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Nitrogen fertilization increase soil carbon dioxide efflux of winter wheat field: A case study in Northwest China

Ruixin Shao [a,*,1], Lei Deng [b,**,1,2], Qinghua Yang [a], Zhouping Shangguan [b,**]

[a] Collaborative Innovation Center of Henan Grain Crops, Agronomy College of Henan Agricultural University, the National Key Laboratory of Wheat and Maize Crop Science, Zhengzhou 450002, PR China
[b] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, Shaanxi 712100, PR China

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ABSTRACT

As the largest reservoir of terrestrial carbon (C), soil is a source or sink for atmospheric carbon dioxide (CO_2). Understanding the processes whereby soil CO_2 is released into the atmosphere as a result of using inorganic nitrogen (N) fertilizers may provide us with knowledge of processes to offset the increasing concentration of CO_2. The main objective of this study was to investigate the effects of different N levels on soil CO_2 efflux with one controlled experiment. A field experiment was carried out in a non-irrigated winter wheat (*Triticum aestivum* L.) – cropland in Northwest China to investigate the effects of N fertilization on soil CO_2 efflux in two consecutive growing seasons (2007–2009). The soil CO_2 efflux to which N was applied at four different levels (0, 90, 180, and 360 kg N ha^{-1}) was measured during the growing seasons in 2007–2009. At most growth stages during the growing season, the soil CO_2 efflux increased significantly with increased N application. The effect of N fertilization on the cumulative soil CO_2 efflux was obvious. In the 10–20 cm soil layer, the seasonal variations in soil CO_2 effluxes were influenced by soil temperature (ST) rather than by soil water content (SWC). When ST >20 °C, however, the low soil CO_2 efflux was mainly due to low SWC, which was close to the permanent wilting point (8.5 g H_2O 100 g dry $soil^{-1}$). In addition, soil CO_2 effluxes after anthesis were higher than those at seedling stage and were highest nearby anthesis stage. The results indicated that N fertilization probably had a positive effect on both the seasonal and cumulative soil CO_2 effluxes during the growing season.

1. Introduction

Soil carbon dioxide (CO_2) emission through soil respiration (SR) is one of the primary fluxes of carbon (C) between soils and the atmosphere (Iqbal et al., 2009), accounting for about 25% of the total annual exchange of C between the atmosphere and terrestrial sources (Post et al., 1990) and more than 11 times of the CO_2 released from fossil fuel combustion (Marland et al., 2000), and is estimated to be 75 Pg C (Schlesinger and Andrews, 2000). Accordingly, a small variation in the turnover intensity of soil organic carbon (SOC) can result in a great change in the CO_2 concentration in the atmosphere (Riley et al., 2005; Iqbal et al., 2009). However, it is difficult to directly measure these small variations in SOC in the field, due to high spatial variability and small changes in SOC content during a single growing season (Ding et al., 2007). Hence, soil CO_2 efflux is commonly measured to investigate short-term SOC turnover.

The process of soil CO_2 efflux is greatly altered by management practices (e.g., soil tillage operations) and weather conditions (e.g., rainfall events) (Ding et al., 2006; Morell et al., 2010; Ji et al., 2012). Additionally, long-term agricultural management practices affect soil CO_2 efflux by changing the soil environment such as soil aeration, soil pH, soil moisture, soil temperature (ST), and C/nitrogen (N) ratio of substances (Iqbal et al., 2009). These soil environmental conditions are characterized with a significant effect on soil microbial activity and the decomposition processes that transform plant-derived C to soil organic matter (SOM) and CO_2 (Franzluebbers et al., 1995; Morell et al., 2010). In previous studies, it has shown that soil CO_2 efflux is strongly related to ST and soil moisture conditions (Iqbal et al., 2008; Liu et al., 2008).

N has been regarded as a significant factor controlling SR in N-deficient terrestrial ecosystems (Peng et al., 2011), especially in

* Corresponding author. Tel.: +86 371 63555778; fax: +86 371 63558122.
** Corresponding authors at: Institute of Soil and Water Conservation, Northwest A&F University, No. 26 Xinong Road, Yangling, Shaanxi 712100, PR China. Tel.: +86 29 87019107; fax: +86 29 87012210.
E-mail addresses: shao_rui_xin@126.com (R. Shao), denglei011124@163.com (L. Deng), shangguan@ms.iswc.ac.cn (Z. Shangguan).
[1] These authors contributed equally to this work and should be considered as co-first authors.
[2] Tel.: +86 15289383034.

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agricultural ecosystems (Ni et al., 2012). Currently, with increasing levels of anthropogenic N deposition and heavy application of fertilizer (Nie et al., 2012), much N enters terrestrial ecosystems and can lead to environmentally damaging pollution to soil and water. The effect of N addition on SOC has already been reported in some studies (Lal, 2008; Ghimire et al., 2012; Tao et al., 2013). On one hand, N fertilization has been shown to increase SOC through increasing biomass production, and hence, C inputs to the soil (Luo et al., 2010; Lu et al., 2013). On the other hand, N fertilization affects SR and C outputs from the soil (Ding et al., 2007; Sainju et al., 2008; Song et al., 2013). As a result, N fertilization may greatly affect the SOC content. However, N addition to soil has been shown to have different effects on soil CO_2 efflux. Some studies have reported that N input remarkably increased SR (Pregitzer et al., 2000; Burton et al., 2002; Bowden et al., 2004), suggesting that the stimulatory effects of N loading on ecosystems can reduce ecosystem C storage (Cao and Woodward, 1998). Conversely, N fertilization has also been observed to reduce organic C decomposition and suppress SR, resulting in increased SOC (Burton et al., 2002; Foereid et al., 2004). With increasing application of N fertilizers, it is, therefore, necessary to further elucidate the real effects of N input on SR in diverse agricultural ecosystems and different planting regions.

In China, more than 50% of the total farmland is cropland located in arid and semi-arid regions (Shangguan et al., 2001), and the arable soils are intensively cultivated using high input of N fertilizers (Ding et al., 2010). Previous studies mainly focused on SR responses to N fertilization application in grassland (Li et al., 2012a), the paddy (Li et al., 2012b), or corn-cropland soils (Song and Zhang, 2009; Ding et al., 2010; Nie et al., 2012) in the region. To our knowledge, however, there is no information for wheat-cropland soils in arid and semi-arid regions of Northwest China, although one study was conducted on N fertilization in North China Plain, in which the climate in agricultural ecosystems is different from that in the arid and semi-arid regions (Chen et al., 2004).

Therefore, we conducted a controlled experiment to investigate the effects of different N levels on soil CO_2 efflux in the arid and semi-arid regions of Northwest China. In the present study, a field experiment was carried out in a non-irrigated winter wheat-cropland to investigate effects of N fertilization on soil CO_2 efflux over two consecutive growing seasons (2007–2009).

Table 1
Selected soil physical–chemical properties in 0–20 cm soil layer before fertilization.

Property	Value
Taxonomy	Eum-Orthic Anthrosols
Texture	
2000–50 μm (g kg^{-1})	64
50–2 μm (g kg^{-1})	694
<2 μm (g kg^{-1})	342
Bulk density (g cm^{-3})	1.23
pH	5.43
Water holding capacity (g H_2O 100 g dry soil^{-1})	23.6
Permanent wilting point (g H_2O 100 g dry soil^{-1})	8.5
Total organic carbon (g kg^{-1})	13.20
C/N	15
Total N (g kg^{-1})	0.80
Available N (mg kg^{-1})	25.10
Available P (mg kg^{-1})	7.90

2. Materials and methods

2.1. Research site and experimental setup

The study was conducted in Yangling, Shaanxi, Northwest China (108°3′50″ E, 34°17′2″ N, 500 m a.s.l.), located in the arid and semi-arid region of Northwest China. Selected soil physical and chemical properties in the 0–20 cm layer are presented in Table 1. Additionally, the soil texture of the experimental location was classified according to US taxonomy. The mean monthly temperatures and rainfalls of 2007–2009 in the study location are shown in Fig. 1. In light of the precipitation and its distribution in 2007–2009, the study years (2007–2009) were considered as regular years in this region.

Nitrogen fertilizer was applied from the autumn of 2004. The location was under a stubble-free winter wheat–corn rotation and a chisel plow tillage system before the experimental design and its land use resulted in the development of Lou soil (Eum-Orthic Anthrosols). The treatments (four N levels) for winter wheat were designed: 0, 90, 180, and 360 kg N ha^{-1}, and N was applied in the form of urea [$CO(NH_2)_2$] each year of 2004–2009. At the same time, phosphorus (P) was applied as phosphate fertilizer coupled with $CaSO_4$ at 75 kg ha^{-1} in every treatment each year. The fertilizers were evenly applied to the soil surface as the basal fertilizers, and

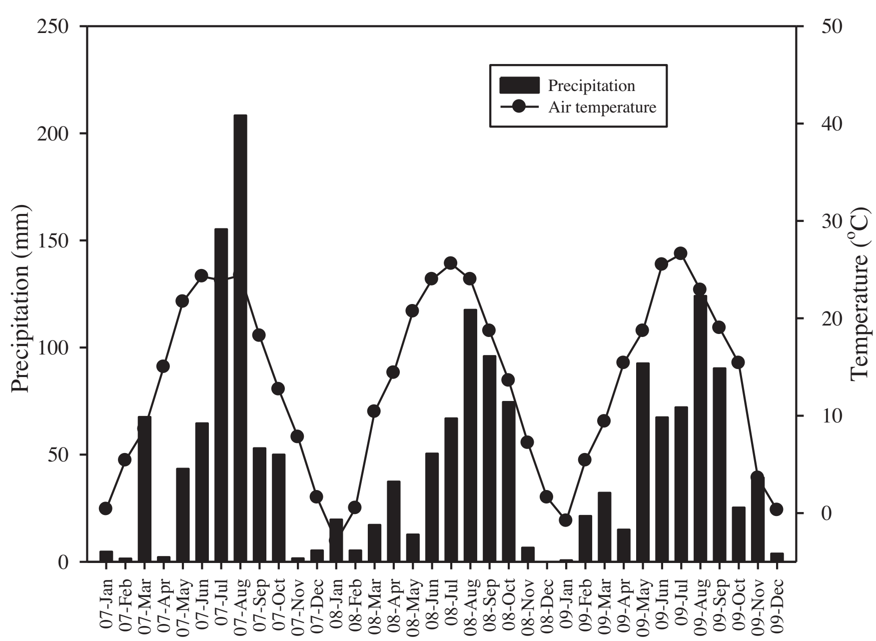

Fig. 1. Monthly precipitations and air temperatures during the sampling periods in Yangling research farm between 2007 and 2009.