Ecological Engineering 91 (2016) 582–589

Contents lists available at ScienceDirect

Ecological Engineering

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

Assessment of the effects of phytogenic nebkhas on soil nutrient accumulation and soil microbiological property improvement in semi-arid sandy land

Chengyou Cao*, Yusuwaji Abulajiang, Ying Zhang, Shuwei Feng, Tingting Wang, Qing Ren, Hailong Li

College of Life and Health Sciences, Northeastern University, Shenyang 110169, PR China

ARTICLE INFO

Article history:
Received 24 May 2015
Received in revised form 20 February 2016
Accepted 21 March 2016

Keywords:
Biolog ecoplate
Enzymatic activity
Horqin Sandy land
Island of fertility
Phytogenic nebkha
Spatial heterogeneity

ABSTRACT

Phytogenic nebkhas formed by shrubs, widely distributed in arid and semiarid ecosystems, commonly results in the patchiness of vegetation and strongly affect the spatial distribution of soil resources. In this study, we investigated the soil nutrient contents (organic matter, total N and P, and available N, P, and K), enzymatic activities (polyphenol oxidase, phosphomonoesterase, dehydrogenase, urease, and protease), and microbial community level physiological profiles for carbon source utilization in varying soil depths in different microsites within nabkhas, under the crown, and outside nabkhas of *Caragana microphylla*, *Atraphaxis manshurica*, and *Salix gordejevii* nebkhas in the western Horqin Sandy Land in Northeast China. Our main objectives were to determine whether "islands of fertility" developed both within and under the crown of the three nabkha types, to test whether the effects of islands of fertility differ among nebkha types, and to study the spatial heterogeneities of soil microbiological properties. Soil nutrients decreased with soil depth and with the distances from the center of each nebkha. The three nebkha types all created spatially heterogeneous patterns of soil nutrient within and around the nebkhas. Island of fertility effect varied among the nebkha types. *C. microphylla* nebkha had the highest enrichment ratios in soil organic matter and available N and P, whereas *A. manshurica* had the highest ratios in total N and P, and *S. gordejevii* had the highest ratio in available K. Phytogenic nebkhas also increased soil enzymatic activities and functional diversity for carbon source utilization of soil microflora. Enzyme activities among the microsites varied with enzyme type and shrub species. Phytogenic nebkhas can be considered major sources of soil nutrient and heterogeneity in microbiological property in the semi-arid ecosystem. Thus, more attentions to the management of phytogenic nebkhas should be considered in ecological restoration practices in semi-arid regions.

1. Introduction

Desertification or land degradation in arid or semi-arid areas is attracting attention as it is a global problem affecting 25% of the total land area on earth (Kassas, 1995; Reynolds et al., 2007). Common in desertified areas are phytogenic mounds (nebkhas), usually named "fertile islands", "resource islands", or "islands of fertility" (Schlesinger et al., 1996; Carrera et al., 2003; Li et al., 2010), which prevent soil erosion and nutrient loss. Shrub nebkhas supply high concentrations of soil nutrients, thereby affecting species diversity, distributions of plant and soil microbe, and productivity of plant communities (Schlesinger and Pilmanis, 1998). Thus, shrub nebkhas are important in the ecological restoration of desertified lands. Shrub nebkhas in arid or semi-arid regions are often formed from wind and water erosions, which lead to uneven micro-topography and the patchy distribution of soil. Along with this is the accumulation of plant litter underneath the shrubs more than in the surrounding bare lands, thereby resulting in uneven distribution of soil nutrients. Spatial heterogeneity of soil properties and nutrient contents result from heterogeneous plant distribution, e.g., shrub nebkhas in arid or semi-arid land, which creates "islands" where high rate nutrient uptake and high rate of plant litter deposition in the soil occur (Rietkerk et al., 2002). Furthermore, improved environmental conditions underneath the plant crown, such as moderate temperature, higher water-holding capacity, and lower wind velocity, accelerate residue decomposition and increase

* Corresponding author.
E-mail address: caochengyou@163.com (C. Cao).

http://dx.doi.org/10.1016/j.ecoleng.2016.03.042
0925-8574/

soil nutrient contents (Aguiar and Sala, 1999; Rossi and Villagra, 2003). Studies have investigated the effect of plant-induced fertile islands on spatial variability of soil nutrients (Augustine and Frank, 2001; El-Bana et al., 2002; Li et al., 2008; Liu et al., 2011; Peng et al., 2013; Wei et al., 2013). However, fertile islands especially in sandland ecosystem, has not been sufficiently explored. How soil nutrients and microbiological properties change with soil depth within nebkhas is not yet known. Furthermore, little is known on the differences among fertile islands induced by different shrubs. Soil microbes participate in the development of “fertile islands” because they contribute to litter decomposition, nutrient cycling, enzymatic production, and aggregate stability, which affect the physical and chemical attributes of soil (Nogueira et al., 2006; Pengthamkeerati et al., 2011; Preem et al., 2012; Vasconcellos et al., 2013), However, studies on the soil enzymatic activities and microbial community level physiological profiles in nebkhas are still scarce. Horqin Sandy Land (42°41′–45°15′N, 118°35′ to 123°30′E) is a severely degraded sandy grassland in the northeast of China, where desertified land accounts for 57.8% of the total area in this region (Zhao et al., 2004). Currently, Horqin Sandy Land is one of the most severely desertified areas in China. Historically, many lakes existed in the area, and the landscape was characterized by an extended forest steppe (Zhao et al., 2004). However, with the increase in populations of domestic animals and local residents since the 1950s, the ecological landscape dramatically changed as a result of overgrazing, excessive land use, and depleted vegetation due to wood gathering for fuel. Overuse and inappropriate management of natural resources resulted in desertified grasslands. At present, the landscape is mainly characterized by an alternation of moving, semi-moving, and stabilized sand dunes. During such ecosystem conversion, shrubs, such as *Caragana mirophylla* Lam., *Atraphaxis manshurica* Kitag., and *Salix gordejevii* Chang et Skv., gradually encroached into the former grassland. The density and cover of these shrubs gradually increased, and finally many phytogenic mounds (nebkhas) formed resulting from the continuous wind erosion and aeolian accumulation. This phenomenon explains the development of the well-known “islands of fertility”. In this study, we investigated three typical nebkhas in the Horqin Sandy Land, i.e., *C. mirophylla*, *A. manshurica*, and *S. gordejevii*, to determine whether “islands of fertility” has developed both within and underneath them and to test whether the islands of fertility effects differ among the three nebkha types. In addition, we also studied spatial heterogeneities of soil enzymatic activities and soil microbial metabolic function of nebkhas.

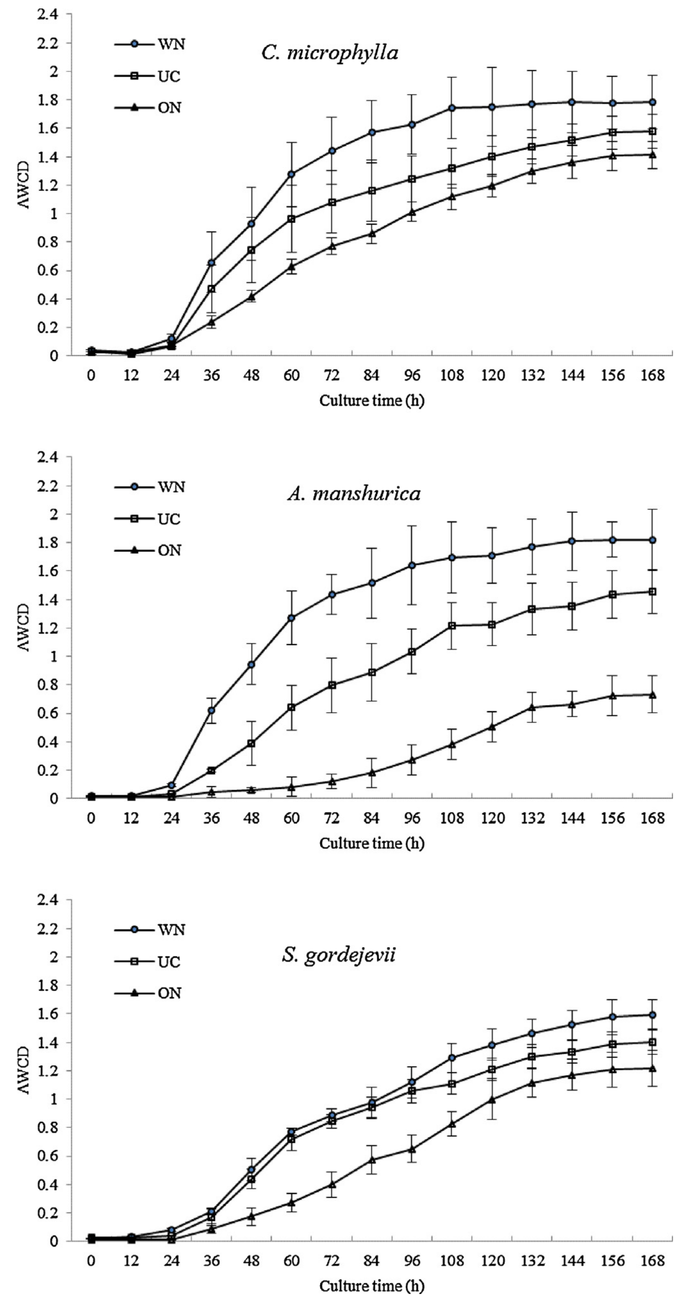

Fig. 1. Variation in average well color development (AWCD) over time in Biolog Ecoplate.
WN: within nebkha; UC: Under crown; ON: Outside nebkha. Data were generated by four replicates.

2. Materials and methods

2.1. Study location and site description

This study was conducted in Wulanaodu Region (43°02′N, 119°39′E, 480 a.s.l.), western Horqin Sandy Land of Northeast China. Wulanaodu Region is located in the temperate zone and has a semi-arid climate. According to Wulanaodu Weather Station, the annual average temperature in the area is 6.3 °C, with a frost-free period that lasts for 130 days. The annual average precipitation is 340.5 mm, 70%–80% of which is received from May to September; and the annual average pan evaporation is around 2500 mm. The annual average wind velocity is 4.4 m s^{-1}, and windy seasons occur from March to May during spring and winter, with frequent occurrence of gales (wind speeds >20 m s^{-1}). The landscape is a mosaic of moving and semi-moving sand dunes with interdune bottomland. Surface sand deposits are 20–120 m thick (Zhang et al., 2004). The soils are classified as cambic arenosols, which are susceptible to wind erosion (FAO, 2006). Strong wind erosion and sand burial on sandlands often occur from March to May. The original vegetation in the Horqin area was elm sparse woodland steppe composed of a considerable number of perennial plants, e.g., *Aneurolepidium chinense* Kitag, *Cleistogenes chinensis* Keng, *Lespedeza davurica* Schindl., *Agropyron cristatum* Gaertn., and *Stipa grandis* P. Smirn., with sparsely scattered *Ulmus pumila* L. However, most of the original vegetation was destroyed over several decades because of prolonged inappropriate use of grassland, e.g., overgrazing, excessive land use, and heavy plant harvesting (Cao et al., 2008). These activities are the major factors that cause grassland desertification and shrub encroachment. At present, the sandy land vegetation is generally dominated by some shrubs and semi-shrubs (e.g., *Caragana microphylla*, *A. manshurica*, *S. gordejevii*, and *A. halodendron*), associated with some herbaceous plants (e.g., *Pennisetum flaecidum*,