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Responses of soil phosphorus fractions to gap size in a reforested spruce forest

Bin Hu [a], Bing Yang [a], Xueyong Pang [a,*], Weikai Bao [a,*], Guanglong Tian [b,c]

[a] Key Laboratory of Mountain Ecological Restoration and Bioresource Utilization of Chinese Academy of Sciences, Ecological Restoration and Biodiversity Conservation Key Laboratory of Sichuan Province, Chengdu Institute of Biology, Chinese Academy of Sciences, PO Box 416, Chengdu 610041, China

[b] Agricultural Nutrient Loss Reduction and Soil Carbon Sequestration Research Group, Environmental Monitoring and Research Division, Metropolitan Water Reclamation District of Greater Chicago, Lue-Hing R&D Complex, 6001 W. Pershing Road, Cicero, IL 60804, USA

[c] Department of Civil, Architectural and Environmental Engineering, Illinois Institute of Technology, 3201 South Dearborn Street, Chicago, IL 60616, USA

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ABSTRACT

Gap created by thinning is a vital practice for the management of degraded forest. However, little information is available about the change in soil P fractions following the gap formation. This study investigated the effects of three gap sizes on soil P fractions in a reforested spruce (*Picea asperata*) forest on a multi-year scale. We created gaps of four sizes at 0, 74, 109, and 196 m^2 by thinning in a 26-year-old reforested spruce forest in Maoxian, northwestern Sichuan, China. Soil samples were collected in August yearly from 2008 to 2013. The *Bowman and Cole* soil P fractionation procedure was used to obtain two inorganic P fractions (P_i) and five organic P fractions (P_o). Thinning did not change the soil total P, total P_o, and P_i concentration but significantly influenced soil available P fractions. Intermediate gap (MG) and large gap (LG) treatments increased soil labile inorganic phosphorus (extracted by $NaHCO_3$) in the year with more precipitation and balanced distribution, and the intermediately labile inorganic and organic phosphorus concentrations (extracted by HCl) in the year with less precipitation after thinning. By contrast, resistant P fractions (extracted by NaOH and H_2SO_4) were not affected by the gap formation. Improvement in soil moisture, organic matter, and microbial and phosphatase activity by the gap formation contributed to the increase in labile P by thinning. Our results highlighted that the effect of gap size on soil microenvironment is the valuable information for assessing the response of soil nutrients, such as soil P to the forest management.

1. Introduction

Soil phosphorus (P), which occurs in organic and inorganic forms, is among the most important macronutrient for plant growth in terrestrial ecosystem (Vincent et al., 2012). Due to soil P fixation, only a small portion of inorganic P in soil is soluble and available to plants (Hinsinger, 2001). Therefore, the P deficiency is a major constraint to forest production, especially in the subalpine plantation of western Sichuan, China (Wu and Liu, 2007). The P availability to microorganisms and plants largely depends on soil P fractions; thus, the knowledge of different soil P fractions is essential to assess P bioavailability in soil (McDowell and Stewart, 2006). There has been an increased interest in studying soil P fractions in terms of labile, intermediate, and resistant forms in inorganic (P_i) and organic P (P_o) fractions (Redel et al., 2008).

Thinning as a simulation of natural gap to enhance tree growth and forest production is a common management practice in forest ecosystems in China and other regions (Martin-Benito et al., 2010; Pang et al., 2013). The responses of soil respiration, carbon mineralization, nitrogen cycling, and microbial community to gap formation in a forest have been comprehensively studied (Moghaddas and Stephens, 2007; Nilsen and Strand, 2008; Pang et al., 2016). However, the impact of forest thinning on soil P fractions and availability was rarely addressed.

Microorganisms play a key role in P_o transformation through P synthesis and release, excretion of phosphatase, and solubilization of insoluble P forms (Oberson et al., 2001). Microorganisms can increase P availability for plants through mineralization of organic P (Richardson et al., 2009). Phosphatase produced by soil microorganisms and plant roots is in control of the P_o availability (Plassard and Dell, 2010). The activity of phosphatase was positively related with P_o content, and negatively related with P_i content in soils (Spohn and Kuzyakov, 2013). On the other hand, microorganisms can decrease the P availability through the immobilization of inorganic P into organic form, decomposition of P solubilizing organic compounds, and changing rhizophere pH decrease (Spohn and Kuzyakov, 2013). Thinning can affect soil microbial community and biomass through altering microenvironments (mainly soil

* Corresponding author at: Chengdu Institute of Biology, Chinese Academy of Sciences, PO Box 416, Chengdu 610041, PR China.
E-mail addresses: pangxy@cib.ac.cn (X. Pang), baowk@cib.ac.cn (W. Bao).

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moisture and temperature increase) and substrate quantity and quality (Pang et al., 2013, 2016). Mosca et al. (2007) and Bolat (2014) reported that soil microbial biomass increased after gaps creation due to the increase of soil organic matter. Because of the increase in rain reaching the soil and the decrease in transpiration (Zhu et al., 2003), higher soil moisture was found in the gap in temperate deciduous forest, boreal coniferous forest, and moist tropical forests (Latif and Blackburn, 2010), and soil moisture increased with gap size in these forest systems. Increase in soil moisture mostly promotes the microbial activity under the field condition, thus accelerating organic phosphorus mineralization. Xu et al. (2008) found that gap treatment significantly increased soil acid and alkaline phosphatase activities, and phosphatase activity increased with increasing in gap size. With the increased availability of resources such as light, water, and nutrients, understory vegetation grow better and utilize some soil phosphorus not available to tree roots. The decomposition of litter from understory vegetation can increase the soil available P fraction. We hypothesize that soil labile P fractions will increase after the gap formation because of the increase in inorganic P solubilization and organic P mineralization due to the improvement of microenvironment after thinning, and this change will be greater with the increasing gap size.

The objective of this study was therefore to investigate the effect of gap formation and gap size on soil P fractions in a subalpine forest in the eastern Tibetan Plateau of China, by quantifying soil P fractions across four thinning treatments (four gap sizes at 0, 74, 109, and 196 m^2) in a 26-year-old reforested spruce (*Picea asperata*) forest from 2008 to 2013.

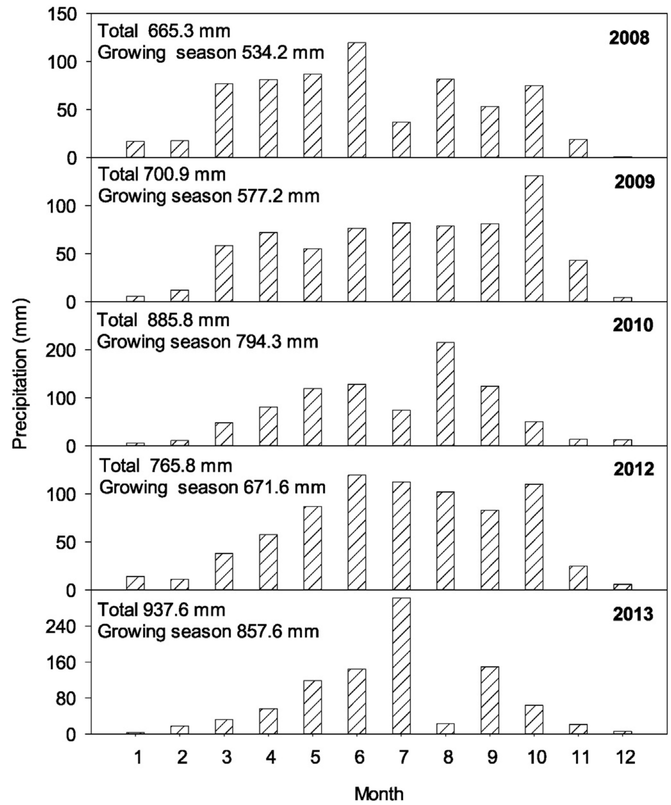

Fig. 1. Monthly distribution of precipitations in 2008, 2009, 2010, 2012, and 2013 at the study site. The growing season of spruce was from April to October.

2. Materials and methods

2.1. Description of study site

The experiment was conducted from July 2008 to August 2013 at the Maoxian Mountain Ecosystem Research Station (103°54′ E, 31°42′ N) of Chinese Academy of Sciences, located on the eastern edge of Tibetan Plateau of China. The experiment site is characterized by a montane temperate climate. The mean annual precipitation is 850 mm, and it has a distinct seasonal pattern with 70% distribution from May to September. The mean annual temperature is 9.3 °C with a mean of 18.6 °C in the warmest month (July) and −0.9 °C in the coldest month (January). Total annual precipitations were 665, 701, 886, 766, and 938 mm in 2008, 2009, 2010, 2012, and 2013, respectively. For the spruce growing season (from April to October), 2010, 2012, and 2013 were wet years with 794, 672, and 858 mm precipitations, and 2008 and 2009 were dry years with 534 and 577 mm precipitations, respectively (Fig. 1). The soil type at the study site was characterized as a Calcic Luvisol according to the IUSS Working Group WRB (2007). The soil texture was silt loam with 15.5% and 15.3% of sand, 62.5% and 63.3% of silt, 21.9% and 21.5% of clay in the 0–10 cm, and 10–20 cm soil depths, respectively (Jiang et al., 2011).

This region is within the transition zone from the Tibetan Plateau to the Sichuan Plain (Chen et al., 2010), colloquially described as “high mountain, deep valley.” The primary subalpine forests in the region were felled at a large scale during the period of 1940s to 2000s (Pang et al., 2011). The reforestation was then conducted on cutting areas and approximately 60% of lands in the region are occupied by planted forest. Due to the initial purpose of timber production, most plantations were designed for monoculture trees (Pang and Bao, 2011). Spruce has been one of the typical cultivated tree species in the subalpine region of eastern Tibetan Plateau. We conducted this study in a 5 ha spruce plantation established in 1980s. Before the start of the study in 2008, the mean height of the trees was 10.0 m with the mean diameter at breast height (DHB) of 19.1 cm. The density of trees with DHB > 3 cm was 1450 stems ha^{-1}. The canopy leaf area index (LAI) and tree canopy coverage was approximately 3.5% and the 81%, respectively. The understory vegetation was composed of mainly *Phlomis umbrosa*, *Asparagus filicinus*, *Thladiantha davidii*, *Plantago major*, *Sinosenecio oldhamianus*, *Carpesium divaricatum*, *Prenanthes henryi*, *Thalictrum uncinulatum*, and *Rosa sericea* (Jiang et al., 2011).

Since planting, the spruce forest had not received any management, although they had frequently been disturbed by litter collection in the fall (16.8–20.2 g C m^{-2} yr^{-1} equivalence) and extraction of wild mushrooms and Chinese medicinal plants in the spring. Previous researches indicated that high-density and monoculture reforested spruce forest in the subalpine region of eastern Tibetan Plateau, China, reduced soil fertility, forest productivity, and ecological function (Bao et al., 2007; Pang et al., 2013). Thinning to create gap in the forest by selectively cutting a cluster of trees within a small area improved the soil fertility and forest productivity of high-density spruce plantations in this area (Wang et al., 2010; Jiang et al., 2011).

2.2. Experimental design

In August 2008, we demarcated 12 plots with the area of about 400 m^2 per plot in a spruce plantation forest. The height, the DBH, and the canopy area of all trees in each plot were measured, and understory species composition and coverage were measured. In November 2008, the 12 plots were randomly assigned to four treatments. Thus, the study was conducted in a completely randomized design with three replications. The four treatments included three forest gaps: 196 m^2 (large gap—LG), 109 m^2 (intermediate gap—MG), 74 m^2 (small gap—SG), and a no-gap (control—CK). The gap was formed by felling trees in the center region of each plot. There were 3, 5, and 12 spruce trees felled in the SG, MG, and LG treatments, respectively. In the control plot (CK), no trees were felled. Gap size was calculated after felling trees based on the polygon area surrounded by gap-edge trees. Stems, branches, and leaves of the cut trees were removed; however, stumps were retained at 50 cm above the ground in thinning plots.