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Response of soil physical, chemical and microbial biomass properties to land use changes in fixed desertified land

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ABSTRACT

Fixed dunes are indicators of successful recovery of desertified land after several years of vegetation restoration. Land use profoundly influences soil properties; however, the effects of changes in land use, after the dunes are fixed, on soil physical, chemical and microbial biomass properties are still unclear. This study investigates the soil physical and chemical properties and soil microbial biomass in a desertified land located in the Xiaojihan desertification control station in northern Shaanxi province, where land use changed from shrub land to arboreal land, arable land and nursery garden. No significant changes in soil properties were found when shrubland was changed to arboreal land. However, changing the fixed desertified land from shrub land to arable land and nursery garden decreased soil porosity, but significantly increased soil bulk density (BD), soil organic matter (SOM), cation exchange capacity (CEC), total nitrogen (TN) and available nutrients (N, P, K). Soil microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP), as well as microbial quotient (MBC/SOC, MBN/TN, MBP/TP), decreased significantly. No significant changes were detected in soil texture, total phosphorus (TP) and total potassium (TK). Results of this study indicated that agricultural land use can improve the fertility of fixed desertified land; however, soil microbial biomass could decrease. Therefore, conversion of fixed dunes to agricultural usage is full of risks.

1. Introduction

Vegetation restoration is a critical and effective measure to control desertification and recover degraded ecosystems (An et al. 2009; Qi et al. 2015; Zhang and Shangguan 2016). The interaction between soil and vegetation systems during the process of vegetation restoration stabilizes soil and adds organic matter and nutrients. Calcium carbonate cementation takes place and results in root constraint. Soil biological crust can also develop, and mobile dunes gradually become fixed (Zhang et al. 2009; Fu et al. 2010; Xiao et al. 2017). Many studies have emphasized the importance of evaluating the success of vegetation restoration in desertified areas (Huang et al. 2007; Ge et al. 2016), which can be done by measuring changes in soil physical, chemical and biological properties (Li et al. 2007; Jiao et al. 2011; Qi et al. 2015). However, monitoring and assessment should focus not just on these properties but also on soil microbes (Ma et al. 2017; van Leeuwen et al. 2017; Zhou et al., 2017).

Microbes improve soil quality and recycle soil nutrients by decomposing plant residue and converting it to soil organic matter (SOM) and soil humus (He et al. 2003; Xue et al. 2007). Microbial activities affect soil development, and improve soil fertility and soil ecoenvironmental quality; however, soil microbes is sensitive to environmental variation (Davidson and Ackeman, 1993). Researchers agree that microbes are indicators of environmental change. Analyzing soil microbial characteristics is a valuable approach to assess the effectiveness of vegetation restoration in desertified areas, and to evaluate the suitability of different vegetation restoration types (Wu et al., 2014a). Microbial quotient refers to the portion of microbial biomass carbon, nitrogen and phosphorus in the total organic carbon, nitrogen and phosphorus pool (Sparling 1992). In recent years, although inconsistent, microbial quotient is shown to indicate the degree to which soil organic carbon was associated with and utilized by soil microbes (Zhou et al., 2017). It could be taken as a key indicator to understanding microbial health with ecosystem succession (Bastida et al. 2008), under human influence or under environmental stresses (Wardle and Ghani 1995).

Land use is a crucial factor affecting ecological restoration and soil quality in ecologically degraded areas (Hu et al. 2010; Bouchoms et al. 2016). Differences in human activities and vegetation have a strong

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influence on the changes in biological properties and stand structure. Biomass and litter types affect SOM, soil nutrients and microbial biomass (Tosi et al. 2016). Field observations in the loess plateau and red soil hilly areas in China prove that, when done properly, vegetation restoration leads to increases in soil nutrients and microbes (Zhang et al. 2010; Liu et al., 2010; Yin et al. 2014). Vegetation restoration increases nutrient accumulation in the top soil layer, and enhances microbe populations and activities (Hu et al. 2016). Climate and human management significantly affect growth of vegetation, decomposition of litters, accumulation of soil nutrients and activity of microbes (Rosenzweig et al. 2016).

After years of vegetation restoration and desert land fixation, the final step is to find a fitting land use to obtain higher economic results. There are several successful examples of desert land rehabilitation through vegetation restoration and oasis farming. For example, in the Xinjiang Uygur autonomous region of China, the oasis area has increased from 71,380 km^2 in 1950 to 161,020 km^2 in 2014 after years of vegetation restoration (Wu et al., 2014b). About 90% of the oasis area is under agricultural land use practicing water conservation techniques. In the desert area, even for the fixed desert land, the ecological environment is fragile, effects of land use on the soil-microbes-vegetation system are full of uncertainties, and response of soil nutrients and microbial biomass on land uses needs further investigations in the desertification area (Pu et al. 2015).

The northern Shaanxi province, an agro-pastoral transitional zone, is one of the most seriously desertified areas in China. Since the 1950s, two projects—the “Three Norths Forest Shelterbelt Program” and the “Grain-for-Green Project”—have been implemented to control desertification (Oñate and Peco 2005; Liu et al. 2008). Many studies have evaluated the performances of the restoration projects by studying vegetation, soils, hydrology and wildlife (Huang et al. 2007; Pei et al. 2008; Qi et al. 2012). In contrast, limited information is available on the effects of restoration projects on the soil microbial biomass. Few studies have paid attention to the relationship between soil nutrients and microbial biomass due to land uses changes (Zhang et al. 2015; Hu et al. 2016). The aim of this paper is to assess the response of soil physical and chemical properties and microbial biomass carbon, nitrogen and phosphorus when shrubland in a fixed desertified land was changed to arboreal land, arable land and nursery garden.

2. Materials and methods

2.1. Research area

The research area, Xiaojihan desertification control station, is located in an agro-pastoral transitional zone in northern Shaanxi Province, China. The Mu Us Desert is to the north of the research area and the loess plateau is to the south (Fig. 1). The research area has predominantly sandy flat topography, and a typical continental semi-arid climate with annual average temperature of 8.3 °C and mean annual precipitation of 365.7 mm. The control station was established in 1958 by the local government to control the expansion of the Mu Us desert. After more than half a century of recovery, about 30,000 ha of dunes have been fixed, including about 24,000 ha of arboreal land, about 4000 ha of shrubland, about 1500 ha of arable land and about 500 ha of nursery garden.

2.2. Sample unit selection, sample collection and analysis

All four land use units—shrubland, arboreal land, arable land and nursery garden—were established in 1976 on a bare sand area. These four units are located near the center of the desert control station (Fig. 1; Table 1). The first unit is a shrubland transformed from a 15-year-old fixed dune by straw checkerboard barrier method with an area of 500 × 680 m. The second unit is arboreal land transformed from a 10-year-old shrubland previously under fixed dunes for 15 years, occupying an area of 400 × 600 m. The third unit is the arable land transformed from a 20-year-old shrubland previously under fixed dunes with an area of 400 × 900 m. The arable land was ploughed, fertilized, irrigated and planted with corn (*Zea mays* L.) every year since 1996. The forth unit is a nursery garden transformed from shrubland in the year 2000 (previously under fixed dunes) with an area of 500 × 800 m. The nursery garden was planted with nursery stocks, and has been ploughed, fertilized and irrigated each year since 2000.

Prior to soil sampling on August 10, 2014, three 5 × 5 m plots were established under each land use, and soil samples were collected from each plot. Three 50 cm deep soil pits were dug in each plot, and soil layers were divided into 0–10 cm and 10–50 cm for shrubland, arboreal land and nursery garden, while soil layers were divided into 0–18 cm, 18–40 cm and 40–50 cm for arable land because distinct plow and plow pan layers were observed. Large triplicate soil samples (each about 2 kg in-situ weight) were collected using a shovel from each plot and layer under each land use, for a total of 18 samples (3 pits × 3 plots × 2 layers) from shrubland, arboreal land and nursery garden. Additionally, 27 samples (3 pits × 3 plots × 3 layers) were collected from arable land. These samples were collected in zip-top plastic bags. The entire sampling area is contiguous, and the four sample units are located next to each other (Fig. 1).

Gravimetric soil moisture content was determined by drying at 105 °C a small subsample of soil at each location, separately (Lu 2000). Air-dried soil samples were passed through a 2-mm sieve. Pipette method was used to determine the particle size distribution (Lu 2000). Soil cores (volume = 100 cm^3) were oven-dried at 105 °C for 24 h, and dry weight of soil was obtained. Soil bulk density (BD) was calculated as the ratio of dry soil weight and the volume of the soil (CAS, 1978). Total soil porosity (P_t) was obtained from known BD and soil particle density (2.65 g cm^{-3}) (Qi et al. 2015). Soil organic matter (SOM) content was determined by the dichromate-wet combustion method (Nelson and Sommers 1982), total nitrogen (TN) by the Kjeldahl method (Bremner and Mulvaney 1982) and available nitrogen (AN) by the alkali diffusion method. Total phosphorus (TP) content was measured colorimetrically with ammonium molybdate after acid digestion. Soil available phosphorus (AP) content was extracted with 0.5 mol L^{-1} $NaHCO_3$ at a pH of 8.5, and P was obtained colorimetrically by the molybdate method (Olsen et al. 1954). For total potassium (TK) content, samples were digested in hydrofluoric acid and perchloric acid. Soil available potassium (AK) content was determined by extraction with 1 N ammonium acetate and using an atomic absorption spectrometer (Lu 2000). A glass electrode was used to measure the soil pH in 1:2.5 soil:water suspension, and cation exchange capacity (CEC) was obtained by the sodium saturation method (Lu 2000).

The chloroform fumigation extraction method was applied to measure microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) (Vance et al. 1987). About 20 g of fresh soil sample were exposed to alcohol-free chloroform ($CHCl_3$) vapor in a vacuum desiccator containing soda lime at 25 °C for 24 h. Fumigated soil was then transferred into an empty desiccator, and residual $CHCl_3$ was removed from the fumigated soils by repeated evacuations. The fumigated soil was extracted immediately following $CHCl_3$ removal by shaking for 30 min with 50 mL 0.5 mol/L K_2SO_4. The unfumigated samples were extracted at the time of fumigation commencement. Automatic analyzers were used to measure total soil organic carbon (Shimadzu, TOC-500) and soil nitrogen (Astoria, Pacific-Inc.).

2.3. Data analysis

Statistical analyses were carried out using the SPSS software version 13.0 for Windows, and included analysis of variance (ANOVA) with least significant-difference (LSD) test. Although the experimental design was not a typical randomized design, random samples were collected from each plot and one-way ANOVA was used to examine the effects of