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CHANGES IN SOIL ORGANIC CARBON AND ITS DENSITY FRACTIONS AFTER SHRUB–PLANTING FOR DESERTIFICATION CONTROL

ABSTRACT: Planting shrubs on sand land and degraded pasture are two main measures for desertification control particularly in northwest China. However, their effects on soil organic carbon (SOC) and its fractions remain uncertain. We assessed the changes in stocks of SOC, light fraction of SOC (LF–SOC) and heavy fraction of SOC (HF–SOC) after planting *Artemisia ordosica* (AO, 17 years), *Astragalus mongolicum* (AM, 5 years) and *Salix psammophila* (SP, 16 years) in sand land and planting *Caragana microphylla* (CM, 24 years) on degraded pasture. Results show that: 1) after planting AO, AM and SP on sand land, SOC stocks increased by 162.5%, 45.2% and 70.8%, respectively, and LF–SOC accounted for a large proportion in the increased SOC. Dry weights of LF–SOC, rather than carbon concentrations, were higher in shrublands than that in sand land; 2) after planting CM on degraded pasture, SOC stock decreased by 9.3% and all the loss was HF–SOC in 60–100 cm soil layer where both herbaceous fine root biomass (HFRB) and soil water content (SWC) also decreased. The results indicate that planting shrubs can result in an increase of SOC in sand land, whereas that can lead to a decrease of SOC in degraded pasture. The increase of SOC in sand land mainly bases on the accumulation of dry weight of LF–SOC. The loss of SOC in degraded pasture is caused by the decrease of carbon concentrations of HF–SOC, which can be related to the reduction of HFRB and SWC in deep soil layer. Therefore, shrub-planting for desertification control not always improve the quantity and stability of SOC in northwest China.

KEY WORDS: shrub-planting, soil organic carbon, density fraction, desertification control

1. INTRODUCTION

Desertification is land degradation in arid, semi-arid and dry sub-humid areas (UNEP 1990), which can raise the atmospheric CO_2 concentration and alter the global climate (Lal 2001, Jabro *et al.* 2008). Land desertification has led to the enrichment of atmospheric CO_2. Lal (2001) estimated that the total loss of carbon because of the desertification is reaching 18–28 Pg. On the contrary, many studies considered that some desertification control practices such as planting shrubs may increase the stock of carbon in soil (Nosetto *et al.* 2006, Yüksek and Yüksek 2011). However, decreases in soil organic carbon resulted from desertification control were also reported (Jiao *et al.* 2009, Wei *et al.* 2009).

Although previous land use, plant species, and soil sample depth have been recognized as factors responsible for above controversy (Wang *et al.* 2011, Yüksek and Yüksek 2011, Zucca *et al.* 2011, Cunningham

et al. 2012), the complexity of soil carbon pool may be an additional crucial factor. Soil organic carbon (SOC) pool is composed of sub-pools with different turnover rates, and the sensitivity of their reaction to the land-use change is quite different (Christensen 1992, 2001). So accurate estimating the SOC changes during land use change needs to separate soil organic matter into different fractions. Except some studies have determined the SOC in soil particle-size fractions (Su *et al.* 2010, Chen *et al.* 2010), changes in density fraction of SOC following desertification control in arid and semiarid area has been rarely reported. The light fraction of soil organic carbon (LF–SOC) consists of plant residues, roots, and fungal hypha that are at different decomposition stages (Janzen *et al.* 1992, Six *et al.* 2002, Wang *et al.* 2009), and has a lower density than soil minerals generally (Christensen 1992). Compared to the LF–SOC, the heavy fraction of soil organic carbon (HF–SOC) is an organo-mineral fraction with lower carbon concentrations, more stable and higher density than soil minerals (Golchin *et al.* 1995a, b, Liu *et al.* 2010). Both LF–SOC and HF–SOC contain almost all the organic carbon in the mineral soil (Boone 1994, Bu *et al.* 2012).

In northwest China, shifting sand land and degraded pasture are two kinds of widespread desertified landscape. Planting shrubs on shifting sand land and degraded pasture are two important measures for desertification control. Many studies have realized the importance of the desertification control contribution to soil carbon (He *et al.* 2009, Su *et al.* 2010, Wang *et al.* 2011), few study have focused on soil organic carbon in density fractions as related to the desertification control. However, it is critical to explore the mechanism of changes in soil carbon pool after vegetation rehabilitation. Therefore, we assessed the stocks of SOC, LF–SOC and HF–SOC after planting shrubs on sand land and degraded pasture, the objectives in this study were to: 1) identify the changes in SOC following shrub-planting for desertification control and; 2) investigate the contribution of each fraction in SOC to the above changes.

Table 1. Characteristics of the sample plots and soil properties.

Study sites	Site A				Site B	
Location	N37°48′, E107°22′				N37°54′, E107°24′	
The characteristics of sample plots						
Sample plot	*Artemisia ordosica*	*Astragalus mongolicum*	*Salix psammophila*	Shifting sand land	*Caragana microphylla*	Degraded pasture
Sample plot area (ha)	4	1.5	5	10	25	25
Canopy coverage (%)	85.3	55.2	48.6	0	45.2	54.3
Planting density (stem ha^{-1})	2680	3540	942		435	
Stand age (yr)	17	5	16	–	24	–
Planting method	Seeding	Seeding	Stock planting	–	Stock planting	–
Soil properties in sample plots						
Soil type	Aripsamment	Aripsamment	Aripsamment	Aripsamment	Calciorthids	Calciorthids
Bulk density (g cm^{-3}) from 0–20cm to 80–100 cm layer	1.48–1.57	1.49–1.58	1.47–1.58	1.52–1.59	1.45–1.55	1.47–1.55
<0.05 mm particle content (%)	8.7	5.5	7.6	4.3	19.6	18.7
PH	8.6	8.4	8.5	8.3	7.7	7.8
Eletrical conductivity (Ms cm^{-1})	9.8	9.6	9.7	9.4	8.4	8.6
CO_3^{2-} (cmol Kg^{-1})	0.06	0.04	0.06	0.04	0.03	0.03
HCO_3^{-1} (cmol Kg^{-1})	0.69	0.57	0.61	0.55	0.44	0.48

2. MATERIALS AND METHODS

2.1. Site description

The study site, covering central and northern Yanchi County in the middle of Ningxia Province, is located between 107°22′–107°24′E and 37°48′–37°54′N at the southwestern edge of the Mu Us Desert (Fig. 1). The site is situated at a transition zone from arid to semi-arid climate and agricultural areas and pastoral areas. The region has a typical temperate continental monsoon climate. The mean annual precipitation is 287 mm, mainly in summer and autumn. The mean annual air temperature is 7°C, and an accumulated temperature ≥ 10°C is 2,944.9°C. The average relative humidity is 51% and the frost-free period lasts 128 days. This region is a place in China where some desertification control projects had been performed, such as the 'Grain for Green Programme', the 'Three-North Protection Forest Programme' and so on. *Artemisia ordosica* (AO), *Astragalus mongolicum* (AM), *Salix psammophila* (SP) and *Caragana microphylla* (CM) have been widely planted for the desertification control. Therefore, the studies were carried out in the four sample plots: AO, AM, SP, and CM. The adjacent shifting sand land and degraded pasture were used as controls, respectively. The characteristics of the sample plots and the controls were shown in Table 1.

2.2. Experiment design and soil sampling

We selected study site A (Fig. 1) in central region of Yanchi country (107°22′E, 37°48′N) in April 2010. The landscape of this area was shifting sand land before rehabilitation. The soil type in this study site is Aripsamment. Many studies (Su and Zhao 2003, Sartori *et al.* 2007, Su *et al.* 2007, Cao *et al.* 2008, Zhang *et al.* 2013a) showed that soil texture and organic carbon would not change on the shifting sand land over a long time, suggesting that the soils we sampled must have relatively similar characteristics before shrub-planting. The recovery treatments consisted of establishing straw checkerboards (1 × 1 m, each side consuming 0.05 kg straw) and planting AO, AM and SP in these checkerboards one month later. Therefore, in this study site, we selected four sample plots including shifting sand land (control), AO land, AM land and SP land. Table 1 showed the distribution and characteristics of the sample plots and soil.

In each sample plot and the control plot, nine replicate 10 × 10 m subplots were

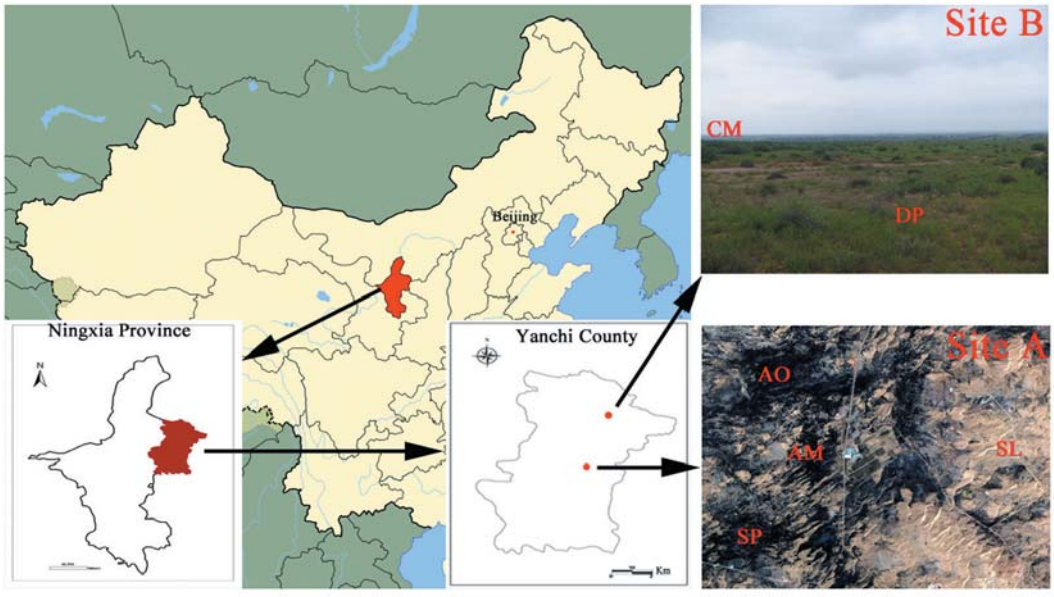

Fig. 1. Map of the study site. Site A – satellite image showed distribute of *Artemisia ordosica* (AO), *Astragalus mongolicum* (AM), *Salix psammophila* (SP) and sand land (SL) in this study site; Site B – photograph showed the transition zone between *Caragana microphylla* (CM) and degraded pasture (DP).

randomly and separately selected, respectively. An S-shaped curve soil sampling pattern was used in each subplot. The soil samples were obtained depths of 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm using a soil auger (10 cm in diameter) after excluding soil surface litter. Five soil samples taken from the same layer were mixed to obtain a composite sample for each subplot. Forty-five composite samples from 9 replicate subplots in each sample plot were obtained, and a total of 180 soil samples were collected from site A.

In August 2010, we selected the study site B (Fig. 1) in northern region of Yanchi country (107°24′E, 37°54′N). Before the rehabilitation, the landscape of this area was degraded pasture. The soil type in this study site is Calciorthids. In this study site, we selected one CM sample plot (25 ha) and one degraded pasture sample plot as the control (25 ha). The livestock had been grazing the degraded pasture until we sampled, so the soils had similar characteristics before planting CM. However, the CM land had been protected with wine fence when it was established. In the CM sample plot and degraded pasture, thirteen replicate subplots (10 × 10 m) were randomly and separately selected, respectively. The sampling procedure was the same as that used in the AO land. Sixty-five composite samples from 13 replicate subplots were obtained from CM land, and other 65 composite samples from 13 replicate subplots were obtained from degraded pasture.

Bulk density was sampled using ring (53 mm height and 70 mm diameter) with 5 replicates for each soil layer in each plot. After air drying, all the roots were picked out from composite sample, and then each mixed sample was separated into 2 subsamples for 150 g. One subsample was grinded and sieved to < 0.05 mm for the analysis of SOC, the other subsample was grinded and sieved to < 2 mm for density fraction separation.

2.3. Soil analyses

SOC was determined by dichromate oxidation of Walkley-Black (Liu 1996).

For LF–SOC and HF–SOC determination density fractionation method of Gregorich and Ellert's (1993) was used to separate LF–SOC and HF–SOC. 10 g soil from subsample (< 2 mm) was shaken with 50 mL of NaI solution (density 1.7 g cm^{-1}) in a 100 mL centrifuge tube for 1 h, and then the tube was centrifuged at 1000 × g–force for 20 min. The supernatant in tube was decanted into a vacuum filter unit with nylon filter paper (bore diameter 0.45 μm). The above process was repeated twice and the residue on the filter paper was light fraction. After the light fraction on the paper was washed with 75 mL $CaCl_2$ (0.01 mol L^{-1}) and 75 mL distilled water, it was transferred into a vial and dried at 60°C for 72 h. The soil residue in the tube was extracted with NaI again and the double light fractions were mixed for one sample and weighted. The sediment in the tube was washed with 100 mL distilled water at least 3 times, dried to constant weight and weighed it as heavy fraction.

The light fractions were grinded and sieved to < 0.075 mm and analyzed for organic carbon concentration (%) in a VARIO EL III elemental analyzer (Germany). The heavy fraction was determined by using the $K_2Cr_2O_7$–H_2SO_4 oxidation method from Walkley and Black (Liu 1996). VARIO EL III elemental analyzer can not be used to measure the organic carbon concentration (%), because SIC was contained in the heavy fractions. Under the action of H_2SO_4, SIC disappeared and did not affect the organic carbon concentration of heavy fraction.

2.4. Fine root sampling and soil water content determining

One hundred and ten soil cores for fine roots were randomly obtained from CM land at five depths (0–20, 20–40, 40–60, 60–80, 80–100 cm) using an auger (8.5 cm diameter), and other 110 soil cores for fine roots were randomly obtained from degraded pasture with the same method. Fine roots (< 2 mm) were separated from soil through hand picking. All roots were transported back to the laboratory and stored in a cool room (4°C) until further processing. They were washed by running pure water, and then oven dried at 70°C constant weight (± 0.0001 g). Soil water content was determined from about 30 g field moist soil that was weighed, dried for 2 days at 105°C, and reweighed from measured on August 15 in 2010.

Table 2. The carbon concentration and dry weight of LF–SOC in *Artemisia ordosica*, *Astragalus mongolicum*; *Salix psammophila* and sand land.

Depth (cm)	AO	AM	SP	SL
		Carbon concentration (%)		
0–20	14.4 (3.5) a	13.1 (3.7) a	12.1 (4.8) a	10.4 (3.1) a
20–40	10.5 (2.4) a	9.3 (2.4) a	10.6 (2.6) a	10.0 (2.9) a
40–60	9.5 (2.0) a	9.2 (2.6) a	8.9 (2.7) a	8.9 (1.2) a
60–80	8.8 (1.5) a	9.1 (0.7) a	8.2 (3.5) a	8.5 (1.4) a
80–100	7.8 (2.4) a	7.8 (2.7) a	6.9 (2.5) a	7.3 (1.1) a
		Dry weight (g kg^{-1})		
0–20	6.5 (1.6) a	3.5 (1.2) b	6.2 (2.5) a	1.5 (0.6) c
20–40	4.5 (1.0) a	3.3 (1.6) b	3.4 (1.1) c	2.0 (0.5) d
40–60	3.5 (0.8) a	3.9 (1.7) a	3.1 (1.21) a	1.6 (0.3) b
60–80	3.6 (0.8) a	2.8 (0.5) b	3.5 (1.6) ab	1.7 (0.4) c
80–100	3.6 (2.3) a	3.4 (1.4) a	2.8 (1.2) ab	1.9 (0.5) b

The carbon concentration and dry weight of LF–SOC in each layer in AO, AM, SP and SL lands (Mean ± SD, n = 9). Different letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments. AO – *Artemisia ordosica*; AM – *Astragalus mongolicum*; SP – *Salix psammophila*; SL – sand land.

Table 3. The carbon concentration and dry weight of HF–SOC and LF–SOC in *Caragana microphylla* and degraded pasture.

Depth (cm)	CM	DP	CM	DP
	Carbon concentration (%) of LF–SOC		Dry weight (g kg^{-1}) of LF–SOC	
0–20	16.7 (2.8) a	15.2 (2.6) a	3.8 (0.8) a	3.8 (0.6) a
20–40	14.9 (3.5) a	12.6 (3.4) a	3.1 (0.8) a	3.8 (2.1) a
40–60	12.6 (2.8) a	10.9 (4.5) a	3.1 (0.9) a	3.4 (1.2) a
60–80	11.0 (3.5) a	10.1 (2.2) a	2.8 (1.1) a	3.4 (1.0) a
80–100	11.4 (3.40) a	9.8 (4.5) a	2.2 (0.8) a	2.8 (1.1) a
	Carbon concentration (%) of HF–SOC		Dry weight (g kg^{-1}) of HF–SOC	
0–20	1.3 (0.1) a	1.4 (0.2) a	989 (3) a	988 (7) a
20–40	1.3 (0.2) a	1.4 (0.1) a	989 (4) a	990 (2) a
40–60	1.5 (0.2) a	1.5 (0.2) a	989 (5) a	989 (4) a
60–80	1.4 (0.2) a	1.9 (0.2) b	988 (4) a	988 (6) a
80–100	1.4 (0.2) a	1.6 (0.2) b	985 (5) a	986 (5) a

The carbon concentration and dry weight of LF–SOC and HF–SOC in each layer in CM and DP lands (Mean ± SD, n = 13). Different letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments. CM – *Caragana microphylla*; DP – degraded pasture.

2.5. Data analysis

The content and stock of soil organic carbon and its fractions were calculated as:

- LF–SOC content (g kg^{-1}) = LF–SOC concentration (%) × light fraction dry weight (g kg^{-1}).
- HF–SOC content (g kg^{-1}) = HF–SOC concentration (%) × light fraction dry weight (g kg^{-1}).
- Soil carbon stock (Mg ha^{-1}) = 0.1 ×B ×D × C × ((100-G) / 100),

where: B is the bulk density (g cm^{-3}); D is soil depth (cm); C is the carbon content (g kg^{-1}); and G is the relative amount of gravel (%). Because there was no gravel in the soil, the gravel content was 0.

SPSS 11.5 for Windows software package (2002) was used to analyze all data. A two-way Analysis of Variance (ANOVA) was carried out to test the effects of soil depth and plant species as well as their interactions on soil carbon stocks (SOC, LF–SOC and HF–SOC). Multiple comparison and one-way analysis of variance procedures (one-way ANOVA) were used to compare the difference in carbon stock (Mg ha^{-1}) of SOC, soil dry weight (g), carbon concentration (%) and carbon stock (Mg ha^{-1}) of LF–SOC and HF–SOC in AO land, AM land, SP land and

sand land (n = 9). Mean comparisons were used the least-significant-difference (LSD) test. T–text was used to compare the difference in SOC stock (Mg ha^{-1}), dry weight (g) of LF–SOC, dry weight (g) of HF–SOC, carbon concentration (%) of LF–SOC (%), carbon concentration (%) of HF–SOC, carbon stock (Mg ha^{-1}) of LF–SOC and carbon stock (Mg ha^{-1}) of HF–SOC between the CM land and degraded pasture (n = 13). For all data, all differences in this paper were tested and considered significant at $\alpha = 0.05$.

3. RESULTS

3.1. Carbon concentration and dry weight of density fractions

No significant differences were observed between the plantation lands and sand land on carbon concentration (Table 2). However, dry weights of LF–SOC were much higher in plantation lands than that in sand land, except for in the 80–100 cm soil depth. In the CM land and the degraded pasture, the carbon concentration (%) of LF–SOC, dry weight (g kg^{-1}) of LF–SOC and the dry weight (g kg^{-1}) of HF–SOC were no significant different (Table 3). However, compared to degraded pasture, the concentrations of HF–SOC in CM land decreased by 26.3 % and 14.8 % in the 60–80 cm and 80–100 cm depth, respectively.

3.2. Changes in SOC, LF–SOC, and HF–SOC stocks

After planting shrubs on sand land, the SOC stocks within 0–100 cm soil depth increased by 162.5% for AO, 45.2% for AM and 70.8% for SP (Fig. 2c), respectively. The proportions of increased LF–SOC among the total increased SOC were 42.7% in AO, 80.6% in AM and 59.8% in SP lands, respectively (Fig. 2a). Compared to the shifting sand land, HF–SOC stocks increased by 148.1% for AO, 14.4% for AM and 45.3% for SP within the 0–100 cm soil layer (Fig. 2b). The SOC and LF–SOC in the

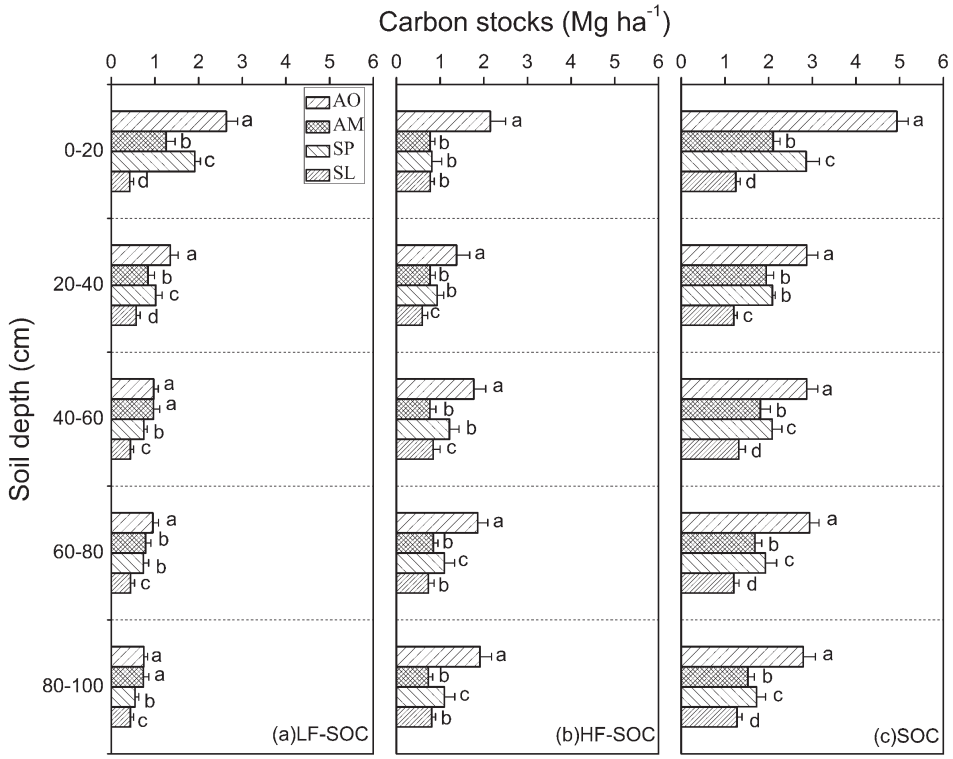

Fig. 2. Soil Organic Carbon (SOC; a), Light Fraction of Soil Organic Carbon (LF–SOC; b) and Heavy Fraction of Soil Organic Carbon (HF–SOC; c) stocks in each layer in *Artemisia ordosica* (AO), *Astragalus mongolicum* (AM), *Salix psammophila* (SP) and sand lands (SL; mean ± SD, n = 9). Different lower–case letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments.

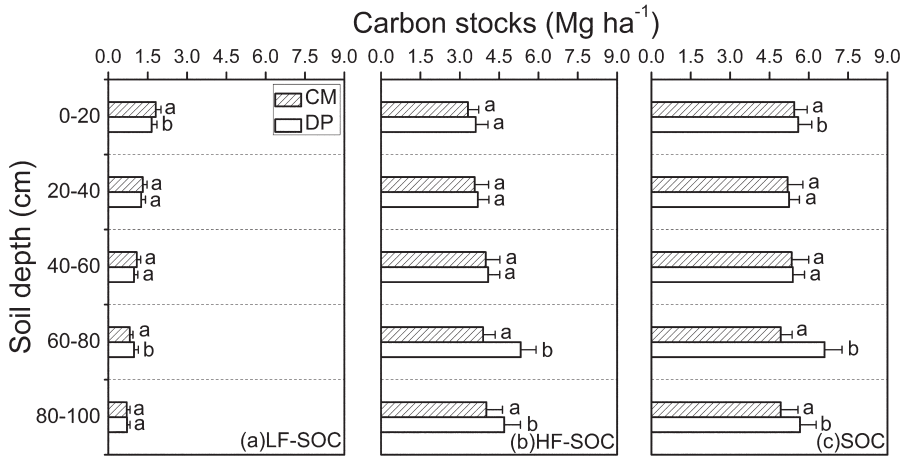

Fig. 3. Soil Organic Carbon (SOC; a), Light Fraction of Soil Organic Carbon (LF–SOC; b) and Heavy Fraction of Soil Organic Carbon (HF–SOC; c) stocks in each layer in *Caragana microphylla* (CM) and degraded pasture (DP) lands (mean ± SD, n = 9). Different lowercase letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments.

AO, AM, and SP decreased gradually with soil depth. However, they were almost evenly distributed in the soil profile in sand land.

After planting CM on the degraded pasture, the SOC stock in CM land (25.9 Mg ha^{-1}) were 9.3% lower than that in degraded pasture (28.5 Mg ha^{-1}, Fig. 3c). The HF–SOC stock in CM land was 2.6 Mg ha^{-1} less than that in degraded pasture within 0–100 cm soil depth (Fig. 3b). The LF–SOC stocks in the CM land and degraded pasture showed no significant difference (Fig. 3a), except for a slight increase was found in the 0–20 cm soil layer in the CM land. The SOC in the CM land and degraded pasture were almost evenly distributed in the soil profile. The LF–SOC stocks in both lands decreased gradually with soil depth, while the HF–SOC stocks showed the opposite trend.

3.3. Fine roots biomass and soil water content in the CM land and degraded pasture.

The fine root biomass (FRB) was 18.0% greater in degraded pasture than that in CM land (Fig. 4) within 0–100 cm soil depth. It was 32.7% and 36.7% higher in degraded pasture than that in the CM land in the 60–80 cm and 80–100 cm soil layer. In addition, the herbaceous fine root biomass (HFRB) in degraded pasture was approximate two times greater than that in the CM land, especially in the 60–100 cm. Furthermore, the herbaceous fine root almost disappeared in the CM land.

Soil water content (SWC) was higher in 60–100 cm soil layer in degraded pasture than that in the CM land (Fig. 5). From May to August in 2010, soil water content had little changed in the 60–100 cm in the CM land. During this period, SWC in degraded pasture was at least 181.4% higher than that in the CM land within each layer in the 60–100 cm soil depth.

4. DISCUSSION

4.1. Effects of two desertification control measures on SOC

After planting shrubs on the sand land, the stocks of SOC increased (Fig. 2). This is consistent with Su *et al.* (2010) in the southern edge of the Badan Jaran Desert, China. However, SOC decreased after planting CM on the degraded pasture (Fig. 3), which is in accordance with Wei *et al.* (2009), who reported that the stock of SOC reduced by 27.7% after CM was planted on the pasture. The two similar methods of desertification control resulted in the different results, indicating that previous land use plays an important role in the change of SOC following desertification control.

Previous land use played an important role in the restoration of SOC after shrubs or

trees were planted (Laganiere *et al.* 2010, Zhang *et al.* 2013b). The greater difference was between the established ecosystem and the previous land use, the greater effect of planting will be displayed. In our study, carbon inputs are much lower in shifting sand land than in shrub ecosystems. The reference value of SOC content in shifting sand land is so low that even a small quantity carbon input could affect the variation of SOC. Unlike the shifting sand land, a number of studies have shown that pasture soils could store more carbon than forest soils and shrub soils (Franzluebbers *et al.* 2000, Garten and Ashwood 2002), and the reference value of SOC is too large to be changed. Therefore, the different initial reference values of SOC content in sand land and degraded pasture may result in the diversity of two desertification control measures on the SOC stocks.

4.2. Effect of shrub-planting on LF–SOC and HF–SOC in sand land

The additional LF–SOC accounted for large proportions in the total increased SOC in AO, AM, and SP lands (Fig. 2). This is in accordance with Llorente *et al.* (2010), who concluded that only LF–SOC changed after afforestation in cropland. Soil type may be the important cause of this. HF–SOC is the organic-mineral complexes adsorbed on the surface of soil mineral particles or hidden in microaggregates (Christensen 1992, 2001), it is positively correlated with silt plus clay content (Paul *et al.* 2008). However, the soil of the study area is Aripsamment with silt plus clay content below 5%. Therefore, due to lack of sufficient silt and clay, even with the introduction of a large amount of organic matter into the soil, it is hard to generate a large number of HF–SOC.

After planting shrubs on the sand land, the dry weight of LF–SOC increased in each soil layer, however, the carbon concentration (%) was no significant different between the shrubslands and the sand land. Bu *et al.* (2012) also reported that the difference of LF–SOC content between broad-leaved forest and coniferous forest resulted from the different values of dry weight, and carbon concentration contributed little to the difference of LF–SOC content. Wang *et al.* (2009) pointed out the reduction of LF–SOC in degraded pasture caused by the decline of its dry weight, not the carbon concentration. Liu *et al.* (2010) found the rising of LF–SOC mainly based on the accumulation of dry weight after planting shrubs on the cropland. The LF–SOC mainly derived from the decomposition of litter such as roots (Laik *et al.* 2009), meanwhile, the decomposition of litter depended on the vitality and quantity of microorganisms. Nevertheless, the vitality and

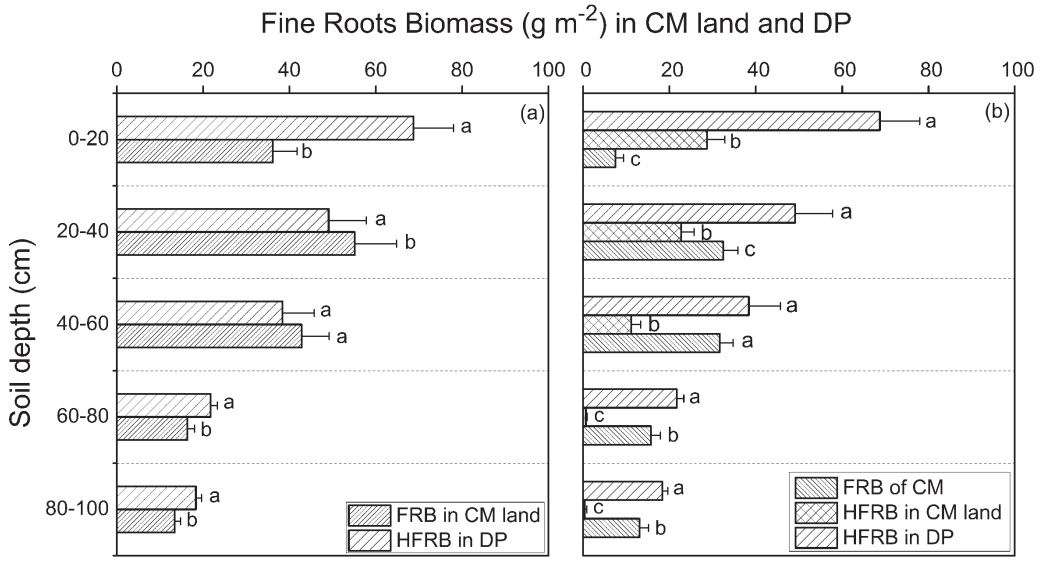

Fig. 4. Fine root biomass in *Caragana microphylla* (CM; a) land and degraded pasture (DP; b) (mean ± SD, n = 110). Different letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments. FRB – fine root biomass; HFRB – herbaceous fine root biomass.

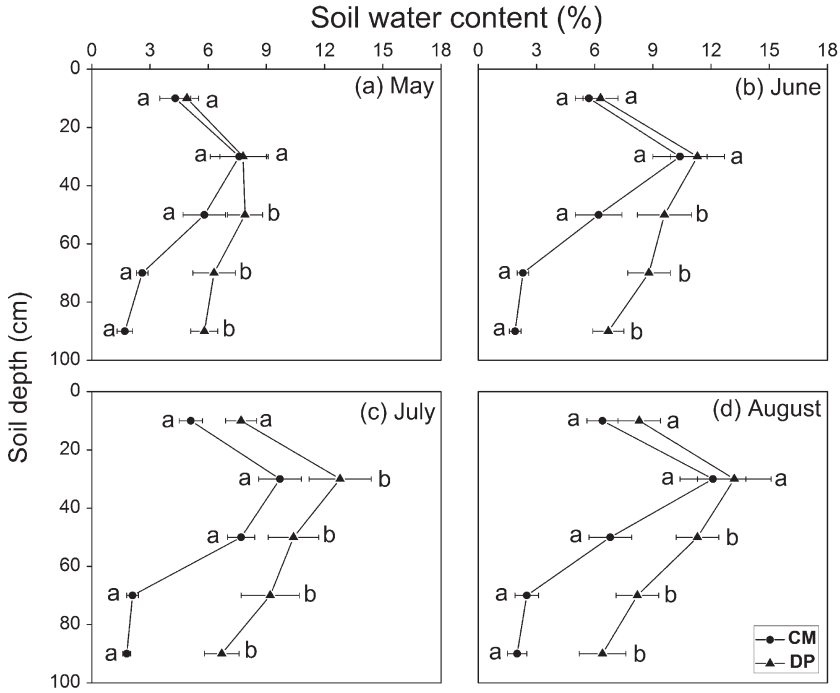

Fig. 5. Soil Water Content (SWC) in *Caragana microphylla* (CM) land and DP (degraded pasture) (mean ± SD, n = 15). Different letters within each soil depth indicate the significant difference of mean values (P <0.05) among the treatments.

quantity of microorganisms would be seriously restricted in the dry and low humidity environment in the semiarid area, so the dry weight accumulates a large number.

Because the mean resident time of LF–SOC was still uncertain, we cannot identify the real benefit for carbon sequestration of this increased LF–SOC.

4.3. Effect of shrub-planting on LF–SOC and HF–SOC in degraded pasture

After the planting CM on degraded pasture, SOC stock decreased by 9.3%, and the loss of SOC was aroused by the decrease of HF–SOC in the 60–100 cm soil layers (Fig. 3). Xu *et al.* (2011) also found that the more stable carbon showed continues reduction after land use change in the Gurbantunggut desert, northwest China.

The decrease of HF–SOC in CM land was not attributed to the grazing by livestock because of the long term protection. It was aroused by its reduction of carbon concentration and that may be related to the changes in FRB and SWC in the deep soil. The reduction of HFRB in the CM land was an important factor for the decrease of HF–SOC. Firstly, FRB in the degraded pasture were more than that (FRB of CM + HFRB) in CM land in the 60–100 cm soil layer (Fig. 4). The quantities of resource which can be decomposed are larger in the degraded pasture than that in CM land. Secondly, in the CM land, the HFRB almost disappeared in the 60–100 cm soil layer (Fig. 4), and most of the HFRB in degraded pasture originally were gradually replaced by that of CM (Marin-Spiotta *et al.* 2009). The turnover rate of FRB is much faster in pasture than in forest environments (Kuzyakov and Domanski 2000, Guo *et al.* 2007), so root carbon inputs are therefore higher in pasture than in the shrub ecosystem. Sharp decline of the root carbon inputs, which can be supplied to be decomposed, can induce the decrease of HF–SOC. Additionally, what is more serious is that SWC exacerbates this reduction. Along with the growth of CM, the SOC derived from grass would be gradually replaced by the SOC derived from CM (Marin-Spiotta *et al.* 2009). Meanwhile, the SWC would be lower and lower with the increase of roots (Fig. 5). Microbial decomposition was seriously restricted in the dry environment so

that the decomposition velocity of FRB was much slower in the CM land and HF–SOC lost more.

A significant reduction in SOC was observed after planting CM on degraded pasture. What is more serious is that the lost organic carbon is HF–SOC with slower turnover rate in deeper layer. This result indicates that desertification control with planting CM on the degraded pasture should be implemented with caution in semiarid area.

5. CONCLUSION

We conclude that planting shrubs for desertification control on sand land can result in an increase in SOC, whereas it can lead to a decrease in SOC on degraded pasture. The increase of SOC in sand land mainly bases on the accumulative dry weight of LF–SOC. The decrease of SOC in degraded pasture may result from the decrease in carbon concentration of HF–SOC, which is induced by the reduction of the HFRB and SWC in the deep soil layer. Therefore, shrub-planting for desertification control do not always improve the quantity and stability of SOC in northwest China.

This study is helpful to understand the causes and mechanism of the changes in SOC related to shrub-planting. It also can provide reference for how to achieve desertification control and soil carbon sequestration synchronously.

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