Pol. J. Environ. Stud. Vol. 24, No. 6 (2015), 2543-2552
DOI: *10.15244/pjoes/59235*

Original Research

Impact of Different Afforestation Systems on Soil Organic Carbon Distribution Characteristics of Limestone Mountains

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Received: June 12, 2015
Accepted: August 27, 2015

Abstract

Research on the soil organic carbon (SOC) distribution using different afforestation systems on limestone mountains is of great significance because it provides guidance for selecting afforestation systems and produces quantitative evaluations of soil conservation. By comparative analysis of the SOC content and SOC storage, the SOC distribution characteristics in the soils of four 7-year-old examples of afforestation systems and unused grassland (UNG) were studied in northern China's Limestone Mountains. The results indicate that:
1) the four afforestation systems showed significantly improved soil properties in comparison with that of the UNG, including a decrease in soil bulk density and an increase in soil porosity, soil organic matter content, total nitrogen, and total phosphorus. The effective improvements in the mixed afforestation systems were greater than that in the pure afforestation systems, and the most effective improvement was a *Platycladus orientalis-Robina pseudoacacia* mixed plantation (PRM), followed by a *Platycladus orientalis-Cotinus coggygria* mixed plantation (PCM), a *Platycladus orientalis-Prunus armeniaca* mixed plantation (PPM), and a pure *Platycladus orientalis* plantation (POL);
2) the SOC content and SOC storage of the four afforestation systems were significantly higher than that of the UNG, and those same parameters in the 0-10 cm soil were significantly higher than those from the 10-20 cm soil; the SOC content was ordered PRM > PCM > PPM > POL > UNG;
3) in the four afforestation systems, the SOC content showed a significant positive correlation with the silt and clay particle content and a non-significant negative correlation with the sand content. In addition, the SOC content showed a significantly positive correlation with soil total nitrogen, total phosphorous, and total porosity, and a significant negative correlation with soil bulk density.

Keywords: soil organic carbon, soil organic carbon storage, afforestation systems, limestone mountain

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Introduction

Soil organic carbon (SOC) is the largest terrestrial organic carbon pool [1]. It is a research focus related to the global carbon cycle and climate change. SOC not only provides a source of carbon for vegetative growth, but also greatly affects the soil structure and aggregate formation, soil physical stability for erosion resistance, and soil biodiversity [2, 3]. Forests are the primary terrestrial biosphere and provide the largest source of SOC storage in the terrestrial ecosystem; therefore, forest SOC pools are an important component in the global carbon cycle. The accumulation and decomposition of forest SOC directly impacts global carbon equilibrium, and only a small change in the forest SOC can lead to a release of carbon into the atmosphere through the greenhouse effect [4, 5]. The key role of forest SOC in maintaining the basic balance of atmospheric CO_2 concentrations has attracted increasing attention [6, 7].

SOC was influenced by many factors, including natural factors and human disturbances such as climatic factors, soil-related factors, and land use [8, 9]. Moreover, the research results showed a significantly positive relationship between SOC content and forest vegetation type [10], and the different forest vegetation types had different effects on SOC. A detailed investigation on forest organic carbon in Canada and the latitude transect in Siberia was conducted, and the storage of forest SOC and its spatial distribution in the two aforementioned areas was analyzed, and indicated that the hydrothermal conditions and soil grain size composition had a significant impact on forest SOC distribution [11]. Maraseni et al. found that, in the central part of Nepal with up to 30 cm soil depth, a dense canopy *Rhododendron-Quercus* forest has the highest amount of SOC (14,136 g C/m^2), followed by dense canopy mixed broadleaf forest (12,576 g C/m^2). Moreover, soils under the mixed species (i.e., mixed broad leaf, *Shcima-Castanopsis*, *Rhododendron-Quercus*) forests are richer in SOC than that of single species-dominated (i.e., Pine and *S. robusta*) forests [12].

In Germany, Don et al. showed SOC contents or stocks decline from primary forest to grassland and to cropland [9], and Wiesmeier et al. also showed that SOC stocks of forest soils were higher than that of grassland soils [13]. Evergreen broad-leaved, Masson pine, Chinese fir, and Bamboo forest are the four kinds of main forest vegetation types in the southern mountain areas of China. The studies of SOC under the above four kinds of main forest vegetation types indicate that the SOC content under Evergreen broad-leaved and Bamboo forest were considerately higher than those under Masson pine and Chinese fir forest, and the SOC content was ordered Bamboo > Evergreen broad-leaved > Chinese fir > Masson pine [14, 15]. In addition, according to the studies of the SOC in Heshan of China, the SOC content of various plantation types changed with soil layer depth, and that of plantation land and grassland soil decreased as the soil layer depth increased; and at the same soil depth, the soil from *Schima superba* plantations had the highest organic content, whereas soil from the *Acacia auriculiformis* plantations had the lowest organic content [16]. The SOC storage at the soil surface level (0-20 cm) for natural vegetation was higher than that for secondary vegetation, which was primarily caused by the artificial disturbance of secondary vegetation and decreased the amounts of fallen twigs and leaves that accumulate on the surface, which leads to an increase of SOC storage at the soil surface [17]. The combination of photosynthesis products and the vertical distribution of root systems for different forest vegetation types also impacted the vertical distribution characteristics of SOC in the soil profile [18]. On the whole, there have been many research reports about the natural forest and artificial afforestation SOC distribution characteristics and its domestic and overseas influence factors. But the research results of forest SOC in rocky mountain areas of northern China, especially for characteristics of SOC of different ecological afforestation systems of the Grain for Green program and soil erosion prevention projects, are rarely reported.

The limestone mountains in southern Shandong Province are a typical rocky mountain area in northern China, and it has thin and loose soil and relatively severe soil erosion [19]. Since the 1980s, the implementation of ecological environmental development projects, such as the Grain for Green program in China, has led to the establishment of numerous ecological afforestation systems that have regional characteristics in the limestone mountains of southern Shandong Province. In addition, numerous investigators have evaluated ecological afforestation techniques and the soil hydrology effectiveness in the region [20, 21]. Moreover, the studies of Li et al. and Qian et al. showed that organic matter was mainly affected by ground vegetation, and the vegetation types improved soil structure by increasing soil organic matter content in the rocky mountain area of northern China [22, 23]. However, few studies have evaluated the SOC distribution characteristics in different afforestation systems. Therefore, the questions of how the Grain for Green program and ecological afforestation projects impact the soil structure and their effect on soil improvement are difficult to answer.

Four afforestation systems and one unused grassland (UNG) in the project area were selected as research objects. Our study was conducted to explore SOC content, distribution characteristics, and storage in the four afforestation systems and the UNG; moreover, the relations among the SOC change and soil texture and main soil physical and chemical characteristics were studied to determine the SOC change pattern in the different afforestation systems. The results can provide a basis for the quantitative evaluation of ecological benefits of the Grain for Green program.

Materials and Methods

Ethics Statement

The research station for this study is managed by Shandong Agricultural University. The study was approved by the Taishan Mountain Forest Ecosystem Research Station of the State Forestry Administration. Moreover, the field study also is not the research base of the Special Fund for Forestry Scientific Research in the Public Interest, it is not a national park or other protected area of land or sea, and it did not involve endangered or protected species.

The Characteristics of the Study Area

The experiment was conducted in Xintai City and Shandong Province (35º45′-38º12′N,117º33′-119º20′E), which are located in the mountainous land of south-central Shandong Province in China (Fig. 1), which is managed by Shandong Agricultural University. It was possible to implement all the activities of the study at this location. The elevation ranges from 310 to 413 m in Xintai City. This area has a typical monsoon climate and is located in a warm temperate zone with distinct seasonal changes. The mean annual precipitation is 798.4 mm, and nearly 70% of the annual precipitation falls between June and September. The average annual evaporation in this region is 1,942.6 mm, and the mean annual temperature is approximately 12.0ºC. The soil type is brown, which is similar to the American soil classification of eutrochrepts. The average soil layer depth is 20 cm, the soil pH is 7.4-7.6, and there is strong soil erosion and water loss. Thus, in 2006 the Grain for Green program was implemented in the study area. According to the floristic-vegetational analysis [24], the vegetation types belong to the coniferous forests and deciduous broad-leaved forests in the warm temperate zone. Moreover, the main tree species include *Platycladus orientalis* (L.), *Pinus thunbergii* Parl., *Cotinus coggygria* Scop., *Robinia pseudoacacia* Linn., *Prunus armeniaca* Mill., and *Juglans regia* Linn., among others; the main shrubs include

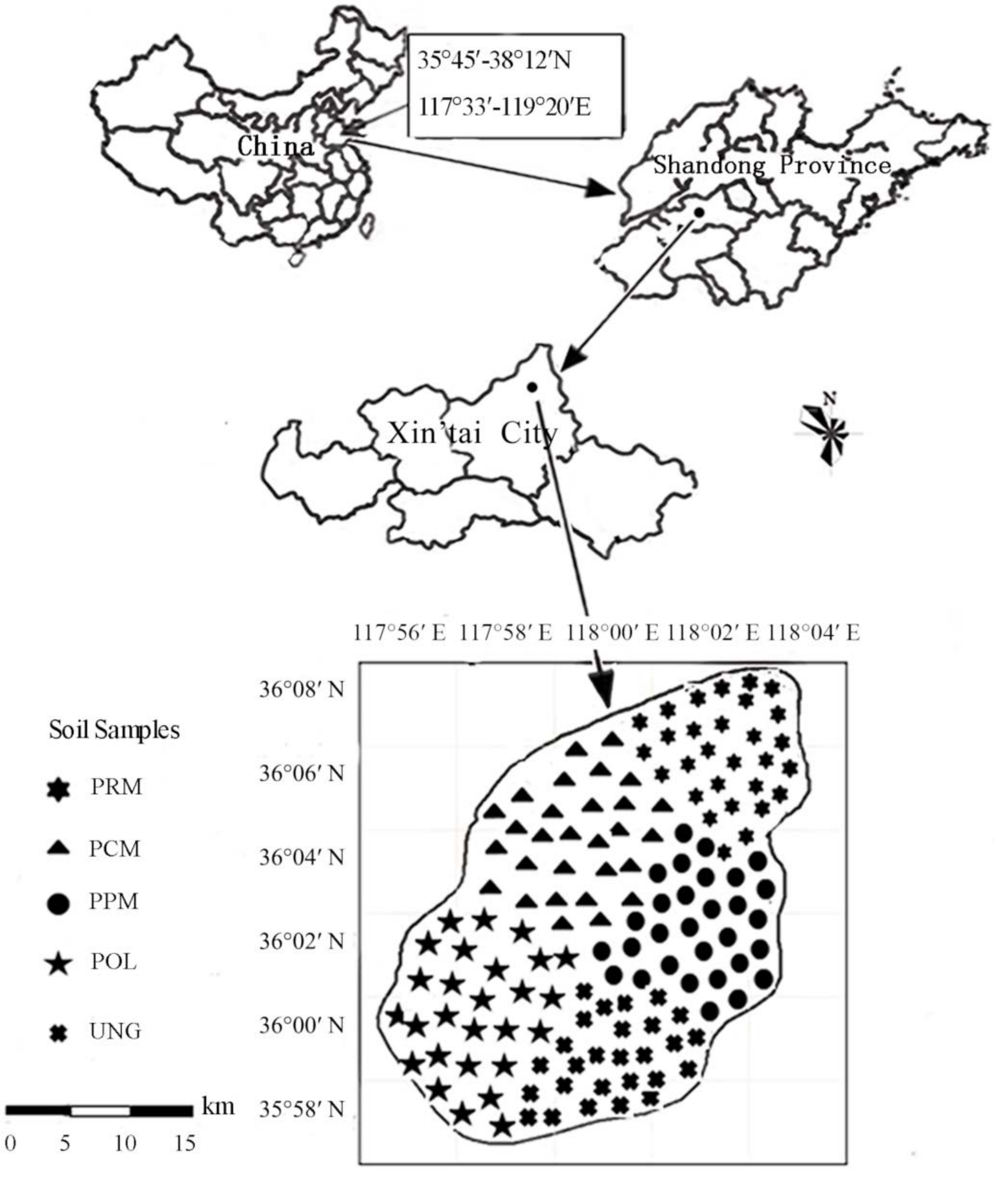


Fig. 1. Map of the location of the study area and soil samples distribution
PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG – Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.).

Table 1. Basic characteristics of different afforestation systems in the study area (in 2013).

Afforestation systems		Vegetation coverage (%)	Tree age (years)	Planting density (m×m)	Elevation (m)	Slope (º)	Longitude and latitude	Aspect*	Soil type
Mixed forest	PRM	91.4	7	2×3	326	10-15	36°04′-36°08′N 118°01′-118°03′E	sunny	Brown soil
	PCM	90.3	7	2×3	330	15-20	36°02′-36°07′N 117°58′-118°01′E	sunny	
	PPM	89.4	7	3×3	340	15-25	36°01′-36°05′N 118°00′-118°03′E	half-sunny	
Pure forest	POL	80.7	7	2×2	336	15-25	35°58′-36°03′N 117°56′-117°59′E	sunny	
Comparison	UNG	35.2	–	–	340	15-25	35°58′-36°01′N 117°59′-118°02′E	sunny	

PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG – Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.).
*the "Aspect" were divided into three classes at 90º intervals from due north, 0º-45º and 315º-360º were shady slopes, 45º-135º and 225º-315º were half-sunny slopes, and 135º-225º were sunny slopes.

Vitex negundo Linn. var. *negundo* and *Ziziphus jujuba* var. *spinosa* Hu, among others; and the main plants in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka, and *Setaria viridis* (Linn.) Beauv., among others [25].

Sampling

The project area setup, observational indicators, and methods were all based on the Specifications for Assessment of Forest Ecosystem Services in China (LY/T 1721-2008), the Indicators System for Long-term Observation of Forestry Ecosystems (LY/T 1606-2003), and the Observation Methodology for Long-term Forest Ecosystem Research (LY/T 1952-2011) [26].

Based on field surveys, the four typical afforestation systems and unused grassland (UNG) were set up in the ecological afforestation project area of Shandong Province as part of the Grain for Green program, and the afforestation consisted of a *Platycladus orientalis-Robina pseudoacacia* – mixed plantation (PRM), a P*latycladus orientalis-Cotinus coggygria* mixed plantation (PCM), a *Platycladus orientalis-Prunus armeniaca* mixed plantation (PPM), a *Platycladus orientalis* pure plantation (POL), and the unused grassland (UNG, which is native). The basic characteristics of the four afforestation systems and the UNG are shown in Table 1. Three sample plots were selected as sampling units in each of the afforestation systems and the UNG, with each sample plot covering an area of approximately 400 m^2 (20 m×20 m). Five soil sampling sites were located in each sample plot. Soil samples were collected from a depth of 20 cm (0-10 cm and 10-20 cm) at the five soil sampling sites for each sample plot and then stored in prepared soil bags and transported to the lab for air drying. Thirty soil samples were collected from layers 0-10 cm and 10-20 cm in each of the afforestation systems and the UNG. A total of 150 soil samples were collected in July 2013. The roots were removed from the soil samples, which were then sifted through a 2 mm sieve. In addition, a cutting ring (with a volume of 100 cm^3) was used to extract five undisturbed soil samples from each sample plot, which were then transported to the lab. They were used for analysis of soil physical and chemical properties, namely soil bulk density and porosity, soil moisture, soil particle size composition, soil total nitrogen, soil total phosphorus, soil organic matter, and SOC, etc.

Determining the Physical and Chemical Properties of the Soil

The four typical afforestation systems and the UNG were planted at the same time as the afforestation (in March 2006), and the physical and chemical properties of the planting area were the same or similar at the beginning of afforestation. The core method was used to determine soil bulk density and porosity (total, capillary and non-capillary), and soil moisture was determined by drying at 105ºC. Based on the U.S. soil particle size grading system, the soil particles of the four afforestation systems and the UNG were described according to the percentages of clay (<0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2 mm). The volume content of the soil particles were determined using a laser particle size analyzer (LS13320, USA) after removing organic matter by digestion in a heated hydrogen peroxide solution with sodium hexametaphosphate as a dispersing agent [27]. The semi-micro Kjeldahl method was employed to determine soil total nitrogen, and the mo anti-antimony colorimetry was used to determine soil total phosphorus [28]. The potassium dichromate external oxidation heating method was used to test for soil organic matter and SOC, and soil organic carbon is divided by 0.58 to obtain the organic content [29].

Table 2. Soil physical and chemical properties of different afforestation systems in the study area.

Afforestation systems	Soil bulk density	Soil total porosity	Capillary porosity	Non-capillary porosity	Soil organic matter	Soil total nitrogen	Soil total phosphorus
	($g·cm^{-3}$)	(%)			($g·kg^{-1}$)		
PRM	1.20±0.02^{d}*	52.3±0.18^{a}	37.3±1.21^{a}	15.0±1.22^{a}	8.78±0.09^{a}	0.76±0.47^{a}	0.53±0.06^{a}
PCM	1.22±0.01^{bc}	45.2±0.85^{b}	35.7±1.04^{ab}	9.8±1.34^{b}	7.41±0.11^{b}	0.68±0.36^{b}	0.45±0.04^{b}
PPM	1.25±0.02^{cd}	44.1±0.71^{b}	34.4±0.83^{b}	10.1±0.89^{b}	7.40±0.10^{b}	0.61±0.06^{b}	0.44±0.05^{b}
POL	1.28±0.03^{c}	44.2±0.63^{b}	34.2±1.01^{b}	9.7±1.04^{b}	6.72±0.11^{c}	0.60±0.08^{b}	0.41±0.02^{b}
UNG	1.44±0.02^{a}	34.0±0.46^{c}	27.0±0.23^{c}	8.8±1.46^{b}	4.99±0.03^{d}	0.49±0.03^{b}	0.31±0.01^{c}

PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG – Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.).
*indicate that the values within a column are significantly different at p<0.05.

Estimating SOC Storage

The equation to calculate SOC storage is as follows [30- 32]:

$$SOC_i = C_i \times D_i \times T_i \times (1-\rho)/10 \quad (1)$$

...where SOC_i is SOC storage ($t·hm^{-2}$) at the i soil layer (soil layer is 0-10 cm or 10-20 cm); C_i is SOC content ($g·kg^{-1}$) at the i soil layer; D_i is bulk density ($g·cm^{-3}$) at the i soil layer; T_i is soil depth (cm) at the i soil layer (T_i =10 cm or 20 cm); ρ is the gravel content (volume percent, %) at the i soil layer, and it can be neglected if ρ is lower than 10% (> 2 mm).

$$TSOC = \sum_i SOC_i \quad (2)$$

...where *TSOC* is the total SOC storage ($t·hm^{-2}$) of the soil layer (0-20 cm), it is the sum of the layers of the SOC storage.

Statistical Data Analyses

A one-way ANOVA (SPSS 17.0) [33] was used to compare the effects of the four afforestation systems and the UNG on the SOC distribution characteristics. The LSD procedure was used to separate the means of these soil properties from layers 0-10 cm and 10-20 cm in each afforestation system, and the UNG at significance levels of p<0.05 and 0.01. The results are expressed as the mean values ±SE of the soil sample observations from layers 0-10 cm and 10-20 cm in each afforestation system and the UNG.

Results

The Physical and Chemical Properties of Soil in the Afforestation Systems

The soil bulk density of the four afforestation systems was 1.20-1.28 $g·cm^{-3}$ and the total porosity was 44.1%-52.3% (Table 2). The soil bulk density order was UNG > POL > PPM > PCM > PRM. The soil bulk density of the UNG was 16.36% higher than the average of the four afforestation systems. The soil total porosity order was the opposite of the bulk density as follows: PRM > PCM > PPM > POL > UNG. The average total porosity, capillary porosity, and non-capillary porosity of the four afforestation systems were 36.53%, 31.25%, and 26.39% higher, respectively, than that of the UNG. Therefore, the soil bulk density of the four afforestation systems was lower than that of the UNG, whereas the total porosity, capillary porosity, and non-capillary porosity were higher than that of the UNG. This observation indicated that the soil structure was improved after afforestation and had a decreased bulk density and increased porosity. In addition, among the four afforestation systems, the PRM system showed the most significant soil improvement, followed by the PCM, PPM, and POL. The ANOVA results indicated that soil bulk density, total porosity, and capillary porosity of the four afforestation systems were significantly different (P<0.05) than that of the UNG. Soil bulk density, total porosity, capillary porosity, and non-capillary porosity of the PRM were significantly different than those of the other three afforestation systems (P<0.05), and several of the physical properties of the PCM, PPM, and POL showed insignificant differences (P>0.05).

Moreover, the ANOVA results showed that soil organic matter, soil total nitrogen, and soil total phosphorus of the four afforestation systems were significantly different (P<0.05) than that of the UNG, and that of the PRM were significantly different (P<0.05) than those of the other three afforestation systems. These results indicated that there was a significant enhancement in the soil nutrient content after afforestation in the UNG. The soil nutrient content of the PRM was the highest, followed by the PCM and PPM and then the POL.

The Distribution Characteristics of the SOC Content in the Afforestation Systems

The SOC content at the 0-10 cm soil depth of the four afforestation systems and the UNG were higher than that of

Table 3. SOC content of different afforestation systems in the study area.

Depth of soil layer (cm)	SOC content (g·kg^{-1})				
	PRM	PCM	PPM	POL	UNG
0-10	6.7±0.19^{a}*	5.8±0.08^{b}	5.7±0.22^{b}	5.4±0.18^{c}	3.8±0.13^{d}
10-20	3.5±0.06^{e}	2.8±0.13^{f}	2.8±0.08^{f}	2.5±0.15^{g}	2.0±0.06^{h}
Average value (0-20)	5.1±0.09^{a}	4.3±0.10^{b}	4.2±0.11^{b}	3.9±0.11^{c}	2.9±0.03^{d}

PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG – Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.). SOC – Soil organic carbon.
*indicate that the values within a column are significantly different at p<0.05.

the 10-20 cm soil depth (Table 3). Among them, the SOC content of the 10-20 cm soil depth in the POL decreased by 53.7% in comparison with that of the 0-10 cm soil depth; this discrepancy was the greatest of the four afforestation systems, with the SOC content in the PCM, PPM, and PRM decreasing by 51.7%, 50.9%, and 47.8%, respectively. Moreover, the results also showed that there was variation in the SOC content (0-20 cm) among the four afforestation systems, but they all had higher SOC contents than that in the UNG. The ANOVA results showed that there was a significant difference in the SOC content between the PRM and the other three afforestation systems (P<0.05), whereas there was no significant difference in the SOC content between the PCM and PPM (P>0.05).

SOC Storage in the Afforestation Systems

Among the four afforestation systems, the PRM at the 0-20 cm soil depth had the highest SOC storage 12.40 t·hm^{-2} (Fig. 2), which was 44.7% higher than that of the UNG and followed by PCM and PPM of 11.30 t·hm^{-2} and 10.71 t·hm^{-2}, and which were 31.8% and 24.9% higher than that of the UNG. The SOC storage was the lowest in the POL 10.26 t·hm^{-2}, which was still 19.7% higher than that of the UNG. The ANOVA results showed that there was a significant difference in the SOC storage between the four afforestation systems and the UNG (P<0.05), and the differences between the PRM and the other afforestation systems were significant (P<0.05). However, the differences among the other three systems were not significant (P>0.05).

Correlation Analysis between the SOC Content and Soil Particles Composition in the Afforestation Systems

Based on the U.S. soil particle size grading system, this study classified the soil particles of the four afforestation systems and UNG in the study area (Table 4). The highest content was of sand particles (0.05-2 mm), which was between 56.0-82.5% of the total, with an average of 68.7%. The soil particle content of silt was 9.3-34.2% (0.002-0.05 mm), averaging 24.5% and the clay was 1.4-4.6% (<0.002 mm), averaging 3.3%.

A correlation analysis was conducted on the soil particle content and SOC content in the four afforestation systems, and the results indicated that there was a significantly positive correlation between the clay particle content of the soil and the SOC content (Fig. 3 A), which had a corre-

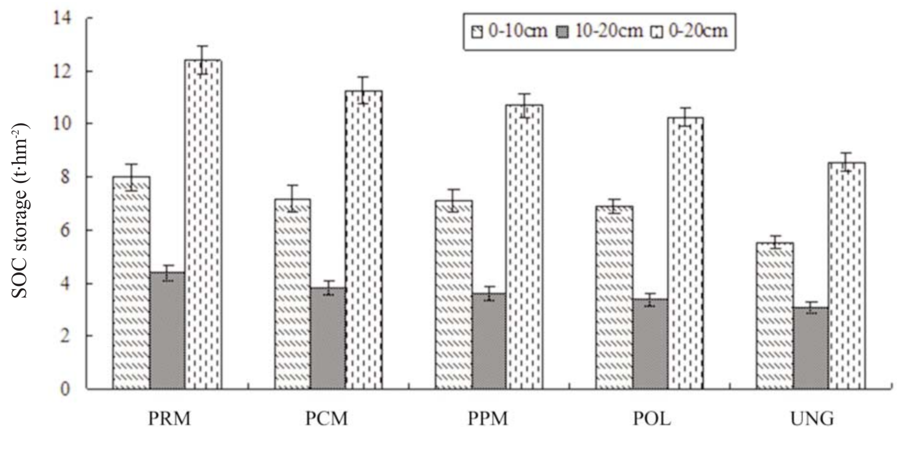


Fig. 2. Effect of different afforestation systems on SOC storage in the study area
PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG –Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.). SOC – Soil organic carbon.

Table 4. Soil particle compositions of different afforestation systems in the study area.

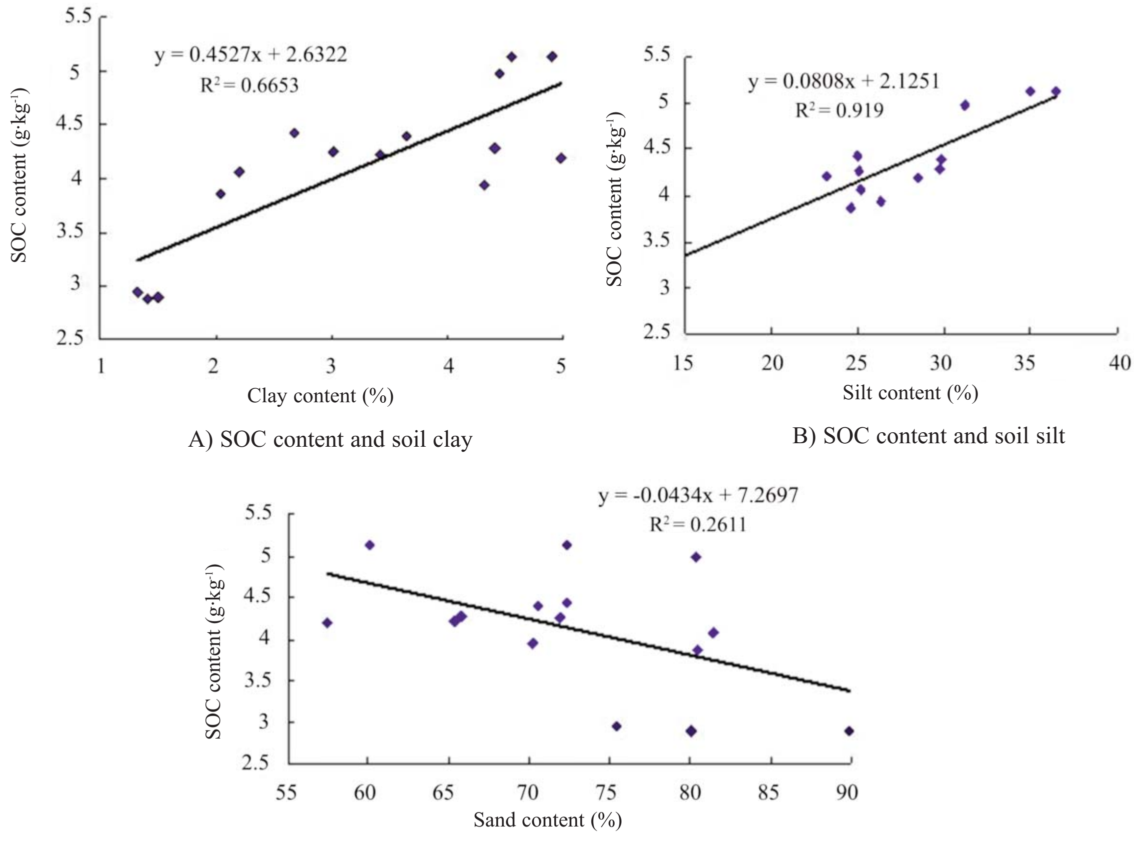
Afforestation systems	Sand volume content (%)					Slit volume content (%)	Clay volume content (%)
	Very coarse sand	Coarse sand	Sand	Fine sand	Very fine sand		
	1-2 mm	0.5-1 mm	0.25-0.5 mm	0.1-0.25 mm	0.05-0.1 mm	0.002-0.05 mm	<0.002 mm
PRM	3.5±0.19[a]*	4.4±0.23[a]	15.4±0.96[a]	23.6±1.20[a]	10.4±0.72[a]	34.2±2.25[a]	4.6±0.24[a]
PCM	5.8±0.27[a]	26.4±1.40[b]	22.1±1.05[b]	12.4±0.82[b]	5.2±0.35[b]	29.4±2.03[a]	4.3±0.22[a]
PPM	8.9±0.31[b]	14.3±0.86[c]	24.1±1.12[c]	20.9±1.01[c]	7.6±0.41[c]	24.4±1.35[b]	3.0±0.17[b]
POL	2.2±0.13[c]	8.5±0.30[d]	18.6±1.02[d]	18.4±1.01[d]	8.4±0.43[d]	25.4±1.42[c]	2.7±0.15[b]
UNG	8.1±0.29[c]	24.4±1.15[e]	26.9±1.48[e]	18.1±0.97[e]	5.0±0.28[e]	9.3±0.37[d]	1.4±0.10[c]

PRM – *Platycladus orientalis* Linn. and *Robina pseudoacacia* Linn. mixed plantation; PCM – *Platycladus orientalis* Linn. and *Cotinus coggygria* Scop. mixed plantation; PPM – *Platycladus orientalis* Linn. and *Prunus armeniaca* Mill. mixed plantation; POL – *Platycladus orientalis* Linn.; UNG – Unused grassland (the species in the unused grassland are *Zoysia japonica* Steud., *Rubia manjith* Roxb. ex Flem., *Themeda japonica* Tanaka and *Setaria viridis* (Linn.) Beauv., etc.).
*indicate that the values within a column are significantly different at $p<0.05$.

lation coefficient of 0.816 and a regression equation of Y=0.4527X+2.6322. There was a significantly positive correlation between the silt particle content of the soil and the SOC content (Fig. 3 B), which had a correlation coefficient of 0.959 and a regression equation of Y=0.0808X+2.1251. There was a non-significant negative correlation between the sand particle content of the soil and the SOC content (Fig. 3 C), which had a correlation coefficient of 0.511 and a regression equation of Y=-0.0434X+7.2697.

Correlation Analysis between the SOC Content and Other Physical and Chemical Properties in the Afforestation Systems

Our study employed four afforestation systems to investigate the relationship between SOC and certain physical and chemical property indices, such as soil total nitrogen, soil total phosphorus, soil bulk density, and soil porosity (Table 5). There was a significantly positive correlation



A) SOC content and soil clay

B) SOC content and soil silt

C) SOC content and soil sand

Fig. 3. Relationship between SOC content and soil particle compositions of different afforestation systems.
SOC – Soil organic carbon.

Table 5. Correlation analysis between SOC and soil physical-chemical properties of different afforestation systems.

Parameter types	SOC content	SOC density	Total nitrogen	Total phosphorus	Bulk density	Total porosity
SOC content	—	0.995**	0.735**	0.873**	-0.935**	0.971**
SOC density		—	0.716**	0.862**	-0.926**	0.968**
Total nitrogen			—	0.576*	-0.786**	0.751**
Total phosphorus				—	-0.812**	0.886**
Bulk density					—	-0.927**
Total porosity						—

SOC – Soil organic carbon.
*indicate that the values within a column are significantly different at $p<0.05$,
**indicate that the values within a column are significantly different at $p<0.01$.

between the SOC content and total soil nitrogen, total soil phosphorus, and total soil porosity, which had correlation coefficients of 0.735, 0.873, and 0.971, respectively. There was also a significantly negative correlation between the SOC content and soil bulk density, which had a correlation coefficient of -0.935.

Discussion

The Impact of the Afforestation Systems on SOC Content

The release of nutrients from the microbial decomposition of plant residue is one of the important energy sources of forest SOC. There is a significant difference in the SOC of different vegetation types. Some studies have shown that carbon storage at the 0-40 cm soil depth provided 35-80% of the storage for the 0-100 cm soil depth and contained an average of 57%, which was more than half of the total forest total storage distribution [34]. Some studies have also shown that meadow and forest vegetation had the highest SOC content, which was followed by shrub, farmland, prairie, and desert, and the SOC content at the 0-10 cm soil for hazelnut shrubs and artificial larch forest was 62.05% and 74.47% higher, respectively, than it was at the 10-20 cm soil [35]. Our study used four afforestation systems and the UNG to investigate SOC content, and we found that it was primarily concentrated in the 0-10 cm soil. The SOC content in the 0-10 cm soil in the four afforestation systems were approximately 0.89-1.16 times higher than they were in the 10-20 cm soil, and the POL showed the greatest difference in SOC content (1.16 times) at the different soil levels, whereas the PRM showed the least difference in SOC content (0.89 times) at different soil depths. These were basically consistent with the above studies. It may because there was a very thick forest litter layer in the 0-10 cm soil of the four afforestation systems, which were easily resolved and beneficial to SOC accumulation [36].

The types of vegetation in the four afforestation systems showed that the SOC content in the conifer and broad-leaf mixed plantation was higher than that of the pure coniferous plantation, which were basically consistent with those found by Maraseni and Pandey [12]. This was primarily because the broad-leaf litter was easily decomposed in the mixed plantation and increased the humus content in the soil, thereby improving the soil structure and enhancing the SOC content [37, 38]. The 7-year-old conifers such as *Platycladus orientalis* (L.) and *Pinus thunbergii* Parl. are still in their young forest period, and their age may partly influence the results. Next, we will continue to monitor the afforestation effects of the four afforestation systems to check these results.

The Impact of the Afforestation Systems on SOC Storage

Studies have shown that the spatial and temporal difference in vegetation related to different land use and vegetation coverage causes significant differences in the accumulation of SOC [39]. Moreover, the study indicated that SOC storage in the *Larix gmelinii* plantation was significantly higher than in the *Pinus sylvestris* var. *mongolica* plantation, which showed that different tree types could have different impacts on SOC storage [40]. Our study found that SOC storage was enhanced by the four afforestation systems in comparison with that of UNG, which was basically consistent with those found by Don et al. [9] and Maraseni and Pandey [12]. With regards to the different soil depths, SOC storage at the 0-10 cm soil depth in the four afforestation systems was higher than that of the 10-20 cm soil depth. It could be that more fresh litter was included in the 0-10 cm soil depth than that of the 10-20 cm soil depth. Our research results were consistent with those found by Miao et al. [41].

The Correlation of the SOC Content and Soil Properties in the Afforestation Systems

Soil particle composition is one of the basic properties of soil, and to a certain extent it reflects the soil structure and properties [42, 43]. Our study showed that the clay and silt particle contents of the four afforestation systems were higher than the values in the UNG soil, whereas the sand particle content was lower than that of the UNG soil. These results were consistent with the results of Yang et al. [44]. Moreover, the results indicated that there was a significantly positive correlation between the clay (or silt) particle content of the soil and the SOC content, but there was a non-significant negative correlation between the sand particle content in the soil and the SOC content.

Forest SOC is impacted by various factors [45, 46]. He et al. conducted a study in the Qilian Qinghai spruce forest to investigate the SOC characteristics and impact factors, and indicated that there was a significantly positive correlation between SOC content and soil moisture content, altitude, soil bulk density, and shrub biomass, and there was a significantly negative relationship with forest canopy density [47]. Our study indicated that there was a significant correlation between SOC content and soil total nitrogen, soil total phosphorus, total soil porosity, and soil bulk density in the four afforestation systems. This result was potentially explained by the effects of the four afforestation systems on soil structure and function in the study area. Because a higher level of soil vegetation coverage, a thicker forest litter layer, and stronger root systems (which were easily resolved and beneficial to the SOC), soil total nitrogen and soil total phosphorus accumulation in the four afforestation systems were better than the UNG to improve soil structure, and so as to make the total soil porosity and non-capillary porosity of the four afforestation systems higher than that of the UNG, the soil bulk density of the four afforestation systems was lower than that of the UNG.

Conclusions

1. Different afforestation systems had a relatively large impact on soil properties. In comparison with the UNG soil, the soil properties (soil bulk density, soil porosity, soil organic matter content, soil total nitrogen, and soil total phosphorus) of the four afforestation systems showed significant improvement. Moreover, the effective improvements in the mixed afforestation systems were greater than that in the pure afforestation systems.
2. Different afforestation systems had a significant effect on SOC content of the four afforestation systems, showing significantly higher SOC content than the UNG, and those parameters were significantly higher at the 0-10 cm soil depth than at the 10-20 cm depth. Moreover, the SOC content of the four afforestation systems was ordered PRM > PCM > PPM > POL > UNG. This indicated that for the SOC content, the mixed afforestation system was higher than the pure afforestation system, and the pure afforestation system was higher than the unused grassland.
3. Different afforestation systems had a significant effect on SOC storage. The highest SOC storage was PRM, followed by PCM, PPM, and POL, respectively.
4. In the four afforestation systems, the SOC content showed a significant positive correlation with the silt and clay particle content of the soil and a non-significant negative correlation with sand content. In addition, the SOC content showed a significantly positive correlation with total soil nitrogen, total soil phosphorous, and total soil porosity, and a significantly negative correlation with soil bulk density.

The results showed that the mixed afforestation system has a greater impact than the pure afforestation system on SOC, and that PRM had the most influence. These will provide some reference for vegetation choice in the rocky mountain area.

Acknowledgements

Our study was supported by the Special Fund for Forestry Scientific Research in the Public Interest (Nos. 201204101 and 201404303). In addition, this paper was supported by CFERN and GENE Award Funds for Ecological Papers.

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