

Land Use Impacts on Soil Organic and Inorganic Carbon and Their Isotopes in the Yanqi Basin



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Abstract Assessments of both soil organic carbon (SOC) and inorganic carbon (SIC) under different land use types are lacking in arid regions. To advance the understanding of soil carbon dynamics and impacts of land use changes, a study was conducted in the central Xinjiang, the Yanqi Basin that had significant land use changes since the 1950s. Soil samples were collected at representative sites under various types of land use and vegetation, and SOC and SIC and their isotopes were measured over the 0–100 cm. This study revealed that both SOC and SIC stocks were the lowest in the desert land, but the highest in the agricultural land. Conversion of native land to cropland has caused a significant increase of SOC in the topsoil, and SIC in the subsoil. Total soil carbon stocks in the 0–100 cm are 11.6 ± 4.8 , 44.7 ± 10.4 , and 51.2 ± 5.6 kg C m⁻² in the desert land, shrub land, and agricultural land, respectively. On average, soil inorganic carbon counts more than 80% of the total carbon stock in the soil profiles. $\delta^{13}\text{C}$ of SOC shows no significant differences between land use types, but $\delta^{13}\text{C}$ of SIC is much different among land use types, following an order: desert land (-0.6‰) > shrub land (-2.2‰) > agricultural land (-3.4‰). Our finding of SIC increase with depletion of ^{13}C in the agricultural land indicates that there has been enhanced accumulation of pedogenic carbonate as a result of cropping.

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1 Introduction

There have been many studies on the terrestrial carbon cycle over the last century because of the great concern on the continuous increase of atmospheric carbon dioxide (CO₂), which may be the main reason for the global warming. Soil organic carbon (SOC), the largest carbon pool in the terrestrial ecosystem, has attracted great attention (Sanderman et al. 2008; Vargas et al. 2011). In contrast, soil inorganic carbon or carbonate (SIC), mainly found in the arid and semi-arid lands, may also play an important part in the global carbon cycle and climate change (Entry et al. 2004; Lal 2004; Schlesinger 1999). Apparently, studying the dynamics of both SOC and SIC is crucial to the understanding of the carbon cycle over the regional and global scales.

There have been significant land use changes (i.e., conversion of native lands to agricultural lands with fertilization and irrigation) in the arid and semi-arid regions of China over the past decades, which may have implications for the carbon cycling. A few studies have indicated that there is an increase in SIC in irrigated agricultural lands in arid regions, relative to non-irrigation lands (Wu et al. 2008, 2009; Zhang et al. 2010). While the topic of soil carbon storage has been a focus of the carbon cycle research (Gang et al. 2012; Su et al. 2010; Wu et al. 2008), there are limited studies of both SOC and SIC profiles (Wang et al. 2010; Yang et al. 2007), and little is done to assess impacts of land use change on soil carbon dynamics in northwest China.

Because of ¹³C discrimination during photosynthesis, different plant has its own isotopic signature. Thus, vegetation type can have influences not only on soil carbon stocks but also on their stable isotopic compositions. It is well documented that C3 and C4 plants have much different isotopic signatures, with a mean δ¹³C value of -27 and -12‰, respectively (Cerling 1984). Thus, δ¹³C in SOC gives us a way to trace vegetation change from C3 to C4, or vice versa (Boutton et al. 1998; Krull and Bray 2005). On the other hand, δ¹³C in SIC may be used to differentiate carbonate origination, i.e., lithogenic carbonate (LIC) and pedogenic carbonate (PIC) (Liu et al. 1996; Nordt et al. 1998).

There are a few methods for determining SOC and SIC. For example, dry combustion with automated analyzers and wet chemical oxidation are common methods for SOC measurements (Walkley and Black 1934). While the automated technique is quick and accurate, the cost is usually high. Commonly, SIC is often measured by determining the CO₂ production following the addition of HCl acid (Dreimanis 1962; Heiri et al. 2001; Presley 1975; Sherrod et al. 2002). Another simple and cheap method is the loss-on-ignition (LOI) that is to heat soils at high temperature to cause combustion of soil organic material (SOM) or carbonate and measure the weight losses (Wang et al. 1996, 2011b). Compared to the automated techniques and chemical methods, LOI techniques are less expensive and labor intensive (Wang et al. 2012).

The Yanqi Basin has had land use changes over the past decades. Majority of the shrub land in the Yanqi Basin was changed to agricultural land that has been used for farming. A set of studies were carried out to understand the impacts of land use

changes on the dynamics of soil carbon, which include the assessments of common methods for SOC and SIC measurements, and evaluations of the profile distributions of SOC and SIC and their isotopic compositions under various land uses.

2 Materials and Methods

2.1 Site Description and Soil Sampling

The Yanqi Basin is located in the northeast brim of the Taklamakan Desert, China. The main soil types are brown desert soil and gray-brown desert soil, which were developed from limestone parent material and classified as a Haplic Calcisol (FAO-UNESCO 1988). There are various land uses, with approximately 70% as agricultural land and ~30% as shrub land and desert. Due to the extremely low precipitation, agriculture land uses water from the Kaidu River; rainfall and underground waters are the water sources for the desert and shrub lands.

We randomly selected 21 sites in the Yanqi Basin during August and November, 2010: 3 sites from desert, 9 sites from shrub land, and 9 sites from agricultural land (Fig. 1). We collected soils over five layers at most profiles in the desert and shrub lands, and six layers in the agricultural land. Initially, soil was air-dried, well mixed, and then sieved to pass a 2-mm screen. Bulk density was determined for all sites and soil texture for representative sites. Soil texture was determined for surface soil samples (0–30 cm) using the Mastersizer 2000 particle size analyzers. Soil pH and electrical conductivity (EC) were determined using a soil:water (1:5) mixture. Representative sub-samples were ground to 0.25 mm for measuring SOC and SIC and their isotopes.

2.2 Basic Soil Properties

Table 1 shows the basic properties of the topsoil (0–30 cm). In general, clay content was low (3–8%) in all land uses, with the highest value in the agricultural soils. Sand content was significantly higher in the desert soils (68%) than in the shrub (25%) and agricultural lands (20%). Silt content was much lower in the desert soils (29%) than in the shrub and agricultural soils (69–72%). Bulk density was the highest in desert land (1.6 g cm^{-3}) and lowest in the agricultural land (1.3 g cm^{-3}). Soil pH was similar between the desert (8.3), shrub (8.4) and agricultural lands (8.2). However, EC was much higher in the shrub land (9.1 ms cm^{-1}) than in the desert and agricultural lands ($0.8\text{--}1.4 \text{ ms cm}^{-1}$).

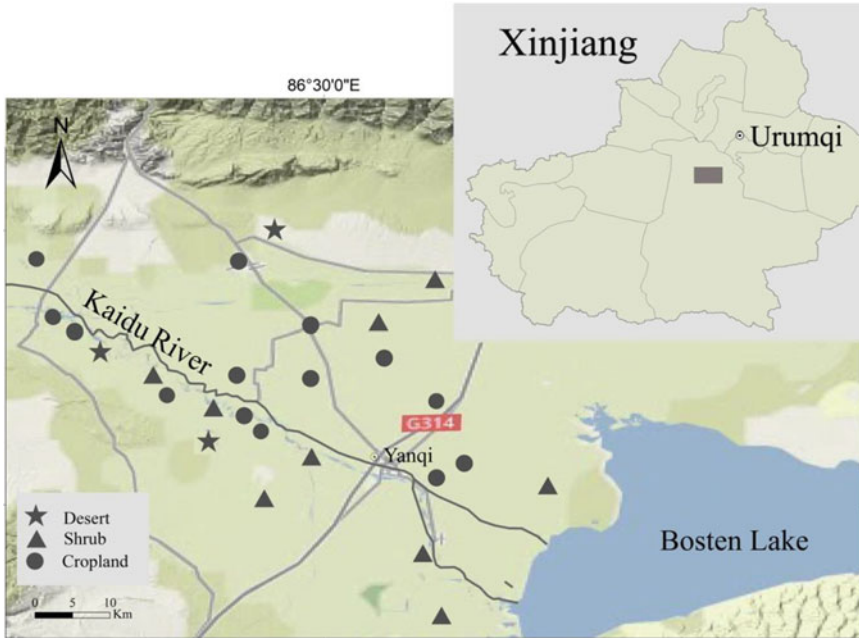


Fig. 1 Map of sampling layout in the Yanqi Basin [Desert land (stars), Shrub land (triangles), and Agricultural land (circles)] (redrawn from Wang et al. 2012)

Table 1 Means (standard deviations) of soil basic properties in desert land (DL), shrub land (SL), and agricultural land (AL) (redrawn from Wang et al. 2012)

	BD	pH	EC	Clay	Silt	Sand
	g cm ⁻³		ms cm ⁻¹	%		
DL	1.6 (0.2)	8.3 (0.2)	1.4 (2.0)	3.1 (0.5)	28.8 (12.1)	68.1 (12.2)
SL	1.4 (0.1)	8.4 (0.3)	9.1 (7.8)	5.5 (1.8)	69.4 (9.8)	25.1 (10.8)
AL	1.3 (0.1)	8.2 (0.2)	0.8 (0.6)	7.6 (1.6)	72.3 (4.4)	20.1 (5.8)

2.3 Soil Carbon Measurements

2.3.1 Traditional Methods

We used a modified Walkley–Black method to determine SOC, which was modified according to the traditional Walkley–Black method (i.e., Walkley and Black 1934). In brief, soil was treated with concentrated H₂SO₄ and 0.5 M K₂Cr₂O₇ at 150–160 °C, then followed by titrating with 0.25 M FeSO₄. The pressure calcimeter method was used for SIC measurement, which was similar to that of Sherrod et al. (2002).

2.3.2 LOI Methods

Based on the methods by Wang et al. (1996) and Wang et al. (2011b), we first heated soil at 105 °C for 24 h to remove soil moisture. We then follow a two-step procedure for both SOC and SIC estimates by combusting soil in a muffle furnace (S1849, KOYO LINDBEERE LTD): At 375 °C for 17 h, then at 800 °C for 12 h. Soil organic matter is calculated as the weight difference between 105 and 375 °C, and SIC as the weight loss during the combustion under 800 °C.

2.3.3 Elemental Analyzer

We also used a CNHS-O analyzer (EuroEA3000) to determine SOC and SIC contents. For SOC estimate, soil is pretreated with 10 drips of H₃PO₄ for 12 h to remove carbonate. Then the sample is combusted and CO₂ production is determined by a thermal conductivity detector. Total soil carbon is measured, using the same procedure without pretreatment with H₃PO₄. We calculated the difference between total soil carbon and SOC as SIC content.

2.3.4 Carbon Isotope Measurement

Stable isotope, $\delta^{13}\text{C}$, in SOC was measured using a Finigan MAT Delta Plus XP at the State Key Laboratory of Lake Science and Environment (SKLLSE), Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (CAS), and $\delta^{13}\text{C}$ in SIC at the Nanjing Institute of Geology and Paleontology, CAS. For $\delta^{13}\text{C}$ in SOC, soil was pretreated with H₃PO₄ to remove carbonate. The pretreated soil was combusted at 1020 °C with constant helium flow carrying pure oxygen to ensure complete oxidation of organic materials. For $\delta^{13}\text{C}$ in SIC, CO₂ was collected during the reaction of soil with 100% H₃PO₄ and transported in a helium stream to the mass spectrometer. Isotopic data were reported in delta notation relative to the Vienna Pee Dee Belemnite (VPDB).

2.4 Evaluations of Soil Carbon Methods

2.4.1 Comparisons of SOC Methods

Figure 2 shows the comparison in SOC measurement between the modified Walkley–Black method and the automated CNS analysis. Clearly, there is a strong linear relationship between the two methods. The regression line is forced through zero since the intercept is not significantly different from zero. The slope value of 1.023 is significantly different from 1. When SOC content is too low (less the 5 g kg⁻¹), the modified Walkley–Black method can cause over-estimate for SOC. If the low-SOC

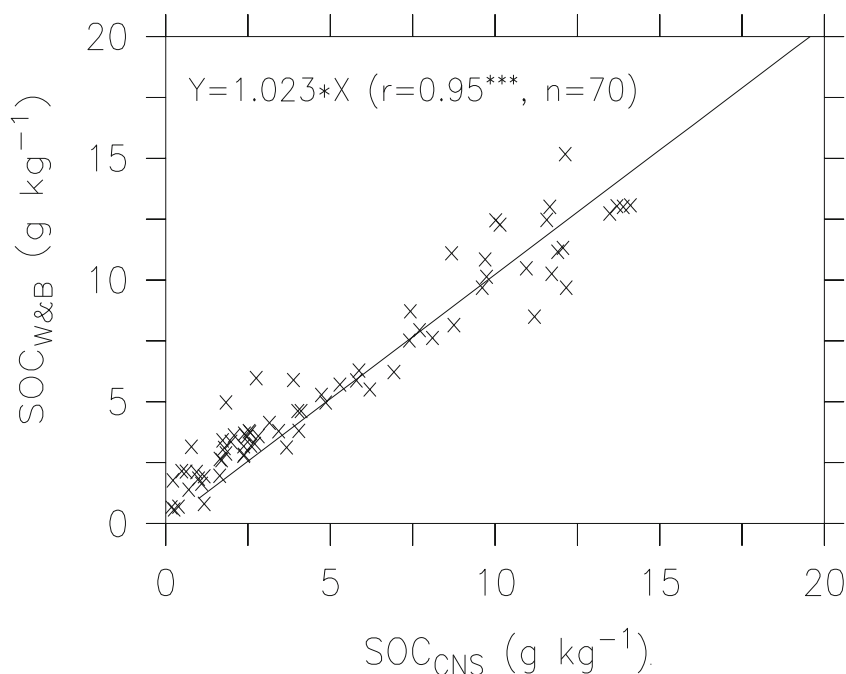


Fig. 2 Linear regression in measured SOC between the automated analysis and the Walkley–Black method (redrawn from Wang et al. 2012)

data are excluded, a new regression line gives a slope value of 0.997. These comparisons demonstrate that near 100% SOC can be oxidized in the soils in this region, which is much higher than previous published values for forest soils in Flanders (De Vos et al. 2007), but in line with those (~100%) in the Tasmanian soils (Wang et al. 1996). The high SOC recovery and large correlation coefficient (0.95) in this study indicate that the modified Walkley–Black method can provide good estimates of SOC, except for soils with very low levels of SOC.

Figure 3 shows the relationship between LOI-derived SOM and automated SOC by the CNS analyzer. There is a large intercept (4.189) for the regression line, suggesting some weight losses of non-SOM materials (e.g., structural water and carbonate) during ignition. The conversion factor (1.792) is little larger than the traditional value (1.724). Accordingly, SOC can be estimated by LOI at 375 °C for 17 h as follows:

$$\text{SOC}_{\text{LOI}} = (\text{SOM}_{\text{LOI}} - 4.189) / 1.792 \quad (1)$$

As demonstrated in Table 2, the calculated SOC using the LOI method (i.e., above equation) has a range of 0.1–13.3 g kg⁻¹, mean value of 6.2 g kg⁻¹, and standard

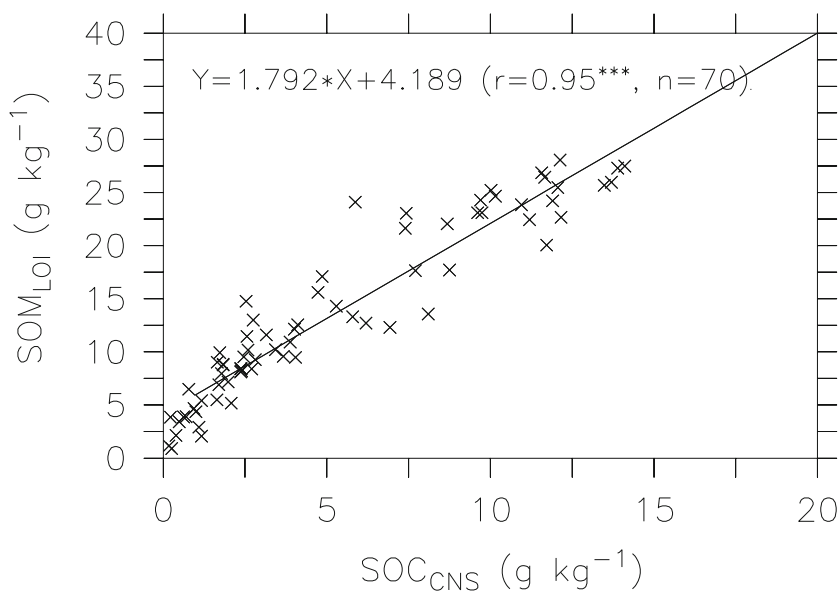


Fig. 3 Linear regression between measured SOC by the CNS Analyzer and LOI-derived SOM (redrawn from Wang et al. 2012)

Table 2 Analyses of soil organic carbon (SOC) (g kg^{-1}) and inorganic carbon (SIC) (g kg^{-1}) determined by three different methods (redrawn from Wang et al. 2012)

	SOC _{CNS}	SOC _{W&B}	SOC _{LOI}	SIC _{CNS}	SIC _{PC}	SIC _{LOI}
Maximum	14.11	15.17	13.32	52.97	51.47	54.93
Minimum	0.78	1.84	0.10	8.53	6.34	9.26
Mean	6.00	6.57	6.20	24.65	23.55	28.28
Standard deviation	4.19	3.79	4.18	10.39	10.73	11.07

deviation of 4.2 g kg^{-1} for the soils tested, which are similar to those ($0.8\text{--}14.1$, 6.0 , and 4.2 g kg^{-1} , respectively) determined by the elemental CNS analyzer.

2.4.2 Comparisons of SIC Methods

SIC determined by the pressure calcimeter method shows significantly linear relationship ($r = 0.99$, $p < 0.001$) with the automated CNS analysis (Fig. 4) although the former yields slightly lower values than the latter (Table 2). Since the intercept is not significantly different from zero, the regression line is forced through the origin. The close-to-1 slope value and large correlation coefficient give us confidence that the pressure calcimeter method is comparable with the automated CNS technique for the tested calcareous soils.

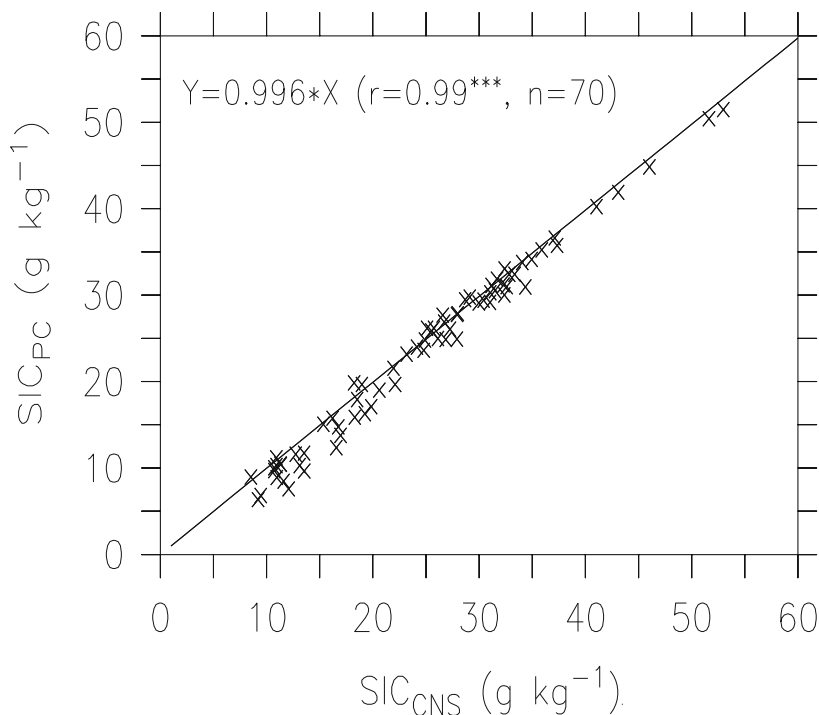


Fig. 4 Linear relationship for SIC between the automated analysis and the pressure calcimeter method (redrawn from Wang et al. 2012)

As shown by Fig. 5, the LOI method produces a very similar range of SIC to the automated CNS analysis, and there is a significant linear relationship between the two methods:

$$\text{SIC}_{\text{LOI}} = 1.043 \text{ SIC}_{\text{CNS}} + 2.582 \quad (2)$$

The intercept value of 2.582 is significantly bigger than 0, indicating that there may be weight losses of non-SIC materials (e.g., dehydration from other compounds) during ignition (Santisteban et al. 2004). However, the slope value is close to 1 and correlation is significant ($r = 0.98$, $P < 0.001$), which suggest that SIC content can be accurately measured by the LOI technique.

Figure 6 shows that there is also a strong linear relationship between the pressure calcimeter method and the LOI technique for SIC:

$$\text{SIC}_{\text{LOI}} = 1.021 \text{ SIC}_{\text{PC}} + 4.241, \quad (3)$$

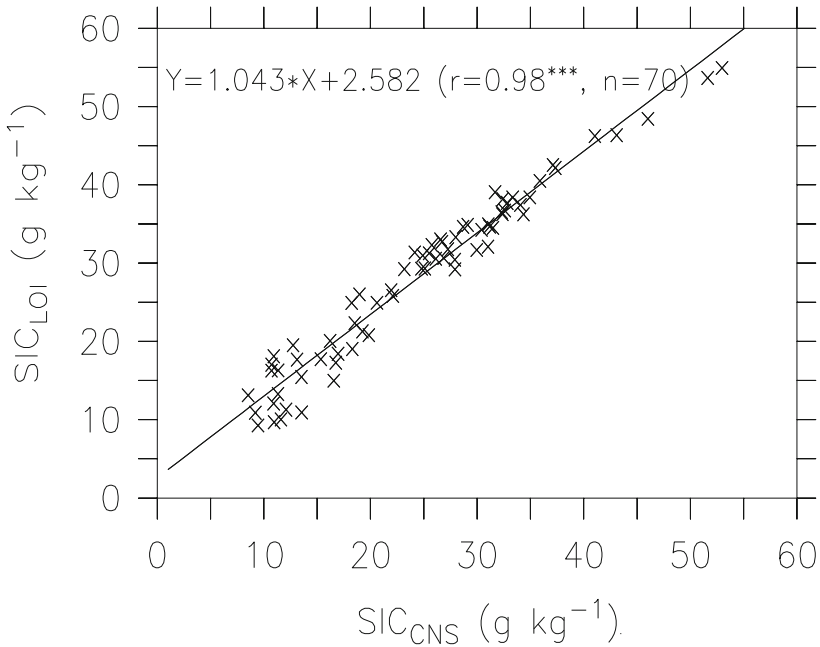


Fig. 5 Linear relationship between the automated analysis and the LOI method for SIC (redrawn from Wang et al. 2012)

which is similar to the regression between the LOI-SIC and the CNS-SIC (see Eq. 2). The much higher intercept (4.241) in Eq. (3) causes higher estimates for SIC by the LOI method, compared to those by the CNS technique (Table 1).

3 Results and Discussion

3.1 Soil Carbon and $\delta^{13}C$ Under Various Land Uses

3.1.1 Vertical Distributions of SOC and Its $\delta^{13}C$

We first assessed the vertical distributions of SOC and its $\delta^{13}C$ value at the desert sites (Fig. 7). As was expected, all the soil profiles show low-SOC content, i.e., less than $4\ g\ kg^{-1}$ except at site D2(0–5 cm) that reveals a rapid decrease of SOC from $\sim 6\ g\ kg^{-1}$ in the topsoil to almost zero in the subsoil. Overall, $\delta^{13}C$ in SOC is more negative in the topsoil (close to -22‰) than in the subsoils (close to -19‰).

Soil organic carbon varies widely in the shrub land in terms of magnitude and vertical distribution (Fig. 8). While more than 50% of the sites show small vertical variations of SOC, there is an obvious decrease (from $\sim 20\ g\ kg^{-1}$ in the topsoil to

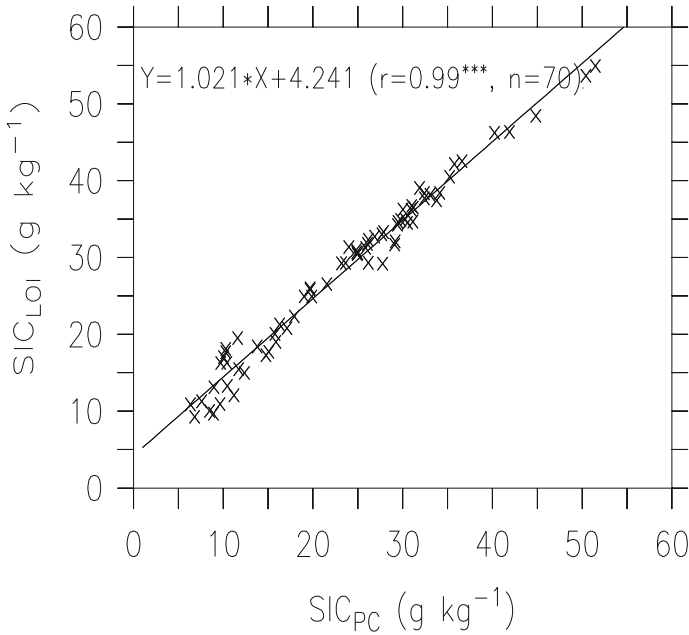


Fig. 6 Linear relationship between the pressure calcimeter and LOI methods for SIC (redrawn from Wang et al. 2012)

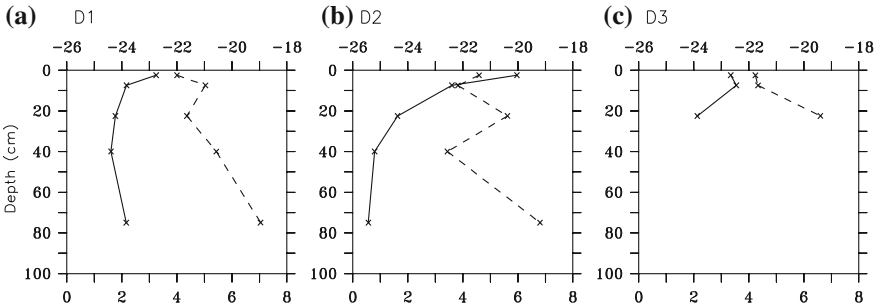


Fig. 7 Vertical distributions of SOC (solid line) and $\delta^{13}\text{C}$ (dashed line) on the desert land

<7 g kg⁻¹ in the subsoil) in SOC in one-third of the profiles. It appeared that $\delta^{13}\text{C}$ in SOC is less negative in the subsoil at most sites, and there is an overall negative correlation between $\delta^{13}\text{C}$ and SOC content. For example, the vertical distribution of $\delta^{13}\text{C}$ is opposite to that of SOC at the sites S3, S4, and S5.

Figure 9 presents vertical profiles of SOC and $\delta^{13}\text{C}$ in the agricultural land. In general, SOC content in the topsoil is greater than 10 g kg⁻¹ in the agricultural land, which is much larger than those in the desert and shrub lands. Generally, SOC vertical distribution on the agricultural land shows a sharp decline from 10 to 15 g kg⁻¹ (above

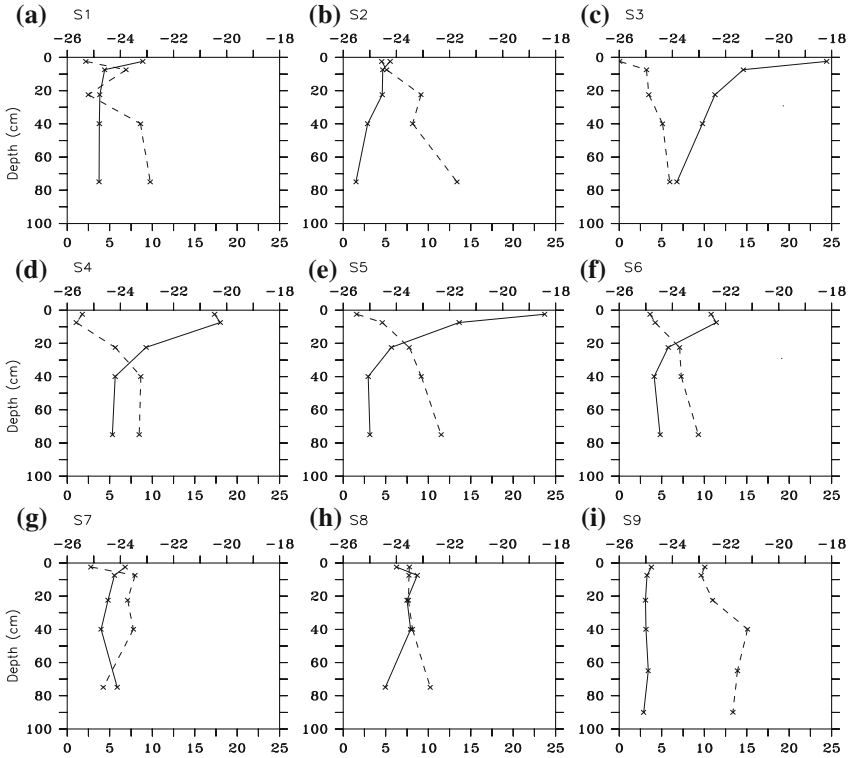


Fig. 8 Vertical distributions of SOC (solid line) and $\delta^{13}\text{C}$ (dashed line) on the shrub land

20 cm) to $<4 \text{ g kg}^{-1}$ (below 70 cm). The $\delta^{13}\text{C}$ value varies narrowly in the topsoil, from -25 to -23‰ , but widely in the subsoil (from -24 to -20‰) in the agricultural land. Similar to the shrub land, there is enriched ^{13}C in the subsoil and a negative correlation between $\delta^{13}\text{C}$ and SOC at almost agricultural sites.

It is well known that C3 and C4 plants have much different isotopic values, with a mean $\delta^{13}\text{C}$ value of -27 and -12‰ , respectively (Cerling 1984). Therefore, $\delta^{13}\text{C}$ in SOC provides us a way to trace land use history such as vegetation change between C3 and C4 plants (Boutton et al. 1998; McPherson et al. 1993). The value of $\delta^{13}\text{C}$ in SOC ranges from -20 to -27.5‰ in the Yanqi Basin, indicating that the dominant vegetation has been C3 type of plants. The $\delta^{13}\text{C}$ value becomes less negative with depth, implying two kinds of possible mechanisms. Firstly, the depletion of ^{13}C in the surface soil that contains newer SOM indicates an expansion of C3 vegetation in the recent years. Secondly, the enrichment of ^{13}C in the deep soil that has relatively older SOM may be caused by isotopic discrimination with SOC decomposition (Fernandez and Cadisch 2003; McPherson et al. 1993).

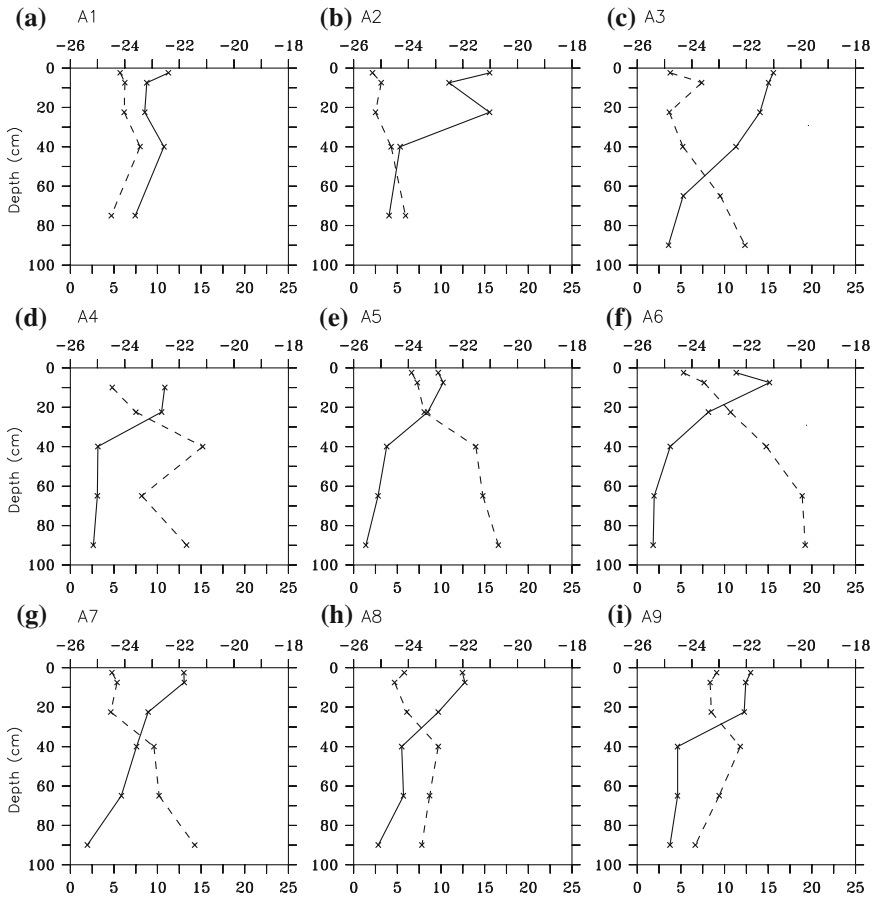


Fig. 9 Vertical distributions of SOC (solid line) and $\delta^{13}\text{C}$ (dashed line) on the agricultural land

3.1.2 Soil Inorganic Carbon and Its $\delta^{13}\text{C}$

Soil inorganic carbon and its $\delta^{13}\text{C}$ value show almost uniform distribution in soil profiles in the desert land (Fig. 10), which ranges from 8 to 14 g C kg^{-1} and -2 to 0‰ , respectively. While SIC shows similar values ($\sim 10 \text{ g C kg}^{-1}$) in both D1 and D2 sites, $\delta^{13}\text{C}$ value in SIC is more negative at the site D1 (close to -2‰) than at D2 (close to 0).

As shown in Fig. 11, SIC content is generally higher in the shrub land ($>15 \text{ g C kg}^{-1}$), except at S9 that reveals the lowest values for both SOC ($<4 \text{ g C kg}^{-1}$) and SIC ($\sim 10 \text{ g C kg}^{-1}$). There is an increasing trend in SIC content with depth in more than half of the profiles, especially at the sites S3, S4, and S5, which have relatively higher SOC ($>19 \text{ g C kg}^{-1}$) in the surface soil (see Fig. 8). The $\delta^{13}\text{C}$ value in SIC varies between -1 and -5‰ in the shrub land, with weak vertical variation in most

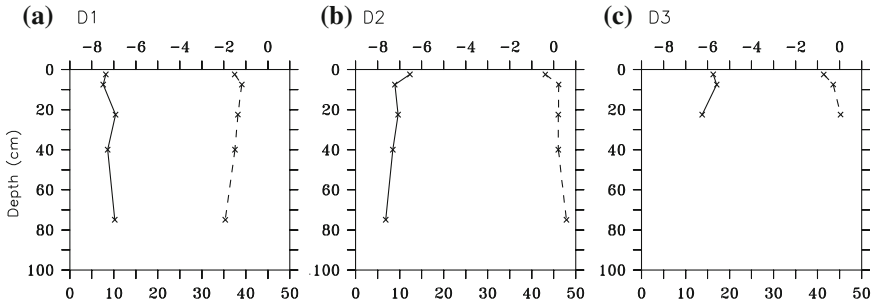


Fig. 10 Vertical distributions of SIC (solid line) and $\delta^{13}\text{C}$ (dashed line) on the desert land

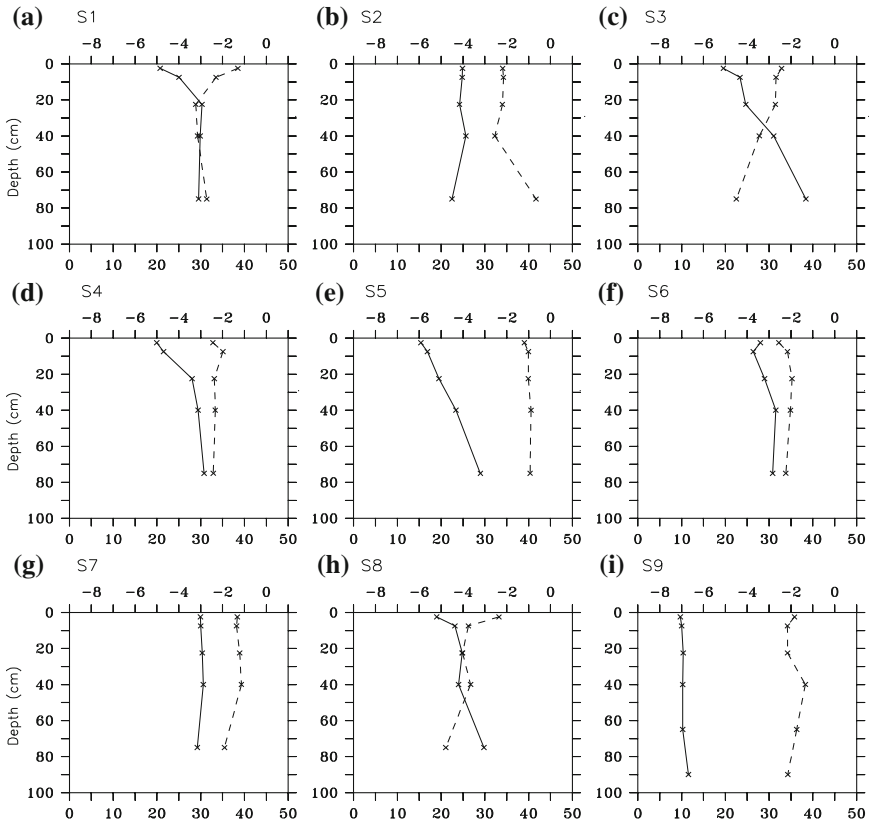


Fig. 11 Vertical distributions of SIC (solid line) and $\delta^{13}\text{C}$ (dashed line) on the shrub land

profiles. But there is a decline in $\delta^{13}\text{C}$ value of SIC with depth at the S1 and S3 where SIC shows an increasing trend with depth.

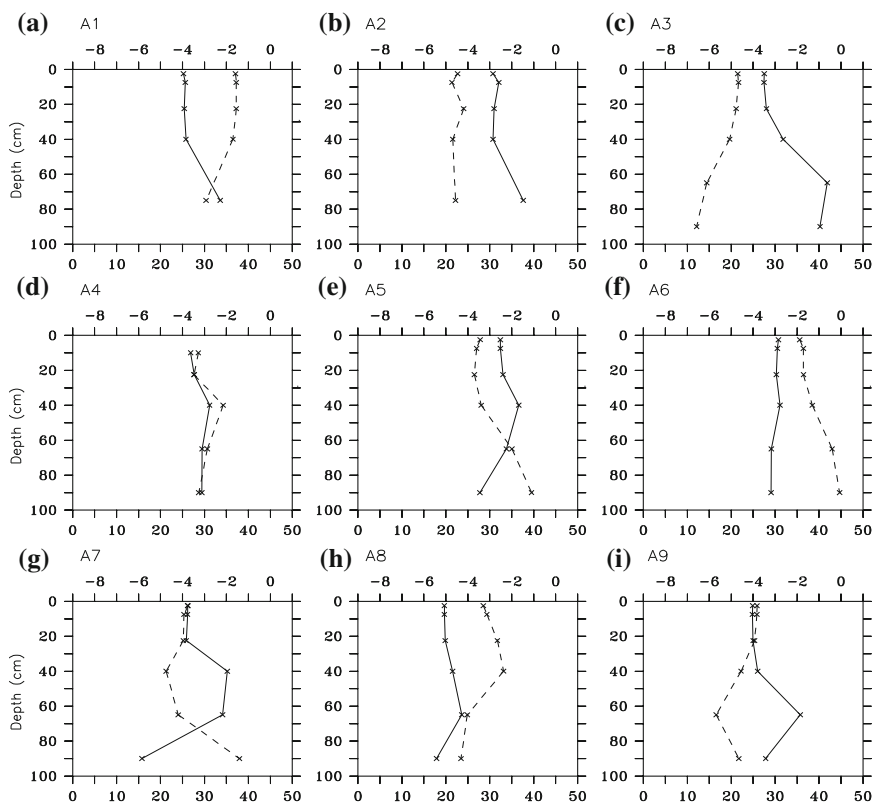


Fig. 12 Vertical distributions of SIC (solid line) and $\delta^{13}\text{C}$ (dashed line) in the agricultural land

Figure 12 presents SIC content and its $\delta^{13}\text{C}$ value in the agricultural land. Relative to the desert and shrub lands, SIC content is much higher, showing $>25 \text{ g kg}^{-1}$ in most profiles. Generally, SIC is uniformly distributed over the 0–30 cm layer. There are high SIC values ($\geq 35 \text{ g kg}^{-1}$) in the subsurface at some sites, i.e., sites A2, A3, A5, and A7. Similar to SIC content, the $\delta^{13}\text{C}$ value in SIC shows little vertical variation above 30 cm. There is a big range in the $\delta^{13}\text{C}$ value, from -5 to -1.5‰ over the 0–30 cm, and -6.5‰ to ~ 0 in the lower soil. Overall, there is a negative correlation between $\delta^{13}\text{C}$ and SIC in the agricultural land, i.e., the higher SIC content, the lower $\delta^{13}\text{C}$ value is.

3.1.3 Comparisons of Soil Carbon and the Isotopes Between Land Uses

Table 3 shows the SOC, SIC, and their stable isotopes for all individual layers. Statistical analyses demonstrate that both SOC and SIC are significantly higher in the shrub land and agricultural land than in the desert land. In spite of the lacking of

Table 3 Average (standard variations) of soil carbon (g C kg^{-1}) and stable isotopes (‰) for the desert land (DL), shrub land (SL), and agricultural land (AL)

Depth (cm)	Land use	SOC	SIC	$\delta^{13}\text{C}_{\text{SOC}}$	$\delta^{13}\text{C}_{\text{SIC}}$
0–5	DL	4.2 (1.5) a	12.3 (4.0) a	−21.72 (0.3) a	−0.87 (0.58) a
	SL	11.9 (7.9) b	20.8 (6.2) b	−24.78 (1.0) b	−1.95 (0.6) a
	AL	12.8 (2.0) b	27.2 (4.1) c	−24.27 (0.7) b	−3.36 (1.1) b
5–15	DL	3.1 (0.8) a	11.2 (5.1) a	−21.60 (0.6) a	−0.41 (0.7) a
	SL	9.4 (5.2) b	22.4 (5.8) b	−24.20 (0.9) b	−2.17 (0.8) b
	AL	12.1 (2.1) b	27.3 (3.9) b	−24.04 (0.5) b	−3.38 (1.1) c
15–30	DL	1.8 (0.2) a	11.3 (2.2) a	−20.47 (1.1) a	−0.37 (0.8) a
	SL	6.2 (2.6) b	24.6 (6.3) b	−23.82 (0.8) b	−2.32 (0.9) b
	AL	10.7 (2.6) c	27.4 (3.9) b	−23.94 (1.5) b	−3.32 (1.1) c
30–50	DL	1.2 (0.5) a	8.5 (0.1) a	−21.56 (1.4) a	−0.64 (1.2) a
	SL	4.9 (2.4) ab	26.2 (6.7) b	−23.22 (0.9) a	−2.27 (1.0) ab
	AL	6.2 (3.0) b	30.0 (4.7) b	−22.70 (1.3) a	−3.33 (1.5) b
50–100	DL	1.4 (1.1) a	8.5 (2.4) a	−19.07 (0.2) a	−0.67 (1.8) a
	SL	4.2 (1.5) b	26.2 (8.9) b	−22.92 (1.0) b	−2.45 (1.4) a
	AL	3.7 (1.7) ab	30.4 (7.2) b	−22.59 (1.5) b	−2.93 (1.5) a

Values followed by the same letter in each column (for the same layer) are not significantly different, based on the LSD tests ($P < 0.05$)

significant differences, SOC content is larger (smaller) in the agricultural land than in the shrub land above (below) 50 cm. In particular, SOC content is significantly different over the 15–30 cm layer between the shrub land and agricultural land.

For all the depth, SIC content has the following order: desert land < shrub land < agricultural land. While statistical analyses only show a significant difference for the 0–5 cm, SIC content is generally higher (>10%) in the agricultural land relative to the shrub land. In addition, the variation in SIC (i.e., standard deviation) is also smaller in the agricultural land than in the shrub land, implying that the uncertainty (in terms of high SIC content) is small in the agricultural soils. The value of $\delta^{13}\text{C}$ in SOC is significantly higher in the desert land than in the shrub and agricultural lands; similarly, $\delta^{13}\text{C}$ in SIC follows an order: desert land > shrub land > agricultural land. Statistical analyses show that $\delta^{13}\text{C}$ in SIC is significantly different in the 5–30 cm between land uses.

Generally, the $\delta^{13}\text{C}$ value in LIC is close to 0, but more negative in PIC (Krull and Bray 2005; Liu et al. 1996). On average, the $\delta^{13}\text{C}$ in SIC of Yanqi Basin is −0.6, −2.2, and −3.4‰ for the desert land, shrub land, and agricultural land, respectively. The relatively depleted ^{13}C in SIC in the agricultural land indicates that there has been more PIC formed related to cropping.

It is well known that SOC is generally low in arid and semi-arid lands. The data collected in the Yanqi Basin show extremely low SOC density in the desert land ($1.9 \pm 1.4 \text{ kg C m}^{-2}$ over the top 1 m) (Table 4). An earlier study by Feng et al.

(2002) showed close values, i.e., 2.3–2.4 kg C m⁻² for the Tarim and Junggar Basins. SOC stocks (7.9–9.2 kg C m⁻²) in the shrub and agricultural lands of Yanqi Basin are slightly lower than those reported by Wang et al. (2003), i.e., 10.9–12.1 kg C m⁻² for shrub and agricultural lands in northwest China. But, the mean SOC stock of 8.6 kg C m⁻² in the Yanqi Basin's shrub and agricultural lands is ~60% higher than the mean value (5.4 kg C m⁻²) for the Xinjiang province reported by Li et al. (2007), but close to the national mean value for SOC (8.0 kg C m⁻²) that was estimated using the China's second soil surveys data (Wu et al. 2003).

The SIC stock (9.7 ± 3.4 kg C m⁻² over the 0–100 cm) in the desert land of the Yanqi Basin is slightly less than that in the Tarim Basin (10.8 kg C m⁻²), but significantly higher than that in the Junggar Basin (3.2 kg C m⁻²) (Feng et al. 2002). On the other hand, SIC stock is much higher (37–52 kg C m⁻² over 0–100 cm) in Yanqi Basin's shrub and agricultural lands (Table 4), comparing with the average SIC density (12.6 kg C m⁻²) for Xinjiang province reported by Li et al. (2007).

More than 80% of the total carbon stock is as the form of SIC in all the land use types of the Yanqi basin (Table 4), which implies the importance of SIC in the carbon storage in arid lands (Entry et al. 2004; Lal 2002; Wu et al. 2009). There is a greater amount of SIC accumulated in the subsoil of shrub and agricultural lands in the Yanqi basin, indicating the importance of deep soils for carbon storages in the arid and semi-arid lands (Wang et al. 2010).

3.1.4 Impacts of Land Use Changes on Soil Carbon Dynamics

It was well known that water limitation due to lower precipitation is a main factor limiting plant growth in arid and semi-arid lands, which is responsible for the low-SOC content in native lands. Earlier studies by Li et al. (2006) and Wang et al. (2011a) revealed an increase of SOC following the conversion of desert land to agricultural land in northwest China. Apparently, agricultural development with irrigation and fertilization can promote plant growth, which subsequently leads to an increase in root biomass and plant residue returned to the topsoil (Khan et al. 2009; Turner et al. 2011).

Land use change can have effects not only on SOC stock, but also on SIC stock in arid and semi-arid regions (Mikhailova and Post 2006; Wu et al. 2009; Zhang et al. 2010). Land use change (from shrub land to agricultural land) results in a large increase in SOC stock (43%) in the topsoil (0–30 cm), but SIC stock (56%) in the subsoil (30–100 cm) in the Yanqi Basin (Table 4). Similarly, Wu et al. (2009) reported an increase of SIC on irrigated croplands in northwest China. The study of Mikhailova and Post (2006) also showed that SIC stock (over the top 2 m) was significantly higher under continuous cultivation (242 Mg C ha⁻¹) than in native grassland (107 Mg C ha⁻¹). However, Wu et al. (2008)'s study reported that land use changes have different impacts on SIC at two sites in California, USA: Increased in the soil of Imperial Valley but decreased in the soil of San Joaquin, which might be caused by the differences in the irrigation waters (e.g., pH and salts contents and compositions).

Table 4 Means and percentages of both SOC and SIC stocks over 0–30 cm and 30–100 cm in the desert land (DL), shrub land (SL), and agricultural land (AL)

	0–30 cm			30–100 cm		
	SOC	SIC	SOC	SIC	SOC	SIC
	kg m ⁻²	kg m ⁻²	%	%	kg m ⁻²	kg m ⁻²
DL	0.86 ± 0.13	4.62 ± 1.30	7.49	40.24	0.94 ± 1.08	5.06 ± 2.67
SL	3.24 ± 1.29	9.79 ± 2.83	7.24	21.91	4.64 ± 2.65	27.01 ± 8.69
AL	4.61 ± 0.56	11.03 ± 1.51	9.01	21.55	4.62 ± 1.82	41.96 ± 5.23
					%	%
					8.19	44.08
					10.38	64.46
					9.02	60.41

4 Conclusions

- (1) Vertical distribution is largely different between soil organic carbon and inorganic carbon, i.e., sharp decrease over depth in the former but various degrees of increasing trend in the latter.
- (2) There are significant differences in soil organic and inorganic carbon contents between land use types in the Yanqi Basin. Both organic and inorganic carbon stocks are lowest in the desert land and highest in the agricultural land. The increase of organic carbon is found in the topsoil, but the increase of inorganic carbon is in the subsoils.
- (3) On average, soil inorganic carbon stock in the Yanqi Basin counts more than 80% of the total soil stocks. The agricultural soils show significant depletion of ^{13}C in soil inorganic carbon, indicating a significant amount of secondary carbonate formed in association with cropping.

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