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Contrasting responses of soil respiration and temperature sensitivity to land use types: Cropland *vs.* apple orchard on the Chinese Loess Plateau

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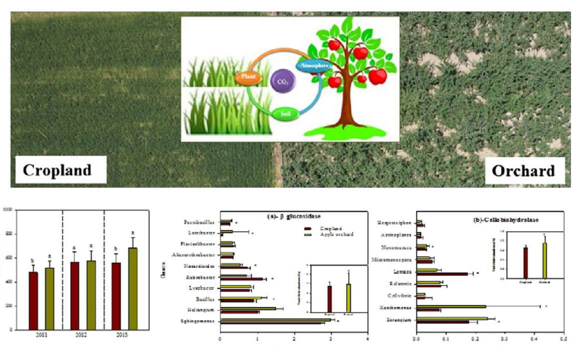
HIGHLIGHTS

- Contrasting responses of soil respiration and Q_{10} to land use types in fragmented Loess Plateau
- Compared to the cropland, the lower Q_{10} in the apple orchard resulted from varied bacterial community structure and β-glucosidase and cellobiohydrolase activity.
- Lower C: N ratios in the apple orchard possibly contributed to its lower Q_{10}.

GRAPHICAL ABSTRACT



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ABSTRACT

Land use plays an essential role in regional carbon cycling, potentially influencing the exchange rates of CO_2 flux between soil and the atmosphere in terrestrial ecosystems. Temperature sensitivity of soil respiration (Q_{10}), as an efficient parameter to reflect the possible feedback between the global carbon cycle and climate change, has been extensively studied. However, very few reports have assessed the difference in temperature sensitivity of soil respiration under different land use types. In this study, a three-year field experiment was conducted in cropland (winter wheat, *Triticum aestivum* L.) and apple orchard (*Malus domestica* Borkh) on the semi-arid Loess Plateau from 2011 to 2013. Soil respiration (measured using Li-Cor 8100), bacterial community structure (represented by 16S rRNA), soil enzyme activities, and soil physicochemical properties of surface soil were monitored. The average annual soil respiration rate in the apple orchard was 12% greater than that in the cropland (2.01 *vs.* 1.80 μmol m^{-2} s^{-1}), despite that the average Q_{10} values in the apple orchard was 15% lower than that in the cropland (ranging from 1.63 to 1.41). As to the differences among predominant phyla, Proteobacteria was 26% higher in the apple orchard than that in the cropland, whereas Actinobacteria and Acidobacteria were 18% and 36% lower in the apple orchard. The β-glucosidase and cellobiohydrolase activity were 15% (44.92 *vs.* 39.09 nmol h^{-1} g^{-1}) and 22% greater (21.39 *vs.* 17.50 nmol h^{-1} g^{-1}) in the apple orchard than that in the cropland. Compared to the cropland, the lower Q_{10} values in the apple orchard resulted from the variations of bacterial community structure and β-glucosidase and cellobiohydrolase activity. In addition, the lower C: N ratios in the apple orchard (6.50 *vs.* 8.40) possibly also contributed to its lower Q_{10} values. Our findings call for further studies to include the varying effects of land use types into consideration when applying Q_{10} values to predict the potential CO_2 efflux feedbacks between terrestrial ecosystems and future climate scenarios.

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1. Introduction

Soil respiration is a key component of terrestrial carbon cycling (Raich and Schlesinger, 1992; Cox et al., 2000; Jiang et al., 2015). A small variation in temperature sensitivity of soil respiration (often expressed as Q_{10}) can cause a large bias in predicting soil CO_2 release into the atmosphere, especially under the ever-changing climate conditions in the future (Xu and Qi, 2001; Wang et al., 2016). Long-term erosion and intensive cultivation has incised the vast Loess Plateau in China into fragmented tableland, slopes or gullies, and valley bottoms (Wang et al., 2017a, 2017b). In order to tackle such soil erosion problems, the "Grain-for-Green" rehabilitation project was initiated in 1980s, which converted all cropland on slopes steeper than 25° to orchard, forest or grassland (Deng et al., 2014). This consequently formed complex combinations of tableland, slopes and valleys with cropland, grassland, orchard and woodland. Therefore, it becomes critically essential to systematically investigate the effects of land use on Q_{10} values in the context of complex landforms so as to better understand the role of soil respiration in the carbon cycling on the fragmented Loess Plateau.

In general, land use conversion alters vegetation coverage, soil physicochemical and microbial properties, which all affect soil respiration (Iqbal et al., 2008; Liu et al., 2008; Javed et al., 2010; Kreba et al., 2013; Wang et al., 2016). For instance, soil respiration can vary among crop species and root biomass amount under different land use types (Lee and Jose, 2003; Raich and Tufekcioglu, 2000; Wang et al., 2016). Even after excluding the variation of root effects, soil respiration can also differ among land use types because of different redistribution of precipitation and solar radiation by vegetation canopy (Bryant et al., 2005; Dan and Giardina, 1998; Smith and Johnson, 2004; Raich and Tufekcioglu, 2000; Ritter et al., 2005; Rutter and Morton, 1977). Furthermore, soil respiration can also change with soil microbial community structure (Asgharipour and Rafiei, 2011; Wallenius et al., 2011; Moon, 2016; Zhang et al., 2016a, 2016b), and soil C-degrading extracellular enzymes *via* secreting by soil microbes (Allison and Vitousek, 2004; Davidson and Janssens, 2006; Burns et al., 2013; Wang et al., 2017). The quantity and stability of substrate under different land use types was another factor influencing soil respiration, as better availability of carbon was reported to produce greater soil respiration (Allison et al., 2014; Fang et al., 2014; Ferreira et al., 2016).

Since Q_{10} represents the sensitivity of soil respiration to temperature changes, all the above-mentioned factors can also cause variation in Q_{10} values. In general, Q_{10} values tends to increase with decreasing soil temperature and increasing moisture (Kirschbaum, 1995; Qi and Xu, 2001; Janssens and Pilegaard, 2003), both of which are essential environment factors for soil microbial growth, community structure and activity (Avrahami et al., 2003; Brockett et al., 2012; Ren et al., 2017; Supramaniam et al., 2016). Similarly, Q_{10} values can also be influenced by the quality of substrate (Conant et al., 2008; Karhu et al., 2010; Conant et al., 2011), as the degradation of low-quality substrate, which has higher total activation energy for microorganism decomposition, has a higher Q_{10} values than simple base on enzyme-kinetic hypothesis (Bosatta and Agren, 1999; Wang et al., 2017a, 2017b). This further suggests that soil nutrient can also influence Q_{10} values by altering the stability of substrate (*e.g.* C: N ratio) (Pregitzer et al., 2000; Leifeld and von Lutzow, 2014). However, very few studies have dedicated to investigate the effects of soil bacterial community structure to soil respiration and Q_{10} values under different land use types.

In this study, the potential effects of soil bacterial community on soil respiration and Q_{10} values were compared between soils from an apple orchard and a cropland on the Chinese Loess Plateau. We hypothesized that different land use types would affect all the above-described factors, which in turn would lead to changes in soil respiration and its sensitivity to temperature changes. Therefore, the aims of this study are to: 1) compare the difference of soil respiration and Q_{10} values between cropland and apple orchard; 2) characterize the changes in bacterial community and soil extracellular enzymatic activity under different land use types; and 3) explore the potential effects of bacterial community and activities on Q_{10} values and soil respiration under different land use types.

2. Materials and methods

2.1. Study site

The study site is located in a typical tableland-gully region of southern Loess Plateau in the middle reaches of Yellow River (35°13′N, 107°40′E; 1220 m a.s.l) in Wangdonggou Catchment, Changwu Country, Shaanxi Province, China (Fig. 1). It has a continental monsoon climate characterized by a seasonal monsoon rhythm with hot summers and cold winters. The annual mean precipitation is 560 mm, 60% of which occurs between July and September. The annual mean air temperature is 9.4 °C, and ≥ 10 °C accumulated temperature is 3029 °C. The annual sunshine hours are 2230 h, annual total radiation is 484 kJ cm^{-2}, and frost-free period is 171 days. The soil at the study site is a uniform loam of loess deposits that belongs to Cumulic Haplustolls according to the American system of soil classification, originated from the parent material of calcareous loess (Wang et al., 2016). All meteorological data during experiment time were provided by Changwu State Key Agro-Ecological Experimental Station (Fig. 2).

2.2. Different land use types

Two ecosystem, apple orchard and cropland, with different agronomic management practices were selected. The apple orchard investigated in this study was dominated by Fuji apple trees (*Malus domestica* Borkh), and the cropland was 0.5 km away from the apple orchard and planted with winter wheat (*Triticum aestivum* L., cv. Changwu 89 (1) 3–40). The detail agronomic management practices were listed in Table 1.

On the cropland, three plastic collars (20 cm in diameter × 12 cm in height) were inserted 2 cm into the soil in a complete randomized block design. In the apple orchard, considering the possible spatial variation, it was divided into trisections along diagonal. In each section, a well-grown apple tree with no diseases or insect pests was selected. At different distances (0.5 and 2 m radial distance) from each tree trunk, plastic collars were inserted into the soil in three different directions (0°, 120°, and 240°).

2.3. Measurements of soil respiration, soil temperature and moisture

Soil respiration was measured every 15 days from March 2011 to November 2013, from 09:00 am to 11:00 am on each measurement day (Javed et al., 2010). During December, January and February, due to cold weather which could inhabit root and microbial activity, no measurements were carried out. The soil respiration rates were determined using an automated and closed soil CO_2 flux system equipped with a portable chamber of 20 cm in diameter (Li-8100, Lincoln, NE, USA). Before each measurement, all visible living organisms were manually removed.

Soil temperature (three measurements per collar) and moisture (four measurements per collar) were measured 10 cm away from the chamber collar at the same time with the soil respiration. Soil temperature was measured using a Li-Cor thermocouple probe and soil moisture at 5 cm depth was recorded by a Theta Probe ML2X with an HH2 moisture meter (Delta-TDevices, Cambridge, England). Soil water-filled pore space (WFPS) was converted from following equation: WFPS (%) = [volumetric water content / 100 × (2.65 − soil bulk density) / 2.65] (Ding et al., 2007).

2.4. Sampling and analysis

Three cropland soil samples (0–20 cm) were collected using a soil auger of 3 cm in diameter in 28 September 2013 (the last experimental