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Impact of tillage management on the short- and long-term soil carbon dioxide emissions in the dryland of Loess Plateau in China

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ABSTRACT

Soil carbon dioxide (CO_2) emission from agricultural areas is a complex phenomenon with high temporal and spatial variability. Tillage practices can affect drivers of CO_2 production and therefore influence emissions by soils. However, the impact of tillage management on CO_2 emissions from soil is uncertain due to specific climate and soil characteristics. A field experiment was initiated in 1992 in Shanxi, China including the no-tillage plots with straw mulching (NT) and conventional-tillage (CT) treatment. In 2012, another treatment (NT0) was conducted during which the straw was not returned to the plots when the winter wheat harvested. The CO_2 emissions, soil temperatures and soil moisture content were measured during the fallow and wheat-growing periods from 2013 to 2015. Results showed that the rate of CO_2 emissions was significantly higher immediately after tillage operation in the CT treatment. The annual CO_2 emission rate in the NT treatment was significantly greater than that in the CT and NT0 treatments ($P < 0.05$). For different season, the highest CO_2 emissions rate occurred in summer (0.20 g CO_2-C m^{-2} h^{-1}) while the lowest CO_2 emissions rate occurred in winter (0.04 g CO_2-C m^{-2} h^{-1}). These rates were only positively correlated with the soil temperatures ($P < 0.05$) and not significantly correlated with the soil moisture contents. Our results indicated that NT farming practices demonstrated increases CO_2 emissions from soil compared with the CT and NT0 treatments under dryland cropping system.

1. Introduction

The carbon dioxide (CO_2) emissions from soil are an important part of the carbon cycle in terrestrial ecosystems. Tillage practices play an important role in the storage and release of C within the C cycle in the agricultural ecosystems (Page et al., 2012). With increasing concern of global warming, changes in tillage management in the agricultural sector can result in significant changes in the CO_2 emissions (Mangalassery et al., 2015; Sheehy et al., 2015). Research on the effect of NT on CO_2 emission has generated mixed results. Some studies have reported stimulation of CO_2 emissions from NT (Plaza-Bonilla et al., 2014; Shahidi et al., 2014), others have reported mitigation (Fuentes et al., 2012) and others have reported no impact (Fortin et al., 1996; Aslam et al., 2000). Thus, the net effect of tillage on CO_2 emission is inconsistent and not widely quantified. Moreover, the potential influence of tillage on CO_2 emission remains uncertain because of the variability site-specific properties (Guardia et al., 2016).

Differences in the CO_2 emissions from soils were the sole result of the short- and long-term combination effect induced by different tillage practices (Oorts et al., 2007). While measurement of change in soil C storage over extended periods indicates the long-term influence of tillage, short-term estimates of CO_2 emissions may provide more information on the mechanisms involved (Ellert and Janzen, 1999). Tillage-induced changes in CO_2 emission from soil (if any) may reflect both the immediate influence of tillage operations on C cycling, and the longer-term influence of tillage on the changes in physical, chemical and biological environment. Some authors reported effects on the short-term CO_2 emissions (Al-Kaisi and Yin, 2005; La Scala et al., 2008). Other studies reported the results from long-term trials comparing with tillage systems in which CO_2 emission was measured continuously in other periods than directly after tillage (Shahidi et al., 2014; Datta et al., 2013). However, there are few integrated studies that focus on

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tillage practices effects on the short- and long-term CO_2 emission from the soil on the Loess Plateau in China.

The response of CO_2 emission from soil to tillage managements may depend on various factors such as soil temperature and soil moisture content, or an interaction between these two, and availability of substrates (Lu et al., 2015). Research has demonstrated that soil temperature and moisture may account for 76%–95% of the variation in soil CO_2 efflux (Xu and Qi, 2001). Moreover, soil properties variation induced by different tillage practices, which, in turn, could affect carbon mineralization and thus CO_2 emission from soil (Bajracharya et al., 2000). Therefore, a better understanding is needed about how the change tillage practices alter the soil CO_2 emission and its relationship with soil properties.

The Loess Plateau is a semiarid region characterized as a dry-farmed ecosystem; this system has little rainfall but high evaporation, resulting in a low crop yield. In this region, the conventional ploughing is widely applied, and the crop residues are scarcely returned to the soils, resulting in low soil organic matter contents (Yu et al., 2007). To date, many studies concerning on the CO_2 emissions from soil have been conducted in China and other countries, but few have focused on the annual soil CO_2 emissions from soils in short- and long-term no-tillage treatments on the Loess Plateau. Thus, the objectives of this study were to (i) determine the short- and long-term CO_2 emissions from soils in no-tillage and conventional-tillage practices (21 years) on the Loess Plateau; (ii) examine the relationship between the CO_2 emissions with soil moisture contents and soil temperature. We hypothesised that, in long-term NT practice, the soil moisture content and temperature would be increased. Therefore, NT treatment will change the annual CO_2 emissions compared to the CT practice.

2. Materials and methods

2.1. Description of field experiment

The long-term experiment began in 1992 in Linfen County, Shanxi, China (38° 6′ N, 113° 26′ E, 456 m asl). The experimental site is classified as semi-arid and sub-tropical area, with a mean annual precipitation of 555 mm, falling mostly between July and September (Fig. 1). The average annual temperature is 10.7 °C, with 180 frost-free days. The fallow period is from mid-June to mid-September. The erosion index is < 400 t km^{-2} $year^{-1}$ (Wang et al., 2008).

Fig. 2. Long-term experimental plots (CT, conventional-tillage; NT, no-tillage with straw mulching).

The soil is a Cinnamon Loess, slightly alkaline with low organic matter. Under the USDA texture classification system, the soil is defined as silt loam and according to the FAO-UNESCO soil map (1988), the soil type is a Chromic Cambisol (sand 23.1%, silt 43.3%, clay 33.6%). The soil physiochemical properties were measured using the methods described by Bao (2005). In the top 20 cm layer, the pH (soil:water, 1:2.5) was 7.7, the soil organic matter content was 13.0 g kg^{-1}, the total N was 0.50 g kg^{-1}, the total P was 0.15 g kg^{-1}, and the total K was 12 g kg^{-1}.

The long-term experimental plots have been maintained in two different treatments: conventional-tillage (CT) and no-tillage (NT) (Fig. 2). Triplicate treatments were carried out in randomised blocks, with plot sizes of 6 m × 80 m. The CT treatment included mouldboard ploughing without returning the wheat straw to the field. For the NT system, all of the residues of the wheat straw were flattened and mulched in the field prior winter. In June 2012, another treatment (NT0) was conducted, during which the straw was not returned to the plots when the winter wheat harvested. The winter wheat (*Triticum aestivum* L.) was sown at the end of September and harvested in the middle of the next June each year. The fallow period lasted from the harvest to the end of September. Herbicides were used for weeds control during this time. The winter wheat seeds used were Linfen 225, sown on 225 kg hm^{-2}. Fertilisers were applied during wheat seeding, mainly urea (150 kg N hm^{-2}), diammonium phosphate (140 kg P_2O_5 hm^{-2}) and potassium chloride (62 kg K_2O hm^{-2}).

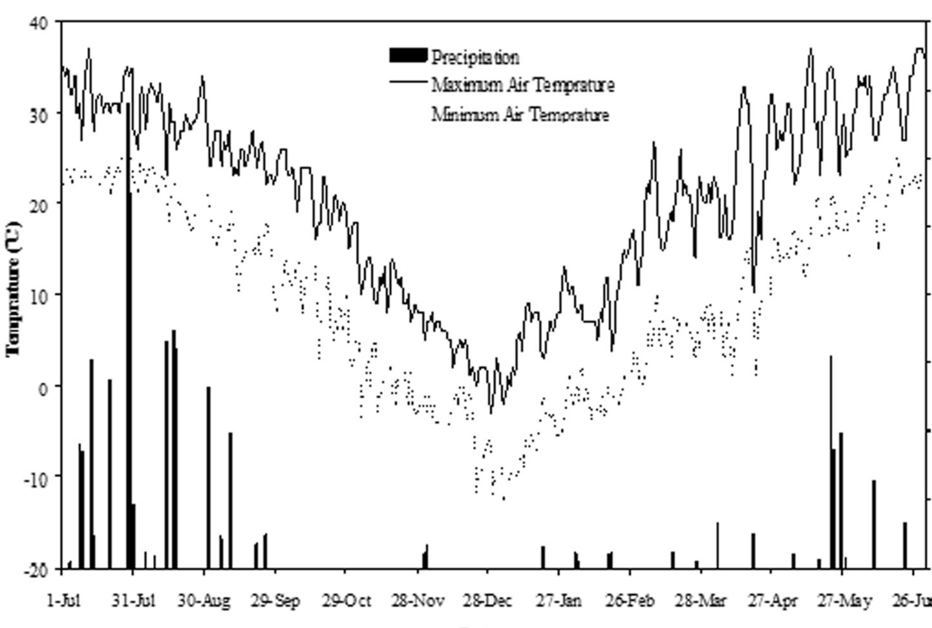

Fig. 1. Air temperature (°C) and precipitation (mm) during the sampling period at the Linfen Long-term Agricultural Research Farm on the Loess Plateau of China.