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Effects of soil improvement of *Caragana intermedia* plantations in alpine sandy land on Tibet Plateau

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ABSTRACT

The restoration of vegetation is an important measure to combat land desertification. In this process, the distribution of soil water, soil organic matter and soil available nutrient may be affected by vegetation. *Caragana intermedia*, a leguminous shrub, is one of the major species widely planted to fix the moving and semi-moving sand dunes in the alpine sandy land in Gonghe Basin on Tibet Plateau. The objective of this study was to determine how soil conditions on sand dune were affected by *C. intermedia* plantation after this shrub grows up. Effects of the plantation age on soil water content (SWC), soil organic matter (SOM) content and available nutrient content were examined in four ages of *C. intermedia* plantation, e.g. 3-, 11-, 25-, and 37-year-old. Soil samples were collected for four replicates from six depths (0–5 cm, 5–10 cm, 10–20 cm, 20–50 cm, 50–70 cm and 70–100 cm) at leeside of the plant. The results showed that: (1) SWC of 25- and 37-year-old *C. intermedia* plantations was significantly higher than 3- and 11-year-old plantations in 0–10 cm and 10–20 cm ($P < 0.05$). (2) SOM content of 25-year-old *C. intermedia* plantation was significantly higher than 3-, 11- and 37-year-old *C. intermedia* plantations in 10–20 cm ($P < 0.05$). With the increase of plantation age, ammonium nitrogen (NH_4^+—N) content of *C. intermedia* plantation increased significantly in 10–100 cm ($P < 0.05$). The nitrate nitrogen (NO_3^-—N) content of 3-, 11- and 25-year-old *C. intermedia* plantations in 0–50 cm increased significantly with the increase of plantation age ($P < 0.05$); however, the NO_3^-—N content of 37-year-old *C. intermedia* plantation decreased significantly ($P < 0.05$). The available phosphorus (P) content of 3-, 11- and 25-year-old *C. intermedia* plantations in 20–100 cm significantly decreased with increasing plantation age ($P < 0.05$). The available *P* content of 25-year-old *C. intermedia* plantation was significantly lower than the other three ages of plantation in 20–100 cm ($P < 0.05$). The available potassium (K) content of 25-year-old *C. intermedia* plantation in 20–50 cm and 50–70 cm was significantly lower than the other three ages of plantations ($P < 0.05$). (3) Two-way ANOVA analysis showed that SWC, SOM, NH_4^+—N, NO_3^-—N, available *P* and available *K* content were affected significantly by plantation age ($P < 0.001$). Therefore, soil property on sand dune could be improved after the establishment of *C. intermedia* plantation in alpine sandy land of Gonghe Basin, including water, organic matter and nitrogen. However, phosphorus and potassium in soil was consumed by plant after *C. intermedia* plantation grows up.

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1. Introduction

Land degradation is one of the most serious ecological problems in the world and concerned by most countries. Desertification is a type of land degradation occurred in arid, semi-arid and part of semi-humid areas. It is induced by the un-coordination between population and land, which the main characteristics are sand mobility and wind erosion [1]. China is one of the countries seriously affected by desertification [2]. Vegetation recovery has been implemented in most area of the northern China to reduce the damage from desertification. Shrub is one of the main types of vegetation restoration in desertified land, which can improve soil properties and promote soil fertility recovery [3]. For instance, in Horqin sandy land, soil nitrogen, phosphorus and potassium contents are improved [4], and soil water holding capacity is also enhanced with the development of *Caragana microphylla* community [5]. In Yulin sand area, soil organic matter (SOM), total nitrogen (N), available phosphorus (P) and available potassium (K) content are significantly increased in five types of sand fixing plantation (*Salix psammophila*, *Hedysarum scoparium*, *Hedysarum fruticosum*, *Amorpha fruticosa* and *Caragana korshinskii*) [6]. In Tengger Desert, with the increase of recovery time, soil water content (SWC) and total nitrogen content are improved in artificial shrub ecosystem

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[7]. These studies mainly focused on the impact of plant species, soil depth and recovery time on soil improvement.

Caragana intermedia Kuang et al., Fu is a perennial leguminous shrub which resistant to drought, has strong adaptability and grow vigorously. It is not only an important xerophytic shrub with property of wind proof, sand-fixation, water and soil conservation [8], but also a valuable pasture. Previous studies have been conducted on the distribution, genetic diversity, physiological and ecological characteristics of *C. intermedia*. The results showed that *C. intermedia* is suitable to distribute in Mongolia Plateau, Ordos Plateau and northern Loess Plateau [8]. The genetic diversity of *C. intermedia* is decreasing from east to west in Inner Mongolia Plateau [9]. *C. intermedia* resist to drought from physiological regulation in Huangfuchuan Basin [10]; moreover, the net photosynthetic rate and transpiration rate of middle-age shrubs are higher than old-age shrubs [11]. In the gully regions of Loess Plateau, the solar radiation intensity is the key factor affecting stem sap flow of *C. intermedia* [12]. In the sandy land of Gonghe Basin on Tibet Plateau, *C. intermedia* plantation can increase water use efficiency to resist drought stress [13], and juvenile plantation uses shallow soil water whereas mature plantation uses deeper soil water. Moreover, the main water source of *C. intermedia* plantations of different ages is affected by their root distribution [14]. However, little attention has been paid to evaluate the effects of soil improvement of *C. intermedia*. Therefore, this study was conducted to determine the soil improvement effects of different ages of *C. intermedia* plantation. It was hypothesized that with the increase of plantation age, soil water content (SWC), soil organic matter (SOM) and nitrogen (N) content increase, but phosphorus (P) and potassium (K) content decrease in *C. intermedia* plantation. This study could provide a reference for the sustainable management of sand fixing plantation, and give theoretical supports for the wide establishment of *C. intermedia* plantation in alpine sandy land in the future.

2. Materials and methods

2.1. Study site

This study was conducted in the Desertification combating experimental site of the Qinghai Gonghe Desert Ecosystem Research Station (E 99°45′–100°30′, N 36°03′–36°40′, altitude 2871 m). It is one of the stations in the Chinese Desert Ecosystem Research Network of the State Forestry Administration of PR China. The station is located in Gonghe Basin on northeastern Tibet Plateau. The administrative region of the station is in Shazhuyu town of Gonghe County, Qinghai Province. The climate in study area is a plateau continental climate with a mean annual temperature of 2.4 °C, a mean annual precipitation of 246.3 mm and a mean potential evaporation of 1716.7 mm. The mean annual frost-free period is only 91 days. The total solar radiation is 6631.69 MJ m^{-2} a^{-1}. The mean annual gale days is 50.6 d, up to 97 days, and the mean annual sandstorm days is 20.7 d. The mainly wind direction is west and northwest. The mean annual wind speed is 2.7 m s^{-1} and the maximal wind speed is up to 40 m s^{-1}. The zonal soils are chestnut soil and brown soil and the a-zonal soils are aeolian sandy soil, meadow soil and bog soil. The main vegetation type is sand fixation plantation in research area, including tree species, e.g. *Populus cathayana* and *Populus simonii*, and shrub species, e.g. *C. intermedia*, *Caragana korshinskii*, *Hippophae rhamnoides*, *Salix cheilophila*, *Tamatix chinensis* and *Salix psammophila*.

2.2. Experiment design and soil sampling

Field study was conducted in early August 2011. The similar plots (20 m × 20 m) were selected in 3-, 11-, 25-, and 37-year-old *C. intermedia* plantations respectively as the sample sites. The slope, aspect, elevation and other natural factors were carefully considered when plots were selected to ensure their topography features roughly consistent. The morphological characteristics of *C. intermedia* were measured in each plot, included height (the height of the highest shoots), crown diameter (the maximum diameter of the shrub canopy from east–west and north–south) and ground diameter (the maximum diameter of the shrub shoot from east–west and north–south). The morphological characteristics of *C. intermedia* are shown in Table 1.

Soil was sampled in four 5 m × 5 m quadrats which were set up in four corners of each 20 m × 20 m plots. A standard shrub was selected according to the average morphological features in different ages of *C. intermedia* plantation as soil sampling location. Soil was collected in three equidistant sampling points, which were set up at leeside of each standard shrub and at the edge of the canopy. The soil samples were collected at depth of 0–5 cm, 5–10 cm, 10–20 cm, 20–50 cm, 50–70 cm and 70–100 cm using a 5-cm diameter soil auger. Three soil samples at the same depth were uniformly mixed to one sample. Some soil sample was put into aluminum box for SWC measurement, and the other soil sample was collected by zip-lock bag and taken back to laboratory, air-dried for soil nutrients measurement.

The fresh mass of soil samples in aluminum box were measured by the electronic balance (0.01 g). The dry mass of soil samples were measured after they were dried at 105 °C for 24 h. SWC of soil samples was calculated by the equation as bellows: SWC = (Fresh mass − dry mass)/dry mass. Roots and other debris were removed from soil samples for nutrient measurement, and then soil was grinded by a micro-pulverizer. Half of each sample was filtrated using a 0.15 mm sieve for SOM analysis, and the other half was filtrated using a 0.25 mm sieve for ammonium nitrogen (NH_4^+—N), nitrate nitrogen (NO_3^-—N), available *P* and available *K* analysis. The SOM was determined by the $K_2Cr_2O_7$–H_2SO_4 heating method. Soil NH_4^+—N was determined by the $C_7H_6O_3$–NaClO method, and soil NO_3^-—N was determined by the phenol disulfonic acid colorimetric methods. Soil available *P* was determined by the $NaHCO_3$ method and available *K* was determined by the $C_{24}H_{20}BNa$ method.

2.3. Statistical analysis

The SPSS 16.0 software was used for all statistical analyses. One-way ANOVA was used to compare the morphological characteristics of *C. intermedia* among different ages of plantations and Duncan's test was used to evaluate differences among the means. Two-way ANOVA was used to analyze the effects of plantation age, soil depth and their interactions on SWC, SOM and available nutrient content of *C. intermedia* plantations.

3. Results

3.1. Variation of SWC in different ages of C. intermedia plantations

The SWC was significantly affected by plantation age at depth of 0–5 cm, 5–10 cm, 10–20 cm and 70–100 cm ($P < 0.05$) (Fig. 1). The SWC of 25- and 37-year-old plantations were significantly higher than 3- and 11-year-old plantations, and the SWC of 25-year-old plantation was significantly higher than 37-year-old plantation at depth of 0–5 cm, 5–10 cm and 10–20 cm ($P < 0.05$). The SWC of all plantations were significantly affected by soil depth ($P < 0.05$). The SWC of 3-, 11- and 37-year-old plantations at depth of 5–10 cm were significantly higher than 0–5 cm ($P < 0.05$). The SWC of 25- and 37-year-old plantations at depth of 0–5 cm, 5–10 cm and 10–20 cm were significantly higher than the other depths ($P < 0.05$). Two-way ANOVA analysis showed that SWC

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