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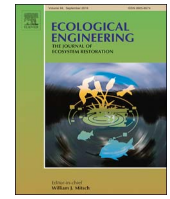

Dynamics of soil microbial biomass and enzyme activities along a chronosequence of desertified land revegetation

Jiao Li[a], Xiaogang Tong[a,*], Mukesh Kumar Awasthi[a,b], Fuyong Wu[a,*], Sier Ha[c], Jianye Ma[c], Xiaohan Sun[a], Chao He[c]

[a] College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi, 712100, China
[b] Department of Biotechnology, Amicable Knowledge Solution University, Satna, India
[c] Institute of Soil and Water Conservation, Northwest A&F University, Yangling Shaanxi, 712100, China

A R T I C L E I N F O

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A B S T R A C T

Large-scale sand control and afforestation in the Mu Us Sandy land of China have greatly improved soil nutrients and physicochemical properties; however, little is known about their effects on soil biological properties. This study aimed to investigate the changes in soil microbial biomass and enzyme activities and their relationships with soil physicochemical properties during sand land rehabilitation. Soil samples were collected from the shrub and arbor plantations with an age sequence of 20, 30, and 51 years in Yulin at depths of 0–10 cm and 10–20 cm and with semi-fixed sand land selected as a control (0-year-old site). The soil physicochemical and biological properties in the 0–10 cm soil layer were significantly ($P < 0.001$) higher than in the 10–20 cm soil layer for all stand lands. The soil microbial biomass (e.g., microbial carbon and nitrogen) in the 0–10 cm and 10–20 cm layers greatly increased, by 1.58–5.59 times and 2.27–6.07 times, respectively, during the revegetation of shrub and arbor from 20 to 30 years on the control land. During the same period, the activities of soil catalase, urease, alkaline phosphatase and invertase also greatly increased, by 1.27–2.18, 0.59–1.23, 0.48–3.66 and 0.57–2.72 times in shrub land, respectively, whereas they increased by 1.51–2.73, 0.46–2.09, 0.97–2.79 and 2.00–6.65 times in arbor land, respectively, compared with the control land. However, during the 30–51 years of revegetation on the control land, the soil microbial biomass and all enzyme activities remained relatively stable or slightly increased in the arbor land, whereas they were reduced in the shrub land. The soil organic carbon (SOC), dissolved organic carbon (DOC), total nitrogen (TN) and available nitrogen (AN) contents also greatly increased after revegetation in the control land. Principal component analysis (PCA) also confirmed that most of the chemical and biological properties were influenced by the afforestation and showed coordinated variation between the analyzed parameters. Moreover, redundancy analysis (RDA) showed that the soil microbial biomass and enzyme activities were correlated with the changes of SOC, DOC and TN, whereas they were negatively correlated with the bulk density, pH and total potassium. Therefore, we concluded that revegetation by the establishment of both shrub and arbor plantations significantly improved soil biological properties. Moreover, SOC, DOC and TN were regarded as the key factors in the enhancement of soil biological activity during desertified land revegetation in the Mu Us Sandy land of China.

1. Introduction

The Mu Us Sandy land is one of the four major sandy lands in China; it has undergone oppressive desertification, mainly attributed to climate and anthropogenic activity such as overgrazing by livestock, excessive farming intensity, and vegetation devastation by fuel wood acquisition. These activities have resulted in a landscape of moving, semi-moving, and stabilized sand dunes in alternation (Cao et al., 2008). The desertification has not only resulted in an increase in bare soil and loss of soil resources (e.g., loss of nutrients and serious degradation of soil) but has also influenced the sustainable growth of the environment of China and the world (Liu and Diamond, 2005). Therefore, to control land desertification and mitigate its negative impacts on grassland and farmland, the government of China has adopted

Abbreviations: BD, bulk density; TP, total phosphorus; AP, available phosphorus; TK, total potassium; AK, available potassium; SOC, soil organic carbon; MBC, microbial biomass carbon; DOC , dissolved organic carbon; TN, total nitrogen; MBN, microbial biomass nitrogen; AN , available nitrogen; C:N, total carbon/nitrogen ratio; ANOVA , Analysis of variance; LSD, Least significance difference; PCA, principal component analysis; RDA, redundancy analysis

* Corresponding authors.
E-mail addresses: xiaogangtong@126.com (X. Tong), wfy09@163.com (F. Wu).

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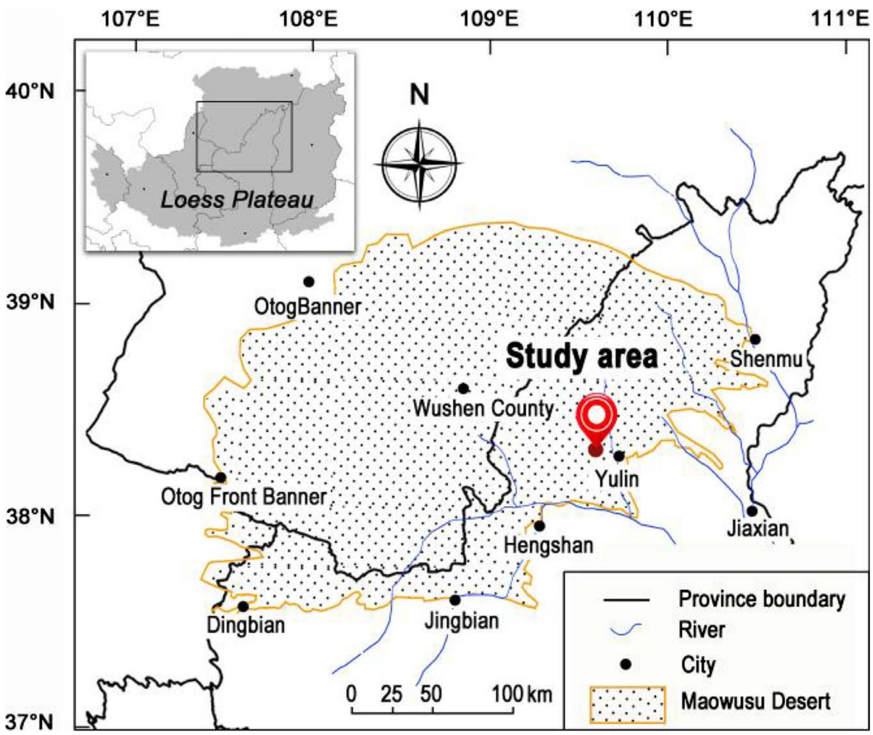

Fig 1. Location of the study area (Hongshixia Afforestation of Sands Experiment Station at Yulin) in the Loess Plateau of China.

many critical mechanical methods (such as the elimination of grazing via fencing, returning degraded farmland to forest and grassland, placing sand arresters and planting indigenous trees, shrubs and grasses) since the 1960s for the revegetation of desertified land in China such as the Mu Us Sandy land (Dai, 2010; Cao et al., 2011). During the past 50 years, the desertification management process on the Mu Us Sandy land has produced good ecological benefits and has significantly improved soil texture and physicochemical properties (Bolling and Walker, 2000; Zhang et al., 2008; Zuo et al., 2009). Nonetheless, very limited studies have focused on the progressive changes of soil biological properties during the reversion of desertification and the relationship among soil physicochemical properties, microbial biomass and enzyme activity along a chronosequence of desertification vegetation reconstruction.

The soil microbial biomass carbon, nitrogen and enzyme activities play an important role in nutrient cycling; they are more sensitive parameters than the physicochemical properties (Zhang et al., 2015) and thus potentially influence the element cycles of terrestrial ecosystems. Cai et al. (2013) observed that the soil microbial biomass and catalase, urease, phosphatase activities gradually increased with increasing stand age and successive rotation duration after farmland was returned to forestland. Moreover, soil biological characteristics, including soil microbial biomass and the activities of urease, invertase, alkaline phosphatase and catalase, decreased from slope farmland to an herbaceous community, significantly increased from an herbaceous community to a shrubby community, and slightly increased or stabilized from a shrubby community to an arboreal community (Cui, 2011). Current studies of microbial biomass and enzyme activity dynamics have mainly focused on the process of vegetation restoration and the conversion of cropland to forest and land degradation (Liu et al., 2007; Nunes et al., 2012; Wei et al., 2011). Most previous researchers were concerned with the study of urease, invertase, alkaline phosphatase and catalase activity because these enzymes are closely related to the transformation of soil carbon and nitrogen (Liu et al., 2007; Zhang et al., 2015); however, no systematic study has been reported on the microbial biomass and enzyme activity during desertification vegetation reconstruction.

Therefore, elucidating the relationship between carbon and nitrogen stock fractions with enzyme activities during vegetation reconstruction, especially for below-ground levels, is crucial in explaining the mechanisms of biogeochemical cycling processes. Li et al. (2008) observed that soil urease, alkaline phosphatase and invertase activities were closely related to soil nutrient levels and cycling. Additionally, Taylor et al. (2002) showed that there was a significant positive correlation between soil enzyme activity and soil organic matter. Baldrian (2008) reported that soil microbial biomass and enzyme activities correlated with the contents of C, N and P in the soil, and a previous study reported that the microbial biomass-related properties correlated with the content of organic C (Frouz and Nováková, 2005). Wang et al. (2010) then found that soil enzyme activity directly correlated with soil nutrient and microbial biomass during the process of vegetation recovery: urease activity was found to be mainly affected by total nitrogen, whereas alkaline phosphatase, catalase and invertase were closely influenced by available nitrogen, although alkaline phosphatase had no significant correlation with total phosphorus and available phosphorus. However, Wang et al. (2012) reported that enzyme activity and nutrient characteristics under different transformation modes of degraded forest land showed a close relation between phosphatase and urease activities with available phosphorus. To date, there has been no clear investigation that confirmed the co-relationship between soil microbial biomass, enzyme activity and soil nutrients under the process of vegetation reconstruction for desertified land.

The previous studies provided a good platform to understand the dynamics of soil physicochemical and biological properties and their relationships. Therefore, we explored the effects of vegetation reconstruction on soil fertility and its microbial biomass as well as enzymatic activities in the Mu Us Sandy land of China. We hypothesized that soil biological properties could be considerably changed by revegetation and that soil biological properties and soil nutrients are synergistically recovered and have significant interaction. The objectives of the present study were 1) to determine the dynamics of various soil physicochemical and biological properties along a chronosequence of 20, 30, and 51 years of desertified land revegetation, including soil nutrient contents, microbial biomass and enzyme activities, and 2) to identify the relationship between soil microbial biomass, enzyme activities and physicochemical properties, as well as find out the key factors that responsible for enhancement of soil biological activity