Science of the Total Environment 537 (2015) 93–99

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The influence of nitrogen fertiliser rate and crop rotation on soil methane flux in rain-fed potato fields in Wuchuan County, China

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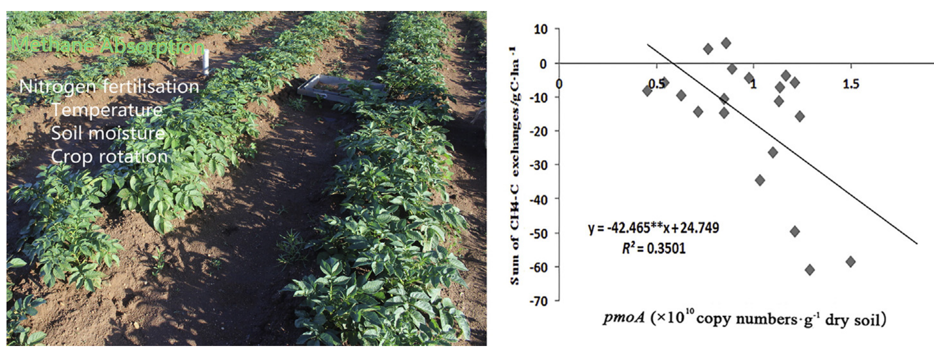
HIGHLIGHTS

- Rain-fed potato fields were a CH_4 sink.
- Increased nitrogen fertilisation and temperature led to higher CH_4 absorption.
- CH_4 oxidation capacity showed a parabolic trend with soil moisture increased.
- Crop rotation increased CH_4 absorption one time higher than continuous cropping.
- A mechanism concept model of the CH_4 exchange in potato fields was advanced.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 January 2015
Received in revised form 27 July 2015
Accepted 1 August 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
CH_4 exchange
CH_4 oxidation
Methanotrophs
Nitrogen fertiliser

ABSTRACT

As one of the important greenhouse gases, the characteristics and principles of methane exchange characteristics in cultivated lands have become hot topics in current climate change research. This study examines the influences of nitrogen fertilisation, temperature and soil water content on methane exchange characteristic and methane exchange functional gene-*pmoA* gene abundance based on experimental observations of methane exchange fluxes using the static chamber–gas chromatographic method and measurements of methanotroph gene copy numbers in three growing periods by real-time PCR in rain-fed potato fields. The results indicate that the rain-fed potato fields were a CH_4 sink with an average annual methane absorption (negative emission) of 940.8 ± 103.2 g CH_4-C/ha/year. The cumulative methane absorption first exhibited flat and subsequently increasing trend with the increase of nitrogen fertilisation from 0 ~ 135 kg N·ha^{-1}. Methane cumulative absorption significantly increased with the increase of temperature when temperatures were below 19.6 °C. Methane oxidation capacity (methanotroph *pmoA* gene copy numbers) showed an increasing and subsequently decreasing trend with the increase of soil moisture. Crop rotation was observed to increase the methane absorption in rain-fed potato fields

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http://dx.doi.org/10.1016/j.scitotenv.2015.08.003

Crop patterns
Rain-fed potato

and nearly one time higher than that under continuous cropping. A mechanism concept model of the methane exchange in rain-fed potato fields was advanced in this paper.

1. Introduction

Global warming is a focus of common concern in recent years, and its primary cause is the increase of atmospheric greenhouse gas concentrations. Although CO_2 is the primary greenhouse gas, and its contribution to global warming is approximately 55%, methane (CH_4) is also one of the most important greenhouse gases, and its contribution to global warming is nearly 15–25% (IPCC, 2007). CH_4 is approximately 20–21 times more effective as a greenhouse gas than is CO_2 (Stocker et al., 2013). The primary sources of atmospheric methane include wetlands, soil, landfills and fermentation of ruminant digestive systems. The primary sinks of atmospheric methane include the oxidation reaction in the troposphere (Smith et al., 2003) and aerobic dry soil, which is the largest terrestrial ecosystem methane sink (Bull et al., 2000). Approximately 6–10% of global methane (nearly 30–50 Tg [1 Tg $= 10^{12}$ g]) has been oxidized to carbon dioxide in aerobic dry soil (IPCC, 1995; Le and Roger, 2001). Although the methane sink in aerobic dry soil is smaller than that of the troposphere, the concentration of methane in the atmosphere would increase at 1.5–2.0 times the present growth rate if there were no methane sink in aerobic dry soil (Whalen, 2005).

Agricultural practices, such as fertiliser management and planting patterns, can affect the soil's ability to act as a sink of atmospheric CH_4 (Gao et al., 2014). The methane exchange characteristics and principles in farmland ecosystems have therefore become hot spots of current research. Methanotrophs are the primary bacteria of methane oxidation in soil. Some ammonia-oxidizing bacteria (nitrification bacteria) and sulphate-reducing bacteria can also provide a small amount of methane oxidation under specific conditions (Mohanty et al., 2006). Therefore, quantitative analysis of the changes in methanotroph numbers is an important method to study the characteristics of methane exchanges in dry land. The particulate methane monooxygenase subunit A gene (*pmoA*) plays the most important role in the metabolic processes of methanotrophs. Methane oxidation capacity can be analysed by measuring *pmoA* gene copy numbers in different periods using real-time PCR. Such factors as moisture, temperature, nitrogen fertilisation, and planting patterns can affect the quantitative changes of methanotrophs' *pmoA* (Martins et al., 2015). Soil moisture can change soil redox potential (Eh), permeability, pH, microbial activity and diffusion rate of gas in soil to the atmosphere, which subsequently affects the emissions of greenhouse gases (Shrestha et al., 2004). The influence of nitrogen fertilisation on dryland soil methanotrophs and soil methane oxidation capacity is complex. Different effects can occur based on when and how fertiliser is used (Dai et al., 2013). Fertilization can reduce absorption of methane in dry land soil in most cases (Seghers et al., 2005), but sometimes it can decrease soil methane absorption rate depending on the application rate of the fertiliser (Hutsch, 2001). Because temperature increases can accelerate the decomposition of organic matter and microbial activity in soil (Baggs and Blum, 2004), temperature increases also accelerate the activity of methanotrophs and the methane oxidation capacity from −5–20 °C (Horz et al., 2005). However, the temperature range differs in various regions, crops and soil types (Livesley et al., 2013). Planting patterns can also exhibit a significant influence on methane oxidation because different planting patterns can change soil physical and chemical properties, which are the very important for soil methane oxidation capacity (Islam et al., 2008).

Previous research on methane exchanges in agricultural activities has mainly concentrated on paddy fields and ruminant breeding, while methane oxidation in dry farmland has been less researched, especially in the north of China. Dry farmland plays a significant role in Chinese agricultural production because its cultivated area covers approximately 48% of the national total arable land (Hu et al., 2014). The potato is one of the main crops in dry farmland in China (Li, 2012), with its planting area making up nearly 40% of the total planting area in the study area (Wuchuan county) (Wang et al., 2013). In this paper, based on a three-year experiment, the characteristics of methane exchange in rain-fed potato fields were studied, and the relationships between methane exchange and its affecting factors were investigated. These findings are significant for increasing soil methane oxidation ability and reducing the greenhouse gas emissions of rain-fed potato fields in dry farmland.

2. Materials and methods

2.1. Study site

This study was conducted at the Wuchuan station (41.1°N, 111.5°E) in Wuchuan County, Inner Mongolia, a Key Ecological and Environmental Scientific Experiment and Field Observation Station for the Chinese Ministry of Agriculture. The station is located in semi-arid region. The annual average temperature is 3.2 °C, and the average annual precipitation is 343 mm (80% of which occurs from June to September). The frost-free period is approximately 105 days each year. The average annual cumulative temperature is approximately 2578.5 degree-days. The soil is light chestnut coloured soil ("Calciustoll" in USDA classification system of soil texture). The soil bulk density is 1.2–1.7 g cm^{-3} between 0 and 100 cm in depth. PH is 8.54 on average. The soil texture is mainly sandy loam soil. The organic matter contents, soil total N, available P, and available K are 10.3 g kg^{-1}, 0.79 g kg^{-1}, 5.0 mg kg^{-1}, and 105.3 mg kg^{-1}, respectively (Yuan et al., 2013). The soil field capacity is nearly 20%. The main crops include potatoes, spring wheat and naked oats in this region.

2.2. Experimental design

The experiment of CH_4 exchange flux observation comprised different nitrogen fertiliser and planting pattern treatments in rain-fed potato fields in 2012–2014.

The different nitrogen fertiliser experiment comprised five treatments in one field: no fertiliser (N0), low fertiliser (N1), farmer conventional nitrogen fertilisation (middle fertiliser) (N2), high fertiliser (N3) and no-crop fields as contrast treatment (CK). This different nitrogen fertiliser experiment was in potato (*Solanum tuberosum* L. Beauv) continuous cropping. The planting patterns experiment had been done in another three fields which comprised two different planting patterns. One field was potato continuous cropping pattern and the other two fields were in potato and grass millet (*Setaria italica* L. Beauv) rotation pattern.

The potato cultivar was Ke XinI, grass millet cultivar was Jin millet 37. All the treatments were organized in a randomized block design with three replicates (each treatment area was 6 m × 8 m). The specific experimental treatment designs are presented in Table 1.

2.3. The determination method of the sample

CH_4 exchange fluxes were observed using the static chamber–gas chromatography method with manual method (Chen et al., 2010). Static chamber size was 60 mm × 50 mm × 45 mm. Gas samples were daily measured five days after fertilisation and then once a week at other times. If rain occurred, gas samples would be measured 1 more time after the rain day. Each sampling time was at 09:00–11:00, and the gas sample amount was 80–120 ml, using an air pump. When gas exchange fluxes were measured, the soil moisture (by oven drying