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Vertical differentiation analysis of sierozem profile characteristics in Yili-River valley, China

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Research on the vertical differentiation of sierozem profile characteristics can provide a basis to implement soil resource assessment and develop sustainable land management system. In this study, 189 sampling data from 50 sierozem profiles along Yili River-valley in northwest of China were chosen to analyze the vertical change of edaphic characteristics and soil ionic composition – including soil organic matter (SOM), pH value, electrical conductivity (EC), total salinity (TS), contents of CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, K^+, Na^+, $Ca^{2+}$and Mg^{2+} in soluble salt. Then sierozem characteristics in Yili-River valley were compared with those in central Asia, Ningxia and Gansu provinces to reveal the vertical change and regional difference. The results showed that vertical difference of sierozem profile characteristics in different regions had some common: SOM content decreased with soil depth, while pH value, EC, contents of TS and most ions increased with soil depth. But there was obvious regional difference in spatial variation and intensity of sierozem characteristics due to more arid climate in Yili-River valley. The results could be used for regional ecological construction and sustainable development.

Key words: Yili-River valley, sierozem, vertical differentiation.

INTRODUCTION

Currently, there is a new concern about feeding the world (UN Millennium Project, 2005) and the land needed for energy and increased animal production (UNEP, 2007). It is necessary to design and study sustainable land management system (Smyth and Dumanski, 1995). Study of soil profile characteristics can provide a basis for implementing soil resource assessment and management.

In arid or semiarid climate region, the natural environmental systems are very fragile and the ecosystems are in precarious balance. Land is believed to be a non-renewable resource at a human time-scale and some adverse effects of degradative processes on land quality are irreversible, especially in fragile environmental system (Eswaran et al., 2001). Western China is a national ecological and environmental security barrier for its special geographical position and semi-arid / arid climate. It is very important for realizing national ecological improvement and sustainable development to make western ecological construction. Studying vertical change of soil properties in Yili-River valley will provide the basis for regional ecological construction and

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sustainable development.

Studies on soil characteristics were mainly from descriptions of the typical soil profiles before 1990s (Xinjiang institute of comprehensive expedition and Institute of soil sciences, Chinese academy of sciences, 1965; Wu and Quan, 1985). However, it was deficient to research regional soil profile groups comprehensively. In recent years, quantitative information on soil variability has become increasingly important for soil resource assessment and management. Much research has focused on spatial distribution and variation of soil elements with the development of geo-statistics and GIS technology (Yost et al., 1982a, b; Xu and Webster, 1983; Webster and Nortcliff, 1984; Tao, 1995a, b; Haefelel and Wopereis, 2005; Liao et al., 2008). However, these studies mainly focused on single soil characteristic, such as soil nutrient, salinity or heavy metals, while less research has been done to analyze soil comprehensive elements. Research focused much more on the horizontal distribution and variation of soil characteristics than on vertical variation of soil attributes (Acosta et al., 2011; McBratney et al., 2000). Recently, although more studies have been done on soil distribution and spatial variation in Yili-River valley (AMAITT et al., 2006; Shi et al., 2009; Mamattuesun et al., 2010; Hamid et al., 2011; Zulpiya et al., 2011; Gulnar et al., 2011), it was scarce to study the soil comprehensive characteristics based on the whole soil profiles.

Sierozem is the soil developed in the dry climate and desert steppe in warm temperate zone, which is ash brown, yellow brown or brown, has low humus and weak leaching (National soil census office, 1998). There is patch or pseudohyphae calcium carbonate deposition and strong lime reaction within full sierozem profile. Most sierozem distributed on hilly loess and high terraces of river, where the underground water level is generally deep. Most parent material of sierozem is loess, while less is the material from alluvial fan and proluvial. The vegetation dominated with perennial dryland grass, shrubs and artemisia.

The distribution of sierozem is incontinuous in China, which can be divided into eastern part (including Gansu, Ningxia etc.) and western part (Yili-River valley). There is obvious difference in seasonal distribution of precipitation and composition of vegetation in two parts. The rainy season is from July to September in eastern part, while the rainfall is even, a little more in spring in western part. The dominant species are *Stipa breviflora*, *Gobi Stipa*, *sandy Stipa*, *Peganum harmala* and drought-tolerant *Artemisia* in eastern part, while *Artemisia*, *Poa annua*, *Carex*, *Kochia scoparia* and other ephemeral plants are the main species in western part. Sierozem in Yili-River valley is believed to be the extension of sierozem zone in central Asia. There are many common characteristics in soil formation between arid regions in northwest of China and central Asian countries. Study of soil profile characteristics in Yili will benefit academic exchange between China and the central Asian countries and promote the development of soil sciencs.In this study, the sierozem profile characteristics were comprehensively analyzed and compared with those from central Asia, Ningxia and Gansu to express the common and difference of vertical change of sierozem profiles, based on field survey, sampling and testing on soil organic matter (SOM), pH value, electric conductivity (EC), total salt (TS) and 8 main ions.

It is supposed that SOM content decreases with soil depth as usual; there is high pH value, EC, more soluble salt in deposition layer of sierozem profile due to the semi-arid/arid climate - strong transpiration, low rainfall and weak leaching in Yili-River valley; there is much difference in sierozem profile characteristics among different regions for that climate and vegetation are the two important factors in sierozem formation.

MATERIALS AND METHODS

Description of study area

The study area is located in Yili-River valley, surrounded by Tianshan Mountains at east, south and north, west open to Kazakhstan. It has a temperate semiarid continental climate, and is dominated by westerly winds throughout the year. The winter climate is controlled mainly by the intensity and position of the Siberia high pressure cell, and is also influenced by the north branch of the westerlies; the summer climate is in part affected by the Indian low pressure cell, when the southern branch of the westerlies shifts northwards (Li, 1991). There is the most abundant rainfalls in Yili valley of Xinjiang, because it is open on the west to humid airflow. The study area lies in the second and third terrace and tilted plain, with elevation ranging from 600 to 1100 m. It has a low annual precipitation (230 to 350 mm) and an annual potential evapotranspiration, reaching 1200 to 1900 mm. The aridity index k1 is between 2.5 to 4.2. The mean annual atmospheric temperature is 7.9 to 9.2°C, with monthly averages ranging from a minimum of -12.2°C in January to a maximum of 22.7°C in July. Natural vegetation is desert Artemisia grassland. There is always 1 to 3 cm yellow grey surface crust. The soil is mainly light-middle loam. The zonal soil of the study area is sierozem, which belongs to Aridisols (Order) – Warm Aridisols (Suborder) – Sierozem (Great Group) – Ordinary Sierozem (Subgroup) according to genetic soil classification of China (Fan and Cheng, 1986; National soil census office, 1998). The genetic soil classification was strongly based on the setting of the soil's location (Scalenghe and Ferraris, 2009). Genetic soil classification of China (GSCC) differs sharply from WRB (IUSS Working Group WRB, 2006) in its underlying understanding about the genetic process. The Aridsols (order) - sierozem (Great group) in GSCC and the Cambisols in WRB reference soil group have a 44.2% maximum referencibility (Shi et al., 2010).

Data sampling, testing and analytical methods

From late June to early July in 2008, the working group made a field survey along Yili-River valley, where 69 soil profiles were

[1] $k = (0.16\sum \geq 10°C)/r$. Where ∑≥10°C: ≥10°C accumulated temperature; r: Rainfall during the same period. K: 2.0-4.0, arid; >4: hyper arid.

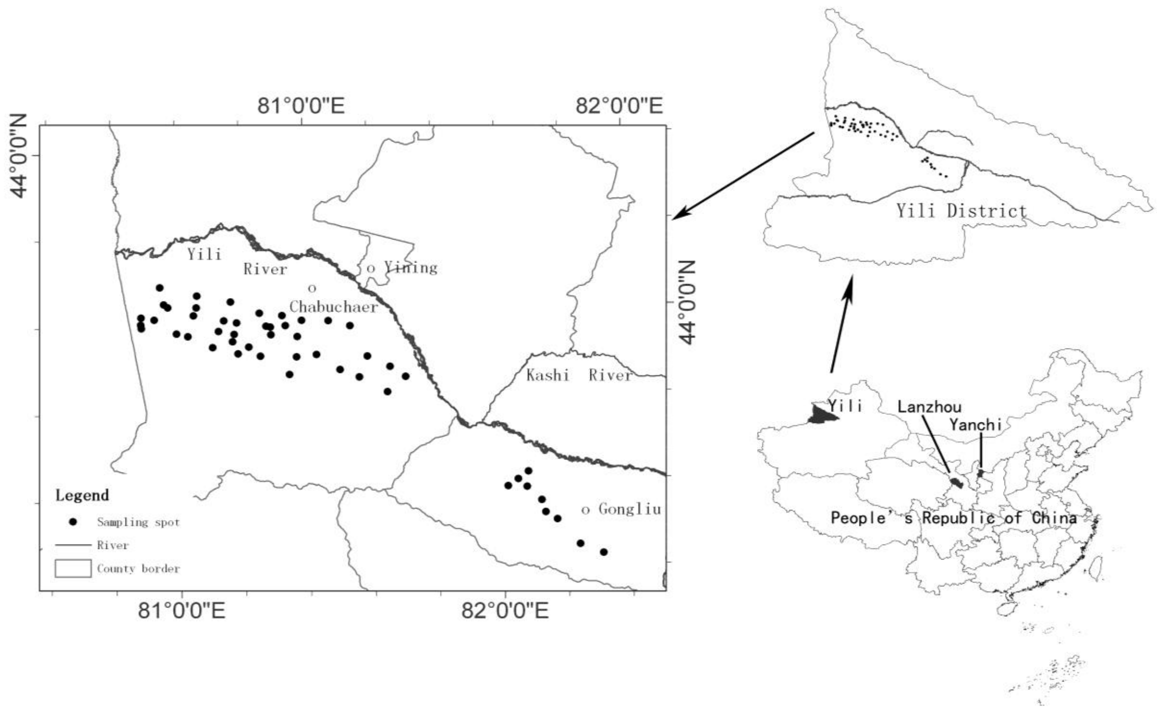

Figure 1. Position of Sierozem soil profiles in the study.

investigated and sampled. The positions of soil profiles were determined by land cover, landform, groundwater and altitude. Most soil profiles lay uncultivated land. Soil samples were collected from middle of each soil physical layer. In this study, 50 sierozem soil profiles and 189 sampling data were used. Position of sierozem soil profiles was shown in Figure 1.

The sampling data were tested in Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. The following soil properties were measured: SOM, pH, EC and soluble salt content. SOM was analyzed using rapid dichromate oxidation techniques (Tiessen and Moir, 1993). Soil pH value was determined with pH electrode in the saturation paste, 1:5 soil: water mixture (pHS-2C, Shanghai, China). EC was measured by conductivity meter (DDS-307, Shanghai, China). TS was determined by using the distillation residue method. CO_3^{2-} and HCO_3^- were measured by means of dual indicator- neutralization titration (Bao, 2000). Cl^- was measured by using the $AgNO_3$ titration (Davey and Bembrick, 1969); SO_4^{2-} was measured by using the EDTA indirect titration. Na^+ and K^+ were measured with the flame spectrometry (Flame photometer 6410, Shanghai, China); Ca^{2+} and Mg^{2+} were measured by using the EDTA compleximetry (Working group on analytical chemistry in department of chemistry, Hangzhou University, 1997). Then sample data were analyzed to get the vertical distribution of soil elements using Matlab7.0 software programming (Figures 2 and 3). Data from each physical layers in soil profiles were identified in the middle of the layer.

In order to get data in every 25 cm below the surface, soil sample data were recalculated by weighted average. Then mean and standard deviation was separately calculated using spss 16.0 software in every 25 cm below the surface (Table 1). Statistical regression analysis was used to model the change of SOM content with soil depth using SPSS 16.0 software. Firstly, specified SOM content as dependent variable, soil depth as independent variable. Then take natural logarithm of dependent variable, and make linear regression using independent variable and natural logarithm of dependent variable. Finaly, calculate the dependent variable. Regional comparison of sierozem profile properties between Yili-River valley and Central Asia, Gansu and Ningxia was used to learn the common and difference of vertical change of sierozem soil profiles.

RESULTS

Characteristic and vertical differentiation of SOM, pH value, EC and TS

Topsoil SOM content, between 7.0 and 19.0 g kg^{-1}, was low in sierozem soil profiles in Yili-River valley. SOM content decreased with soil depth in sierozem profiles (Figure 2 and Table 1). Averaged SOM content was 11.18 g kg^{-1} at 0 to 25 cm depth, while 5.92 g kg^{-1} at 50 to 75 cm depth, 3.64 g kg^{-1} at 100 to 125 cm depth. The distribution of SOM content with soil depth was simulated to exponential function,

$$y = \exp\left(\frac{x + 109.85}{36.957}\right) \qquad r^2 = 0.4696$$

Where y was the SOM content (g kg^{-1}); x was the soil depth (cm); r: Correlation coefficient.

The quantity and vertical distribution of sierozem SOM content were tightly related to the remnant body of plant and decomposition, mineralization and leaching of humus. In the study area, zonal vegetation was desert

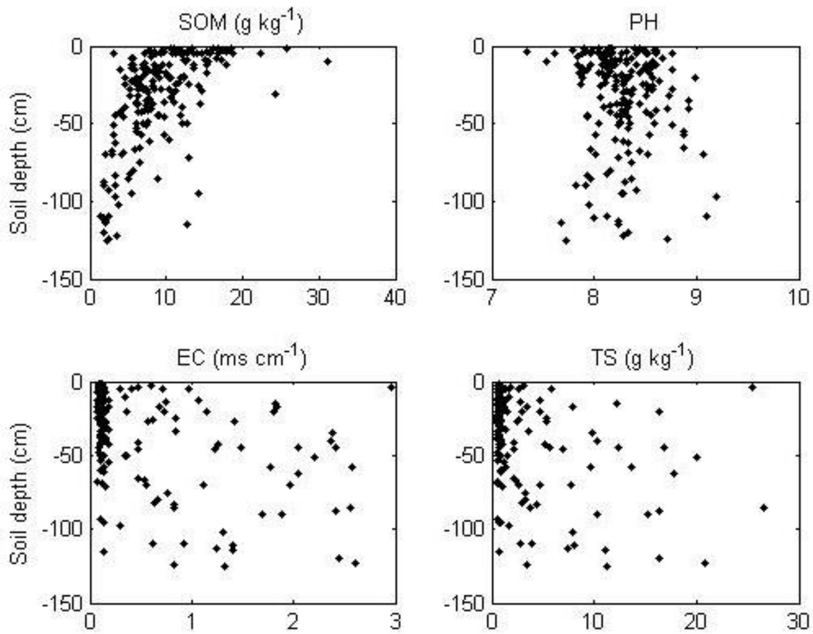

Figure 2. Vertical distribution of SOM, pH value, EC and TS in Sierozem soil profiles in Yili-River valley.

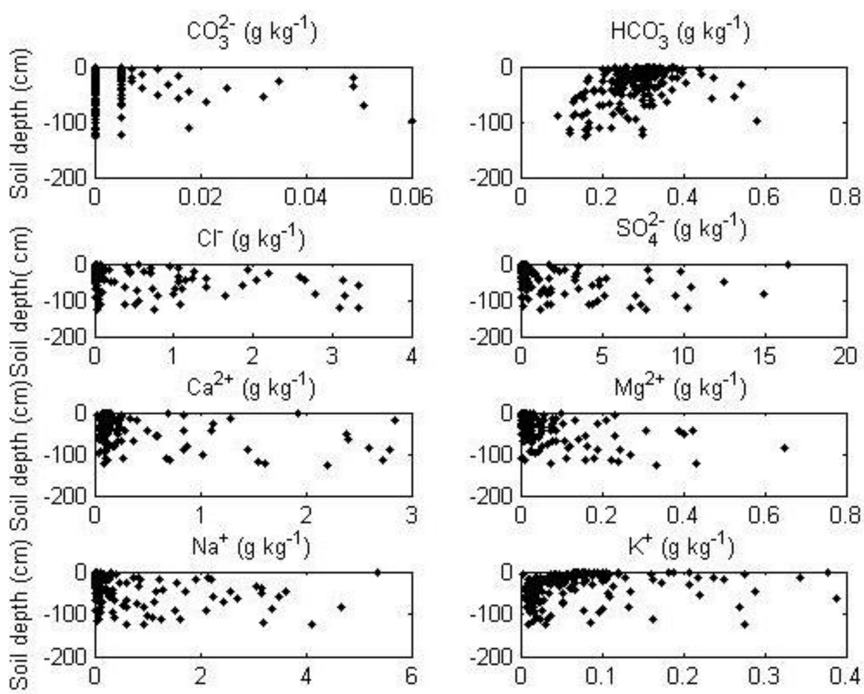

Figure 3. Vertical distribution of main cations and anions in Sierozem profiles in Yili.

steppe, whose cover degree was about 20 to 35% (Wu and Quan, 1985). Main species were *Stipa breviflora*, *Artemisia* and *Chenopodiaceae* pod. The vegetation structure was simple and had low production. In arid climate, decomposition and leaching of humus was slow, which had low contribution on sierozem SOM content and made SOM mainly accumulate in surface soil.

The pH value in Sierozem topsoil mainly ranged from 7.8 to 8.7, which showed soil was alkaline in Yili-River valley. pH value fluctuantly increased with soil depth in

Table 1. Statistics of soil characteristics every 25 cm depth in sierozem profiles in Yili-River valley.

Soil depth (cm)	SN	SOM (g kg^{-1})		pH		EC (ms cm^{-1})		TS (g kg^{-1})	
		Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
0-25	42	11.18	4.39	8.24	0.24	0.32	0.44	1.90	3.05
25-50	28	8.07	3.69	8.36	0.23	0.70	0.81	4.02	5.20
50-75	20	5.92	2.81	8.40	0.31	0.95	0.87	5.91	6.79
75-100	16	4.82	2.98	8.29	0.37	1.02	0.79	6.69	7.23
100-125	10	3.64	3.45	8.34	0.50	1.18	0.82	8.08	7.00

Soil depth (cm)	SN	CO_3^{2-} (g kg^{-1})		HCO_3^- (g kg^{-1})		Cl^- (g kg^{-1})		SO_4^{2-} (g kg^{-1})	
		Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
0-25	42	0.00	0.01	0.31	0.05	0.16	0.32	0.79	1.94
25-50	28	0.01	0.01	0.28	0.07	0.62	0.90	1.74	2.85
50-75	20	0.01	0.01	0.26	0.10	0.75	0.95	2.89	3.88
75-100	16	0.01	0.02	0.24	0.11	0.73	1.00	3.49	4.08
100-125	10	0.01	0.02	0.23	0.14	0.83	1.26	4.29	3.80

Soil depth (cm)	SN	Ca^{2+} (g kg^{-1})		Mg^{2+} (g kg^{-1})		Na^+ (g kg^{-1})		K^+ (g kg^{-1})	
		Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
0-25	42	0.20	0.35	0.03	0.04	0.27	0.59	0.08	0.07
25-50	28	0.30	0.48	0.08	0.11	0.81	1.15	0.06	0.08
50-75	20	0.50	0.74	0.11	0.13	1.14	1.33	0.08	0.10
75-100	16	0.66	0.87	0.15	0.15	1.17	1.32	0.06	0.07
100-125	10	0.96	1.02	0.17	0.15	1.22	1.40	0.08	0.08

SN, Sample number.

sierozem profiles (Figure 2 and Table 1). pH values were discrete at the bottom of soil profiles, which showed much difference among parent materials beneath soil profiles. Soil pH value was related to soil parent material, bio-climate and agricultural activities (Xiong and Li, 1987). Sierozem parent material was alkaline, which was composed of loess and loess-like material with high calcium. Calcium was usually leached to the lower layer slowly and deposited to calcium carbonate, which made pH value high in the deposition layer. Besides, there was weak humification in the surface soil, which could neutralize part alkalescence. So pH value increased with depth in sierozem profile and had a peak value in the deposition layer.

Soil EC and TS are indicators of water-soluble salt content. Figure 2 showed that most sierozem soil profiles depth less than 60 cm had low EC and TS, which were respectively less than 0.2 ms cm^{-1} and 2.0 g kg^{-1}. In general, EC and TS increased with soil depth in sierozem profiles (Table 1). The standard deviations of EC and TS were very high, which indicated that there was much difference among different soil profiles. Soil soluble salt content was related to the climate, groundwater level and composition, parent material, vegetation and human activities (National soil census office, 1998). In the study area, underground water level was low (Wu and Quan, 1985), which had little effect on soil salt. In the parent material of sierozem soil, quartz and feldspar contents were more. But silicate and aluminum silicate were mostly insoluble. So soluble salt content was less and EC was low in the sierozem soil. Due to the arid climate, evaporation was much greater than precipitation. Soluble salt could partly leach in soil profile with low rainfall.

Characteristic and vertical differentiation of main ions

Among 4 anions, SO_4^{2-} content was the most, while CO_3^{2-} content was the least. Among 4 cations, Na^+ content was the most, followed by Ca^{2+}, K^+ and Mg^{2+} contents were less (Table 1). So there were more SO_4^{2-}, Na^+ and Ca^{2+} contents in sierozem profiles in Yili-River valley. In four anions, only HCO_3^- content decreased with soil depth, while other anions contents increased with soil depth. Averaged SO_4^{2-} content was 0.79 g kg^{-1} at 0 to 25 cm.depth, while 2.89 g kg^{-1} at 50 to 75 cm depth, 4.29 g kg^{-1} at 100 to 125 cm depth. Averaged Cl^- content was 0.16 g kg^{-1} at 0 to 25 cm.depth, while 0.75 g kg^{-1} at 50 to 75 cm depth, 0.83 g kg^{-1} at 100 to 125 cm depth. Averaged HCO_3^- content was 0.31 g kg^{-1} at 0 to 25cm.depth, while 0.26 g kg^{-1} at 50 to 75cm depth, 0.23 g kg^{-1} at 100 to 125cm depth.

In sierozem profiles calcium carbonate lay from top to bottom. In the surface soil, there was more CO_2 resulted from respiration of plant roots. Carbonate could be easily hydrolyzed to bicarbonate under the effect of humus. Thus, in the sierozem profiles, HCO_3^- content was more in the surface soil, less and less with the profile down.

In four cations, only K^+ content fluctuates with soil depth, while other cations' contents increased with soil depth. Averaged Na^+ content was 0.27 g kg^{-1} at 0 to 25 cm.depth, while 1.14 g kg^{-1} at 50 to 75 cm depth, 1.22 g kg^{-1} at 100 to 125 cm depth. Averaged Ca^{2+} content was 0.20 g kg^{-1} at 0 to 25 cm.depth, while 0.50 g kg^{-1} at 50 to 75 cm depth, 0.96 g kg^{-1} at 100 to 125 cm depth.

DISCUSSION

The result showed that our assumption was partly right. SOM content really decreased with soil depth as usual and there is high pH value in the deposition layer of sierozem profile. But EC, contents of TS and 8 ions was different from our assumption. Above analysis showed that other ions and TS' contents and EC increased with soil depth, except HCO_3^- and K^+.

Comparison of sierozem SOM in Yili-River valley and in other regions

Sierozem in Yili-River valley is believed to be the extension of sierozem zone in central Asia. The climate in Yili-River valley is similar to the climate of northern Sierozem zone in central Asia. Annual temperature was 8°C and annual rainfall was 150 to 400 mm in northern sierozem zone in central Asia (Luozan, 1958). Northern sierozem in central Asia was divided into light northern sierozem and ordinary northern sierozem by A.H. Luozan. Light northern sierozem was mainly located in the ground and Alluvial slope, where humus layer was thin (30 to 60 cm), humus content was 0.8 to 1.7%; ordinary northern sierozem mainly lay hillside, where humus layer was thick (50 to 80 cm), humus content was higher, about 1.5 to 3.0% (Luozan, 1958). Compared with them, the sierozem humus layer was thinner, only 8 to 15cm in Yili-River valley (Xinjiang institute of comprehensive expedition and Institute of soil sciences, Chinese academy of sciences, 1965; Soil cencus office in Chabucha'er, 1984); SOM content was also less, only between 0.7 and 1.9% in the topsoil. This situation may be related to the arid climate in Yili-River valley.

The sierozem humus layer was 20 to 40 cm and average SOM content was 0.89%, which ranged from 0.45 to 1.33% in Ningxia hui autonomous region (Ningxia Institute of agriculture exploration and design, 1990). Meanwhile, the sierozem humus layer was 20 to 30 cm and averaged SOM content was 1.19%, which ranged from 0.64 to 1.74% in Gansu province (Gansu soil census office, 1993). According to our research, averaged sierozem SOM content was 1.20% at 0 to 12 cm depth in Yili-River valley. So the sierozem SOM content in Humus layer in Yili-River valley was close to that in Gansu province, a little more than that in Ningxia hui autonomous region. But the thickness of sierozem humus layer was thinner in Yili-River valley than that in Gansu and Ningxia. The differences were related to the different climate, vegetation composition and growing season in three places. Compared with typical Sierozem soil profiles in Lanzhou, Gansu and Yanchi, Ningxia, the Sierozem SOM content decreased faster with soil depth in Yili-River valley (Figure 4). The situation was related to both arid summer and light-might loam in Yili-River valley, which led to weak infiltration of humus.

Above sierozem SOM characteristic showed that vegetation had a little contribution for soil SOM and the vegetation - soil system was not quite stable in Yili-River valley. The sierozem could only be moderately reclaimed, with the ecological protection in the area.

Comparison of sierozem pH value, TS and 8 ions in Yili-River valley and in other regions

In Gansu province, average soil pH value was 8.45 in the topsoil of sierozem (22 cm thickness), 8.5 in the middle of soil profiles (41.2 cm thickness), 8.61 at the bottom (50.1 cm thickness) (Gansu soil census office., 1993). Meanwhile, averaged sierozem pH value was 8.24 at 0 to 25 cm depth, while 8.40 at 50 to 75 cm depth, 8.34 at 100 to 125 cm depth in Yili-River valley. Obviously, sierozem alkaline was stronger in Gansu than that in Yili-River valley. Both pH value increased with soil depth and had a peak value in the deposition layer. Figure 5 showed that sierozem pH value also increased with soil depth and had a peak value in the deposition layer in Yanchi, Ningxia.

In Ningxia hui autonomous region, averaged sierozem TS was 0.04% in Humus layer, 0.13% in sabach, 0.07% in parent material horizon (Ningxia Institute of agriculture exploration and design, 1990). While averaged Sierozem TS was 0.19% at 0 to 25 cm depth, 0.59% at 50 to 75 cm depth, 0.81% at 100 to 125 cm depth in Yili-River valley. It was obvious that both sierozem TS contents increased with soil depth, but sierozem TS contents were many more in Yili-River valley than that in Ningxia. Figure 5 showed that sierozem TS content also increased with soil depth in Lanzhou, Gansu province. Vertical differentiation of sierozem TS content was related to local arid climate. Soluble salt could partly leach in soil profile with low rainfall. TS contents' characteristics showed that drainage system should be set up if the sierozem was reclaimed. Otherwise, second salinization of soil would easily appear.

In the central profile about 75 cm, which was located transition of deposition layer and parent rock horizon, sierozem TS contents had an obvious peak in Lanzhou and Yili-River valley. The reason remain to further

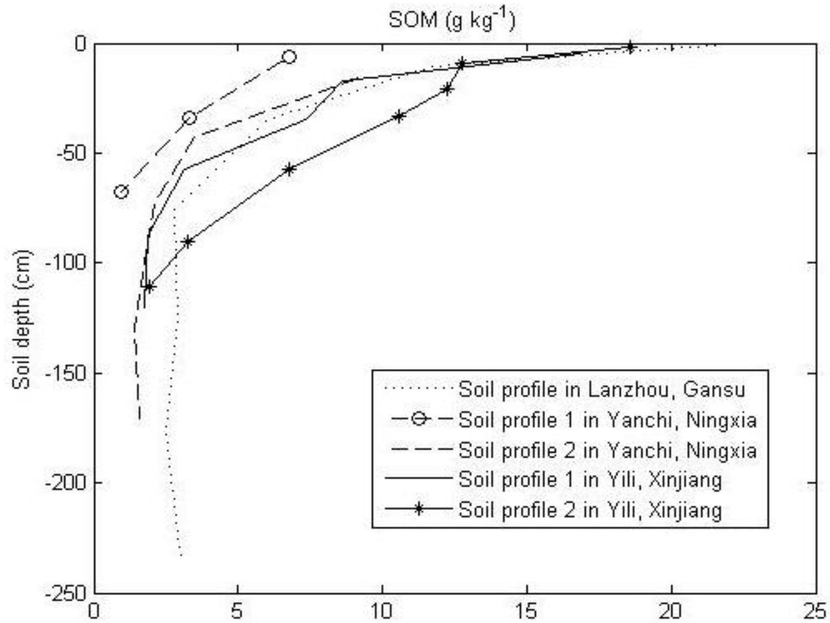

Figure 4. Comparison of SOM contents in typical Sierozem soil profiles (Data in Yili-River valley was from the field survey; Data in Yanchi, Ningxia was from reference (Hu et al., 1991); Data in Lanzhou, Gansu was from reference (Xiong and Li, 1987).

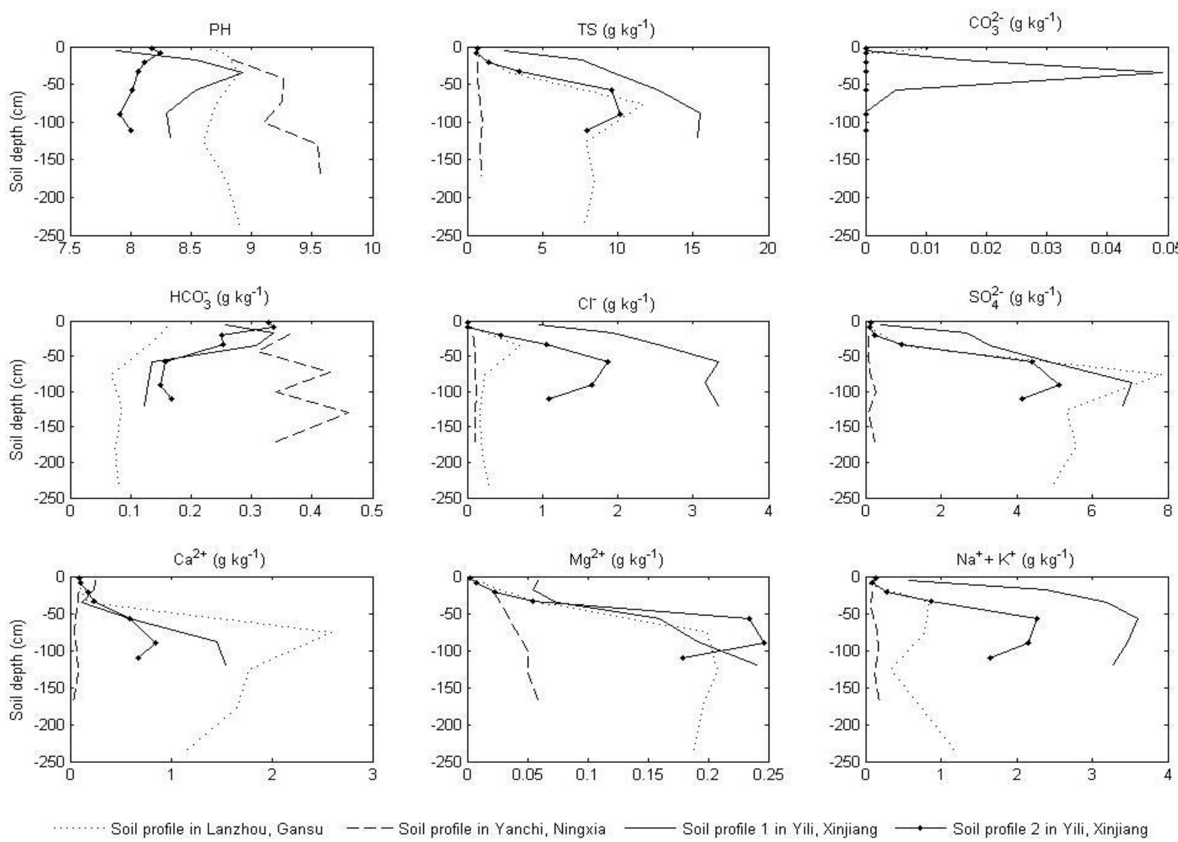

Figure 5. Comparison of Sierozem pH value, TS and 8 ions in Yili-River valley, Yanchi, Ningxia and Lanzhou, Gansu (Data in Yili-River valley was from the field survey; Data in Yanchi, Ningxia was from reference (Hu et al., 1991); Data in Lanzhou, Gansu was from reference (Xiong and Li, 1987).

research, which was perhaps related to the above $CaCO_3$ deposited (Ningxia Institute of agriculture exploration and design, 1990). Among the anions, sierozem CO_3^{2-} content was the least in the three regions. Sierozem SO_4^{2-} content was more in Yili-River valley and Lanzhou, Gansu. However, HCO_3^- content was more in Yanchi, Ningxia (Figure 5). Among the cations, sierozem Na^++K^+ and Mg^{2+} contents were many more in Yili-River valley. While Ca^{2+} and Mg^{2+} contents were many more in Lanzhou, Gansu. The composition of the soil salt was related to that of parent material and water table fluctuations (Agriculture Bureau in xinjiang uygur autonomous region, 1996; Riha et al., 1986; Johnston et al., 2001).

Figure 5 showed that sierozem HCO_3^- content decreased with soil depth in Yili-River valley and Lanzhou, Gansu. However, sierozem HCO_3^- content increased with soil depth in Yanchi, Ningxia. Sierozem SO_4^{2-} and Cl^- contents increased with soil depth in Yili-River valley, Yanchi and Lanzhou.

Sierozem Ca^{2+} content increased with soil depth in Yili-River valley and Lanzhou. However, sierozem Ca^{2+} content decreased with soil depth in Yanchi. Sierozem Mg^{2+}, Na^++K^+ contents increased with soil depth in Yili-River valley, Yanchi and Lanzhou.

Conclusions

Sierozem was a particular soil type which was formed between desert and grassland in arid region. Vertical difference of sierozem profile characteristics in China different regions had some common: SOM content decreased with soil depth, while pH value, EC, contents of TS and most ions increased with soil depth. But there was obvious regional difference in spatial variation and intensity of sierozem characteristics due to more arid climate in Yili-River valley. Above vertical change of sierozem properties could provide important theoretical basis for implementing regional ecological construction and sustainable development in Yili-River valley.

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