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Understory management and fertilization affected soil greenhouse gas emissions and labile organic carbon pools in a Chinese chestnut plantation

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ABSTRACT

Management practices markedly impact carbon (C) cycling in forest plantations. However, the interactive effects of understory management and fertilization on soil greenhouse gas (GHG) fluxes and labile organic C pools remain unclear in forest plantations. To investigate the effects of understory replacement, fertilization, and their interaction on soil GHG fluxes and labile organic C pools in a Chinese chestnut plantation, we conducted a 2×2 factorial experiment over a 12-month field study with four treatments: Control (understory removed without understory replacement or fertilization), understory replacement (understory removed and seeded with *Medicago sativa* L., MS), fertilization (F), and MS + F. The GHG fluxes were determined using a static chamber/GC technique. The seasonal pattern of GHG fluxes did not change in any of the treatments in this one-year study; however, soil GHG fluxes, total global warming potential (GWP) of GHG fluxes, and soil organic C (SOC), water soluble organic C (WSOC), microbial biomass C (MBC), and NO_3^-–N concentrations were significantly affected by MS, F, and their interaction. In addition, GHG fluxes, GWP, and SOC, WSOC, MBC and NO_3^-–N concentrations were markedly increased by fertilization, regardless of the understory replacement treatment ($P < 0.05$), but they were increased by understory replacement only in the fertilized plots. The GHG fluxes were correlated with soil temperature and WSOC in all plots ($P < 0.05$), but not with soil moisture and MBC. These findings suggest that understory replacement likely is the optimum management technique for reducing/minimizing GHG fluxes, while F can enhance the effects of MS on increasing soil organic C and nutrient availability. We conclude that a combination of a moderate rate of fertilization and understory replacement with legume species should be adopted to increase soil C sequestration, maintain soil fertility and sustainably develop chestnut plantations.

1. Introduction

Anthropogenic emissions of greenhouse gases (GHG), particularly carbon (C) dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), have increasingly become major contributors to global climate change (Manne and Richels, 2001; Jassal et al., 2011; Lavoie et al., 2013). Although CO_2 has been considered the most important GHG, CH_4 and N_2O also play major roles in global warming because their global warming potential (GWP) are 25 and 298 times greater, respectively, than that of CO_2 over a time span of 100 years (Forster et al., 2007). In most forest soils, CO_2, CH_4 and N_2O are formed through soil respiration, organic matter decomposition, and nitrification and denitrification, and these processes are strongly influenced by environmental factors and forest management practices (Tang et al., 2006; Wang et al., 2010, 2013; Lavoie et al., 2013). Forest management practices can greatly influence how forests, especially forest plantations, mitigate climate change through long-term C sequestration (Peng et al., 2008; Song et al., 2013).

China has the largest plantation area in the world, covering more than 62 million ha and accounting for approximately one-third of the world's total plantation area (Piao et al., 2009; Chen et al., 2011). Historically, forest management practices, such as understory vegetation management and fertilization, have been

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used to increase forest productivity and enhance ecosystem C storage (Peng et al., 2008; Powers et al., 2013). In addition, these practices can markedly affect soil physical, chemical, and biological properties in plantations (Xiong et al., 2008; Wu et al., 2011b; Krause et al., 2013; Zhao et al., 2013), and consequently affect soil GHG fluxes and organic C pools (Wang et al., 2011; Zhang et al., 2014)

Fertilization, especially the application of chemical fertilizers, is one of the most important and commonly used methods for plantation management and has a significant effect on soil GHG emissions in forest plantations (Mo et al., 2008; Deng et al., 2010; Tu et al., 2013; Gao et al., 2014). Nitrogen (N) fertilizer applications have been reported to increase primary production in most terrestrial ecosystems across the world (Elser et al., 2007), but their effects on soil GHG emissions were not fully understood or contradictory. Several previous studies have reported that N application increased soil GHG emissions in tropical or subtropical plantations (Zhang et al., 2008a,b; Zhang et al., 2011; Tu et al., 2013; Gao et al., 2014). However, other studies found that N addition had no effect or negative effects on GHG emissions in plantations (Janssens et al., 2010; Jassal et al., 2010; Krause et al., 2013). For example, Mo et al. (2007, 2008) found that N addition significantly decreased CO_2 emissions in a mature forest but had no effect in a disturbed forest in southern China. In a Pacific Northwest Douglas-fir forest, N application increased N_2O emissions in the first year but there was a small N_2O uptake in the second year (Jassal et al., 2010). In addition, Krause et al. (2013) found that long-term N addition increased N_2O and CH_4 emissions, but did not significantly change CO_2 emissions in a mountain spruce forest. These contradictory results may be attributed to the differences in the initial C and N status, the microbial community composition, the fertilizer type and application rate (Mo et al., 2008; Zhang et al., 2008a; Iqbal et al., 2009; Janssens et al., 2010; Liu et al., 2011).

As a component of forest ecosystems, the understory vegetation plays a vital role in maintaining the status of biota as well as biodiversity, microclimate and ecosystem nutrient cycling both above- and belowground (Wang et al., 2013, 2014; Zhao et al., 2013; Zhang et al., 2014). Commonly, understory vegetation management is one of the most important measures of plantation management (Powers et al., 2013; Zhao et al., 2013). Understory vegetation removal decreases the surface coverage and leads to more sunlight reaching the forest floor, and consequently increases soil temperature and causes changes in soil nutrient availability and microbial activity (Zhao et al., 2011, 2013; Wu et al., 2011a; Wang et al., 2014). In addition, understory species can, to some extent, reduce tree productivity in plantations, due to their competitions for N and other resources with forest trees (Zhao et al., 2011; Wang et al., 2014). The ecological function of understory vegetation and the effect of understory management on soil properties and microbial communities have been studied in forest plantations (Zhao et al., 2012, 2013; Wang et al., 2013, 2014; Zhang et al., 2014), but the effects of understory management (e.g., removal or addition) on soil GHG emissions in plantations are inconsistent among previous studies (Li et al., 2009, 2010; Li, 2010; Zhang et al., 2014). For example, in a 23-year-old *Acacia mangium* plantation, understory removal and keeping the site understory vegetation free did not affect soil organic C (SOC), microbial biomass C (MBC), or available N and P in the 0–20 cm soil layers (Xiong et al., 2008). Wang et al. (2014) found that removal of understory twice a month had little influence on soil pH, C/N, available P, NH_4–N and NO_3–N, but decreased SOC content over a six-month experiment in *Eucalyptus urophylla* and *Acacia crassicarpa* plantations in southern China. In addition, Wang et al. (2011) reported that soil respiration (Rs) rate was reduced by frequent manual understory removal (UR), increased by understory vegetation addition with *Cassia alata* (CA), but was not changed by UR + CA in a mixed species forest plantation in southern China. Removal of understory vegetation and addition of N-fixing species can exert variable influences on GHG emissions, depending on the understory vegetation type and structure, soil temperature, moisture content, SOC and nutrient status in plantation forests (Li et al., 2009; Wu et al., 2011a; Wang et al., 2011; Zhang et al., 2014).

Chinese chestnut (*Castanea mollissima* Blume) is a member of the *Fagaceae* family and is an important economic forest tree species. This species is distributed across 26 provinces and occupies about 1.25 million ha in China, which comprises 38% of the world's total chestnut plantation area and 75% of the total chestnut production (Chen et al., 2011; Li et al., 2014). Over the past two decades, intensive management practices such as fertilization, tillage and understory vegetation management have increasingly become common in Chinese chestnut plantations because of the demand for high yield and high economic return (Wu et al., 2010). Our previous study demonstrated that understory removal without replacement with legume species increased soil CO_2 and N_2O emissions and CH_4 uptake in a one-year field study, but had no effect on water soluble organic C (WSOC) and MBC (Zhang et al., 2014). However, the interactive effect between understory vegetation management and fertilization on soil GHG emissions and labile organic C pools in these types of intensively managed plantations has not been studied.

Replacement of understory vegetation with N-fixing species increased soil GHG emissions in tropical and subtropical plantations (Li et al., 2009, 2010; Zhang et al., 2014), but these studies rarely considered if the understory replacement effects on soil GHG emissions and C pools are affected by fertilization. In addition, the effects of fertilization on soil GHG emissions were rather complicated, with conflicting results reported for forest plantations (Zhang et al., 2008a; Janssens et al., 2010; Zhang et al., 2011; Krause et al., 2013; Tu et al., 2013). To improve our understanding of how understory replacement with legume species and/or fertilization influence soil GHG emissions and soil C and N pools, we conducted an one-year field study in which understory was removed or replaced in plots with or without fertilization in a Chinese chestnut plantation, and we measured their effects on soil temperature, moisture content, WSOC and MBC concentrations, and GHG fluxes. The objectives of this study were (1) to examine the short-term (one-year) effects of fertilization, replacement of understory with legume species, and their interaction on soil GHG fluxes and C and N pools in a Chinese chestnut plantation and (2) to determine the relationships between soil GHG fluxes and biotic and abiotic factors such as soil temperature, moisture content, WSOC, and MBC.

2. Materials and methods

2.1. Study area

The experiment was conducted in typical Chinese chestnut stands located at Tianze Forest Farm (30°25′N, 119°86′E) in Qing-Shan Township, Lin'an City, Zhejiang Province, China. This region has a typical subtropical humid monsoon climate with four distinct seasons. The mean annual air temperature and precipitation were 15.9 °C and 1450 mm, respectively, between 2001 and 2010. The monthly precipitation and mean air temperature during the experimental period are shown in Fig. 1. The annual sunshine and frost-free period averaged 1774 h and 239 days, respectively. The site was located in a hilly area at 150–250 m above sea level. The soils at this site were classified as Ferralsols according to the FAO soil classification system (WRB, 2006).

The Chinese chestnut plantation at this site was converted from natural evergreen broadleaf forests by planting chestnut trees after