CONVERSION FROM GRASSLAND TO CROPLAND AND LENGTH OF CROPPING HISTORY DRIVING SOIL METHANE UPTAKE IN CHINA

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Abstract. The change of land use from grassland to cropland in Northern China has raised serious concern about regional carbon (C) cycle and greenhouse gas balance. We measured soil methane (CH_4) uptake using manual static chambers in grassland and cropland soils in the agro-pastoral ecotone of Inner Mongolia over three growing seasons (2010-2012). The primary aims were to assess the effect of undisturbed grassland and croplands from converted grassland with different land use histories on gas fluxes and systematically compare the site-specific CH_4 uptake factor. We found a significant difference (P < 0.001) in CH_4 uptake between grassland and croplands from reclaimed grassland for 5, 10 and 50 years old, and cropland soils in 5 and 10 years old were a significant sink of CH_4. Compared with cropland soils, the grassland had the lowest cumulative CH_4 uptake, with 141.4, 210.0 and 236.0 mg/m^2 during growing seasons of 2010, 2011 and 2012, respectively. Over the 3 growing seasons, the cumulative CH_4 uptake of croplands aged 5, 10 and 50 was 544.5, 361.7 and 266.1 mg/m^2. With the increase of farming time, the methane accumulation and absorption of C5, C10 and C50 decreased. Differences in CH_4 uptake of grassland and cropland with different length of cropping history can be explained by the amount of soil ammonium nitrogen (NH_4^+-N) and soil moisture. We conclude that (i) croplands for 5 and 10 years old from reclaimed grassland are the best approach considered here for optimizing the land use as a sink for atmospheric CH_4, and (ii) the practice that croplands from grassland reclaimed for more than 10 years old should be planted into grasslands is recommended for managing CH_4 uptake and soil carbon sink in the agro-pastoral ecotone of Inner Mongolia, China.
Keywords: *land-use change, greenhouse gases, soil physical and chemical properties, carbon sink*

Introduction

Methane (CH_4) is the second most important greenhouse gas in the atmosphere after carbon dioxide (CO_2). The atmospheric concentration of CH_4 has been increasing by 0.3%/yr (Liu et al., 2007). Although the main sink for atmospheric CH_4 is its oxidation in the troposphere by hydroxyl(-OH) (Khalil, 2000), aerobic soils are the only biological sinks for atmospheric CH_4 with an estimated global sink of 20-45 Tg CH_4/yr^2 (IPCC, 2007). Methane uptake is influenced by several factors including land use change, temperature, precipitation, N input and soil properties (e.g., moisture, temperature, texture, pH and C/N ratio) (Liu et al., 2009; Mou et al., 2014). Among these factors, land use change and soil properties are considered to be important drivers of the magnitude of methane uptake (Dörr et al., 1993; Ojima et al., 1993; Steudler et al., 1995). Changes in land use or intensification of land management directly affect the

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CH_4 uptake and the atmospheric CH_4 budget (Smith et al., 2000; Verchot et al., 2000; Merino et al., 2004).

Inner Mongolia steppes account for approximately 80% of grassland in China. Land use conversions from grassland to cropland have occurred in the arid and semi-arid lands of Asia (ASAL) during the 20th century. The agro-pastoral ecotone of Inner Mongolia is included in the ASAL of Asia. The transition from livestock grazing to farming causes changes in land use practice. The grassland in Inner Mongolia is a typical *Leymus chinensis* temperate steppe, where land use types are often diverse with frequent changes. Wang et al. (2005) and Liu et al. (2007) found that CH_4 uptake rates and soil moisture were negatively correlated, while other soil properties were not discussed in these studies (Wang et al., 2005; Liu et al., 2007). How these changes have altered or will alter the CH_4 uptake remains unknown. Moreover, although much is known regarding CH_4 uptake, few data specific to soils of agro-pastoral ecotone is available, and few studies have been conducted on the effect of length of cropping history or soil properties on CH_4 uptake in this region. The effects of the conversion of grassland to cropland on CH_4 uptake are uncertain. The determining factors that mediate the influence of land use change on CH_4 uptake have not been elucidated.

Therefore, we conducted a study in the agro-pastoral ecotone of Inner Mongolia to investigate the effects of land use change on CH_4 uptake. The objectives were to understand the impact of cropping history and soil properties on CH_4 uptake from the conversion of grassland to cropland. This study investigated CH_4 uptake throughout 3 years in an agro-pastoral ecotone in Inner Mongolia, China. We compared cropland soils with different length of cropping history and adjacent grassland that were derived from the same parent material of soil under the same climate.

Materials and methods

Description of the study site

The study was conducted in Taipusi County, Inner Mongolia (China), located 41º49′52″north latitude and 115°13′26″east longitude, at an elevation of 1400 m above sea level (*Fig. 1*).

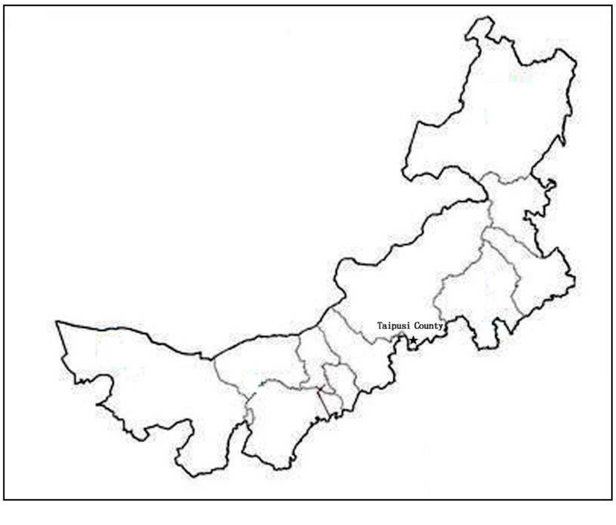

Figure 1. *Location of study area in Inner Mongolia, China*

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Located in the south of the Xilin River and characterized by scattered farms in the steppe, the study area is very representative of both the Eurasian temperate grasslands (Wang et al., 2007) and the steppe region of Inner Mongolia (Tong et al., 2004). The grassland is dominated by *L. chinensis* which is the typical vegetation of the region's grassland (Geng et al., 2010). The grassland in the study site was a natural clearing of native vegetation, without grazing or additional treatments such as fertilization or grass seeding. This region falls in the semi-arid temperate climatic zone. The mean annual temperature is approximately 1.6ºC, ranging from a mean monthly temperature of -17.6ºC in January and 17.8ºC in July. The region receives an average of 400 mm of precipitation annually. The growing season is from late April to early October.

Four sites were selected for the study, including an area of grassland (reference site) and croplands (farmer-managed fields) for 5, 10, and 50 years old from reclaimed grassland (*Table 1*). The length of cropping history was determined according to a field inventory and Taipusi County records. Hereafter, the four sites are referred to G (grassland), C5 (5 y old cropland), C10 (10 y old cropland) and C50 (50 y old cropland). The 4 sites presented similar slope and soil type within the adjacent ecosystems including flat areas of grassland soil and cropland soil. N, P and K compound fertilizers were applied before planting. Agriculture management in C5, C10 and C50 soil after conversion was carried out similarly.

Table 1. *Site characteristics of the agro-pastoral ecotone on Taipusi County, Inner Mongolia*

Site†	**Coordinates**		**Land use history**
	Latitude N	Longitude E	
G	41º49′52″	115°13′26″	Natural grassland
C5	41º50′29″	115°13′19″	Cropland reclaimed for 5 years old
C10	41º50′49″	115°13′43″	Cropland reclaimed for 10 years old
C50	41º50′53″	115°13′23″	Cropland reclaimed for 50 years old

There were three replicates plots for every natural grassland (G) and cropland from reclaimed grassland with different length of cropping history (C5, C10, and C50), respectively, and the area of each plot is 100 m × 100 m. Grassland vegetation was *L. chinensis* and *Stipa capillata.* Potatoes (*KexinNO.1*) and oats (*Avena sativa L.*) were grown in the three cropland sites in 2010, 2011 and 2012. Potatoes and Oats were alternatively planted in 2010, 2011 and 2012, respectively. Cropland was plowed once a year before planting. The plowing depth was 30-35 cm via machine plow. N, P and K compound fertilizer ($N:P_2O_5:K_2O$ = 15:10:10)(450 kg/ha) was incorporated into the soil before planting once a year. The crops were planted in May and were harvested in September, and the soil was bare from October to the following April. The croplands were irrigated in spring and autumn.

Measurement of methane flux

Field measurements of CH_4 flux were conducted in the four soils from April 2010 to October 2012. Measurements were taken every 15 days between June and August and once a month in April, May, September and October.

Three square chambers (n = 3) were randomly placed in each plot replicate and were in the same location for the duration of the measurements. All the chambers were fixed to the ground, reaching approximately 10 cm down into the soil. Aluminum flux collars

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were permanently installed to ensure reproducible placement of the gas collection chambers for successive CH_4 flux measurements throughout the growing season. The top edge of the collar had a groove that could be filled with water to seal the rim of the chamber. The chamber was equipped with a circulating fan to ensure complete gas mixing and was wrapped with a layer of sponge and aluminum foil to minimize air temperature changes inside the chamber during the period of the measurement. Cross-section of the chamber was 0.25 m^2 (0.5 m × 0.5 m). The height of chamber (or H) was 0.5 m. Samples were collected over a 30-min period (0, 10, 20 and 30 min) after closing the chambers at 8:00-11:00 am. Gas samples were taken using 25 mL gas-tight plastic syringes which were closed with stopcocks. The air temperature inside the chamber was recorded by thermometer for each measurement. Soil temperature (0-5 cm depth) was continuously recorded using temperature sensors interfaced with data loggers (HSY-TL881). During the CH_4 flux measurement period, soil water content was monitored using a TDR instrument (MP-406 Kits for moisture measurement). Five temperatures and five soil moisture data were measured on each plot. The aboveground biomass of the potatoes and oats under the sampling chamber (0.25 m^2) were determined by harvesting followed by oven-drying at 105ºC to constant weight.

Air samples were analyzed for CH_4 using a modified gas chromatograph (Agilent 6820D, Agilent Corporation) equipped with a flame ionization detector (FID) (Wang and Wang, 2003). Nitrogen was used as the carrier gas (30 mL/min). The oven was operated at 55ºC and the FID was operated at 200ºC. Flux was determined from the slope of the mixing ratio change in four samples taken 0, 10, 20 and 30 min after chamber closure. The gas samples were rejected if they did not yield an R^2 greater than 0.90 over the 30 min period. If the detected mixing ratio in the samples is decreased with the prolonging of time, it is a negative value, representing uptake. Carbon sinks into soil. Otherwise, it represents emissions.

Flux calculation

The CH_4 flux was calculated with *Eq. 1* (Yang et al., 2018):

$$F = 1000 \cdot S \cdot H \cdot M \cdot \left({Pa}/{Ps} \right) \cdot \left({Ts}/{Ta} \right) / 22.4 \quad \text{(Eq.1)}$$

where F refers to CH_4 flux (μg/(m^2 min)), S is the linear slope of the concentration change with time over the measurement period (μL/(L min)), H is the valid height of the sampling chamber (m) and M is the molar mass of CH_4 (16 g/mol). Pa and Ta are the actual measured atmospheric pressure and temperature inside the chamber, respectively. Ps and Ts are the standard conditions (760 mm Hg, 273.15K). The standard molar volume of CH_4 (L/mol) is 22.4. Seasonal (7 month values) amounts of CH_4 uptakes were sequentially accumulated from the uptakes between every two adjacent intervals of the measurements.

Soil property measurements

Soil samples were collected for chemical analysis during the CH_4 flux measurements. The measurements were taken once every 15 days from June to August and once a month in April, May, September and October. Three replicates were collected from each site (G, C5, C10 and C50), with 10 sampling locations for each composite replicate. The samples were air-dried and sifted through 2 mm for

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physicochemical analysis. The sample of soil bulk density was collected using a steel cylinder (5 cm of diameter, 5 cm of height). Soil organic carbon (SOC), total nitrogen (TN), NH_4^+-N and NO_3^--N were determined following procedures. SOC was determined using a TOC (Total Organic Carbon) analyzer (Sievers 5310 C, GE Analytical Instruments, USA) (Lim and Choi, 2014), and TN was measured via the dry combustion method using a C/N Analyzer (Vario Macro, Elementar, Germany) (Yan et al., 2012). Soil ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) were measured using a micro-Kjeldahl procedure (Aulakh et al., 2000). Soil microbial biomass C (MBC) and microbial biomass N (MBN) were determined using the chloroform ($CHCl_3$) fumigation–incubation method (Nunan et al., 1997). The pH value was measured in 1:2.5 soil/H_2O (w/w) suspension with a Titrino pH meter (Metrohm Ltd. CH.-901, Herisau, Switzerland) fitted with a glass electrode (Godsey et al., 2007).

Data analysis

Data were analyzed using ANOVAs and General Linear Mixed Model to assess the effect of the study site. Pearson's correlation analysis was performed to investigate the relationship between CH_4 uptake and soil properties (i.e., soil temperature, soil moisture and soil NH_4^+-N content etc.). The R^2 (square of Pearson correlation coefficient) values were used to determine the fitness of regression functions. For all analysis, statistical significance was determined at $P < 0.05$. All statistical analyses were performed using SPSS 11.5 (SPSS Inc., Chicago, IL, USA).

Results

Seasonal change on CH_4 uptake flux from the soils of grassland and croplands with different ages reclaimed

The CH_4 uptake flux in the grassland, C5, C10, and C50 soils showed obvious seasonal variability from 2010 to 2012 in the study (*Fig. 2*). During the first month of the growing season, CH_4 uptake increased rapidly in C5 soil. However, the seasonal uptake of CH_4 in G and C50 soils increased moderately, and there was no significant uptake peak. Throughout the testing stage, CH_4 uptake was lower in grassland and C50 soil than that in C5 and C10 soils. The maximum uptake flux of CH_4 in the grassland soil was 0.06, 0.12 and 0.11 mg/(m^2 hr), and was 0.09, 0.13 and 0.20 mg/(m^2 hr) in the C50 soil during the growing seasons in 2010, 2011 and 2012, respectively (*Fig. 2*). CH_4 uptake flux was the highest in C5 and C10 soils during the experimental period. The peak of CH_4 uptake flux in C5 and C10 soils was detected between June and July. The maximum CH_4 uptake flux of C5 soil was 0.27, 0.23 and 0.29 mg/(m^2 hr), and was 0.22, 0.20 and 0.29 mg/(m^2 hr) in C10 soil in 2010, 2011 and 2012, respectively. CH_4 uptake declined in all of the study sites at the end of the growing season (*Fig. 2*).

Cumulative methane uptake in the soils of grassland and croplands with different land use history

There were significant differences for cumulative CH_4 uptake in the grassland soil, C5, C10, and C50 cropland soils in 2010 (F=273.7, $P < 0.0001$), 2011 (F=264.8, $P < 0.0001$) and 2012 (F= 362.4, $P < 0.0001$). The land use conversion in more recently-established croplands (5 and 10 years old) from grassland to cropland promoted greater atmospheric CH_4 uptake compared to C50 and grassland type.

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The grassland and C50 soils exhibited lower cumulative CH_4 uptake with 141.4 and 224.0 mg/m^2 than that of the C10 and C50 soils in 2010, 2011 and 2012, respectively (*Fig. 3*). Cumulative CH_4 uptake during the growing season was 544(±103) and 361(±47) mg/m^2 in C5 and C10 soils, respectively. The cumulative uptake flux in C5, C10, and C50 soils was 190%, 90% and 38% higher than that of the grassland soil. As the cropping history increased, the cumulative CH_4 uptake decreased in C5, C10, and C50 soils.

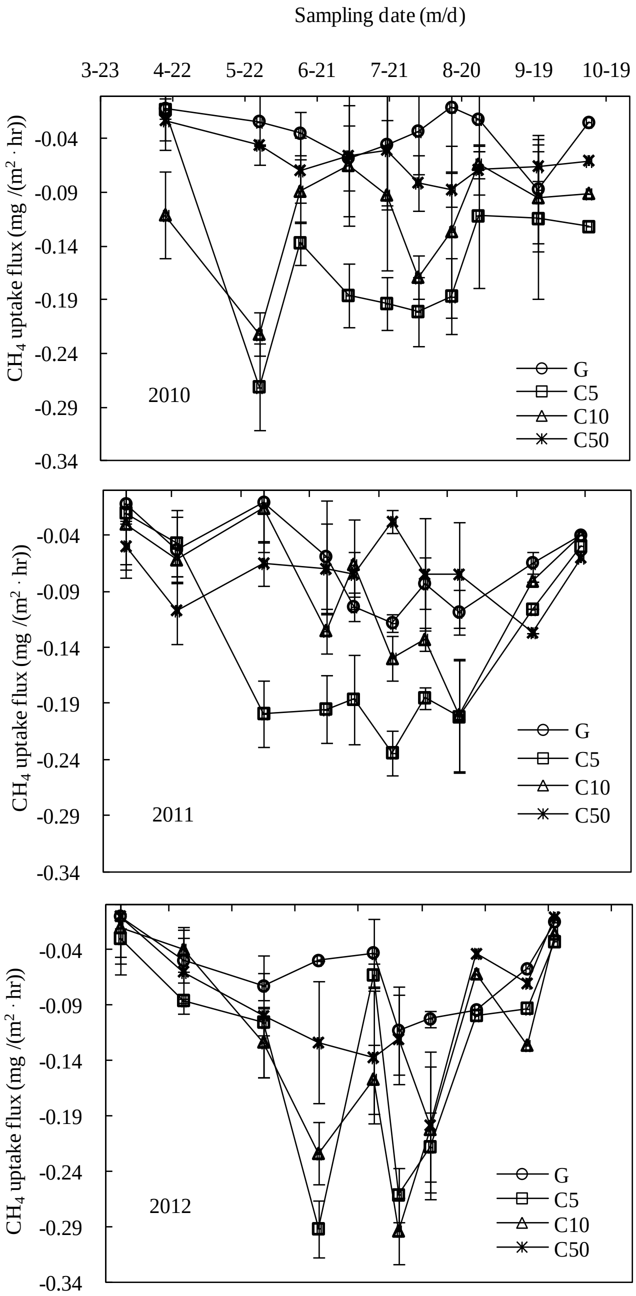

Figure 2. *Seasonal CH_4 uptake flux from the grassland and cropland with different length of cropping history during the growing season in 2010, 2011, and 2012; G: natural grassland; C5, C10, and C50: cropland for 5,10, and 50 years old from reclaimed grassland, respectively; The vertical bars represent standard error*

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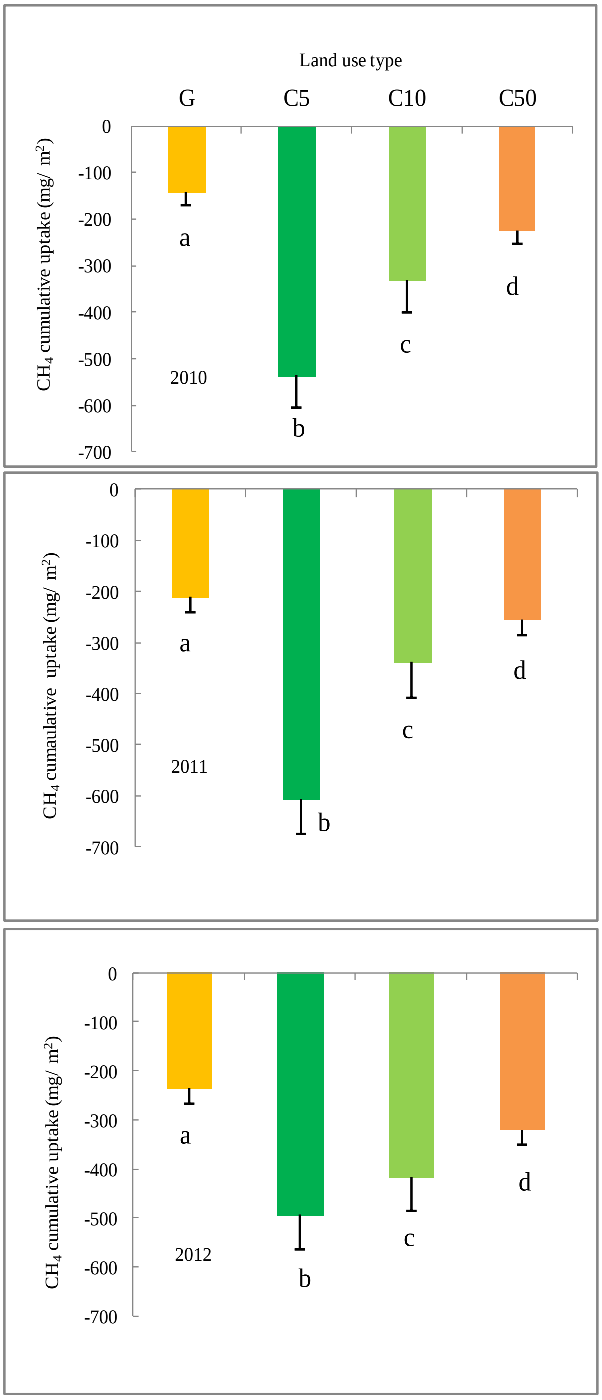

Figure 3. *Cumulative CH_4 uptake from the grassland and cropland soils during the growing seasons in 2010, 2011, and 2012; G: natural grassland; C5, C10, and C50: cropland for 5,10, and 50 years old from reclaimed grassland, respectively; The vertical bars represent standard error; different letters represent significant differences between the treatments*

The changing relationship between CH_4 uptake and moisture or temperature of soil from different land use types

A significantly negative correlation in grassland, C5, C10, and C50 soils (r = 0.52, 0.75, 0.63, 0.62; P < 0.01) was detected between CH_4 uptake flux and soil volumetric

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moisture (% v/v) when soil temperature was above 5ºC (*Fig. 4a-d*). Soil moisture was a major factor affecting CH_4 uptake flux in the soils. The correlation between temperature and CH_4 uptake flux was not observed in the soils (P > 0.05) (*Fig. 5*). Soil moisture was the important controlling factor for CH_4 uptake flux when the temperature was not the limiting factor.

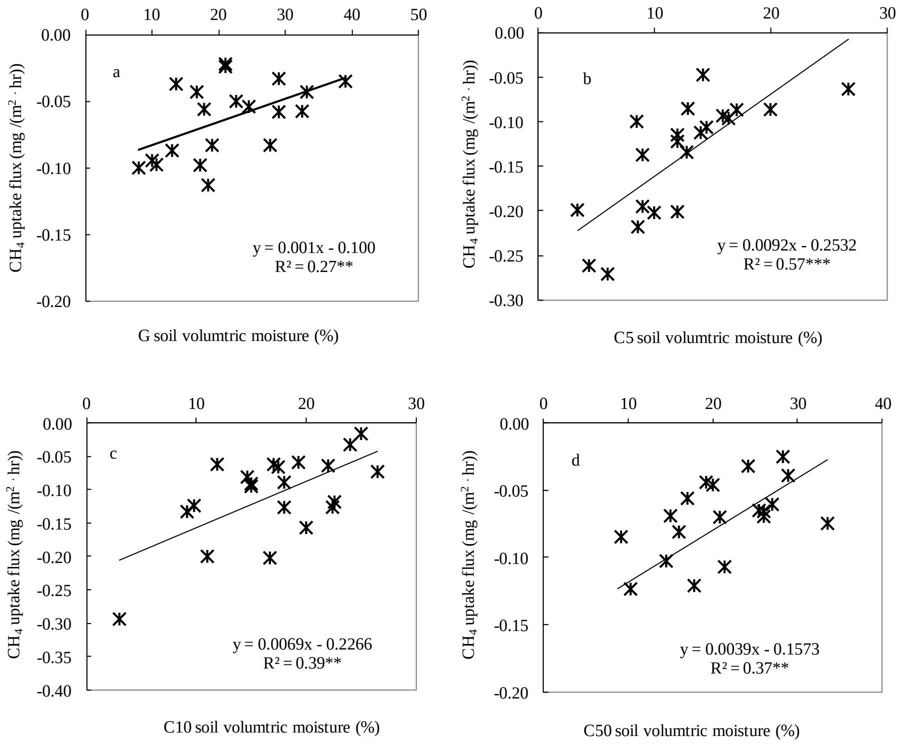

Figure 4. *Correlation between CH_4 uptake flux and soil moisture from grassland and cropland soils; The soil volumetric moisture was simultaneously measured when gas sample were collected from 2010 to 2012; C5, C10, and C50: cropland for 5, 10, and 50 years old from reclaimed grassland, respectively*

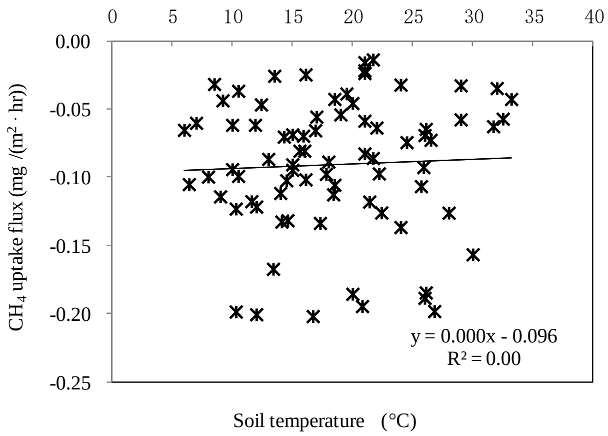

Figure 5. *Correlation between CH_4 uptake flux and soil temperature in grassland and cropland soils; Soil temperature was simultaneously measured when gas sample were collected from 2010 to 2012*

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Potential links between cumulative methane uptake and soil NH_4^+-N

A negative relationship (*r* = -0.86; *P* < 0.01) was found between cumulative CH_4 uptake and soil NH_4^+-N in the soils (*Fig. 6*). Soil NH_4^+-N and NO_3^-–N were greater in the cropland soils than that in the grassland soil in our study (*Table 2*). The soils with a high NH_4^+-N content showed lower cumulative CH_4 uptake. However, no correlation was observed between cumulative CH_4 uptake and soil NO_3^-–N in the growing season. The regression analysis indicated that a linear combination of soil NH_4^+-N explained more than 73% of the variability in the cumulative CH_4 uptake, and may account for the difference of the cumulative CH_4 uptake in the soils (*Fig. 6*).

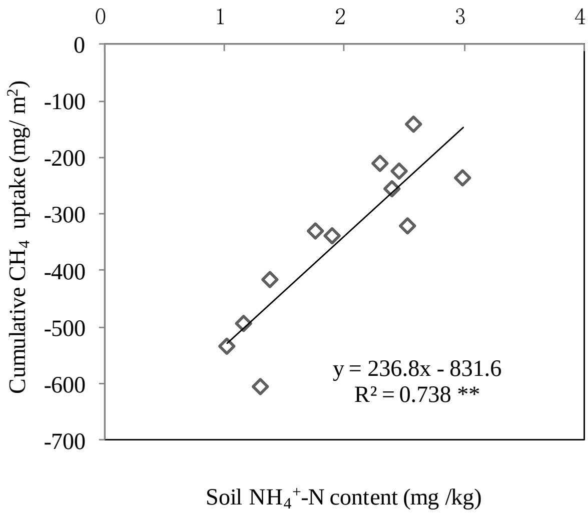

Figure 6. *Correlation between cumulative CH_4 uptake and soil NH_4^+-N in grassland and cropland soils; NH_4^+-N content was seasonal mean value from 2010 to 2012*

Table 2. *Physical and chemical properties of grassland and cropland soils with different length of ropping history (means±SD)*

Years	Soil code	‡SOC %	TN g kg^{-1}	Soil bulk density g cm^{-3}	pH	‡MBC mg kg^{-1}	MBN mg kg^{-1}	NH_4^+-N mg kg^{-1}	NO_3^-N mg kg^{-1}
2010	†G	2.46±0.01	0.25±0.01	1.42±0.18	8.0±0.05	271±33.3	105±28.0	1.02±0.35	7.08±9.78
	C5	1.58±0.05	0.17±0.01	1.32±0.08	7.6±0.08	976±146.2	66±4.6	2.58±0.45	10.36±7.73
	C10	1.30±0.02	0.13±0.01	1.20±0.02	7.6±0.01	454±42.1	51±13.3	2.46±0.22	20.10±14.89
	C50	0.79±0.13	0.09±0.01	1.40±0.06	7.6±0.03	442±46.2	36±10.5	1.76±0.32	24.89±12.42
2011	G					232±47.4	49±9.7	1.30±0.30	8.00±0.84
	C5					857±89.1	48±20.8	2.50±0.20	13.60±1.21
	C10					426±72.5	25±9.2	2.40±0.10	20.00±3.84
	C50					272±106.3	22±5.3	1.90±0.13	32.00±2.09
2012	G					183±38.5	48±9.8	1.16±0.37	7.30±1.60
	C5					885±36.2	37±12.0	2.99±0.36	10.60±1.12
	C10					365±23.6	30±11.2	2.53±0.38	11.00±1.04
	C50					233±28.3	15±6.4	1.38±0.75	23.60±3.03

† G: natural grassland; C5, C10, and C50: cropland for 5, 10, and 50 years old from reclaimed grassland
‡ SOC: soil organic carbon; BD: bulk density; TN: soil total nitrogen
‡ MBC: microbial biomass C; MBN: microbial biomass N

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Discussion

Cropland soils from reclaimed grassland increasing methane uptake

The CH_4 uptake flux in the grassland soil was 0.001-0.120 mg/(m^2 hr) from 2010 to 2012 in our study. This falls in the range of a study conducted by Wang et al. (2015) (0.017-0.162 mg/(m^2 hr)) in a typical steppe dominated by *Leymus chinensis* (Trin.) Tzvel at Guyuan State Key Monitoring and Research Station of Grassland Ecosystem (Wang et al., 2015). In our study, the cropland soil after conversion from grassland to cropland increased the CH_4 uptake from 2010 to 2012 (141-235 mg/m^2 in G, 534-737 mg/m^2 in C5, 210-605 mg/m^2 in C10, and 235-493 mg/m^2 in C50). We found that the croplands from reclaimed grassland accelerated the CH_4 uptake. Compared to natural grasslands, agricultural soils from reclaimed grassland experience more physical disturbance due to fertilizer application as well as plowing, planting and harvesting with heavy agricultural equipment, which increases the aeration and porosity of the soils, affects mineralizable carbon and the other biochemical attributes (Rong et al., 2015), and creates favorable conditions for CH_4 oxidation. The oxidation of atmospheric CH_4 in upland soils is a biological process governed by CH_4-oxidizing bacteria and is dependent on the availability of both CH_4 and oxygen (O_2) in the soil profile (Yang et al., 2018). Boeckx et al. (1997) also reported that grassland had a lower methane uptake capacity than arable land in a study conducted in Belgium.

Decreasing methane uptake in cropland soils with the increase of cropping history from reclaimed grassland

CH_4 uptake rule on a temporal trend of cropping history was discovered in the agro-pastoral ecotone of Inner Mongolia. CH_4 uptake in cropland soil decreased with the increase of cropping history from 5 to 50 years after the grassland was converted into cropland (*Fig. 3*). Higher CH_4 uptake in the cropland soils from C5 and C10 was found in more recently-established croplands. The CH_4 uptake of C50 soil is close to that of grassland soil. Changes in soil carbon and soil properties after long-term fertilizer application affect methane oxidative bacteria community structure and soil methane oxidation rate (Hütsch et al., 1993). To reduce CH_4 uptake was proved on a period (7 years) of inorganic nitrogen application (Mosier et al., 1998).This study showed that enhancing or reducing CH_4 uptake by soil cultivation depends partly on the time elapsed from the conversion of grassland to cropland. In the field experiment, none of the CH_4 uptake was correlated with potatoes and oats biomass production ($P > 0.05$).

Methane uptake driven by the soil physicochemical properties of different land use type

Our study showed that the conversion of natural grassland to cultivated land can temporarily increase the uptake of CH_4 from the atmosphere depending on soil moisture level and soil NH_4^+-N. Soil moisture ranged from 6%-26% in C5, 3%-25% in C10, and 9%-34% in C50. Soil moisture in grassland is the highest (8%-39%) from 2010 to 2012. CH_4 uptake decreased as soil moisture level increased, which is consistent with previous studies (Price et al., 2004). There was negative correlation between CH_4 uptake and soil moisture in a semi-arid steppe. Moisture content is an important factor on regulating the transport process of methane from soil macro pores to methane oxidizing bacteria and the diffusion of methane into the soil (Wang et al., 2005; IPCC, 2007). Quantity and activity of methanotrophs significantly reduce on higher moisture levels in the soil

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(Castro et al., 1992; Sitaula et al., 1995). As soil moisture increases, the soil microbial community is covered by a thick water film which reduces the microorganisms activity and hinders the spread of CH_4 oxidation. CH_4 in soil water diffuses at a slower rate compared to soil air.

The effect of temperature on CH_4 uptake capacity in our study was not pronounced between 10ºC and 26ºC in grassland soil and cropland soils (*Fig. 5*). Castro et al. (1995) found that soil temperature was not an important controller of CH_4 uptake when temperature ranged between 10°C and 20°C (Castro et al., 1995). Warming (4.5°C) increased the average seasonal CH_4 uptake by 65.9% in the permafrost region of an alpine meadow (Chen et al., 2017). Soil moisture on CH_4 uptake was more important than temperature when the temperature was not the limiting factor. Irrigation and management in cropland create an optimum temperature for soil methanotrophs. The seasonality of CH_4 uptake exhibited a strong dependency on the seasonal variation of soil moisture in a typical semi-arid steppe in Inner Mongolia (Chen et al., 2010).

The negative correlation between CH_4 uptake and soil NH_4^+-N is detected over the whole testing stage (r=0.86, n=12). This result was consistent with previous findings in an incubation experiment under ambient CH_4 levels (Chan and Parkin, 2001). Soil NH_4^+-N is a key determinant on CH_4 oxidation capacity due to the significant competitive inhibition of CH_4 uptake by NH_4^+-N in recently cultivated soils (Jacinthe and Lal, 2005).

There were no significant correlations between CH_4 uptake and soil properties such as SOC content, MBN concentration, MBC, TN, soil sand content, pH, soil clay content and soil bulk density in all of the soils ($P > 0.05$) (*Table 2*, *Fig. 3*). As there was no significant difference for SOC, TN, soil bulk density and pH between the four types of land use in 2010. In addition, they change more slowly than other physicochemical properties such as NH_4^+-N, NO_3^-N, MBN, and MBC. Therefore, these data were not measured in 2011 and 2012. Variation in soil moisture and soil NH_4^+-N may have concealed the changes in soil bulk density, SOC, TN, soil MBN content, MBC, soil clay content and soil pH from land use change, although CH_4 uptake is affected by various factors. In our study, soil moisture (*Fig. 4*) and soil NH_4^+-N content (*Fig. 6*) were the major factors determining the difference on CH_4 uptake between grassland and cultivated land.

This study was designed to address how land use change affects CH_4 uptake and what soil parameters are the most important for assessing CH_4 uptake from the conversion of grassland to cropland in the agro-pastoral ecotone of Inner Mongolia. These efforts will improve our understanding of land use change on the CH_4 uptake in the agro-pastoral ecotone. The observed effects of physical and chemical properties of soil on CH_4 uptake in this study will support to estimate CH_4 fluxes based on soil properties from different land use types using model and simulation method. However, in our study, we examined the effects of land conversion on soil methane uptake in Inner Mongolia. The effects of nitrogen fertilizer application on methane uptake in croplands and grassland need to be further studied in the future.

Conclusions

The four land-use types (G, C5, C10 and C50) that we studied in the semi-arid steppe of the agro-pastoral region of northern China were sinks for atmospheric CH_4 with an average uptake flux of 0.06-0.29 mg m^{-2} hr^{-1}. Cropping history of the conversion from

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grassland to cropland affects CH_4 uptake. Land-use types exhibited different soil CH_4 fluxes with the maximum CH_4 uptake occurring in the C5 land-use type, and CH_4 uptake was higher for C10 compared to C50 type. The CH_4 uptake of C50 soil was approximately equal to that of grassland soil. Soil moisture and soil NH_4^+-N content are the key driving factor on CH_4 uptake of the observed differences between grassland and arable lands with different reclaimed history and may provide a possible approach for estimating soil CH_4 fluxes. Our results contribute to understanding soil uptake levels of atmospheric CH_4 in four important land-use types in northern China. The cropland reclaimed more than 10 years old should be planted into grasslands to facilitate CH_4 uptake and soil carbon sequestration in the agro-pastoral ecotone of Inner Mongolia. However, how long will the cultivated grassland be grazed and reclaimed into cropland be conducive to carbon sink? These tasks need to be studied in the future.

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