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Soil respiration patterns for four major land-use types of the agro-pastoral region of northern China

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ABSTRACT

Land-use types and management practices are critical factors that affect soil CO_2 efflux (R_s). In the agro-pastoral area of northern China, land-use types have changed considerably during the last 60 years due to changes in the social-economic status of the human population and associated changes in land-use needs. Only a few studies have examined R_s in this region of China, and these studies have mainly focused on grazing intensity effects on R_s rather than comparisons among land-use types. The aim of this study was to evaluate annual variation of R_s for the dominant land-use types in the agro-pastoral region of northern China, including ungrazed grassland (UG), moderately grazed grassland (MG), perennial pasture (PP), and cropland (CL). Measurements of R_s were obtained throughout the year for these four land-use types using a mobile greenhouse gas analyzer. Values of R_s from the four land-use types for the growing season, non-growing season, and across the entire year were in the order PP > CL > UG > MG. Annual values of R_s in PP and CL were 1.6- and 1.1-fold greater, respectively, than that for UG, while R_s in MG was 94% of UG. Daily mean soil temperature (T_s) was the main factor that controlled R_s and explained 52–71% of the variability in daily R_s. Monthly mean temperature and precipitation explained 67–87% of the variability in monthly cumulative R_s. Annual R_s for all land-use types averaged 1.9 kg C m^{-2} yr^{-1} (range: 1.6–2.5) with about 94% of annual R_s occurring during the growing season. No pulses of R_s were observed during the autumn and spring freeze-thaw period, probably because of the large snow accumulation, which minimized R_s during these two periods. These results showed that land-use types exhibit different R_s that were associated with differences in temperature and precipitation. Results also suggest that conversion of UG or MG to CL and PP will likely increase R_s.

1. Introduction

Grasslands comprise almost 10% of the world's terrestrial surface area, are important global soil sinks for carbon (White et al., 2000), and play a critical role in the global carbon cycle. Grassland management practices such as intensity of livestock grazing and conversion of grassland to cropland can have a large impact on soil carbon (Allen et al., 2011; Wu et al., 2003). During the past 120 years, grasslands were converted to croplands or other land-use types, which significantly altered biomes globally (Clark et al., 1986). Soil respiration (R_s) is the major pathway through which carbon fixed by photosynthesis is returned to the atmosphere (Allen et al., 2011), which is estimated to emit 68–80 Pg C per year to the atmosphere (Raich et al., 2002; Raich and Potter, 1995). The rate of R_s is controlled by the rate of CO_2 production, consumption and diffusion processes in the soil (Jassal et al., 2004; Mielnick and Dugas, 2000; Wu et al., 2010). Soil moisture, temperature and soil disturbance are important factors that affect these processes (Gulledge and Schimel, 2000; Shrestha et al., 2004).

Land-use types have different vegetation cover and management practices that affect soil physical and chemical properties and soil microbial activities (Flechard et al., 2007; Frank et al., 2002, 2006), which can greatly impact R_s. Grassland degradation and conversion of grasslands to cropland in semi-arid regions can reduce soil carbon storage by increasing R_s (Klumpp et al., 2007; Xie et al., 2007) and rapidly decomposing soil organic matter (Wang et al., 2011). Changes in R_s are primarily driven by changes in soil temperature (T_s) and soil water content (SWC) (Flanagan and Johnson, 2005; Frank et al., 2002; Hao et al., 2010; Liu et al., 2007), which can change with alterations in land-use (Conant et al., 2001,

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2004; Guo and Gifford, 2002; Ojima et al., 1994; Qi et al., 2007; Wang et al., 2011). However, the effects of livestock grazing on soil CO_2 emission have not been consistent among studies. Some studies showed that grazing reduced soil CO_2 emission (Chen et al., 2013; Zou et al., 2007), while other studies found that grazing increased soil CO_2 emission (Frank et al., 2002; Klumpp et al., 2007). Furthermore, stocking rate did not significantly impact soil carbon fluxes during the long-term in the semi-arid northern Great Plains of the USA (Liebig et al., 2013). They found that soil CO_2 fluxes during the growing season were greater in cultivated pastures of crested wheatgrass [*Agropyron desertorum* (Fisch. ex. Link) Schult.] compared to grazed and ungrazed native prairie pastures. Therefore, additional studies are needed to clarify the influence of land-use on soil carbon fluxes in grasslands.

Temperate grasslands in China cover 40% of the land area and are located in one of the regions where the impact of global climate change is predicted to be large. Land degradation is a serious concern in this region because of rapid population growth, which has markedly increased demands on grasslands and croplands for food production (Zhao et al., 2002). Previous studies of R_s in northern China have primarily focused on ungrazed grasslands (Fan et al., 2012; Wu et al., 2010) and the influence of grassland management practices such as grazing (Chen et al., 2013; Holst et al., 2008) and fencing (Wu et al., 2010) on R_s. Not many studies have addressed how the conversion of grassland to perennial pastures and croplands affects R_s. Therefore, understanding the response patterns of R_s for major land-use types is important because land-use is being markedly altered with changes in the social-economic status of the human population and climate (Ojima et al., 1994).

The objectives of our study were to: (1) quantify seasonal and annual patterns of R_s in four major land-use types of northern China and (2) evaluate the influence of SWC and T_s on R_s in these major land-use types. We hypothesized that R_s would increase with annual tillage and stubble winter grazing due to increasing soil porosity and available substrate for soil microbial activity. We hypothesized that grazing will directly affect R_s because reduced green biomass and litter, which will alter soil temperature and water, the primary driving factors for R_s.

2. Materials and methods

2.1. Site description

Our study site located at the Guyuan National Grassland Ecosystem Research Station in the agro-pastoral transition region of northern Hebei Province in China (41°46′N, 115°41′E, elevation 1380 m). The climate is a semi-arid continental climate, which in summer is dominated by warm, moist air currents and other seasons are dominated by cold, dry air currents. Mean annual precipitation is 400 mm, nearly 75–80% of which is received from June to August (Ma et al., 2014). Mean annual temperature is 1 °C with a mean minimum temperature of −18.6 °C in January and mean maximum of 17.6 °C in July. The mean frost-free growing period is 85–95 days.

We conducted our experiment in four land-use types: ungrazed grassland (UG), moderately grazed grassland (MG), perennial pasture (PP), and cropland (CL). The UG type was not grazed since 2010, while the MG type was grazed at a stocking rate of 6.7 sheep ha^{-1} during the growing season with 50–55% biomass removal, equivalent to 1.43 sheep units ha^{-1} year^{-1} (Ma et al., 2014). Vegetation in UG and MG was dominated by perennial grasses [*Leymus chinensis* (Trin.) Tzvelev, *Stipa krylovii* Roshev., *Cleistogenes chinensis* (Maxim.) Keng and *Phragmites communis* Trin.], a sedge (*Carex duriuscula* C.A. Mey.), and several broad-leaf species (*Taraxacum mongolicum* Hand.-Mazz., *Artemisia frigid* Willd., and *Polygonum sibiricum* Laxm.). The PP type was converted from natural grassland to a *Leymus chinensis* pasture in 2009 and was cut for hay during 15–20 Aug. each year with the remaining stubble grazed by cattle and sheep during autumn and winter. The estimated stocking rate of PP site during the non-growing season was 2.3 sheep units ha^{-1} year^{-1}. The CL type was converted from grassland in 1980 and has been plowed each year since, with a crop rotation of two years of *Avena nuda* L. and one year of *Linum usitatissimum* L. Manure was applied at 100 kg ha^{-1} to CL each year about 3 weeks before sowing, and urea was applied at 40 kg ha^{-1} at sowing. No irrigation was applied to any of the land-use types. The four land-use types were 5–24 ha in size and were located 50–500 m apart. Soils for all land-use types were chestnut soil (Chinese classification) or a Calciorthic Aridisol (USA classification).

2.2. Soil respiration measurements

In Sept. 2012 (about one week before measurements commenced), five PVC collars (20-cm diameter, 15-cm height, 1.5–2-mm thickness) were inserted 12 cm into the soil for each land-use type. During the growing season about 48 h before each measurement period, aboveground biomass was removed from the area inside the PVC collars. A mobile Greenhouse Gas Analyzer (LGR-9080010, Los Gatos Research Inc., CA, USA) was used to measure soil CO_2 concentration in the chamber head space. This instrument was connected to MCC-1-8 multiple soil flux chambers (five chambers were used in this study) with an auto-mobile lid through five Teflon tubes (10 m long). The equipment records CO_2 concentration in units of μmol sec^{-1}. The chamber lid was sealed tightly to the chambers, and the conditions were allowed to equilibrate for several sec. During the next 2 min, values of CO_2 concentrations within the chamber head space were determined, and average R_s (μmol m^{-2} s^{-1}) was calculated using the following equation:

$$R_s = \frac{10V \times P \times (1 - \frac{W}{1000})\mathrm{d}c}{R \times S \times (T + 273.15)\mathrm{d}t} \quad (1)$$

where V is volume of the chamber (cm^3), P is atmospheric pressure (kPa), W is the initial concentration of water vapor (mol/cm^3), R is value of the gas constant (R = 8.314 J mol^{-1} K^{-1}), S is the base area of the chamber (cm^2), T is temperature inside chamber (°C), and dc/dt is the concentration gradient of CO_2 through time.

The measurements were conducted from 30 Sept. 2012 to 30 Sept. 2013. During the growing season (May–Sept.), measurements were obtained every 3 days if there was no precipitation. After each precipitation event, measurements were obtained each day for the following three days. During the freeze-thaw period in winter-spring (March and April) and autumn–winter (Oct. and Nov.), measurements were obtained every two days. During the winter (Dec.–Feb.), measurements were obtained once or twice each month. Each soil chamber measurement lasted about 2 min with measurements for each land-use type taking a total of 10–15 min. Each cycle of measurements was a campaign that included four land-use types, and each type was measured twice. The measurements were always conducted at the same time of the day (0830–1130 am). During the year, a total of 70 campaigns were obtained for the UG and MG types, and 77 campaigns were conducted for the PP and CL types.

This sampling scheme allowed a detailed characterization of R_s for the four land-use types throughout an entire year, including the growing season, freeze-thaw periods during the winter and spring, and the permanently frozen period during winter. However, it must be cautioned that these measurements were obtained during only one year and may be biased to the climatic conditions for that