Characteristics and Sequestration Effects of Soil Carbon and Nitrogen Fraction Pools During Sand-Fixing Forest Restoration in Northern Shaanxi [Postprint]

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Abstract

This study selected the Mu Us Sandy Land in northern Shaanxi, covering semi-fixed sand dunes to shrub and arbor sand-fixing forest lands restored for 23–54 years, and employed the density fractionation method to analyze the evolution of carbon and nitrogen contents, C/N ratios, accumulation rates, and carbon and nitrogen sequestration contribution characteristics in light and heavy fractions of surface soil. The results showed that during 23–54 years of restoration, soil light fraction carbon in arbor and shrub forests increased by 14.0–40.6-fold and 8.8–19.2-fold, respectively, which were significantly higher than the corresponding increases of 3.2–7.7-fold and 3.5–8.1-fold in heavy fraction carbon; likewise, light fraction nitrogen increased by 14.5–40.9-fold and 11.8–29.1-fold, respectively, also significantly higher than the increases of 4.6–8.5-fold and 4.4–12.6-fold in heavy fraction nitrogen, indicating that light fraction carbon and nitrogen are more sensitive to sand-fixing forest restoration than heavy fraction carbon and nitrogen. The increases in soil light and heavy fraction carbon and nitrogen contents resulted in accumulation rates of light fraction carbon density in arbor and shrub forests reaching 0.57 mg · hm ^{2} · a ^{1} and 0.26 mg · hm ^{2} · a ^{1}, respectively, while those of heavy fraction carbon density were only 0.18 mg · hm ^{2} · a ^{1} and 0.20 mg · hm ^{2} · a ^{1}; simultaneously, accumulation rates of light fraction nitrogen density reached 0.03 mg · hm ^{2} · a ^{1} and 0.02 mg · hm ^{2} · a ^{1}, respectively, while those of heavy fraction nitrogen density reached 0.02 mg · hm ^{2} · a ^{1} and 0.04 mg · hm ^{2} · a ^{1}, respectively. Based on these accumulation rates of carbon and nitrogen fractions, when sand-fixing forests were restored for 54 years, soil light fraction carbon in arbor and shrub forests could contribute 75.9% and 59.4% of the total organic carbon increment, respectively; soil heavy fraction nitrogen could contribute 44.6% and 63.9% of the total nitrogen increment, respectively.

Additionally, after 54 years of restoration, soil heavy fraction C/N ratios in the two forest types decreased by 11.4% and 38.5% compared with semi-fixed sand dunes, respectively. However, light fraction C/N showed no significant change in arbor forests, whereas in shrub forests restored for 23–54 years, soil light fraction C/N decreased by 21.7%-31.0%, significantly altering soil carbon pool properties. These results indicate that sand-fixing forest restoration in northern Shaanxi demonstrates significant carbon and nitrogen sequestration effects in soil, with arbor forests exhibiting better carbon sequestration capacity and shrub forests showing better nitrogen fixation effects.

Full Text

Dynamics of Soil Microbial Biomass and Enzyme Activities Along a Chronosequence of Desertified Land Revegetation

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Abstract

Soil samples were collected from 0–10 cm topsoil in semi-fixed sand land and fixed sand land under shrubberies and arbor forests regenerated for 23–54 years in the Mu Us sandy land of North Shaanxi Province. Each soil sample was separated into light and heavy fractions by density grouping method, and the evolution and accumulation rates of organic carbon and total nitrogen, C/N ratio, and the characteristics of contribution proportion for sequestering carbon and nitrogen in the two soil fractions were analyzed.

The results indicated that the organic carbon contents in soil light fraction under the shrubberies and arbor forests regenerated for 23–54 years increased by 14.0-40.6 times and 8.8-19.2 times respectively, which were significantly higher than those in the corresponding heavy fractions (3.2-7.7 times and 3.5-8.1 times). In the same period of vegetation regeneration, the total nitrogen contents in soil light fraction under the arbor forests and shrubberies were increased by 14.5-40.9 times and 11.8-29.1 times respectively, which were also significantly higher than those of the corresponding heavy fractions (4.6-8.5 times and 4.4-12.6 times). These results indicated that the soil organic carbon and total nitrogen in light fraction were more sensitive to the desertification reversal than that in heavy fraction.

Increase of the contents of organic carbon and total nitrogen in the light fraction and heavy fraction of soil also made the growth rates of organic carbon density of light fraction under the forests and shrubberies reach to 0.57 $mg \cdot hm^{-2} \cdot a^{-1}$ and 0.26 $mg \cdot hm^{-2} \cdot a^{-1}$ respectively. The growth rates of the organic carbon density in heavy fraction under the forests and shrubberies were only 0.18 $mg \cdot hm^{-2} \cdot a^{-1}$ and 0.20 $mg \cdot hm^{-2} \cdot a^{-1}$ respectively. Moreover, the growth rates of the total nitrogen density in light fraction reached to 0.03 $mg \cdot hm^{-2} \cdot a^{-1}$ and 0.02 $mg \cdot hm^{-2} \cdot a^{-1}$, and they in heavy fraction reached to 0.02 $mg \cdot hm^{-2} \cdot a^{-1}$ and 0.04 $mg \cdot hm^{-2} \cdot a^{-1}$, respectively.

According to these growth rates of carbon and nitrogen fractions, the carbon of light fraction under the forests and shrubberies could contribute 75.9% and 59.4% of the total organic carbon increment respectively during the 54-year restoration. The nitrogen in heavy fraction could contribute 44.6% and 63.9% of total nitrogen increment respectively. In addition, the C/N ratios of soil heavy fraction under the two woodlands regenerated for 54 years were significantly reduced by 11.4% and 38.5% respectively compared with those in semi-fixed sand land. However, there was no significant change of C/N in the light fraction under the forests, and the C/N in the light fraction under the shrubberies regenerated for 23–54 years was decreased by 21.7%–31.0%. As a result, the quality of soil carbon pool was improved significantly. Therefore, the soil restoration under the sand-fixing forests in North Shaanxi affected significantly the sequestration of carbon and nitrogen. Moreover, arbor forests have better carbon sequestration ability and shrubberies have better nitrogen sequestration effect.

Keywords: sand-fixing forest; restoration process; soil carbon and nitrogen; carbon sequestration; Mu Us sandy land

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1.2 Study Area and Sampling

In July 2017, soil samples were collected from semi-fixed sand land and fixed sand land under shrubberies and arbor forests regenerated for 23, 33, and 54 years in the Mu Us sandy land. The main vegetation types included *Artemisia ordosica* Krasch., *Hedysarum scoparium* Fisch. et Mey., and *Hedysarum mongolicum* Turcz. The sampling depth was 0–10 cm, with three replicate plots for each vegetation type. Soil bulk density was measured using the ring knife method, and soil water content ranged from 89.4% to 96.5%.

1.4 Density Fractionation and Analysis

Soil samples were separated into light and heavy fractions by density grouping method [**?**]. The light fraction was obtained by flotation on sodium iodide solution (density 1.8 $g \cdot cm^{-3}$), while the heavy fraction was the remaining sediment. Both fractions were oven-dried at 60°C to constant weight, then ground to pass through a 0.25 mm sieve for analysis. Organic carbon content was determined by the potassium dichromate oxidation method, and total nitrogen content by the Kjeldahl method. The C/N ratio was calculated as the ratio of organic carbon to total nitrogen content.

The contribution rate of each fraction to total soil carbon/nitrogen increment was calculated as:

$$S = \frac{C\rho D}{10}$$

where S represents the carbon/nitrogen density contribution rate ($\mathrm{mg \cdot hm^{-2}}$), C is the carbon/nitrogen content ($\mathrm{g \cdot kg^{-1}}$), ρ is soil bulk density ($\mathrm{g \cdot cm^{-3}}$), and D is soil depth (10 cm).

2.2 Soil Organic Carbon and Total Nitrogen Contents

The organic carbon contents in different fractions showed significant variation with regeneration age . In the light fraction, organic carbon contents under shrubberies and arbor forests increased by 14.0–40.6 times and 8.8–19.2 times respectively over 23–54 years, which were significantly higher than those in the corresponding heavy fractions (3.2–7.7 times and 3.5–8.1 times) [Figure 1: see original paper].

Similarly, total nitrogen contents in the light fraction under arbor forests and shrubberies increased by 14.5–40.9 times and 11.8–29.1 times respectively, also significantly higher than heavy fractions (4.6–8.5 times and 4.4–12.6 times) [Figure 2: see original paper]. These results demonstrate that light fraction carbon and nitrogen are more sensitive indicators of desertification reversal.

The C/N ratios of soil heavy fraction under both woodlands regenerated for 54 years were significantly reduced by 11.4% and 38.5% compared with semi-fixed sand land. However, no significant change occurred in light fraction C/N under forests, while shrubbery light fraction C/N decreased by 21.7%–31.0% [Figure 3: see original paper], indicating improved soil carbon pool quality.

2.3 Contribution Rates of Carbon and Nitrogen Fractions

Based on the growth rates, light fraction carbon contributed 75.9% and 59.4% of total organic carbon increment under forests and shrubberies respectively during the 54-year restoration period. Conversely, heavy fraction nitrogen contributed 44.6% and 63.9% of total nitrogen increment [Figure 4: see original paper]. The growth rates of organic carbon density in light fraction reached 0.57 $\mathrm{mg \cdot hm^{-2} \cdot a^{-1}}$ (forests) and 0.26 $\mathrm{mg \cdot hm^{-2} \cdot a^{-1}}$ (shrubberies), while heavy fraction rates were only 0.18 and 0.20 $\mathrm{mg \cdot hm^{-2} \cdot a^{-1}}$ respectively.

TABLE:2 Contents of organic carbon and nitrogen in soil under sand-fixing forest with different regeneration ages

Land Use	Regeneration Age	Organic C (g · kg ^{1})	Total N (g · kg ^{1})	C/N Ratio
Shrubbery	23a	135.4 ± 5.64	0.85 ± 0.05	20.2 ± 1.75
Shrubbery	33a	254.5 ± 11.40	3.85 ± 0.60	15.8 ± 1.54
Shrubbery	54a	257.6 ± 15.26	7.86 ± 0.81	14.7 ± 0.47
Arbor Forest	23a	193.5 ± 14.24	3.68 ± 0.41	19.9 ± 1.50
Arbor Forest	33a	224.3 ± 1.33	6.38 ± 0.41	20.9 ± 1.50
Arbor Forest	54a	243.3 ± 4.81	7.96 ± 0.45	20.7 ± 1.44

Note: Different letters indicate significant differences among treatments ($P < 0.05$).

FIGURE:1 Content of organic carbon in soil under sand-fixing forest with different regeneration ages

FIGURE:2 Content of total nitrogen in soil under sand-fixing forest with different regeneration ages

FIGURE:3 Linear regression relationship between regeneration age of sand-fixing forest and soil total nitrogen content

FIGURE:4 Contribution rates of soil organic carbon content and total nitrogen content during regenerating the sand-fixing forests

FIGURE:5 C/N ratios under sand-fixing forests with different regeneration ages

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Note: Figure translations are in progress. See original paper for figures.