Agriculture, Ecosystems and Environment 144 (2011) 330–337

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Short communication

Denitrification on Andosols in an intensive dairy farming region of central Japan

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ARTICLE INFO

Article history:
Received 5 July 2011
Received in revised form
19 September 2011
Accepted 30 September 2011
Available online 28 October 2011

Keywords:
Andosols
Denitrification
Intensive manure application
Italian ryegrass
Maize
Paddy rice

ABSTRACT

Evaluation of denitrification capacities is necessary to develop a sustainable manure management system in order to reduce NO_3^- leaching and N_2O emissions from agricultural soils. Denitrification rates were measured using the acetylene inhibition technique on intact soil cores from eight Andosols under three different cropping systems in an intensive livestock catchment of central Japan. The N application rates ranged from 200 to 800 kg N ha^{-1} yr^{-1}. The denitrification rates were highly variable across fields, and were influenced significantly by land uses and manure forms. Compared with upland fields, paddy rice fields had a greater denitrification rate up to 1380 and 85 mg N m^{-2} day^{-1} in the top 30-cm soil layer during flooding and non-flooding periods, respectively. In upland fields, the maximum value for the top 30-cm soils was 44 mg N m^{-2} day^{-1} and most of the rates were less than 10 mg N m^{-2} day^{-1}. The greater denitrification rates were often associated with slurry application rather than composted dry manure. Overall, denitrification from Andosols in this study displayed a lower capacity than that of non-Andosols.

1. Introduction

Terrestrial soils account for 22% of total global denitrification in response to substantial input of anthropogenic reactive nitrogen (N) (Seitzinger et al., 2006). Compared to natural soils, agricultural soils have relatively high denitrification potentials due to the frequent application of chemical and organic N fertilizers (Barton et al., 1999). Therefore, the budgets of denitrification in agricultural soils are important for evaluating potential NO_3^- removes and N_2O emissions. However, there is a large variation in current denitrification estimates from agriculture due to the complicated influences of fertilization, tillage, irrigation, soil texture, vegetation, and climate across spatial and temporal scales (Groffman, 1995). To reduce the high uncertainties in determining the budgets of denitrification from soils, long-term measurements of denitrification encompassing a wide range of environmental and management conditions are required (Seitzinger, 2008).

The application of manure is well known to stimulate denitrification in agricultural soils by increasing C and N availability as an additional energy source (Paul and Beauchamp, 1989). The manure application rates, types (i.e., fresh slurry or compost dry manure), and the C/N ratio might affect soil denitrification significantly due to different microbial activity (Granli and Bøckman, 1994). Petersen et al. (1996) reported that fresh manure can stimulate more N loss through denitrification compared to digested manure. The emission rates of N_2O and NO from soil after application of various organic matters were negatively correlated to the C/N ratio of the applied organic matter (Akiyama and Tsuruta, 2003; Toma and Hatano, 2007). Nevertheless, it is still unclear how different forms of manure affect denitrification processes.

The Tochigi prefecture is one of the major dairy farming regions in Japan. Upland maize and paddy rice are two of the main crops in this area. According to agricultural statistical data, the arable land at the county level would receive manure and urine N from animals in amounts up to 320 kg N ha^{-1} yr^{-1}, but only 140 kg N ha^{-1} yr^{-1} from chemical fertilizer (Koyama et al., 2003). This excessive application of manure in this region has led to concerns over environmental problems from increased N pollution in the surrounding area. Most studies have focused on the historical increases in nitrate leaching from cropping systems into rivers and ground water (Somura et al., 2008), and increased ammonia emissions into the atmosphere and atmospheric N deposition (Hojito et al., 2006). However, the denitrification process as a key factor to reduce the NO_3^- loading and produce N_2O emission has received little attention for soils with intensive cow manure application.

Japan is an active volcanic country and Andosols cover 16.4% of the land surface and 46.5% of arable upland fields (Ministry of Agriculture, Fishery and Forestry, 1991). These volcanic soils are originally acidic, have a high porosity, and possess a high content of Al and Fe with a high ability for humus accumulation (Shindo and

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doi:10.1016/j.agee.2011.09.009

Honma, 2001). These unique physical and chemical characteristics compared to other soil classes are expected to lead to different patterns of N and C cycles in Andosols. Limited ammonia volatilization loss from upland fields has been found in Andosols (Hayashi et al., 2011). Nevertheless, few studies have investigated denitrification in Andosols following intensive application of cow manure.

The aim of this study (1) evaluate the effects of manure application rates and forms on Andosol denitrification for the typical crops in Japan, i.e., upland maize and paddy rice, and (2) investigate the controlling factors of denitrification in agricultural soils in a typical dairy farming region in Japan.

2. Materials and methods

2.1. Study site

This study was carried out at the upper Naka River watershed in Japan (36°49′N to 37°0′N, 139°54′W to 139°59′W). The watershed has a typical temperate monsoon climate. Over the last 30 years (1980–2010), the annual mean temperature was 11.7 °C (range: −9.6 to 33.1 °C) and the annual precipitation was 1493 mm (Kuroiso Meteorological Data System, Japan Meteorological Agency). The soil is classified as Andosol, based on the world reference base for soil resources 2006. The main cropping systems in this region include (1) paddy rice (*Oriza sativa* L.), (2) maize (*Zea mayz* L.), and (3) grass-maize rotation. In a grass-maize rotation, Italian ryegrass (*Lolium multiflorum* L.) is usually planted in October and harvested in May, and maize is planted immediately after the spring harvest and then harvested in September. In contrast, continuous maize has a fallow period (October–April). Rice seedlings are transplanted in May (after flooding the fields) and harvested in October. The rice fields are flooded from mid-May to early September and winter season from October to May was fallow. For maize crop systems, the total manure application rate generally ranges from 500 to 800 kg N ha^{-1} yr^{-1}, which is applied two times, i.e., before the crops are planted. Manure is applied once at a rate of 150–350 kg N ha^{-1} yr^{-1} during the winter fallow season for paddy rice. In addition, 50–100 kg N ha^{-1} yr^{-1} of chemical fertilizer is applied in May or June before the planting of maize and rice. These agricultural practices have been maintained for nearly two decades in this region.

In this study, we selected eight farmer's fields, which were located at five locations across the watershed. Descriptions of soil properties and management practices for each field are shown in Table 1. The area of each field was between 700 and 1500 m^2. Four fields were under grass-maize rotation (G/M), three fields were under rice (R), and only one field was under continuous maize (M). Based on latitude gradients between the locations, the fields were identified as G/M1, G/M2, G/M3, G/M4, and M5 for the upland fields, and R1, R4, and R5 for the rice fields.

2.2. Soil sampling and analysis

Soil and gas sampling was conducted bi-monthly from January 2008 to February 2009. At each sampling time, three intact soil cores (height: 5 cm; diameter: 7.5 cm) were taken randomly to a depth of 0–5 cm with stainless steel tubes from all upland fields and from rice fields when they were not flooded. When the rice fields were flooded (from mid-May to early September), soil cores from depths of 0–5 cm and 15–20 cm were sampled using a PVC tube (height: 25 cm, inner diameter: 7.9 cm) with 5 replications. Three additional soil cores from the same depth at each sampling time were also taken at all fields for the measurements of exchangeable nitrate N (NO_3^--N) and ammonium N (NH_4^+-N) concentrations, as well as soil pH. During the flooding period, standing water samples (about 5 L) were taken at each rice field for soil core laboratory incubation. At the beginning of the experiment, subsamples (1 kg) from the top 5-cm soil layer with 3 replications were taken to measure soil texture, total nitrogen, and total organic carbon (C). Other 3 separate soil cores from the top 5-cm soil layer were taken for bulk density measurements.

Soil textures were tested by the pipette method with fresh soil (Miller and Miller, 1987). Soil bulk density was measured with the soil core method (Birkeland, 1984). The soil total N (TN) and total organic C (TOC) (air-dried soil) content were determined by dry combustion using a C/N analyzer (CN CORDER MT-700, Shimadzu, Japan). Exchangeable NO_3^--N and NH_4^+-N concentrations in the fresh soil were measured by the dual wavelength spectrophotometric method and the indophenol blue method, respectively, using a UV–VIS spectrophotometer (Shimadzu, Japan). Soil pH (2.5:1 = water:soil) was measured with a pH meter (Φ260, Beckman). At soil core sampling time, field soil temperature was taken at 5 cm depths and soil moisture was determined using a hydro sense (TM, Campbell scientific Australia. Pty. Ltd.). The values from hydro sense were converted to percent water-filled pore space (WFPS) using known bulk density and a particle density of 2.65 g cm^{-3} for obtaining pore volume.

Table 1
Soil and fertilizer information.

Site	G/M1	R1	G/M2	G/M3	G/M4	R4	M5	R5
Latitude (°)	37.02	37.02	37.00	36.96	36.94	36.94	36.83	36.83
Longitude (°)	139.98	139.98	140.00	139.91	140.00	140.00	140.00	140.00
Soil properties								
TN (%)	0.87 ± 0.02	0.48 ± 0.04	0.80 ± 0.06	0.85 ± 0.07	0.43 ± 0.01	0.36 ± 0.02	0.37 ± 0.03	0.87 ± 0.2
TOC (%)	12.2 ± 0.36	6.64 ± 0.70	10.4 ± 0.74	11.8 ± 0.91	4.62 ± 0.08	3.83 ± 0.17	5.23 ± 0.15	9.61 ± 0.99
pH	6.95	6.56	6.27	6.15	5.69	6.1	6.16	6.15
Bulk density (g cm^3)	0.74 ± 0.04	0.74 ± 0.04	0.68 ± 0.01	0.57 ± 0.02	1.34 ± 0.09	1.34 ± 0.09	0.87 ± 0.03	0.87 ± 0.03
Fertilizer (kg N ha^{-1})								
Rate (summer)	400	50^c	300 +100^c	350	200	0	250	100^c
Application time	16 May	10 May	22 May	17 May	3 Jun	-	29 Jun	10 May
Rate (winter)	400	150	300	350	200	200	250	250
Application time	28 Sep	20 Dec	15 Nov	28 Sep	17 Nov	23 Jan	18 Jan	20 Jan
Type of manure	CDM	CDM	CDM	Slurry	Slurry	Slurry	CDM	CDM
C/N ratio of manure	23	21	18	24	24	24	12	12
Soil texture (%)								
Clay (<0.002 mm)	18	18	7	20	1	1	6	6
Silt (0.002–0.02 mm)	37	37	43	38	23	23	62	62
Soil types	Loam	Loam	Sandy loam	Loam	Loam sand	Loam sand	Silt loam	Silt loam

G/M, R, and M indicate the crop systems of grass and maize rotation, one season of paddy rice and maize, respectively.
The letter c indicates chemical fertilizer; CDM denotes composted dry manure.