Geoderma 325 (2018) 172–182

Contents lists available at ScienceDirect

Geoderma

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

Temperature sensitivity of soil respiration to nitrogen and phosphorous fertilization: Does soil initial fertility matter?

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ARTICLE INFO

Handling Editor: Junhong Bai

Keywords:
Soil fertility
NP fertilization
Q_{10}
Soil respiration

ABSTRACT

Temperature sensitivity of soil respiration (Q_{10}) is an important parameter when modeling the effects of global warming on terrestrial ecosystem carbon release. Widely applied chemical fertilizers can significantly affect soil productivity and carbon cycling in agroecosystems. However, little is known about how Q_{10} responds to chemical fertilization under different levels of initial soil fertility. On the Chinese Loess Plateau, changes in soil respiration rates and Q_{10} were investigated in soils of two fertility levels: low fertility (L) and high fertility (H). For each soil fertility level, there was one control plot and one chemical fertilized plot (+NP), which in total formed four treatments: L, L + NP, H and H + NP. All the treatments were replicated for three times on a continuous winter wheat cropping system. Respiration rates of surface soil in each treatment were in situ monitored from October 2010 through September 2015. Our results showed that after NP fertilization, soil respiration rates were increased by 46% in low fertility soil, yet only by 14% in high fertility soil ($P < 0.05$). The Q_{10} after NP fertilization was significantly decreased by 6.9% in low fertility soil, but was unchanged in the high fertility soil. The Q_{10} variation might be attributed to the different response of microbial respiration Q_{10} in the two soils. The decreased Q_{10} with NP fertilization in the low fertility soil was possibly due to N-induced increase of substrate quality for soil microbes and increased activities of both cellobiohydrolase and polyphenol oxidase. In the high fertility soil, the unchanged Q_{10} with NP fertilization may be the integrated result of less affected substrate quality and neutral response of polyphenol oxidase activity. Overall, our results suggested that the effects of NP fertilization on soil respiration and its temperature sensitivity varied with soil initial fertility levels, and therefore must be properly accounted for when estimating potential effects of local agricultural management to regional agroecosystems under future climate conditions.

1. Introduction

Temperature sensitivity of soil respiration in an ecosystem (Q_{10}: multiplier of soil respiration rate for a 10 °C increase in temperature) partially governs the amount of carbon released from soils to the atmosphere in response to global warming (Cox et al., 2000; Zhou et al., 2009). Large variations in the responses of soil respiration to temperature (Q_{10}) have been reported in different land uses, ecosystems or climatic conditions (Lloyd and Taylor, 1994; Davidson and Janssens, 2006; Zheng et al., 2009). The variation of the Q_{10} value in carbon cycle models may result in significant bias in the estimation of soil respiration (Townsend et al., 1997; Xu and Qi, 2001), which is regulated by multiple factors. For a certain soil, Q_{10} is closely related to the availability (Gershenson et al., 2009; Lützow and Kögelknabner, 2009) and quality (Davidson and Janssens, 2006; Wang et al., 2016) of respiration substrates, nutrient availability (Burton et al., 2002; Wang et al., 2017a; Zeng and Wang, 2015), the composition and size of soil microbial population (Coucheney et al., 2013; Ramirez et al., 2012) and activities of extracellular microbial enzymes (Stone et al., 2012; Wallenstein et al., 2009). All these factors are related to soil fertility (Lauber et al., 2008; Liu et al., 2010b), the effect of which on Q_{10} has been acknowledged but not well understood (Zheng et al., 2009; Uchida et al., 2010).

Chemical fertilization is a common field practice to sustain food production in agroecosystems (Liu, 1999; Fan and Zhang, 2000).

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https://doi.org/10.1016/j.geoderma.2018.04.001
Received 1 December 2016; Received in revised form 20 March 2018; Accepted 2 April 2018

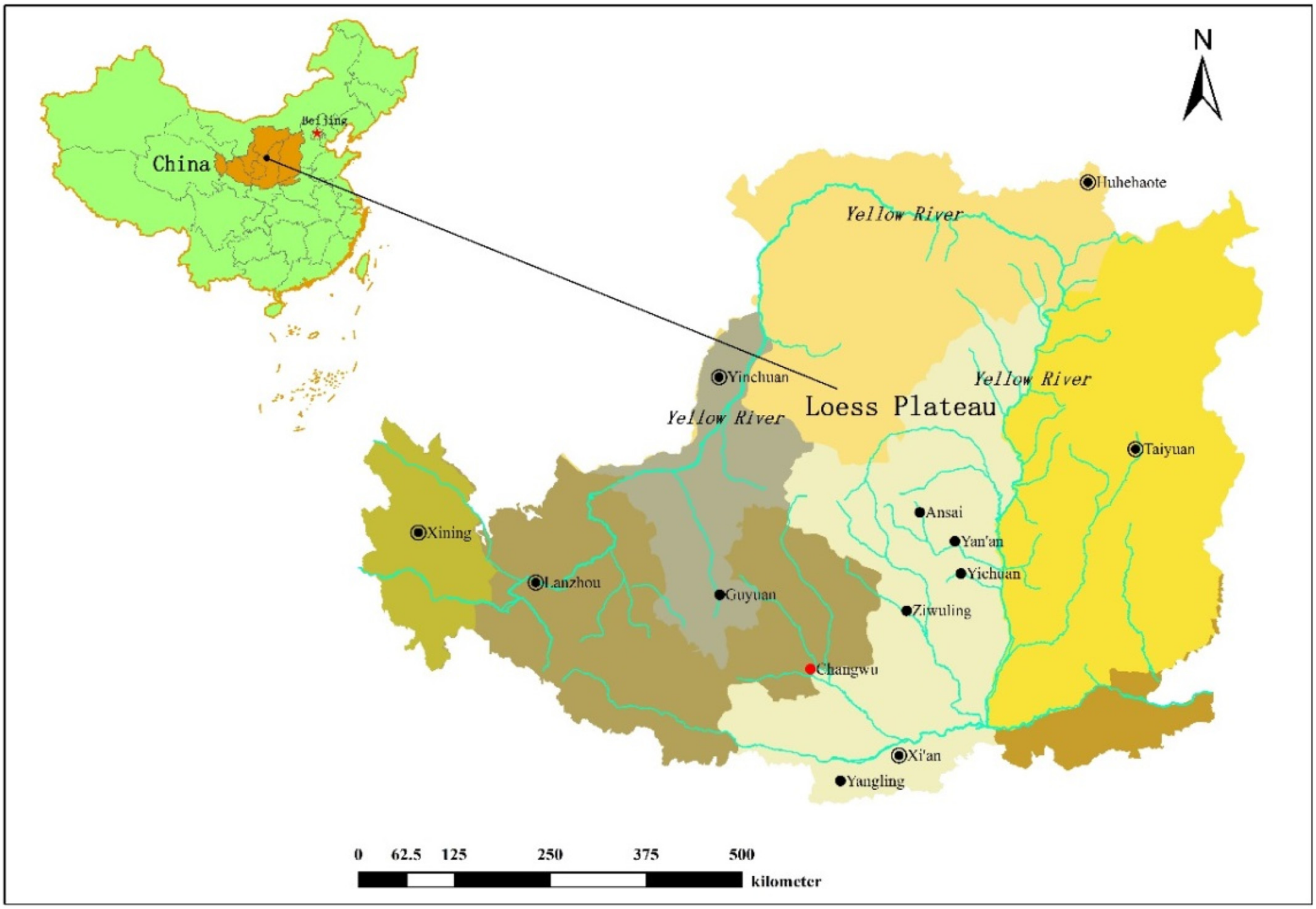

Fig. 1. Location of the experimental site in the Loess Plateau, China (cited from Wang et al., 2017a).

Agroecosystems on Loess Plateau, characterized by low yet highly variable soil fertility (Wang et al., 2014), normally have low availability of natural N in soils, with the typical total N concentrations ranging from 0.042 to 0.077% (Zhu et al., 1983). Depletion of soil nutrients is a major constraint on sustainable food production in the loess region (Guo et al., 2012). To meet the local food requirement, arable soils in the Loess Plateau are normally heavily fertilized, especially with N and P fertilizers ($> 200\,\mathrm{kg\,N\,ha^{-1}}$ each crop, $> 60\,\mathrm{kg\,P\,ha^{-1}}$ each crop) (Guo et al., 2010; Ju et al., 2004), which results in even more variable soil fertility. In addition, climate change has resulted in increases in temperature and decreases in rainfall across the Loess Plateau since 1970 (Zhi et al., 2010; Sun et al., 2015). Therefore, how chemical fertilization affects the response of soil respiration to temperature changes at different fertility levels is of great relevance to management of agroecosystems, especially when confronting future climate change.

As one of the most effective ways regulating soil fertility (Liu et al., 2010a; Nest et al., 2014), chemical fertilization is playing increasingly important role in the carbon cycle of agroecosystems (Zhang et al., 2017). Chemical fertilization influences the magnitude of soil respiration and its components by altering soil physicochemical and biological properties and belowground carbon allocation (Chen et al., 2017; Ding et al., 2010). Specifically, through enhancing soil N availability, N fertilization could change microbial community (Allison et al., 2007; Ramirez et al., 2012; Xun et al., 2015) and soil enzyme activities (Allison and Vitousek, 2005; Stone et al., 2012; Waldrop et al., 2004), which is highly related to C turnover (Jiang et al., 2014). Furthermore, N and P fertilization generally exerts significant effect on photosynthetic rate and the belowground allocation of the photosynthesis especially in N-limited ecosystems (Wang et al., 2017a; Zeng and Wang, 2015). Moreover, increased nutrient (N in particular) inputs can change plant tissue N concentration (Burton et al., 2002; Burton et al., 2015; Lovelock et al., 2006) and then shift plant carbon supply to microbes (Högberg et al., 2003), further affecting microbial decomposition (Graham et al., 2012). The soil C:N:P ratio, highly related to substrate quality (Dignac et al., 2002; Leifeld and von Lutzow, 2014), drives key ecological processes (de Menezes et al., 2015; Dignac et al., 2002; Ma et al., 2013; Sardans et al., 2012) and may strongly affect the ecosystem C storage (Zeng and Wang, 2015). Previous studies have reported the effects of chemical fertilization on Q_{10}, yet the results varied with ecosystems (Zhou et al., 2014). For instance, N (and P) fertilization or N (and P) deposition reduced Q_{10} was more reported in forest (Mo et al., 2008; Sun et al., 2014), grassland ecosystems (Li et al., 2015; Zhang et al., 2014), and less in agroecosystems (Chen et al., 2017). In contrast, increased Q_{10} with increasing N (and P) inputs was reported in a Tibetan alpine meadow (Guo et al., 2017) and cold temperate forest (Liu et al., 2016). In addition, neutral responses were also reported in a young *Cunninghamia lanceolata* forest (Wang et al., 2017b) and a temperate grassland in Inner Mongolia, China (Li et al., 2015). However, at present, no consensus has been achieved with regards to the response of Q_{10} to chemical fertilization, as initial soil fertility is not always appropriately accounted for in these studies.

In this study, changes in surface soil respiration and its temperature sensitivity, soil and crop properties were investigated after applying NP fertilization for five years on soils of low and high fertility under a continuous winter wheat cropping system on the Loess Plateau. The aim of this study was to examine the responses of Q_{10} to NP fertilization in low and high fertility soils, and to further explore the driving factors for different responses. We proposed two hypotheses that 1) soil respiration