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Cross-Reference System for Translating Between Genetic Soil Classification of China and Soil Taxonomy

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ABSTRACT

Soil classification systems are not consistent among countries or organizations thereby hindering the communication and organizational functions they are intended to promote. The development of translations between systems will be critical for overcoming the gap in understanding that has resulted from the lack of a single internationally accepted classification system. This paper describes the application of a process that resulted in the translation of the Genetic Soil Classification of China (GSCC) to Soil Taxonomy (ST). A brief history of soil classification in China is also provided to familiarize readers with GSCC and its origins. Genetic Soil Classification of China is the attribute base for the recently assembled digital form of the 1:1 000 000 soil map of The People's Republic of China. The translation between GSCC and ST was based on profile, chemical, and physical descriptions of 2540 soil series. First, the 2540 soil series were classified to their equivalent soil order, suborder, great group, and subgroup according to ST and GSCC subgroup descriptors. Order names for both classification systems were then linked to corresponding map units in the 1:1 000 000 digital soil map of China using a geographic information system (GIS). Differences in classification criteria and in the number of orders of the two systems (there are more GSCC orders than ST orders) meant that each GSCC order could possibly be assigned to more than one ST order. To resolve the differences, the percent correspondence in area between orders was determined and used as the criterion for assigning GSCC orders to ST orders. Some percentages of correspondence were low so additional processing was used to improve the assignment process. The GSCC suborders were then matched with ST orders. When the area for each order was summarized, the percentage of correspondence increased except for two subgroups in the Ferrasols order.

CLASSIFICATION is a fundamental part of the rational study and management of soil resources, serving as an organizational framework and descriptor of soil properties. Systematic soil classification is also a vehicle for communicating research results and extending the benefits of new knowledge to other locations. Classification in conjunction with soil mapping provides a method for planning agricultural output, makes possible the application of new management techniques, and supports the use of environmentally sound land use practices.

To date there is no universally accepted soil classification system. Internationally, only Soil Taxonomy (ST) (Soil Survey Staff, 1994) and World Reference Base for Soil Resources (WRB) (FAO/ISRIC/ISSS, 1998) are used extensively. "Soil Classification–A Global Desk Reference" edited by noted soil taxonomists, was published recently, to stimulate formation of an international soil classification system (Eswaran et al., 2003). Even given the development of an internationally recognized system, a great deal of time will have to be dedicated to translating existing systems into the new global standard.

Soil classification in China provides an interesting example of how systems can be cross-referenced to improve the understanding of soil properties. Soil classification in China has undergone several important transformations, resulting in the creation of two soil classification systems based on different academic philosophies, namely GSCC and Chinese Soil Taxonomy (CST). Currently the two systems are used together. Nevertheless, the large volumes of soil data and information gathered and accumulated since the initiation of the study of soil science in the early 1930s, including soil maps and soil survey reports, have mostly been prepared and sorted on the basis of GSCC. For example, the second national soil survey (1979–1994) was documented using GSCC, as were all the soil maps and soil survey reports at all administrative levels (township, county, city, province, and country).

Genetic Soil Classification of China, however, differs sharply from ST, which is used extensively throughout the world. Since non-Chinese scientists and other users of soil data outside of China do not know much about GSCC, it is extremely difficult for Chinese soil scientists to exchange information, cooperate with foreign colleagues, and publish papers in international journals. Further, it is difficult for soil scientists from countries outside of China to acquire a working knowledge of GSCC terminology and criteria, because the source materials are published in Chinese, which is not a familiar second language for many soil researchers.

To overcome these obstacles, Chinese scientists know and are compelled to translate all soils information on the basis of ST. However, such translations are performed on an individual basis without guidance on how to conduct them, increasing the possibility for inconsistencies when relating soils from one system to another. So that while Chinese soil scientists are familiar with ST, there is no national standard for translating between the two systems.

The solution was to establish a reference system between GSCC and ST. To that end, Chinese soil scientists have been devoting untiring efforts (Shi and Gong, 1996, 2004b; Gong et al., 1999, 2000). Some initial studies have been done to get an idea of how the two systems might

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Abbreviations: GIS, Geographical Information System; GSCC, Genetic Soil Classification of China; ST, Soil Taxonomy.

be related. The study of the 20 red soil profiles in Jiangxi and Fujian provinces revealed that 12 of them were Ultisols, 4 Alfisols, and the other 4 Inceptisols in ST (Shi and Gong, 1996). In 1999, the soil orders of the "Chinese Soil Taxonomy" were used as guides and for each soil order, several soil profiles were cited. A total of 64 soil profiles were used for attempting a link between the Chinese Soil Taxonomy, GSCC, ST, and FAO legend units (Gong et al., 1999).

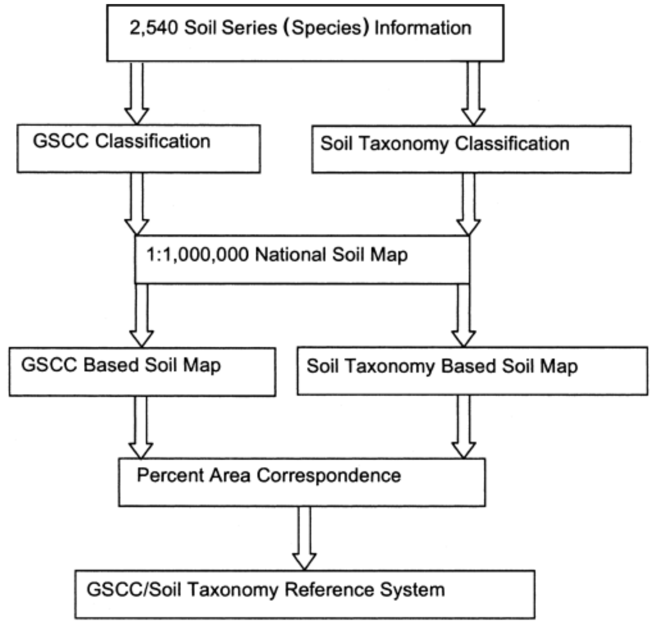
Although much work has been done in studying references between some soil series, the number of soil profiles examined in the previous studies were far too limited to form definitive relationships. A translation method to date was needed to help develop soil science in China and to enable academic exchanges with foreign investigators. Moreover, based only on dozens of soil profiles, the reference between the two systems was not robust by drawing from a limited sample of the diversity of soils found across the country. To improve the range of soils considered in the reference system, "Soil Species of China (six volumes)" and "Soil Species of Selected Provinces" were consulted to identify attributes of each soil species according to GSCC and ST. Statistics were used to help define rules that were a reference for establishing the correlation between the two systems.

A note about terminology is appropriate here, as we have used the words soil species to denote a basic unit of soil classification, which makes it equivalent to soil series as it is understood by those familiar with American soil science. Soil species was a term adopted from the former Soviet Union, which had the dominant influence on soil classification in China after the revolution in 1954. After this point we will use the soil series exclusively except when referring to accepted translations of references, but readers should be aware that the term soil species is still widely used in Chinese soil literature.

HISTORY OF SOIL CLASSIFICATION IN CHINA

Soil classification research in China began in the early 1930s, through the introduction of methods from the USA, developed from the work of C.F. Marbut. As a result some 2000 soil series were identified. In 1930, the first paper describing soil survey and classification in China was released, followed in 1934 by the first research report concerning the same topic. In 1936, a book entitled "Soil Geography of China" presented the first general description of soils in China at a national scale (Thorp, 1936). In 1941, the first Chinese soil classification system was drafted and used as a basis for the identification of soils in most of the country.

In 1954, the genetic classification approach was introduced from the former Soviet Union, which was strongly based on the setting of the soil's location. From this introduction, a genetic soil classification was proposed for adoption as a national system. Extensive investigations were made for classifying and naming cultivated soils, further modifying the genetic soil classification system according to the formation factors relevant to the country. In 1978 a standard genetic soil classification of China—"Provisional Draft of Soil Classification of China" (Gong et al., 1978) was established. The proposed classification had three levels: soil order, great group, and subgroup. This classification had an extensive basis and adopted soil names that had long been used in the country. The system was soon recognized by the soil science community in China and accepted as the basis for soil classification in the second national soil survey. In 1979, the "Soil Working Classification System (Revised draft)" was formulated for the second national soil survey. The draft, after several amendments, was developed into the "Genetic Soil Classification System of China" in 1992. And in 1998, a six level soil classification system was completed, that is, order, suborder, great group, subgroup, family, and series (Xi et al., 1998).



MATERIALS AND METHODS

The flow of the investigation is depicted in a series of steps used to create the cross reference between GSCC and ST (Fig. 1). Two data sets were used in this investigation, which were processed using a GIS to efficiently summarize the different soil classification descriptors, and match them across systems.

The first data set used in the cross-reference study was taken from "Soil Species of China (six volumes)" (The Office of the Second National Soil Survey of China, 1993, 1994, 1995, 1996) and "Soil Species of Selected Provinces," which provided information on 2540 soil series collected from locations throughout China. The attributes of the soil profiles are used as the initial link between GSCC and ST. It should be noted that these were selected from a set of 30 000 profile descriptions collected as part of the second National Survey. The second National Survey resulted in the creation of a 1:1 000 000 scale map for the whole country (The Office for the Second National Soil Survey of China, 1995), among other documents and studies. The 2540 soil series records were the ones from the total 30 000 that were deemed complete enough to provide sufficient information for determining the classification in both GSCC and ST.

The basic attributes for each soil series are composed of descriptive and quantitative data recorded in thematic sections. One section lists classification (soil great group, subgroup, and family), geographic distribution, major soil properties, profile characteristics and production capacity. Major soil properties recorded include parent material and soil profile structure and thickness of the soil layer. The data for profile characteristics detail location, elevation, parent material, climatic information (such as annual mean temperature), natural vegetation, and crops on the profile site. The second section is referred to as the field profile record, which describes each soil layer with such characteristics as color, texture, and structure of the soil layer and plant root system therein. The third and final section lists such attributes as soil physical properties, soil chemical properties, and soil nutrients.

A group of experienced pedologists and mapping experts were assembled to review the soil series information and assign both GSCC and ST classifications to the subgroup level. The process was an iterative one, with classifications proposed and then reviewed, to assure consistency in the assignment process.

The second data set used in this investigation is the newly created digital version of the 1:1 000 000 scale soil map of China. A geographic information system (GIS) was used to link the 1:1 000 000 scale soil map to the profile attribute information based on the GSCC family descriptor. The basic map unit is the soil family, of which there are 909. In total the actual number of polygons mapped for the entire country is ~94 000, of which there are 235 soil subgroups, 61 soil great groups and 12 soil orders (Shi et al., 2004a). The original form of the map was a hardcopy series, each of which was compiled on a provincial basis. The hardcopy maps exist now as a single digital database and include all the original detail.

RESULTS

Distribution of Chinese Soils according to Genetic Soil Classification of China and Soil Taxonomy

Attribute data for the 2540 soil series described above serve as the initial link between GSCC and ST. Among the 12 GSCC soil orders, Anthrosols dominate, accounting for 571 of the 2540 soil series. Anthrosols are followed by Amorphic soils and Semi-Aquatic soils, accounting for 367 and 361 of the 2540 soil series, respectively. Profile data for Ferralsols, Alfisols, Semi-Alfisols, Pedocals, and Alpine soils, number between 100 and 300 each. Aridisols, Desert soils, Aquatic soils, and Alkali-saline soils are represented by <100 soil series within each group.

By aggregating soil series into higher and higher levels, a ST soil order distribution map of China was compiled (Fig. 2). Based on the digital soil map, the total area of each soil order for the two soil classification systems and the percentage of China's total land area were determined (Table 1). Note that the percentages listed do not include 3% of the land mapped as non-soil. As is shown in the table, Alpine soils and Morphic soils are the two soil orders in GSCC that have the greatest area, accounting for 1980 and 1630 $\times 10^3$ km^2 or 20.7 and 17.0% of the country's total land area, respectively. The areas of the ST soil orders, however, are rather uneven. Among the 12 soil orders, the Inceptisols cover 3350 $\times 10^3$ km^2, accounting for 35.0% of the country's total; while Andisols, Histosols, Oxisols, Spodosols, and Vertisols, each cover <1.0%, Alfisols, Aridisols, and Entisols, each range between 10 to 20%, and Ultisols and Mollisols between 6 to 10%.

Table 2 compares ST soil orders according to the 1:1 000 000 China national soil database and ST soil orders as mapped with the Global Soil Suborder Map (USDA, 2000). The NRCS Global Soil Suborder Map was produced by modifying the FAO-UNESCO Soil Map of the World with another NRCS product, a soil climate map. For consistency the suborders have been aggregated to orders. As can be seen there is little correspondence between the percentage of area mapped by the two sources. Equally interesting, is the amount of non-soil land, 3 and 35% for the national China soil database and NRCS map, respectively. It is beyond the scope of this article to explain these differences, but certainly they can be attributed to such factors as scale, source information, and human interpretation.

Cross-reference Between GSCC and ST Soil Orders

The systems can be cross-referenced now that the 1:1 000 000 soil map has been attributed according to both ST and GSCC. A frequency operation was performed on the database so that each unique GSCC order was listed with each ST order that share a mapped polygon. The area and percentage of the total area of each GSCC order accounted for by each associated ST order identified by the frequency operation were then determined. For example, 75.6 and 23.5% of the area mapped as Anthrosols in GSCC occur as Inceptisols and Alfisols in ST, respectively. The referencibility or co-occurrence, of GSCC soil orders to their corresponding ST orders is listed in Table 3. As can be seen, the correspondence between orders from the different systems varies widely.

From Table 3 it can be seen that Desert soils in GSCC are directly equivalent to Aridisols in ST. However, Amorphic soils in GSCC could be interpreted into seven different ST soil orders: Entisols, Inceptisols, Alfisols, Aridisols, Ultisols, Andisols, and Mollisols, with their referencibility being 62, 26.9, 6.96, 6.96, 0.41, 0.18, and 0.05%, respectively. The maximum percentage of referencibility for each GSCC matching a ST order varies widely from 100 to 42.2%. Based on referencibility, the soil orders in GSCC can be divided into three categories, high, intermediate, and low. Soil orders in GSCC with referencibility values above 80% fall into the high category, including Desert soils, Aridisols, and Semi-Aquatic soils. The maximum referencibility values for Desert soils and Aridisols to Aridisols in ST reaches 100 and 97%, respectively. The intermediate category for frequency values varies between 60 and 80%, and includes Anthrosols, Alkali-saline soils, Amorphic soils, Alfisols, and Ferralsols, whose respective counterparts in ST are Inceptisols, Aridisols, Entisols, Alfisols, and Ultisols. The low category has referencibility values below 60%, including Semi-Alfisols, Pedosols, Aquatic soils, and Alpine soils, whose respective counterparts in ST are Alfisols, Mollisols, Inceptisols, and Inceptisols.

Improving the Cross-reference of GSCC to ST

In the discussion above, it is obvious that some soil orders in GSCC have high referencibility. For instance, Desert soils in GSCC have a 100% correspondence to Aridisols in ST, that is to say there are no other ST soil

Table 1. Genetic Soil Classification of China (GSCC) and Soil Taxonomy (ST) soil order area and proportion in GSCC and ST based on the 1:1 000 000 China National Map.

GSCC Soil Orders from 1:1 000 000 China National Map	Area	Percentage of the country's total land area	ST Soil Orders from 1:1 000 000 China National Map	Area	Percentage of the country's total land area
	10^3 km^2			10^3 km^2	
Ferralsols	1120	11.8	Alfisols	1210	12.7
Alfisols	1060	11.1	Andisols	2.97	0.03
Semi-Alfisols	428	4.48	Aridisols	1720	18.0
Pedocal	591	6.18	Entisols	1370	14.3
Aridisols	306	3.21	Histosols	62.8	0.66
Desert soils	604	6.32	Inceptisols	3350	35.0
Amorphic soils	1630	17.0	Mollisols	673	7.04
Semi-Aquatic soils	747	7.82	Oxisols	53.7	0.56
Aquatic soils	147	1.53	Spodosols	1.36	0.01
Alkali-saline soils	184	1.92	Ultisols	810	8.47
Anthrosols	489	5.11	Vertisols	27.0	0.28
Alpine soils	1980	20.7			

Table 2. Soil order area and proportion in Genetic soil classification of China (GSCC) from the 1:1 000 000 China National Map and Soil Taxonomy (ST) based on the USDA Global Suborder Map.

ST Soil Orders from 1:5 000 000 NRCS Map	Area	Percentage of the country's total land area	ST Soil Orders from 1:1,000,000 China National Map	Area	Percentage of the country's total land area
	10^3 km^2			10^3 km^2	
Alfisols	245.5	2.5	Alfisols	1210	12.7
			Andisols	2.97	0.03
Aridisols	1029.8	10.8	Aridisols	1720	18.0
Entisols	1303.4	0.4	Entisols	1370	14.3
Histosols	36.8	0.4	Histosols	62.8	0.66
Gelisols	103.9	1.0			
Inceptisols	1528.4	16.0	Inceptisols	3350	35.0
Mollisols	733.0	7.7	Mollisols	673	7.04
			Oxisols	53.7	0.56
			Spodosols	1.36	0.01
Ultisols	1097.4	11.5	Ultisols	810	8.47
Vertisols	93.3	0.9	Vertisols	27.0	0.28

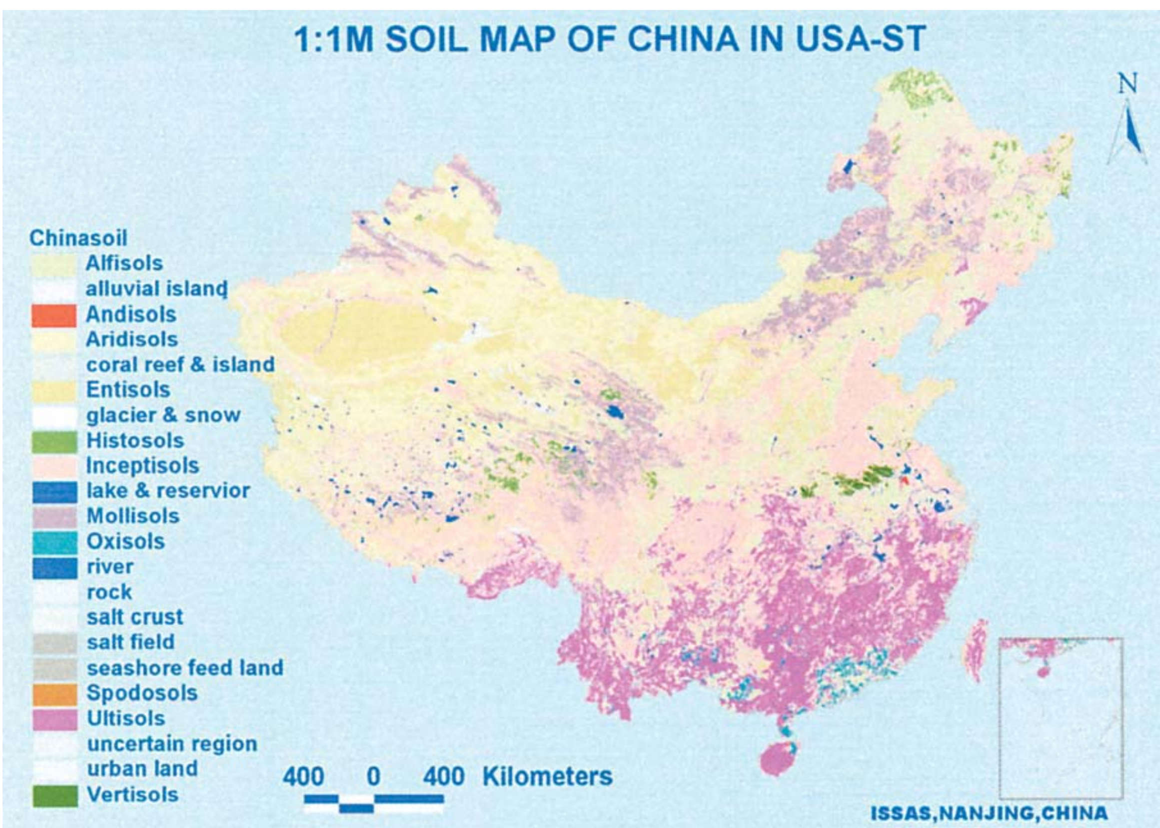


Fig. 2. Soil Taxonomy soil order distribution map of China.

Table 3. Cross-reference of soil orders in Genetic soil classification of China (GSCC) to those in Soil Taxonomy (ST).

GSCC Soil Order	ST Soil Order	1000 km^2	Referencibiliy%	GSCC Soil Order	ST Soil Order	1000 km^2	Referencibility%
Ferralsols	Alfisols	8.2	0.73	Amorphic soils	Alfisols	112	6.91
	Inceptisols	294	26.2		Andisols	1.4	0.08
	Oxisols	84.1	7.49		Aridisols	29.4	1.81
	Ultisols	727	64.7		Entisols	1133	69.8
	Vertisols	9.8	0.87		Inceptisols	349	21.5
Alfisols	Alfisols	716	67.6	Semi-Aquatic soils	Entisols	74.6	9.99
	Inceptisols	202	19.0		Inceptisols	650	87.0
	Spodosols	0.1	0.01		Mollisols	0.4	0.06
	Ultisols	142	13.4		Vertisols	22.1	2.95
Semi-Alfisols	Alfisols	232	54.3	Aquatic soils	Alfisols	0.2	0.11
	Inceptisols	120	28.0		Histosols	57.7	39.3
	Mollisols	75.7	17.7		Inceptisols	88.8	60.6
Pedocal	Alfisols	114	19.3	Alkali-saline soils	Alfisols	1.0	0.52
	Aridisols	11.2	1.89		Aridisols	82.4	44.9
	Inceptisols	49.1	8.31		Entisols	24.4	13.3
	Mollisols	417	70.5		Inceptisols	76.0	41.4
Aridisols	Alfisols	5.6	1.84	Anthrosols	Alfisols	104	21.3
	Aridisols	298	97.2		Inceptisols	385	78.7
	Inceptisols	2.9	0.96	Alpine soils	Aridisols	574	29.0
Desert soils	Aridisols	604	100		Entisols	299	15.1
					Inceptisols	996	50.4
					Mollisols	109	5.52

orders that were included in the classification of Desert soils. Some, however, have a low correspondence. Ferralsols in GSCC have its greatest proportion of matched area to Ultisols in ST, being only 60.7%. That means that nearly 40% of the area classified in GSCC as Ferralsols are cross-referenced as some ST order other than Ultisols. So to make the reference system more consistent, additional processing was undertaken. It was decided to cross reference those GSCC great groups with low correspondence on the basis of soil orders.

Table 4 shows reference of soil groups under Soil Order Ferralsols in GSCC to soil orders in ST. Under the order of Ferralsols there are four great groups, Latosols, Latosolic red soils, Red soils, and Yellow soils. The number of soil orders in ST that each great group is referenced to is generally limited. For instance, Latosols and Yellow soils have only two orders each. On the other hand, the referencibility of Latosols and Red soils to Ultisols in ST is raised by a large margin to 83.3 and 74.5%, respectively. But the referencibility of the other two groups, Latosolic red soils and Yellow soils, is otherwise. In this case, changing the soil classification unit for cross-referencing doesn't improve the correspondence. Another approach to improve the referencibility might be to use a regional subdivision of the soil data. A regional subdivision might capture variability related to climate differences in the country.

Table 4. Reference of soil groups under the order of Ferralsols in Global soil classification of China (GSCC) to soil orders in Soil Taxonomy (ST).

Order in GSCC	Ferralsols Great Group	Order in ST	1000 km^2	% of ST order
Ferralsols	Latosols	Oxisols	7.05	16.7
		Ultisols	35.2	83.3
	Latosolic red soils	Inceptisols	24.9	12.0
		Oxisols	77.1	37.3
		Ultisols	105	50.7
	Red soils	Alfisols	8.17	1.30
		Inceptisols	143	22.7
		Ultisols	468	74.5
		Vertisols	9.8	1.56
	Yellow soils	Inceptisols	127	51.6
		Ultisols	119	48.4

SUMMARY

After classification of the 2540 soil profiles and linking the profile attributes to the 1:1 000 000 soil map, it is found that the 12 soil orders in ST distribute unevenly in China. Among Andisols, Histosols, Oxisols, Spodosols, and Vertisols, none exceeds 1.0% of the country's total land area; Inceptisols have the largest land coverage, being 3350×10^3 km^2 or 35.0% of the country's total; Alfisols, Aridisols, and Entisols range between 10 and 20%, whereas Ultisols and Mollisols range between 6 and 10%.

In terms of maximum proportion of correspondence to soil orders in ST, the soil orders in GSCC vary significantly from 100 to 42.2%. The category with agreement greater than 80% includes Desert soils, Aridisols and Semi-Aquatic soils. The category with moderate agreement, lower than 60%, includes Semi-Alfisols, Pedocals, Aquatic soils, and Alpine soils. Soil orders in GSCC with referencibility above 80% fall into the category of high, including Desert soils, Aridisols, and Semi-Aquatic soils. The referencibility of Desert soils and Aridisols to Aridisols in ST reaches 100 and 97.7%, respectively. The intermediate referencibility category varies between 60 and 80%, including Ferrasols, Alfisols, Amorphic soils, Alkali-saline soils, and Anthrosols, whose respective counterparts, determined by referencibility, in ST are Ultisols, Alfisols, Entisols, Aridisols, and Inceptisols. Although the two soil classification systems differ sharply in theory and basis, the application of GIS for determining a relation bridging them is a promising initial step. Nevertheless, more efforts shall be devoted to establish coincidence relationships with higher referencibility between the two systems. For instance, establishing the reference from a lower classification level or subdividing the data based on some regional basis may provide better coincidence between the two systems.

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