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Effects of different management approaches on soil carbon dynamics in Moso bamboo forest ecosystems

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ABSTRACT

Moso bamboo (*Phyllostachys pubescens*) is a very important forest resource in subtropical China, and it has excellent carbon sequestration potential, and can play an important role in mitigating climate change. The international community has gradually recognized the benefits of Reducing Emissions from Deforestation and Forest Degradation (REDD+) forest carbon sequestration mechanisms, and the areas available for the development of forest carbon sinks have greatly expanded. Therefore, in this study, we use a two-factor randomized complete block design in which fertilization rate and harvesting intensity were selected to investigate the changes in soil organic carbon (SOC) concentration and carbon (C) storage from 2010 to 2016. With 3^k orthogonal method, a factorial analysis with 3 levels of fertilization (high (1800), medium (900) and low (0 kg ha^{-1} year^{-1})) and 3 levels of harvesting intensity (high (100%), medium (50%) and low (0%) cutting of the bamboo of 4–5 years old) has been taken. Our results show that fertilization, harvesting, and the fertilization × harvesting interaction had significant effects on SOC concentration changes, but not on C storage after six years of management. Only the interaction between high fertilization and high intensity harvesting, which we called the intensive management model, caused a decrease of 4.48 Mg C ha^{-1} in the 0–50 cm soil layer C storage. The interaction between no fertilization and low intensity harvesting, which we called the traditional management model, increased soil carbon C by 7.90 Mg C ha^{-1}. The optimized management model of high fertilization and medium intensity harvesting increased soil C the most; by 59.94 Mg C ha^{-1}, which is 2.36 times larger than that of the intensive management model, and 1.86 times larger than that of the traditional management model. The results clearly reveal that the soil carbon pools in Moso bamboo forest have a great carbon sequestration potential under the optimized management model.

1. Introduction

Bamboo, with 1250–1500 species in 75–107 genera (Ohrnberger, 1999; Scurlock et al., 2000; Zhu, 2001), is an important component of many forest ecosystems in subtropical and tropical regions (Song et al., 2011). Bamboo is distributed across approximately 31.5 million ha of land, accounting for approximately 0.8% of the world's total forest area in 2010 (FAO, 2010; Song et al., 2011). China has approximately 4.84–5.71 million ha of bamboo forests (Chen et al., 2009; Li and Kobayashi, 2004; FAO, 2010; Song et al., 2011), mostly in the south, and 63% of these are Moso bamboo (*Phyllostachys pubescens*) forests (Wang et al., 2008). Moso bamboo forests play an important role in atmospheric C sequestration and soil erosion control in degraded areas (Zhou et al., 2011).

Moso bamboo can sequester great quantities of carbon as their very high growth rate results in a corresponding increase in CO_2 uptake through photosynthesis (Zhou et al., 2009; Du et al., 2010; Düking et al., 2011; Lobovikov et al., 2012) and decelerate climate change (Lobovikov et al., 2009; INBAR, 2010; Nath et al., 2015). For example, mean above ground carbon uptake of a 29-year-old Taiwan red cypress (*Chamaecyparis formosensis*) and a 33-year-old Japanese cedar (*Cryptomeria japonica*) was reported as 2.83 and 4.44 Mg C ha^{-1} year^{-1}, respectively, which was much lower than the 8.13 Mg C ha^{-1} year^{-1} reported for Moso bamboo (Nath et al., 2015). The results of comparing aboveground carbon sequestration between Moso bamboo and Chinese fir forests showed that Moso bamboo (8.13 Mg ha^{-1} year^{-1}) had a

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higher carbon sequestration rate than that of Chinese fir (3.35 Mg ha^{-1} $year^{-1}$) (Yen and Lee, 2011). In addition, Moso bamboo may be used for commercial purposes. The edible shoots of Moso bamboo are valued for their taste, and the timber of Moso bamboo has been widely used for furniture manufacturing, housing construction, outdoor terrace building, and fuel (bamboo charcoal) (Restrepo et al., 2016).

For these reasons, intensive management practices have been widely applied in the past few decades to increase the growth of Moso bamboo, and thus achieve higher economic returns (Wang et al., 2008; Liu et al., 2011; Qin et al., 2017). Such management practices include inorganic fertilizer application, cutting, tillage, and regular removal of understory vegetation. Previous studies indicate that the long-term application of these practices may cause negative ecological consequences such as soil erosion and nutrient leaching (Shinohara and Otsuki, 2015), increases in soil CO_2 emission (Liu et al., 2011), acceleration of soil organic C mineralization (Zhou et al., 2006; Jiang et al., 2009), and decreasing soil organic C storage (Li et al., 2013).

The benefits from Reducing Emissions from Deforestation and Forest Degradation (REDD+) forest carbon sequestration are increasingly recognized, and the area allocated for the development of forest carbon sinks has been greatly expanded. What means that forest management has an important potential role in REDD projects for increasing forest soil carbon. This has created opportunities and challenges for China's bamboo management in recent years (Wang et al., 2013; Zhang et al., 2014; Nath et al., 2015). Therefore, previous intensive management methods in Moso bamboo forests, which aimed to maximize economic benefits, might be transformed to methods to improve carbon sequestration, in order to achieve a new balance between economics and ecology. This study evaluated the effects of different management approaches on soil carbon dynamics, and explored the relationships between management intensity and soil C storage changes in Moso bamboo forests in subtropical China. In addition, our results provide theoretical and technological knowledge for carbon sink management in Moso bamboo forests.

2. Materials and methods

2.1. Study site

The study site is located in Linan county (E119°45′, N30°10′) Zhejiang Province (Fig. 1), China. This site had an undulating topography, with elevation ranging from 90 to 200 m a.s.l. The climate is a subtropical monsoon climate, with an average precipitation of 1350–1500 mm per year, and a mean annual temperature of 15.9 °C, with the highest temperature in July, and the lowest in January. It has 1774 h of sunshine annually, and a frost-free period of 236 d. The forest coverage rate was up to 65%. The main tree species was Moso bamboo. The soils in the experimental site were derived from siltstone, and were classified as a slightly acidic red soil in the Chinese system of soil classification (State Soil Survey Service of China, 1998), equivalent to the Ferralsols in the FAO soil classification system (WRB, 2006). Soil thickness was 50 cm.

Prior to the start of our experiment, the old bamboo (> 6 years) was harvested every two years, while the young bamboo (< 6 years) was left standing. The stocking density of the bamboo forests was 3236 stem ha^{-1}, with a mean diameter at breast height of 9.1 cm. The understory had few shrubs, but many weeds. The permanent sample plots were established in 2010, no tillage was applied, and the understory vegetation was retained.

2.2. Experimental design

A two-factor randomized complete block design was employed, in which fertilization rate and harvesting intensity were selected. The fertilization and harvesting were applied as follow:

(i) Fertilization rate: large amount of fertilizer (1800 kg ha^{-1} $year^{-1}$, applied twice a year, referred to hereafter as 'high fertilization'), medium amount of fertilizer (900 kg ha^{-1} $year^{-1}$, applied twice a year, referred to hereafter as 'medium fertilization'), and no fertilizer applied. Bamboo shoot special fertilizer (N 13%, P 3%, K 2%, amino-acid ≥8%, organic matter ≥15%, and humic acid ≥10%) was applied by furrow beginning in January 2010.

(ii) Harvesting intensity: high intensity harvesting (all bamboo of 4–5 years old was cut), medium intensity harvesting (half of the bamboo of 4–5 years old was cut), and low intensity harvesting (all bamboo of 4–5 years old was left uncut). Under this management, all bamboo of 1–3 years old was left standing, and all bamboo older than 5 years was cut. Selective cutting occurred every two years.

With the 3^k orthogonal method, The field experiment consisted of nine management treatments (high fertilization and high intensity harvesting [F_1H_1], high fertilization and medium intensity harvesting

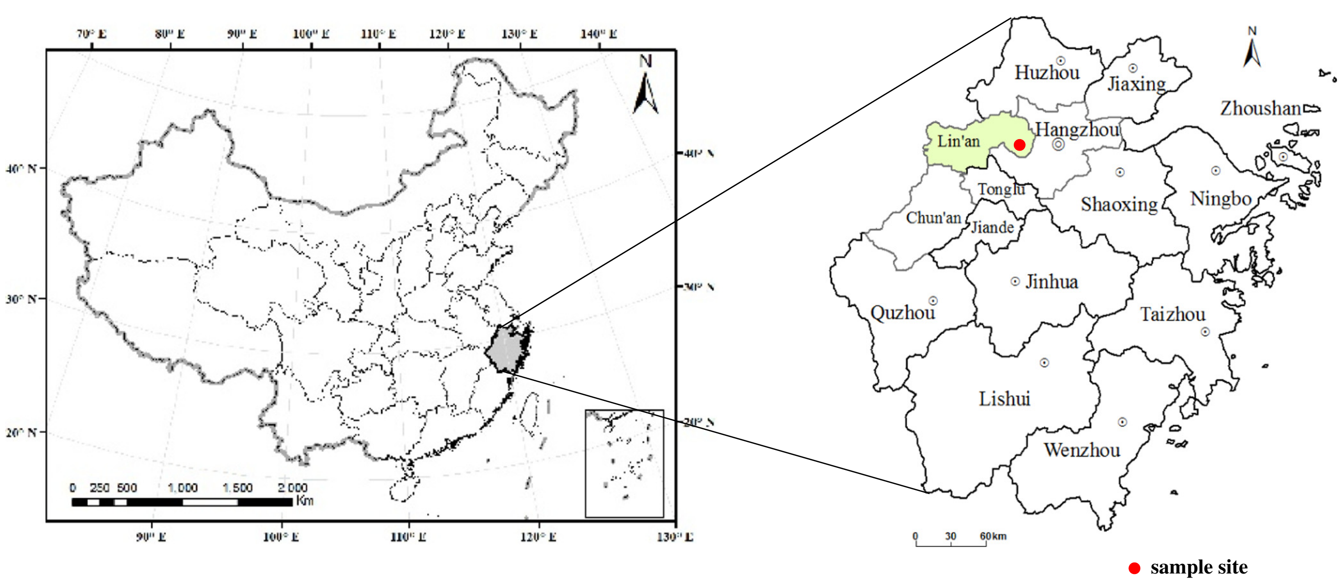

Fig. 1. Location of the sample site.