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Reference benchmarks relating to great groups of genetic soil classification of China with soil taxonomy

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Abstract **Soil classification forms the basis for the exchange and extension of research findings in soil science and for the modernization of management of soil resources. This paper systematically reviews the compatibility of the genetic soil classification of China (GSCC) and soil taxonomy (ST). This includes a study of the evolution and consummation of the GSCC and assessment of the databases and methods of the study. Using the "Soil Species of China (six volumes)" and some provincial soil species as the basic material, the authors gathered information from 2540 soil species. Based on the key described in ST, the 2540 soil species were taxonomically classified into corresponding soil orders, suborders, great groups and subgroups and then matched with corresponding map units in the 1∶1000000 digital soil map of China. Using the high-level classification units of the two soil classification systems, and the attributes of each soil species, the sizes of distribution areas were mapped. The soil distribution results were analyzed and compared statistically. The reference compatibility between the great groups used in GSCC system and the soil orders of the ST is discussed. It is believed that 20 great groups display maximum referencibility >95% and 15 great groups depict maximum referencibility in the range of 70%—95%, which can be cited as reference benchmarks. The remaining 25 great groups are less compatible (with maximum referencibility <70%) and need further study, or require referencing at lower classification levels or at a regional level to help to improve the accuracy of the reference.**

Keywords: GSCC, ST, reference benchmark, referencibility, soil type referentiality, soil species, 1∶1 million digital soil maps.

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A soil classification system is an essential basis for modernized management of soil resources and an indispensable medium for academic exchange of findings in soil science with other countries as well. The world, however, has not yet seen the birth of a fully unified soil classification system. The ST (Soil Survey Staff in USDA, 1992)[1] and WRB (World Reference Base for Soil Resources) (FAO/ISRIC/ISSS, 1998)[2] are currently the only mainstream soil classification systems, which have been used quite extensively in international academic exchange and cooperation in soil science. The study on soil reference has attracted more and more attention worldwide. Recently, noted soil taxonomists compiled and published a book entitled "Soil Classification——A Global Desk Reference" (Eswaran et al., 2003)[3] to promote the formation of an international soil taxonomy. However, no system of benchmarks has yet been established for referencing between different soil classification systems. In China, since the initiation of the study on soil science in 1930s, hundreds of thousands of items of soil data have been accumulated on the basis of GSCC, which is quite different in academic ideology from ST. As the outside soil science community does not know much about GSCC, Chinese soil scientists find it very difficult to perform academic exchanges, carry out international cooperation or even publish papers in international journals. The same is true for foreign soil scientists involved with collaborative research in China, as it is difficult for them to make use of any large volumes of material and data gathered because they do not understand GSCC. To find a solution to this problem, it is essential to establish a reference system between the GSCC and the ST. A few studies by Chinese soil scientists have addressed this issue. In 1996, the study on 20 red soil profiles of GSCC from Jiangxi and Fujian provinces revealed that 12 of them were Ultisols, 4 Alfisols and the other 4 Inceptisols in ST (Shi X. Z. et al. 1996)[4]. In 1999, another study examined 64 soil profiles, and for each case study an analysis of the profiles was carried out for reference compatibility between the Chinese soil taxonomy, GSCC, ST and FAO legend units (Gong Z. T. et al., 1999)[5]. Although in the past few years, some work has been done on reference between soil types, the majority of the work has focused on the commonly used soil great groups of GSCC and nothing has been performed on benchmarks for reference to soil orders of ST on a countrywide scale. So the work in this respect is far from adequacy to meet the needs required for development of soil science in China and also for academic exchange with foreign research institutions. Therefore, this research work used soil data from the "Soil Species of China (six volumes)"[6−11] and some provincial soil species as source material to identify the key attributes of each soil species. The inherent relationships between the soil great groups of the GSCC and the soil orders of the ST were identified and laws summing up their relationship were recorded. Benchmarks of different grades of reliability for referencing between great groups in GSCC and orders in ST were developed. The establishment of a benchmark system will contribute to development of the soil science in China and academic exchange with other countries.

1 Basis and methods for study on reference

The study of soil classification in China started in the early 1930s, using C. F. Marbut's soil classification system. This American system was used to catalogue over 2000 soil series. In 1936, a book entitled "Soil Geography of China" (Thorp, 1936)[12], was published. This is the oldest comprehensive monograph introducing, the first general soil classification of China. In 1954 the geographic genesis classification system was introduced from the former Soviet Union and formed the basis for genetic soil classification. In 1978, a uniform and relatively complete GSCC "Provisional Draft of Soil Classification of China" (Gong Z. T. et al., 1978)[13] was established, which included 3 classification categories: soil order, great group and subgroup. As the classification system has been used extensively and the soil nomenclature was familiar throughout the country, the system was soon recognized by the soil science circle of China and accepted as the basis for soil classification in the second national soil survey conducted from 1979 to 1994. In 1998, a new six-category soil classification system was completed, the categories now included: order, suborder, great group, subgroup, family and species (Xi C. F. et al., 1998)[14]. For the soils in China this resulted in 12 soil orders, 29 suborders, 61 great groups and 231 subgroups. The last two categories are most familiar to and most commonly used by soil scientists in China. Soil great groups are classified on the basis of the commonness of the conditions, processes and genetic attributes associated with soil formation.

(ⅰ) Data basis of the study on reference. From 1979 to 1994, the second national soil survey was carried out using GSCC system. The findings of the survey are the most complete soil data records that have been gathered, with samples taken from every town or township in every part of the country. As a result of the survey, "Soil Species of China (six volumes)" was published (National Soil Survey Office, 1993, 1994a, 1994b, 1995a, 1995b, 1996)[9−11]. These data, with some additional data taken from a number of provincial soil species records, provided a total of 2540 soil species that were used as the basic material for this reference comparison study. The data for each soil species is composed of two parts, a description of the soil properties and analytic data. The former covers four aspects: attributes and distribution, major properties, typical soil profile and production performance. The attributes listed describe which soil family, subgroup and great group the soil species belongs to. The properties include information on the parent material and under what natural conditions the soil species was developed, for instance, soil profile structure, thickness of the soil layer, etc.; the typical soil profile describes the location of the profile, for instance, altitude, soil-forming parent material, climatic information (annual mean temperature, etc.), natural vegetation, crops, etc. and then information about the profile in the field, for instance, color, texture and structure of the soil and plant root systems, etc.; the production performance is divided into three parts: soil physical properties, soil chemical properties and soil nutrients. This study also used the "1∶1 million Soil Maps of the People's Republic of China" (The Officer for the Second National Soil Survey of China, 1995)[15]. The map utilizes the soil family as its basic mapping unit for the majority of the country and soil subgroup for a limited part. The soil map has a total of 909 basic mapping units, under 235 subgroups, 61 great groups and 12 orders. This is the first set of 1∶1 Million soil maps and also the most detailed countrywide soil maps that have been compiled so far and were based on the abundant data and material accumulated over the past years. The digitalized soil maps reflect the appearance of the original soil maps and have inherited the mapping units used in the compilation of the original soil maps series. The development of the 1∶1000000 soil database adopted the soil type method in linking reference information of the 2540 soil profiles on to the digital soil map, thus forming an integrated soil database combining space and reference material (Shi X. Z. et al., 2002)[16].

(ⅱ) Methods for study on soil reference. With the soil species information as the basic material, some soil scientists experienced in soil surveys and soil classification interpreted attributes of each soil species to the level of soil order, suborder, great group and subgroup according to the "Key to Soil Taxonomy" (Soil Survey Staff in USDA, 1992). Out of the 2540 soil species, 5 were selected as reference examples (Table 1). After repeated discussion and amendment, the interpretations of each soil species agreed with each other. The 2540 soil species were then matched with their corresponding mapping units in

Table 1 An example for the reference of 5 out of 2540 soil species

Soil profile location (county/province)	GSCC				Subgroup in ST
	Great group	Subgroup	Family	Species	
Qiongshan/Hainan	Latosols	Latosols	Clayey Latosols	Light Latosols	Rhodic Paleudults
Ji'an/Jiangxi	Red soils	Red soils	Clayey red earths	Red yellow earth with clayed bottom	Plinthudults
Wujiang/Jiangsu	Paddy soils	Periodically submergic paddy soil	Yellow paddy earths	Yellow paddy earths	Typic Endoaquepts
Anyang/Henan	Fluvoaquic soils	Fluvoaquic soils	Aquic loam	Clayey layer with sandy layer	Aquic Ustochrepts
Hailun/Heilongjiang	Black soils	Black soils	Yellow black soils	Dark yellow black soils	Pachicudic Haploborolls

the 1∶1000000 digital soil map of China. Then statistical analysis of the attribution of each soil species in every higher-level classification unit and the size of distribution area it represents was carried out. Based on the results of the statistics, benchmarks for reference between soil great groups in GSCC and orders in ST were summarized.

2 Results and discussion

The national 1∶1 million-scaled soil database encompasses soil reference types and the statistics of distribution areas of GSCC soil great groups and ST soil orders. The percentage of each type of soil in GSCC that can be interpreted as a type of soil in ST in terms of distribution area is called, for the sake of discussion, referencibility, which indicates the amount of similarity between the two as well as reliability of the reference. The higher the referencibility, the more similar the two classifications of the soil types. The dark brown soils in the order of Alfisols in GSCC, for example, can be interpreted as Alfisol and Inceptisols in the ST system, being 63.1% and 36.9%, respectively, in terms of their distribution area. That is to say, the referencibility between dark brown soils and Alfisols in ST is 63.1% and that between dark brown soils and Inceptisols in ST only 36.9%. It was often found that a GSCC great group could be divided into several ST orders. The highest referencibility among the orders is then termed as the maximum referencibility, indicating the most likelihood of reference between the GSCC great group and the ST order. For instance, Latosolic red soils under Ferralsols could be sorted into Ultisols, Oxisols and Inceptisols in ST by means of reference, and their referencibilities are 82.0%, 15.2% and 2.8%, respectively. In this case, the referencibility between Latosolic red soils and Ultisols is maximum, being 82.0%. With GSCC great groups as basic units, referencibilities between GSCC great groups and ST orders can be divided into 3 grades, that is, >95%, 70%—95%, and <70%. The commonness and individuality of the three grades of referencibilities are discussed in the following paragraph.

(ⅰ) Soil great groups with maximum referencibility >95%. Soil great groups with maximum referencibility >95% between GSCC great groups and ST orders are listed in Table 2. These are the types of soils showing the highest referencibility. Soils with maximum referencibility >95% mean that the reliability of their reference is higher than 95%. For instance, soils classified as Gray desert soils under the GSCC system, an order of Aridisols, can completely be sorted into ST Aridisol by reference, which indicates that the reliability of reference reaches 100%. The number of great groups with maximum referencibility >95% amounts to 20, accounting for one third of the 60 soil great groups with data available in GSCC. The 20 great groups can be sorted into 9 orders under GSCC, and interpreted as Spodosol, Aridisol, Entisol, Inceptisol and Histosol in ST by means of referencing, respectively. Among the 20 great groups the number of groups sorted into Aridisol in ST amounts to 10, the largest portion, while only 4 and 3 are sorted into Inceptisol and Entisol in ST, respectively. The areas of the GSCC soil groups that could be sorted into ST soil orders by means of referencing vary sharply, ranging from 630000 km^2 (Aeolian soils) to 100 km^2 (bleached podzolic soils) or from 6.565% to 0.001% of the country's total land area, respectively, and the areas of the groups of Brown caliche soils, Gray-brown desert soils, Brown desert soils, Aeolian soils and Meadow soils are all over 200000 km^2, whereas the areas of the groups of Bleached podzolic soils, Takyr, Peat soils and Frigid plateau solonchaks are less than 1000 km^2. The study expected to find as many soil types and as large areas as possible with maximum referencibility >95%. Comparison analysis shows that when GSCC great groups are used instead of GSCC orders for reference, the referencibility between the two systems improves significantly. When reference is made between orders of the two systems, only the referencibility between Desert soils and Aridisols in GSCC and 5 soil great groups in ST is higher than 95% but the areas of the two orders account only for 9.45% of the country's total land area. When reference is made between GSCC great groups and ST orders, the great groups with maximum referencibility >95% rise up to 20 in number and 25.7% of the country's total land area, being 4 times or approximately 3 times as great as those in origin when reference is made between orders. It is clearly shown that lowering the soil classification level in GSCC for reference is an effective measure to improve accuracy of the reference. In short, it is completely feasible to perform reference between the soil groups with referencibility > 95% and corresponding ST orders, so the former can be cited as reference benchmarks.

(ⅱ) Great groups with maximum referencibility in the range of 70%—95%. GSCC great groups with maximum referencibility in the range of 70%—95% are listed in Table 3.

As shown in Table 3, there are 15 great groups with maximum referencibility in the range of 70%—95%, falling into 8 soil orders in GSCC and 7 soil orders in ST separately. Of the 15 great groups, there are only 2 with maximum referencibility >90%, i.e. Fluvo-aquic soils under the order of Semi-aqueous soils and Acid sulphate soils under the order of Alkali-saline soils, 7 great groups with maximum referencibility in the range of 70%—80% and 6 great groups in the range of 80%—90%. The areas referencible in the GSCC soil groups vary sharply. Only 3 groups have referencible areas exceeding 200000 km^2, 4 have areas less than 10000 km^2 and 6 range between 100000 and 200000 km^2. Among the six, Alpine meadow soils have the largest referencible area, being 427100 km^2 or 4.467% of the country's total and the soil group of Acid sulphate soils has the least referencible area, being only

Table 2 GSCC soil great groups with maximum referencibility >95%

GSCC orders	GSCC great group	ST orders	Area/10^3 km^2	Percentage of the country's total land area (%)	Maximum RB(%)[a)]
Alfisols	Bleached podzolic soils	Spodosols	0.1	0.001	100.0
Aridisols	Brown caliche soils	Aridisols	253.6	2.653	97.5
	Sierozems	Aridisols	45.7	0.478	98.5
Desert soils	Gray desert soils	Aridisols	67.0	0.701	100.0
	Gray-brown desert soils	Aridisols	288.1	3.013	100.0
	Brown desert soils	Aridisols	249.2	2.606	100.0
Primarosols	Takyr	Aridisols	5.5	0.057	100.0
	Aeolian soils	Entisols	627.7	6.565	96.4
	Lithosols	Entisols	172.9	1.808	100.0
Semi-aqueous soils	Meadow soils	Inceptisols	323.6	3.385	98.7
	Shruby meadow soils	Inceptisols	22.5	0.235	100.0
Aqueous soils	Peat soils	Histosols	5.2	0.055	100.0
Alkalin-saline soils	Desert solonchaks	Aridisols	28.1	0.294	99.3
	Frigid plateau solonchaks	Aridisols	9.0	0.095	100.0
Anthrosols	Irrigated warped soils	Inceptisols	20.5	0.214	100.0
	Irrigated desert soils	Inceptisols	11.1	0.116	98.7
Alpine soils	Frigid desert soils	Aridisols	26.6	0.278	100.0
	Cold desert soils	Aridisols	2.8	0.029	100.0
	Frigid frozen soils	Entisols	298.9	3.127	100.0

a) RB, Referencibility.

Table 3 GSCC soil great groups with maximum referencibility in the range of 70%—95%

GSCC orders	GSCC great groups	ST orders	Area/10^3 km^2	Percentage of the country's total land area (%)	Maximum RB[a)] (%)
Ferralsols	Latosols	Ultisols	34.6	0.362	82.0
Alfisols	Brown soils	Alfisols	178.4	1.866	70.7
	Brown coniferous Forest soils	Alfisols	83.3	0.871	78.4
Semi-Alfisols	Cinnamon soils	Alfisols	188.6	1.973	70.8
	Chernozems	Mollisols	125.1	1.308	89.3
Primarosols	Volcanic ash soils	Andisols	3.0	0.031	87.4
	Purplish soils	Inceptisols	185.0	1.935	81.7
	Fragmental soils	Entisols	126.7	1.325	77.5
Semi-Aquatic soils	Fluvo-aquic soils	Inceptisols	322.7	3.375	94.0
Alkalin-saline soils	Acid sulphate soils	Inceptisols	0.4	0.004	94.7
	Solonetzs	Alfisols	4.5	0.047	86.5
Anthrosols	Paddy soils	Inceptisols	338.0	3.535	74.0
Alpine soils	Alpine meadow soils	Inceptisols	427.1	4.467	84.4
	Sub-alpine meadow soils	Inceptisols	185.5	1.941	73.4
	Cold brown calcic soils	Aridisols	6.6	0.069	78.5

a) RB, Referencibility.

400 km^2, only 0.004% of the country's total. The maximum referencibility of these great groups ranges in 70%—95%, which means the reliability of the referencing is also in the range of 70%—95%. Although errors do exist, the authors still think the results listed in Table 3 can be taken as reference benchmarks for academic exchange until more detailed update is available.

(iii) Soil great groups with maximum referencibility <70%. GSCC great groups with maximum referencibility <70% are listed in Table 4. A total of 25 great groups accounts for 42% of the total of great groups in GSCC, falling into 10 of the 12 soil orders. Desert soils and Aridisols in the arid regions are the two exceptions. In terms of percentage in each great group, Ferralsols, Alfisols, Semi-Alfisols and Pedocals are in the lead. For instance, in Ferralsols and Pedocals, 3 out of 4 great groups therein are of the type, and in Alfisols 4 out of 7 of the type. Analysis reveals that the main cause of these great groups being low in the maximum referencibility is the difference between GSCC and ST in theory and standard for classification. Consequently, any great group in GSCC may be interpreted as several orders in ST. For instance, Latosolic red soils can be sorted into Ultisols, Oxisols, Alfisols and Inceptisols in ST by reference, with referencibilities being 56.0%, 16.6%, 8.6% and 18.8%, respectively, and again dark brown soils can be sorted into Inceptisols and Alfisols with referencibilities being 36.9% and 63.1%, respectively. All seem quite scattered, lacking a major referencible target in ST. In this case, although the results in Table 4 may be used as benchmarks, their reliability is very low, less than 70%. It is, therefore, believed that further study on reference at a lower classification level or at a regional level may help to improve accuracy of the reference.

Table 4 GSCC soil great groups with maximum referencibility <70%

GSCC orders	GSCC great groups	ST orders	Area/10^3 km^2	Percentage of the country's total land area (%)	Maximum RB (%)[a)]
Ferralsols	Latosolic red soils	Ultisols	115.7	1.210	56.0
	Red soils	Ultisols	435.5	4.555	69.3
	Yellow soils	Inceptisols	127.8	1.336	52.0
Pedocals	Castanozems	Mollisols	209.5	2.191	54.1
	Castano-cinnamon soils	Alfisols	23.4	0.245	53.3
	Dark loessial soils	Inceptisols	9.7	0.102	50.1

a) RB, Referencibility.

3 Conclusion

When reference is made between GSCC great groups and ST orders, the number of great groups with referencibility >95% reaches 20, accounting for one third of the data available in GSCC. The results of the reference can be taken as benchmarks for extensive application. The number of great groups with reliability in the range of 70%—95% is 15. Although the reference may have some errors, the results of the reference can be used as benchmark for application until more detailed update is available. The number of great groups with reliability <70% remains to be 25. The main cause of these great groups being low in the maximum referencibility is the sharp difference between GSCC and ST in theory and standard for classification. These great groups scatter widely in ST orders. In order to improve accuracy of the reference, it is essential, as the authors think, to further study the reference at lower categories or at a regional level.

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References

1. Soil Survey Staff in USDA, Keys to Soil Taxonomy (Sixth Edition), 1992, 1—306.
2. FAO/ISRIC/ISSS, World Reference Base for Soil Resources, World Soil Resources Reports, 1998, 84: 1—88.
3. Eswaran, H., Rice, T., Ahrens, R. et al., Soil Classification, A Global Desk Reference, Boca Raton: CRC Press, 2003, 1—263.
4. Shi, X. Z., Gong, Z. T., Reference comparison of soil types in southeast China under different soil classifications, Chinese J. of Soil Science (in Chinese), 1996, 27(3): 97—102.
5. Gong, Z. T., Chen, Z. C., Lou, G. B. et al., The reference of Chinese soil taxonomy, Soil (in Chinese), 1999, (2): 57—63.
6. The Officer for the Second National Soil Survey of China, Soil Species of China (The First Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1993, 1—924.
7. The Officer for the Second National Soil Survey of China, Soil Species of China (The Second Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1994a, 1—739.
8. The Officer for the Second National Soil Survey of China, Soil Species of China (The Third Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1994b, 1—744.
9. The Officer for the Second National Soil Survey of China, Soil Species of China (The Fourth Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1995a, 1—806.
10. The Officer for the Second National Soil Survey of China, Soil Species of China (The Fifth Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1995b, 1—886.
11. The Officer for the Second National Soil Survey of China, Soil Species of China (The Sixth Volume) (in Chinese), Beijing: Chinese Agriculture Press, 1996, 1—880.
12. Thorp, J., Geography of the Soils of China, The National Geological Survey of China, Nanjing, China, 1936, 1—552.
13. Gong, Z. T., Zhao, Q. G., Zeng, S. Z. et al., A drafting proposal for soil classification of China, Soil (in Chinese), 1978, (5): 168—169.
14. Xi, C. F., Zhu, K. G., Zhou, M. Z. et al., Soils of China (in Chinese), Beijing: Chinese Agriculture Press, 1998, 1—1253.
15. The Officer for the Second National Soil Survey of China, Soil Map of People's Republic of China (in Chinese), Beijing: Sino Maps Press, 1995, 1—60.
16. Shi, X. Z., Yu, D. S., Pan, X. Z. et al., A framework for the 1∶1000000 soil database of China, in Proceedings of the 17th World Congress of Soil Science, Bangkok, Paper number 2002, 1757 (1—5).

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