Applied Soil Ecology 57 (2012) 59–64

Contents lists available at SciVerse ScienceDirect

Applied Soil Ecology

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

Response of selected soil biological properties to stump presence and age in a managed subtropical forest ecosystem

Qingkui Wang[a,c], Fuming Xiao[b], Silong Wang[a,c,*], Guangbiao Xu[c]

[a] Huitong Experimental Station of Forest Ecology, State Key Laboratory of Forest and Soil Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110164, PR China
[b] Jiangxi Academy of Forestry, Nanchang 330032, PR China
[c] Huitong National Research Station of Forest Ecosystem, Huitong 418307, PR China

ARTICLE INFO

Article history:
Received 27 July 2011
Received in revised form 14 February 2012
Accepted 25 February 2012

Keywords:
Coarse woody debris
Soil microbial biomass
Soil organic matter mineralization
Soil enzyme
Chinese fir
Redundancy analysis

ABSTRACT

Stumps are an important component of coarse woody debris in intensively managed forest ecosystems. However, the effect of stumps on soil biological properties is poorly understood. Therefore, the present work investigated soil microbial biomass C, soil respiration, potentially mineralizable N, and enzyme activities related to nutrient cycling (invertase, urease and acid phosphatase) in both bulk and stump soils with four different stump "ages" (stumps 5, 11, 20 and 27 years after tree cutting) in Chinese fir (*Cunninghamia lanceolata* Hook.) plantation ecosystems. The presence of stumps significantly enhanced invertase and acid phosphatase activities, but reduced soil microbial biomass C and urease activity. However, the effect of stump presence on soil respiration and potentially mineralizable N had an inverse pattern. Additionally, the effect of stump presence on soil biological properties depended upon stump age. Soil respiration and invertase activity were highly and positively related to stump presence, but negatively related to stump age and soil pH. On the other hand, soil microbial biomass C and urease activity showed inverse results. Acid phosphatase activity was highly and positively related to soil total P and organic C, but negatively related to Olsen-P. Potentially mineralizable N was negatively related to NO_3-N content and stump age. Using variation partitioning, stumps and soil chemical variables together explained 88.3% of the total variance in soil biological properties. When either stumps or soil chemical variables was adjusted, soil chemical properties and stumps explained 30.8% and 13.7% of the total variance, respectively. These results suggest that soil chemical properties should be considered when assessing the effect of stumps on soil biological properties.

1. Introduction

Coarse woody debris (CWD) is an important driver of forest ecosystem functions. CWD acts as both a sink and source of C and nutrients and serves as a habitat for numerous forest organisms, consequently affecting soil properties (Kappes et al., 2007; Palviainen et al., 2010a; Freschet et al., 2012). In intensively managed forest ecosystems, stumps are usually present at the sites after thinning or clear-cutting, generally representing up to 10–25% of total biomass in live trees and storing 15–20% of N, P, K, Ca, and Mg (Feng et al., 1982; Finér et al., 2003). Therefore, stumps are a major pool of soil organic matter and nutrients, thus playing an important role in maintaining soil fertility.

The ecological importance of stumps has given rise to studies on various aspects of their role in ecosystem processes, including stump attributes and amounts (Keller et al., 2004; Yang et al., 2010), decomposition (Shorohova et al., 2008; Melin et al., 2009), and stocks and cycles of C and nutrients (Hafner et al., 2005; Metzger et al., 2008; Palviainen et al., 2010a,b). Moreover, the need for understanding the consequences of stump management practices has placed increasing pressure on ecologists to quantify the effects of stumps on soil properties in intensively managed forests. However, little is known about the effect of stumps on soil properties (Hafner and Groffman, 2005; Kappes et al., 2007), particularly on biological properties. Such information is urgently needed to understand how stump management practices affect soil fertility and site productivity (Walmsley and Godbold, 2010).

Studies on the effects of stump management practices on soil properties have been increasing in recent years (Spears et al., 2003; Hope, 2007; Sucre and Fox, 2009). However, most studies primarily focused on the effects of stump removal on soil properties (Hope, 2007; Walmsley and Godbold, 2010). Stump removal resulted in

* Corresponding author at: Huitong National Research Station of Forest Ecosystem, Huitong 418307, PR China.
E-mail address: slwang@iae.ac.cn (S. Wang).

0929-1393/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsoil.2012.02.019

a decline in soil organic C and nutrient input and changed their cycling in soil (Hope, 2007; Walmsley and Godbold, 2010). Soil microbial biomass and enzymes have important roles in nutrient cycling, decomposition, and the synthesis of organic matter (Bandick and Dick, 1999). Moreover, given their sensitivity, soil microbial biomass and enzymes are also early indicators of soil biological processes (García et al., 2000; Benedetti and Dilly, 2006).

CWD can alter the soil physical properties and the availability of soil organic C and nutrients (Kappes et al., 2007). However, as an important management practice of CWD, information on the mechanism by which stump presence affects soil biological properties remains scarce, although Sucre and Fox (2009) found that potentially mineralizable N in stump soil was higher than that in bulk soil in mature hardwood stands. In addition, C and nutrients have different release patterns from decomposing stumps. Such patterns affect soil microbial processes (Palviainen et al., 2010a,b). Thus, the response of soil biological properties to stump presence may be related to stump age. However, reports on such a relationship cannot be found in the existing literature.

The current study investigated the effects of stump presence and age on soil microbial biomass C, respiration, potentially mineralizable N, and enzyme activities involved in the main nutrient cycles (i.e., invertase, urease, and acid phosphatase) of Chinese fir (*Cunninghamia lanceolata* Hook.) forest soils with various chemical properties. To consider changes in soil biological properties induced by differences in soil chemical properties, redundancy analysis and variation partitioning were used to reduce data set complexity and to establish relationships between soil biological properties and environmental variables.

The present work attempted to answer the following questions: (1) Does stump soil have higher microbial biomass C, respiration, potentially mineralizable N, and enzyme activities compared with bulk soil?; (2) How do the effects of stump presence vary among stump ages?; (3) To what extent are soil biological properties affected by stumps and soil chemical properties?

2. Materials and methods

2.1. Study sites

This study was conducted at the Huitong National Research Station of Forest Ecosystem (26°51′N, 109°36′E), Hunan Province, Southern China. The site is at an elevation of 500–600 m. The average annual precipitation is approximately 1200 mm. Average annual temperature is approximately 15.8 °C, ranging from 1.9 °C in winter to 29 °C in summer. Forest soils in this region are often derived from slate and shale and are classified oxisol according to the United States Department of Agriculture soil taxonomy. In the 0–10 cm mineral soil layer, sand, silt, and clay contents were 10.6%, 42.6%, and 46.8%, respectively.

The experiment was conducted in two pure Chinese fir plantations established in 1983 and 1990, respectively, after clear-cutting. Row thinning of the two plantations was conducted in 1998 and 2004, respectively. As a result, four stump "ages" (comprising extant stumps 5, 11, 19 and 27 years after cutting live trees, shown as Y5, Y11, Y19, and Y27, respectively) were found in these plantations. The stand stocking density was 1100–1300 trees ha^{-1} after thinning. The residual biomass (branch, leaf, and bark) that resulted from thinning was removed from the plantation, and live trees and stumps were distributed almost evenly and coincided spatially.

2.2. Experimental design and soil sampling

The present study defined stump soil as the soil directly altered by input from decomposing stumps over time (Sucre and Fox, 2009). Therefore, stump soils were collected from a 0 cm to 1 cm area surrounding stumps, in a level 0–10 cm deep. Only mineral soils were sampled in this study, with the exception of O-horizon soil. Bulk soils were collected at least 100 cm away from the corresponding stumps. In each of the two pure plantations, three 25 m × 35 m plots representing three replications for stump ages were randomly established in March 2009. Therefore, 12 replications (3 plots × 4 stump ages) were established for stump presence. One plot was approximately 80–100 m away from another plot. The 11- and 27-year-old stumps were in the plantation established in 1983, and the 5- and 19-year-old stumps were in the plantation established in 1990. For one stump age, six stumps were randomly chosen from each plot in one plantation. In the two plantations, soil properties and management were similar among plots. Therefore, differences in soil biological properties between stump and bulk soil were assumed to have resulted from stump presence.

Soil samples were collected from the five plots in April 2009. In each plot, for each stump age, four stump-soil cores, one from each of the four cardinal directions, were collected around each stump. Correspondingly, four bulk-soil cores were also collected 100 cm from each stump using the above methods. Therefore, in each plot, 24 stump-soil cores for each stump age were collected and then mixed into a composite sample to decrease soil heterogeneity, and 24 bulk-soil cores were also collected and then mixed into a composite sample. In this study, a total of 12 stump composite samples and 12 composite bulk soil samples were collected. Visible roots and organic residue were immediately removed by hand after sampling. Each sample was divided into two parts. One part was immediately sieved through a 2 mm mesh and then stored at 3 °C until analysis for the estimation of microbial biomass C, soil respiration, potentially mineralizable N, enzyme activities, and extractable N (NH_4^+-N and NO_3^--N) within 7 d. The remaining part was air-dried and ground to determine pH, soil organic C, total N and P, available P, and exchangeable cations (K^+, Na^+, Ca^{2+} and Mg^{2+}).

2.3. Soil analysis

Soil organic C ($g\,kg^{-1}$) and total N were measured using a C/N analyzer. Extractable N (NH_4^+-N and NO_3^--N) in fresh soil was extracted with a 1 mol l^{-1} KCl solution. The filtered solution was measured by colorimetry. Total P was measured colorimetrically. Soil Olsen-P was analyzed colorimetrically using the molybdate blue method after the soil was extracted with 1 mol l^{-1} NH_4F (Olsen and Sommers, 1982). The exchangeable base cations (K^+, Na^+, Mg^{2+}, and Ca^{2+}) were extracted with ammonium acetate at pH 7.0. Ca^{2+} and Mg^{2+} in the extracts were measured by atomic absorption spectrophotometry, whereas K^+ and Na^+ were determined by flame emission spectrophotometry (Black et al., 1965). Soil pH was measured using a pH meter in a 1:2.5 (weight:volume) mix of soil and deionized H_2O.

Soil microbial biomass C was determined using the chloroform fumigation extraction method (Vance et al., 1987) and calculated by applying the factor (2.2) used by Wu et al. (1990). The chloroform fumigation–extraction method lyses soil microbial cells with chloroform over a period of 48 h. Following the 48 h incubation time, a dilute salt solution (0.5 mol l^{-1} K_2SO_4) was used to extract C. Soil basal respiration was measured using the methods described by Chen et al. (2000). In brief, the field-moist soils (50 g oven-dry equivalent) were aerobically incubated at 28 °C in a 500 ml sealed glass jar for 48 h. The CO_2 evolved from soil was trapped in 0.1 M NaOH and measured by titration with 0.05 M HCl. The evolved CO_2 was calculated from the difference in normality between NaOH blanks and samples. Soil potentially mineralizable N was determined through 7 d aerobic incubation at 25 °C. The amount of mineralized N was the difference in soil mineral N (NH_4^+-N and NO_3^--N) before and after incubation.