Catena 125 (2015) 135–145

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effects of slope aspect on soil nitrogen and microbial properties in the Chinese Loess region

Yi-Mei Huang [a,b,*], Dong Liu [b], Shao-Shan An [a]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling 712100, China
[b] Key Laboratory of Plant Nutrition and the Agri-environment in Northwest China, Ministry of Agriculture, College of Resources and Environment, Northwest A&F University, Yangling 712100, China

ARTICLE INFO

Article history:
Received 14 August 2013
Received in revised form 13 September 2014
Accepted 22 September 2014
Available online 5 November 2014

Keywords:
Caragana korshinskii
Slope aspect
Soil microbial activity
Nitrogen
PLFA

ABSTRACT

Revegetation is a very important way to improve soil quality and fertility in the hilly–gully region of the Loess Plateau, where serious soil nutrient loss and degradation due to water loss and soil erosion were experienced. The creation of an artificial forest is an important measure to restore the local vegetation. *Caragana korshinskii* (CK) is an ideal tree species in the recovery of vegetation in the Loess hilly regions because it has a strong compatibility and reproduction ability and the ability to artificially regenerate vegetatively. The slope aspects of the Loess Plateau influenced its community and asexual reproduction characteristics. Determining the relationship between the soil physicochemical properties and the soil microbial characteristics under different slope aspects can provide useful information for vegetation restoration in the Loess Plateau. This study aimed to investigate the effects of different slope aspects on soil nitrogen, soil microbial activity and community structures in a Loess hilly–gully region. According to the levels of sun exposure, four sample sites (about 35-year-old CK plantation) were selected from four different slope aspects, including sunny, shady, half-shady and hilltop slopes in the Zhifanggou watershed of Ansai (Shaanxi Province). The soil samples were collected at three different depths (0–10 cm, 10–30 cm and 30–60 cm) at each site and analyzed to determine the nitrogen (N) content, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), basal respiration (BR) and level of microbial phospholipid fatty acids (PLFAs). The slope aspect affected ($p < 0.05$) the six nitrogen forms (nitrate-N, organic N, mineralizable N, MBN, soluble organic nitrogen (SON) and ammonium-N) and the proportion of each form of nitrogen. Five of the nitrogen forms (with the exception of SON), the basal respiration (BR), the microbial quotient (MBC/total organic C) and the relative abundance of anaerobe on the shady/half-shady slopes were significantly ($p < 0.05$) greater than those on the sunny or hilltop slopes. The relative abundance of Gram-negative (G^-) bacteria and aerobes was the greatest on the shady slope. On the hilltop, the content of available P and MBP, as well as the proportion of SON and ammonium-N, was the greatest, whereas the total PLFA was the lowest. The canonical variation mainly reflected the relationship between the mineralizable N and the MBC, which were the most sensitive indicators that were related to slope changes.

1. Introduction

The Loess hilly–gully area is one of the most fragile zones in the Chinese Loess Plateau region, but it is also a key area of vegetation construction in the Loess Plateau. Due to unreasonable slope cultivation and low natural vegetation cover, the Loess Plateau is still considered to be one of the most severely eroded areas in the world (Kimura et al., 2004; Wang et al., 2006). Wind and water erosion has occurred in as much as 80% of the region. Accelerated erosion has been a constant threat to the livelihoods of rural families and a major problem for the ecosystem and environment (van den Elsen et al., 2003). In an attempt to control the soil and water losses and to improve the ecological environment of the area, the Chinese Central Government has enacted a policy entitled “Shift from Cropland to Forest or Grassland” for the restoration of vegetation since the late 1990s. Vegetation has become a tool in restoring the slope's physical condition and stability throughout the succession process (Osman and Barakbah, 2011). *Caragana korshinskii* (CK), a legume shrub, has strong reproductive and self-renewal ability and is a valuable shrub species in the hilly–gully zone of northern China (Niu et al., 2003). CK not only effectively improves the soil structure and nutrition but also significantly conserves the soil and water resources (An and Huang, 2009; Zhang et al., 2010). The environmental heterogeneity arising from slope

---

* Corresponding author at: College of Resources and Environment, Northwest A&F University, Yangling 712100, China. Tel.: +86 29 87082583; fax: +86 29 87080055.
E-mail address: ymhuang1971@nwsuaf.edu.cn (Y.-M. Huang).

http://dx.doi.org/10.1016/j.catena.2014.09.010
0341-8162/

differences greatly affects the growth, population density and water use efficiency of CK (Wang and Wang, 2010).

The soil microclimate conditions (e.g., soil temperature and moisture) on different slope types can influence the soil development and processing (Egli et al., 2006) and can affect the stability of the soil aggregate (Schoorl et al., 2004). The properties of soil are closely linked to the region from which the soil is derived (Tsui et al., 2004). In addition, slope differences can directly affect the environmental conditions of the soil, including its temperature, light exposure and moisture levels (Bennie et al., 2008; Sidari et al., 2008). The slope angle and aspect, as well as plant growth, have significant effects on the bulk density, porosity, the availability of nutrients and hydraulic conductivity of the associated soil (Wang et al., 2008). The slope aspect also has significant effects on the spatial variability of some soil physicochemical properties (Bennie et al., 2008; Sidari et al., 2008; Salehi et al., 2011) and on the productivity and species composition of hilly grasslands (Gong et al., 2008). The slope aspect and vegetation also affect the organic carbon and total nitrogen stocks in the soil (Yimer et al., 2006).

Nitrogen is one of the most important soil nutrients, and it affects the plant growth and viability, which can affect the plant water use efficiency (Sardans et al., 2008). Therefore, research into the influence of the slope aspect on the soil nitrogen is of great importance to understanding the growth and population succession of CK. Previous studies have indicated that the soil nutrient cycling is driven by microbial activity (Burke et al., 2011). The soil microbial biomass, microbial quotient and microbial physiological indices (e.g., F/B, G^+/G^-) are all sensitive bio-indicators that can be used to estimate the soil quality (Harris, 2003) and health (Zhou and Ding, 2007).

As an index of the total soil microbial activity (Insam, 1990), soil respiration quotient (qCO_2) has a great potential for improving our understanding of the development of living microbial communities in the ecosystem (Anderson and Domsch, 1990, 2010; Bastida et al., 2008). Fungi/bacteria ratio can be used as an important index that reflects physiological state of the microbial communities especially associated with organic matter transformation and storage (Bailey et al., 2002), as well as ecosystem's self-control and buffering capacity (Bardgett and McAlister, 1999; Bossio et al., 1998). To date, most studies have focused on the changes in the soil microorganisms during ecological restoration (Zhang et al., 2012; Xue et al., 2008) or the transfer of soil inorganic N on the Loess slope (Xue et al., 2013; Zhang et al., 2007). However, little is known about the different forms of N or the relationship among the soil N, the microbial biomass and the microbial diversity on different slopes that are populated by CK. The objectives of this study were, therefore, 1) to investigate the different forms of soil N and their relative abundance, as well as the microbial activity and community structures on different slopes; 2) to explore the relationship between N and microorganisms; and 3) combined with canonical correlation analysis, to identify the most significant soil N and microbial parameters associating with slope aspect change. The results from this study may offer theoretical guidance for CK reproduction and for the ecological restoration of the loess plateau.

2. Materials and methods

2.1. Study area description

The study area is located in the Zhifanggou watershed, which belongs to the Ansai Research Station of Soil and Water Conservation of Chinese Academy of Science. It is located in the northern Shaanxi Province, China (108°5′–109°26′E, 36°30′–37°39′N), with an elevation of 1010–1400 m. The mean annual temperature of the area is 8.8 °C, the mean annual precipitation is 513 mm, the aridity index is 1.48, the annual sunshine hours are 2300–2400 h, the total solar radiation is 492.95 kJ cm^{-2} and the frost-free period is approximately 160 days. The climate is a typical temperate continental semiarid monsoon climate. The region's soil is classified as a typical loess soil and is susceptible to erosion. The vegetation type is of the forest-grassland belt variety, which represents a transitional environment between the warm, temperate deciduous broadleaved forest and the dry grassland belt (Xu et al., 2009).

The Zhifanggou Watershed is located in the second sub-region of the gullied rolling Loess area. The valley is a secondary forest with an area of 8.27 km^2. In 1938, the entire basin contained 24 households, 94 people, 13.4% of the index of cultivation, a forest coverage rate of 76.5%, and a per unit area yield of grain of 1449 kg/hm^2. Due to the great increase in the population demand for food and wood, the vegetation was greatly destroyed, and the capacity of agricultural production continued to decline until 1958, when the index of cultivation was 51.5%, only fruit trees and shrubs were left in a 3.5 hm^2 area and the per unit area yield of grain was 415.5 kg/hm^2. In the early 1970s, the comprehensive experiment of small watershed management was performed in this area. Vegetation restoration measures began, and artificial forests and artificial grasslands were created according to the natural environment in the watershed. In 1986, this valley was listed as the comprehensive restoration management area of the Loess Plateau experimental demonstration zone, and it went into a sustained restoration and reconstruction period. In 2008, this valley contained 124 households, 562 people, a vegetation coverage rate of 56.53% and a per unit area yield of grain of 4289 kg/hm^2 (Wang et al., 2009). These measures gradually restored the damaged vegetation. Among the construction plantations of the region, *C. korshinskii* is the main afforestation tree species. This forest in this study was 35 years old, and the soil preparation was consistent with other CK plantations within the watershed.

2.2. Soil sampling design and sampling

In July of 2011, four different slope research sites with an area of 100 m × 100 m were selected based on their variations in sun exposure and were used as four experimental treatments termed sunny, shady, half-shady and hilltop. The geographical and undergrowth characteristics of the investigated sites are given in Table 1.

In each site, two subplots with a “S” shape random-sampling strategy, with an area of 10 m × 10 m of approximately 35 years of artificial *C. korshinskii* (CK) shrub land (with *Artemisia sacrorum* and *Lespedeza dahurica* as major vegetative species) were selected for the soil sampling and analysis. Two plots in each site were used as two replicates for each treatment. Six soil sampling points were selected in a zigzag sampling layout from each plot, and in each point, three samples were taken from depths of 0–10 cm, 10–30 cm and 30–60 cm separately by soil auger. The six soil samples were then mixed to form a pooled sample of approximately 1 kg from each depth of each plot. At the same time, six cutting ring soil samples were collected in each plot to determine the soil bulk density. The fresh soil samples were then sealed in plastic bags and transported to the laboratory on ice boxes. Parts of each sample were sieved (<2 mm) to remove large roots, stones and macro-fauna and were air dried to measure the soil physical and chemical properties. Parts of the samples were stored at −20 °C for the phospholipid fatty acid analysis or at 4 °C for the microbial biomass and basal respiration analyses.

2.3. Soil sample analysis method

2.3.1. Physical and chemical properties of the soil

The soil water content was measured gravimetrically by weighing the soil sample, drying it in an oven at 105 °C for 24 h and then re-weighing the sample. The bulk density was determined using the cutting ring method. After removing the top mineral soil with an auger or shovel and then hammering the corer to the desired soil depth, the corer was removed, and the drying soil was weighed. The volume of the corer and the bulk density were calculated by dividing the drying soil weight by the volume of the soil. The soil pH and electric conductivity were determined in a 1:2.5 soil:water slurry using a Delta