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Sensitivity of soil respiration to soil temperature decreased under deep biochar amended soils in temperate croplands

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ABSTRACT

Long-term effects of biochar application on soil carbon mineralization are important to evaluate the potential of biochar in carbon sequestration. Over a one-year period of time, we monitored soil respiration from a wheat-maize rotation cropping system after five years (once a year) of consecutive biochar application. In doing so four treatments with three replications each in a random design were examined: (1) a control plot without biochar and straw addition (CT), (2) 4.5 Mg biochar ha^{-1} $year^{-1}$ (B4.5), (3) 9.0 Mg biochar ha^{-1} $year^{-1}$ (B9.0) and (4) straw return (SR, ~15 Mg wheat + maize aboveground biomass ha^{-1} $year^{-1}$). An equivalent amount of inorganic fertilizers with biochar was broadcasted on the soil surface and then plowed into ~16 cm soil depth prior to seeding. Both temporal dynamics and cumulative amounts of soil respiration were not significantly changed under the two biochar applications than under CT, but significantly increased under straw return than under CT and two biochar treatments. The annual respiration was 29.42, 29.96, 30.08, and 39.00 Mg CO_2 ha^{-1} $year^{-1}$ in CT, B4.5, B9.0 and SR treatments, respectively. Meanwhile, soil respiration positively correlated with soil temperature but negatively with soil moisture. Sensitivity of soil respiration to temperature (Q_{10}) was significantly decreased due to biochar addition. These results indicated the potential of applying biochar to enhance soil carbon sequestration.

1. Introduction

The increasing interest in applying biochar to soil is predominantly from its potential for increasing soil carbon (C) sequestration and crop productivity concurrently (Verheijen et al., 2014), while these benefits should be thoroughly evaluated since the mean residence time of biochar in soil is estimated from decades to millennia (Lehmann et al., 2008; Zimmermann et al., 2012). To increase soil C sequestration without increasing native soil organic C (SOC) mineralization and/or greenhouse gas emission is a major challenge of biochar application, since the biochar effects varied with biochar features, application rates, soil types, climate, and crop systems (Fernandez et al., 2014; Liu et al., 2016).

Biochar could increase, decrease, or has no effect on greenhouse gas emission (Fernandez et al., 2014; Liu et al., 2016). For instance, the application of biochar that was derived from barley straw had no effects on CO_2 and CH_4 emission in the pasture or rice paddy soil while decreased N_2O emission in the pasture soil, but biochar from swine manure did increase N_2O emission in the paddy soil (Yoo and Kang, 2012). Biochar application also rapidly increased soil respiration in the first few hours or days (Jones et al., 2011; Smith et al., 2010), suppressed CO_2 emission by 33% (Case et al., 2014), or 4–40% during 1-month incubation (Li et al., 2013), but no significant cumulating of soil respiration over a 2–5 year long-term field experiment (Lu et al., 2014a,b; Zhang et al., 2012).

Effects of biochar on native SOC mineralization were also uncertain. For instance, over a 10-year period of buried bag incubation in forests the biochar addition showed little biochar degradation but greater soil humus decomposition (Wardle et al., 2008). Increased native SOC mineralization due to grass biochar was also found in an 87-day incubation experiment (Luo et al., 2011). In contrast, no influence (Jones et al., 2012) and negative priming effects (Singh and Cowie, 2014) of biochar on

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native SOC mineralization were observed. These uncertainties might limit the practical application of biochar.

Soil respiration is a good indicator to study soil C mineralization, though sampling conditions or procedures and low sampling frequency, could bias its estimation (Ryan and Law, 2005). At present, most studies of the biochar application on soil respiration or priming effects on C mineralization were based on laboratory controlled incubations or short-term field experiments (Jones et al., 2012; Lu et al., 2014a; Liu et al., 2016). The optimized conditions, for instance, a 60–70% soil water holding capacity with constant temperature during the whole incubation period, may not reflect the effects of frequent field drying and rewetting events on soil respiration (Yuste et al., 2007). Meanwhile, a short-term field experiment may not reflect the effect of biochar aging on soil respiration, as well as limited sampling times could underestimate the accuracy of cumulative C emission. Moreover, effects of the same biochar application rate on soil respiration would be different under one-time than under more than one-time application.

Moreover, besides C input, soil temperature and soil moisture are perhaps the most relevant factors affecting soil respiration. Biochar application could change soil temperature (Zhang et al., 2013b) and soil moisture patterns (Karhu et al., 2011), thus we hypothesized that biochar application might also affect the sensitivity of soil respiration to soil temperature or moisture, particularly in a long-term period of time. In doing so, we investigated the potential effects of a 5-year (annually) field application of biochar on soil respiration with an intensive sampling frequency of every 3–5 days. Under different biochar application rates over a 5-year long-term period, our objectives were therefore to determine (i) How could the soil respiration be affected and (ii) How could the sensitivity of soil respiration be varied with soil temperature or soil moisture?

2. Materials and methods

2.1. Experimental design

The field study was conducted in a traditional cropping area (36°57′N, 117°58′E, 17.6 m above the sea level) in Huantai County, Shandong, China, where has a warm temperate, continental

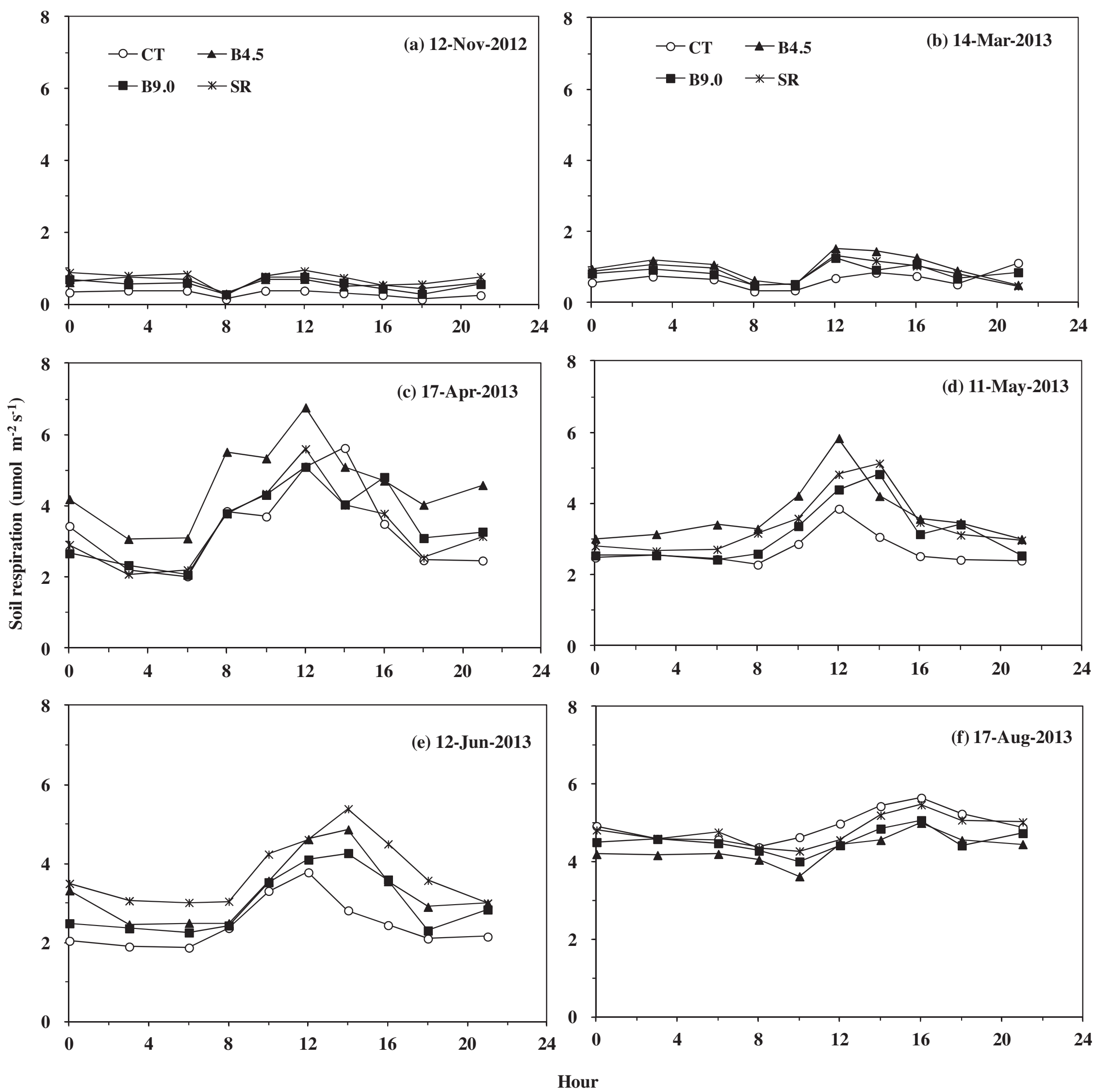

Fig. 1. Diurnal patterns of soil respiration in selected days (one or four month interval) between 12 November 2012 and 17 August 2013. Abbreviations: CT, non-biochar and non-straw return control; B4.5 and B9.0, 4.5 and 9.0 Mg ha^{-1} year^{-1} biochar without straw return; SR, straw return.