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Effects of site preparation treatments before afforestation on soil carbon release

Jianlei Wang [a,b], Huimin Wang [a,*], Xiaoli Fu [a,*], Mingjie Xu [a], Yidong Wang [c]

[a] Qianyanzhou Ecological Research Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100039, China
[c] Tianjin Key Laboratory of Water Resources and Environment, Tianjin Normal University, Tianjin 300387, China

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ABSTRACT

Site preparation, as an important procedure before afforestation, can affect soil C release. However, the effect of site preparation on soil C release has not been sufficiently investigated. Two site clearing treatments (brush clearing and controlled burning) followed by three soil preparation treatments (overall soil preparation, spot soil preparation, and no soil preparation (control)) were carried out in subtropical China. Soil basal respiration (R_S) and C release of biomass burning were measured as soil C release on an area basis from March 2011 to March 2013. The site preparations changed the soil C release in the first year but had no effects in the second year. Compared with brush clearing (control), controlled burning (control) significantly increased the annual soil C release (decreased R_S but increased C release of biomass burning) during the first year. Within the brush clearing plots, overall soil preparation significantly increased the R_S rate over eight months and resulted in an increase in annual soil C release during the first year compared to the no soil preparation. In contrast, spot soil preparation increased the R_S rate only for three months and did not affect the annual soil C release during the first year relative to the no soil preparation. In the controlled burning plots, both overall and spot soil preparation increased the R_S rate across six months, but only overall soil preparation caused a significant increase in the annual soil C release. Our study suggests that minimizing the disturbance of the site preparation would decrease soil C release. Concluding, the spot soil preparation followed brush clearing is a good choice for site preparation in term of soil C storage.

1. Introduction

In the context of global climate change, how to enhance C sequestration and reduce C emission are major subjects. The Kyoto Protocol and IPCC Report (2007) suggested that afforestation is a potentially useful approach to mitigate the increasing atmospheric CO_2 concentration (Berthrong et al., 2012), and the area of forest plantations is rapidly increasing throughout the world (Nouvellon et al., 2008). In China, forestation has been carried out as an effective measure against environment degradation since the 1970s and has brought a remarkable increase in the forest C stock of 0.45 Pg (Fang et al., 2001).

Apart from vegetation C stock, afforestation also influences the soil C stock. Approximately 75% of the total terrestrial C is stored in the world's soils, and forest soils hold approximately 40% of all belowground C (Dixon et al., 1994; Huntington and Center, 1995). Therefore, even a small disturbance of the soil may result in a significant effect on the global C budget (Paul et al., 2002). Following afforestation, an initial decrease in soil C stock has been commonly observed (Trouvé et al., 1994; Paul et al., 2002, 2003) and a new soil C equilibrium is eventually reached after several years (Guo and Gifford, 2002). In recent years, a process-based model and a meta-analysis indicated that soil C stock decreased after afforestation, reached the minimum value after 5–10 years, and then recovered to pre-disturbance levels after approximately 20 years (Huang et al., 2007; Li et al., 2012). One possible reason was that the new C input from the young stands was too low to match the C decomposition (Vesterdal et al., 2002), and the plants-derived fresh organic matter (litter, root exudates, etc.) input may accelerate soil organic matter (SOM) decomposition due to the rhizosphere priming effects (Dijkstra et al., 2006). Another possible reason was the increase of soil C release caused by site preparation, because it can disturb soil structure, modify

* Corresponding authors.
E-mail addresses: wanghm@igsnrr.ac.cn (H. Wang), fuxl@igsnrr.ac.cn (X. Fu).

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microclimate and enhance aeration (La Scala et al., 2005; Mallik and Hu, 1997). However, most researches did not investigate the effects of site preparation without plants on soil C release.

Site preparation is typical site treatment before afforestation to favor the survival and growth of planted trees by reducing competition from understory vegetation (Karlsson, 2002). Site preparation generally includes site clearing (brush clearing and controlled burning) and soil preparation (overall soil preparation, spot soil preparation and no soil reparation). The effect of controlled burning on soil C release is more complex than that of brush clearing. Compared to brush clearing, controlled burning can affect soil C release not only during the burning process but also during the post-burning period (Fernández et al., 1999). During the burning process, 60–80% of the surface organic materials are burned out and revert to the atmosphere as CO_2 (González-Pérez et al., 2004), leading to a remarkable decrease in soil C stock (Guo et al., 2006). The long-term impact of burning on the ecosystem-atmosphere C exchange has been reported, however, these results were inconsistent (Phillips et al., 2002; Wuthrich et al., 2002; Hubbard et al., 2004; Ma et al., 2004). These contradictory results may be attributed to the difference of the burning intensity, soil microclimate, topography, and vegetation (McCarthy and Brown, 2006). During the burning, the burning intensity determines the amount of ash (Certini, 2005), soil properties (Boerner et al., 2000), soil microbial and root mortality (Chapin et al., 2004). In addition, ash deposition can increase the soil respiration (R_S) through increased nutrient release and hence available C substrate for microbes (Fritze et al., 1994), whereas alterations in soil chemistry can reduce microbial activity (Pietikäinen and Fritze, 1995; Badía and Martí, 2003). However, the relative importance of each of these components of burning on R_S is largely unknown.

Soil preparation, such as ploughing, ripping or disking, enhances soil C release (Post and Kwon, 2000; McLaughlin et al., 2000; Bernoux et al., 2006) by several mechanisms. Soil preparation mixed the organic surface layer with mineral soil, which created new conditions for organisms and may enhanced the decomposition rates of the buried organic matter (Johansson, 1994). In addition, soil preparation could disrupt soil aggregates and transfer labile organic matter to soil microorganisms (La Scala et al., 2008), resulting in a reduction in the amounts of intra-aggregate soil organic C. Soil preparation also affects soil C release by modifying the soil surface microclimate, e.g., the soil water content and temperature (Mallik and Hu, 1997). Enhanced R_S after soil preparation has been demonstrated (La Scala et al., 2005; Mallik and Hu, 1997), but the effects varied with on soil texture, initial soil C stocks and climate (Post and Kwon, 2000; Six et al., 2002). However, few studies have assessed the soil preparation effects on R_S in subtropical soils (Feller and Beare, 1997). Compared with the overall soil preparation, spot soil preparation affects the soil microclimate and properties with a relatively lower intensity. However, few studies have assessed the effects of spot soil preparation on R_S (Pumpanden et al., 2004; Strömgren and Mjöfors, 2012).

In subtropical China, forests encompass a total area of approximately 53 million hectares, of which approximately 41% are young plantations. Brush clearing, controlled burning and soil preparation before planting are traditional silvicultural practices to improve the survival rate and growth in South China (Yang et al., 2005). However, these measures can cause substantial loss and redistribution of organic matter (Johnson and Curtis, 2001; Certini, 2005). Furthermore, subtropical forests are characterized by the East Asian monsoon climate with a clear wet season and dry season and approximately 60% of precipitation occurred during the short rainy season from March to June (Wang et al., 2012a). Such higher rainfall, not only advantaged of moister soil for decomposition (Post et al., 1982), but also accelerated the soil surface compaction because of the rain splash (Mataix-Solera et al., 2011), and then may influence the duration of soil preparation on R_S. However, there is very little information available regarding the effect of site preparation on soil C release in this area (Guo et al., 2010). Especially, with climate-change-induced changes in precipitation amount and patterns, we need a better understanding to the impacts of site preparation on soil C release in subtropical China.

The main objectives of the present study were to assess the effects of different site preparation treatments before afforestation on soil C release. Based on previously documented R_S after similar site preparation (Guo et al., 2010; Mallik and Hu, 1997) and soil C stock change after afforestation in the same area (Huang et al., 2007), we hypothesize that (1) compared with brush clearing, controlled burning would decrease the annual cumulative R_S because litter and organic carbon are consumed in burning; (2) overall soil preparation increases the annual cumulative R_S, but spot soil preparation has less effects on the annual cumulative R_S due to the small disturbance area; and (3) site preparation effects on R_S may decline gradually over time, because of its direct effect on soil physical property might be weakened and lack of fresh organic matter input.

2. Materials and methods

2.1. Experimental site

The experiment was carried out at the Qianyanzhou Ecological Research Station (26°44′39″N, 115°03′33″E) in subtropical China. The site is controlled by a warm and humid monsoon climate and is characterized by a clear summer drought due to the unevenly distributed rainfall. The annual mean air temperature was 17.9 °C, and the precipitation was 1469 mm yr^{-1} from 1985 to 2008 (Wang et al., 2011). The soil was iron-rich red soil and classified as Typic Dystrudepts Udepts Inceptisols according to U.S. soil taxonomy (Wang et al., 2013). This study was conducted in an abandoned orange orchard. The vegetation was predominated by Loropetalum chinensis (R. Br.) Oliv, Cogon grass (*Imperata cylindrica* (L.) Beauv.) and Canadian Fleabane (*Conyza canadensis* (L.) Cronq.).

2.2. Experimental design

The experiment used a paired, nested design with site clearing (brush clearing and controlled burning) as primary treatments and soil preparation (overall soil preparation, spot soil preparation and no soil preparation) as secondary treatments. Three blocks of 14 m × 9 m were established for brush clearing and controlled burning treatments. Each block was placed about 1 m apart and was divided into six 4 m × 4 m subplots (Fig. 1). In two subplots of each block, sites were fully ploughed (brush clearing + overall soil preparation, BCOP; controlled burning + overall soil preparation, CBOP) with a depth of 30 cm or patch scarified (brush clearing + spot soil preparation, BCSP; and controlled burning + spot soil preparation, CBSP) with a size of 50 × 50 × 40 cm^3 (Length × Width × Depth). The two remaining subplots acted as no soil preparation controls (brush clearing control, BCCT; controlled burning control, CBCT). Further descriptions of site preparation were listed in Table 1.

2.3. Measurement of soil basal respiration

After site preparation, polyvinyl chloride (PVC) collars (11 cm in diameter, 6 cm in height) were immediately placed. In each subplot for BCCT, BCOP, CBCT and CBOP, four PVC collars were pressed