor regulating SOC[1,7]. The SOC dynamics was influenced strongly by the climatic variables at small scales[2,5-7]. But generally weak relationships between climatic variables and SOC on a continental scale or a regional scale make it difficult to predict changes in SOC as a function of projected climate change[8]. Therefore, to better understand and predict the changes in SOC at a large scale, we need to evaluate the effects of site variables on SOC.

Site variables are particularly important to characterize SOC variation[9-10]. Soil texture, especially clay concentration, has significant influence on the sequestration and depletion of SOC in many cases[6,11-12]. Tan et al estimated the contribution of site variables (soil taxon, texture, drainage class, slope gradient and elevation) to the variation of SOC pools in Ohio, USA[12]. Altitude is often employed as a site variable to study the effects of climatic variables on SOC dynamics[13]. Altitude influences SOM by controlling climate, soil water balance,

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soil erosion and geologic deposition processes[5,12]. Garten et al. has emphasized the advantages of altitude gradients for testing the effects of environmental variables on soil organic matter dynamics in forest soil[13].

Even now, the effects of site variables on SOC are still not well documented for a variety of soil orders and land use systems. This study was conducted to clarify the effects of site variables on SOC concentration and identify the significance of each site variable to the SOC concentration variation in the zonal soils of China.

1 Materials and methods

1.1 Data source and selection

The data used in this study were taken from the 2nd State Soil Survey of China and extracted from a series published book of monographs in the China Soil Series Vols. 1 – 6[14 – 19]. In order to better understand the influences of selected site variables on SOC concentration, 886 taxonomically recognized typical zonal soil series profile were selected. Surface soil represents the soils in taxonomic A horizon (taxonomic A horizon, not including plowpan, Ap, in cultivated soils). These soils classify into seven soil orders of Ferro-allitic, Eluvial, Semi-eluvial, Caliche, Arid, Desert and Alpine soil[20]. The original data of soil organic matter content in surface soil was converted to SOC concentration by multiplying a constant of 0.580, since C determination was carried out by rational wet combustion[21]. Selected soil properties and site variables are presented in Table 1.

Table 1　Selected soil properties of surface soils (A horizon) and site variables

Soil orders	No.	SOC (g kg^{-1})	Particle fraction (g kg^{-1})			pH_{H_2O}	Altitude (m)
			<0.002mm	0.02 – 0.002mm	0.2 – 0.02mm		
Ferro-allitic soils	211	18.5 ± 12.8	283 ± 126	277 ± 107	255 ± 136	5.2(3.7 – 7.5)	610 ± 582
Eluvial soils	213	25.9 ± 23.0	206 ± 83	339 ± 111	303 ± 114	6.1(4.1 – 7.7)	843 ± 928
Semi-eluvial soils	194	16.4 ± 17.2	200 ± 82	315 ± 117	375 ± 137	7.5(5.2 – 8.7)	804 ± 816
Caliche soils	172	14.6 ± 10.3	197 ± 87	253 ± 138	450 ± 153	8.1(6.6 – 9.1)	1281 ± 951
Arid soils	47	6.2 ± 3.3	132 ± 66	270 ± 139	540 ± 162	8.5(8.0 – 9.7)	1631 ± 788
Desert soils	28	5.0 ± 3.2	153 ± 89	300 ± 150	473 ± 215	8.4(7.9 – 9.1)	1342 ± 896
Alpine soils	21	49.5 ± 25.4	151 ± 82	313 ± 113	462 ± 195	7.2(4.8 – 8.4)	3890 ± 656
All soils	886	18.7 ± 17.9	215 ± 104	297 ± 124	358 ± 165	6.8(3.7 – 9.7)	1001 ± 988

1.2 Site variables and scoring

Soil taxon at the soil order level (SO), land use (Lu), acidity/alkalinity (pH), texture (Tex), and altitude (Alt) were selected as site variables in this study. Twelve types of soil texture were recognized[20] and scored from 1 for sand to 12 for clay in the order of sand, loamy sand, sandy loam, silty loam, loam, sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, loamy clay and clay, ranked according to their clay content, water holding capacity and CEC. Soil acidity/alkalinity classes, which were designated with acidity ($pH < 5.5$), somewhat acidity(pH5.5 – 6.5), neutrality(pH6.5 – 7.5), somewhat alkalinity(pH7.5 – 8.5) and alkalinity($pH > 8.5$)[20], were scored from 1 for acidity to 5 for alkalinity. Altitude category was assigned for 6 classes, and scored from 1 for altitude <200m to 6 for altitude >3000m in the order of altitude <200m, 200 – 500m, 500 – 1000m, 1000 – 2000m, 2000 – 3000m and >3000m, ranked according to the type of landform in China[20]. Land use score was assigned with 1 for cultivated soils, and 2 for un-cultivated soils. A digital number from 1 to 7 was assigned to Alpine, Eluvial, Ferro-allitic, Semi-eluvial, Caliche, Arid and Desert soil, respectively, in the order of decreasing average SOC concentration, so that soil orders can be used as one of site variables for quantifying its contribution to surface SOC variation.

2 Results and discussions

2.1 Analysis of variance

Effects of site variables on surface SOC concentration were generally tested significant at $p < 0.001$ probability level, but influence of individual site variable varied within and between land uses (Table 2).

Clearly, land use showed a significant impact on SOC in all soils. Altitude, soil order and acidity/alkalinity all showed a significant impact on SOC in all soils and two land use category ($p < 0.001$). Soil texture showed a significant impact on SOC in cultivated soils ($p = 0.004$), whereas it did not significantly in un-cultivated soils ($p = 0.158$).

The data in Table 3 indicate the extent to which the variation of SOC concentration could be attributed by each site variable. With all 886 soils, all site variables explained 44.3% of SOC concentration variation: land use accounting for 7.7%, altitude for 18.9%, soil order for 10.7%, soil acidity/alkalinity for 3.5 and texture for about 3.5%. Fractions of SOC concentration variation contributed by all variables varied markedly though there was a similar order of significance within each land use system. Approximately 48.5% of SOC concentration variation within un-cultivated soils could be explained by these variables, of which altitude made the greatest contribution (22.5%), followed by soil order (16.8%), whereas soil texture and acidity/alkalinity made the slight contribution. Only 24.7% of SOC concentration variation within cultivated soils could be explained by these site variables, of which the contribution of different site variables was almost similar and relative smaller.

Table 2 ANOVA factorial model for the main effects of site variables on surface SOC concentration

Source of variance	Type III SS	df	MS	F	P>F
All soils: total	125326	27	4476	24.3	<0.001
Land use	11281	1	11281	61.3	<0.001
Altitude	36865	5	7373	40.1	<0.001
Texture	3782	11	344	1.9	0.040
Soil order	14986	6	2498	13.6	<0.001
Acidity/alkalinity	10000	4	2000	10.9	<0.001
Cultivated soils: total	8392	24	336	5.4	<0.001
Altitude	2427	5	485	7.8	<0.001
Texture	1641	10	164	2.6	0.004
Soil order	1600	5	320	5.2	<0.001
Acidity/alkalinity	2465	4	493	7.9	<0.001
Un-cultivated soils: total	103996	26	3852	14.7	<0.001
Altitude	35003	5	7001	26.6	<0.001
Texture	4124	11	375	1.4	0.158
Soil order	13419	6	2237	8.5	<0.001
Acidity/alkalinity	9163	4	1833	7.0	<0.001

Table 3 Fraction of SOC concentration variability contributed by individual site variables

Variable	All soils %	Cultivated soil %	Un-cultivated soil %
Land use	7.7		
Altitude	18.9	4.6	22.5
Texture	3.5	7.2	4.3
Soil order	10.7	4.4	16.8
Acidity/alkalinity	3.5	8.5	4.9
Total fraction	44.3	24.7	48.5

In comparison to those reported by Homann et al.[9] and Tan et al.[17], so small fraction of the variance explained by all the selected site variables in cultivated soils implies that other factors, such as anthropogenic influences, may play a more important role in C sequestration there. As shown in Table 3, the same site variable has the different contribution to SOC concentration variation in two land uses. Comparison with un-cultivated soil, the contribution of altitude and soil order to SOC concentration variation was decreased obviously in cultivated soils, as while the contribution of texture and acidity/alkalinity was increased, this may because that the vegetation and its productivity were relative uniform in cultivated soils within different altitude and soil order comparing with natural vegetations, and surface SOC concentration in cultivated soils may mainly influenced by soil properties which controlling the community and magnitude of soil microorganism (such as soil acidity/alkalinity) and the decomposability of soil organic matter.

2.2 Canonical correlation analysis

2.2.1 Correlations between surface SOC concentration and site variables Besides the large variation in SOC concentration with soil order as showed above (Table 1), there was a significant correlation between SOC concentration and other site variables for different land uses (Table 4), suggesting that C sequestration in surface soil is highly land use specific. Also, SOC concentration is significantly correlated

Table 4 Correlation coefficients of Surface SOC concentration with site variables

Variable	All soils	Cultivated soil	Un-cultivated soil
Total	0.560^{***}	0.426^{***}	0.617^{***}
Altitude	0.238^{***}	0.241^{***}	0.286^{***}
Texture	0.147^{***}	0.183^{***}	0.094^{*}
Soil order	-0.369^{***}	-0.080	-0.496^{***}
Acidity/alkalinity	-0.374^{***}	-0.264^{***}	-0.273^{***}

$*$, $**$ and $***$ = significant at 0.1, 0.01 and 0.001 probability levels, respectively.

with individual site variables at $P < 0.001$ probability level within each land use category except for soil order in cultivated soil ($P = 0.094$) and soil texture in un-cultivated soil ($P = 0.047$). Soil acidity/alkalinity showed a strong negative correlation with SOC concentration in two land use systems, suggesting that C sequestration is highly soil type specific. On the other hand, C sequestration in surface soil is highly sensitive to altitude. It may be because that soil C sequestration is influenced significantly by precipitation and temperature, which are influenced significantly by altitude. As shown in Table 4, soils with higher altitude and lower pH value favored C sequestration in A-horizons regardless of land use categories. This can be attributed to the fact that soils with higher altitude and lower pH are usually present on regions with favorite climatic variables for sequestration.

2.2.2 Canonical correlations The magnitude and sign of a canonical coefficient indicate the strength of its contribution to the specific canonical variate. The first canonical variate of site variables (S^{1st}) for each land use was expressed by their original site variables as follows (numeric values are standardizes canonical coefficients):

$$S^{1st}(\text{All soils}) = -0.852(SO) + 0.349(Tex) - 0.902(pH) + 0.638(Alt) + 0.723(LU) \quad (1)$$

$$S^{1st}(\text{Cultivated soil}) = 0.297(SO) + 0.361(Tex) - 0.883(pH) + 0.812(Alt) \quad (2)$$

$$S^{1st}(\text{Un-cultivated soil}) = -0.782(SO) + 0.116(Tex) - 0.775(pH) + 0.790(Alt) \quad (3)$$

As indicated in Eqs. (1), (2) and (3), a positive coefficient was shown by variables soil texture and altitude, whereas a negative coefficient occurred with soil pH in all land use systems. But soil order shows a negative coefficient in all soils and Un-cultivated soil, and a positive coefficient in cultivated soil. Another, a positive coefficient was shown by variables land use category in all soils. (Note: a positive or negative sign totally depends how to rank individual variables: ascending or descending). Canonical variate was weakly correlated with soil texture, and relatively strongly correlated with other site variables in all land use systems excepting soil order index number in cultivated soil. Therefore, canonical variates in all soils were interpreted as a SOC-soil order/pH/altitude/land use association; canonical variates in un-cultivated soil were interpreted as a SOC-soil order/pH/altitude association; canonical variates in cultivated soil were considered as a SOC-soil pH/ altitude association.

Canonical redundancy analysis was conducted to clarify to what extent Set2-variable (i.e. site variables, including soil order, texture, pH, altitude and land use) are independent of and responsible for the variation of Set1-variable (i.e. SOC concentration). In all soils, cultivated soil and un-cultivated soil, 34.5%, 26.7% and 36.8% of the variation within site variables could be explained by their canonical variate. The canonical correlation coefficients between Set1-variable and Set2-varizble were 0.598, 0.425 and 0.671 in all soils, cultivated soil and un-cultivated soil, respectively, and they were all significant at 0.001 levels. The contribution of selected site variables to SOC concentration variation only accounted for 35.8%, 18.1% and 38.1%, respectively, which are more different to the results from ANOVA above (Table 3), clarifying a relative weak association between two sets of variables and suggesting that selected site variables themselves are likely to be predominated by other factors which are probably related to biological, ecological and pedogenic processes.

There was an interaction between Set1-variable and Set2-variable because 21.4%, 15.3% and 23.6% of variances within Set2-variable were revealed of being associated with Set1-Var in all soils, cultivated soil and un-cultivated soil, respectively, in other words, SOC concentration level could in turn affect aspects of some selected site variables, such as SOC concentration could affects soil pH in some degree[20].

2.2.3 Regression analyses The univariate multiple regression statistics was used to predict surface SOC concentration by site variables for zonal soils of China. Taking surface SOC concentration (Set1-variable) as a dependent variable and the site variables (Set2-variable) as independent ones, surface SOC concentration can be predicted significantly ($p < 0.001$) by soil order (SO), texture (Tex), acidity/alkalinity (pH), altitude (Alt) and land use (Lu), particularly in un-cultivated soils (Table 5). The regression capacity of these site variables on SOC concentration was, however, markedly differentiated for different land use category as indicated by R^2 values (Table 5). The role of each variable in SOC prediction revealed by the power analysis was also markedly differentiated for different land use category, and it showed the order of significance as follows: altitude > soil order > land use > acidity/alkalinity > texture for all zonal soils of China, and acidity/alkalinity > altitude > texture > soil order in cultivated soils, and altitude > soil order > acidity/alkalinity > texture in un-cultivated soils, which is confirmed by the significance test, and this order of significance consistent with ANOVA(Table 3).

Table 5 Linear regression between SOC concentration and site variables for zonal soils

Source of variance	df	TSS	SS	MS	F value	P>F	R^2
All pedons	5	282988	101397	20279	98.3	<0.001	0.358
Cultivated soil	4	33995	6156	1540	24.0	<0.001	0.181
Un-cultivated soil	4	214379	81576	20394	68.0	<0.001	0.381

All pedons: $SOC = 15.813 - 3.994(SO) + 0.540(Tex) - 1.149(pH) + 4.490(Alt) + 3.153(LU)$ $R^2 = 0.358, P < 0.001, n = 886$

Cultivated soil: $SOC = 21.856 + 0.686(SO) + 0.729(Tex) - 2.827(pH) + 1.476(Alt)$ $R^2 = 0.181, P < 0.001, n = 438$

Un-cultivated soil: $SOC = 33.319 - 5.839(SO) + 0.621(Tex) - 1.317(pH) + 6.520(Alt)$ $R^2 = 0.381, P < 0.001, n = 448$

This results and discussion above indicated that the main site variables which influence surface SOC concentration was different in different land use systems, surface SOC concentration in cultivated soils was influenced mainly by soil pH, altitude and texture because of the strong dependency of C sequestration on anthropogenic influences, whereas SOC concentration in un-cultivated soils was influenced mainly by altitude, soil order and pH because of the strong dependency of C sequestration on nature pedogenic processes and climatic condition.

3 Conclusions

The SOC concentration in surface zonal soils (A horizon) of China was correlated significantly with selected site variables, but the strength varies with land use categories. The higher contribution of selected site variables to variation of SOC concentration was observed in un – cultivated and the lesser in cultivated. The results derived from different statistical procedures showed that SOC concentration is highly soil order specific, especially in un-cultivated soils. Higher altitude and lower soil pH were revealed to favor C sequestration in two land use systems. Analyses of correlation and regression indicated a possibility to predict SOC concentration in un-cultivated soils using selected site variables (soil order, texture, soil pH and altitude). Unfortunately, it is difficult to determine the extent to which these variables are responsible for the variation of SOC concentration in cultivated soils because of small R^2 value despite its statistical significance. Low fraction of SOC concentration variation attributed to selected site variables in cultivated soils suggested that more variables such as those related to biological and pedogenic processes and anthropogenic influences have to be taken into account for explaining SOC concentration variation.

References

[1] ALVAREZ R, LAVADO R S. Climate, organic matter and clay content relationships in the Pampa and Chaco soils, Argentina[J]. Geoderma, 1998, 83: 127-141.

[2] GANUZA A, ALMENDROS G. Organic carbon storage in soils of the Basque Country (Spain): the effect of climate, vegetation type and edaphic variables[J]. Biol Fertil Soils, 2003, 37: 154-162.

[3] POST W M, KING A W, WULLSCHLEGER S D. Soil organic matter models and global estimates of soil organic carbon[C]// Poulson D S. Evaluation of Soil Organic Matter Models. Berlin: Springer, 1996.

[4] AMUNDSON R. The carbon budget in soils[J]. Annual Review of Earth & Planetary Sciences, 2001, 29: 535-562.

[5] HONTORIA C, RODERIGUEZ-MURILLO J C, SAA A. Relationships between soil organic carbon and site characteristics in peninsular Spain [J]. Soil Sci Soc Am J, 1999, 63: 614-621.

[6] BURKE I C, YONKER C M, PARTON W J, et al. Texture, climate, and cultivation effects on soil organic matter content in US grassland soils[J]. Soil Sci Soc Am J, 1989, 53: 800-805.

[7] JENNY H. The Soil Resource: Origin and Behavior[M]. New York: Springer, 1980.

[8] KERN J S, TURNER D P, DODSON R F. Spatial patterns in soil organic carbon pool size in the northwestern United States[C]// Lal R. Soil Processes and the Carbon Cycle. Boca Raton FL: Lewis Publishers, 1998.

[9] HOMANN P S, SOLLINS P, CHAPPELL H N, et al. Soil organic carbon in a mountainous, forested region: relation to site characteristics [J]. Soil Sci Soc Am J, 1995, 59: 1468－1475.

[10] SCHIMEL D S, BRASWELL B H, HOLLAND E A, et al. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils [J]. Glob Biogeochem, 1994, 8:279－293.

[11] PARTON W J, SCHIMEL D S, OJIMA D S, et al. A general model for soil organic carbon dynamics: sensitivity to litter chemistry, texture and management[C]// Bryant R B. Quantitative Modeling of Soil Forming Processes. Soil Sci Soc Am J,1994.

[12] TAN Z X, LAL R, SMECK N E, et al. Relationships between surface soil organic carbon pool and site variables[J]. Geoderma, 2004, 121: 187－195.

[13] GARTEN C T, POST W M, HANSON P J, et al. Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains[J]. Biogeochemistry, 1999, 45: 115－145.

[14] 中国土壤普查办公室.中国土种志.第1卷[M]. 北京:中国农业出版社, 1993.

[15] 中国土壤普查办公室.中国土种志.第2卷[M].北京:中国农业出版社,1994.

[16] 中国土壤普查办公室.中国土种志.第3卷[M].北京:中国农业出版社,1994.

[17] 中国土壤普查办公室.中国土种志.第4卷[M].北京:中国农业出版社,1995.

[18] 中国土壤普查办公室.中国土种志.第5卷[M].北京:中国农业出版社,1995.

[19] 中国土壤普查办公室.中国土种志.第6卷[M].北京:中国农业出版社,1996.

[20] 中国土壤普查办公室.中国土壤[M].北京:中国农业出版社,1998.

[21] 中国土壤普查办公室.土壤普查技术报告[M].北京:中国农业出版社,1996.

地点因素对中国地带性土壤表层有机碳含量的影响

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摘　要:利用中国第二次土壤普查确定的886个典型地带性土种剖面资料,通过统计分析方法研究了地点因素(土纲、质地、海拔、酸碱度和土地利用方式)对地带性土壤表层有机碳含量的影响.结果表明,地点因素显著影响地带性土壤表层有机碳含量;地点因素对耕作土壤表层有机碳的影响明显强于非耕作土壤;地点因素分别解释耕作土壤和非耕作土壤表层有机碳含量变异的24.7%和48.5%.耕作土壤和非耕作土壤有机碳含量的主要控制因素有所不同.

关键词:地点因素;土壤有机碳;地带性土壤;方差分析;典型相关分析

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