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Short communication

Limited ammonia volatilization loss from upland fields of Andosols following fertilizer applications

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ABSTRACT

The present study first aimed to investigate the ammonia (NH_3) volatilization loss from broadcast ammonium sulfate at an upland field of volcanic ash soil (Andosol) in Hokkaido, northern Japan. Ammonium sulfate was applied for the regrowing stage of wheat at a rate of 300 kg ha^{-1} (= 63.6 kg N ha^{-1}). A micrometeorological technique (i.e., the gradient method) was used to determine the atmosphere-upland field exchange of NH_3. A dynamic chamber method was also tested to separate the contributions of the soil surface and wheat to the exchange fluxes. Although the NH_3 volatilization began one day after the fertilizer application, the cumulative loss accounted for only 0.2% of the applied nitrogen. Hence, the present study also examined the features of Andosols in terms of the inhibition of NH_3 volatilization. Existing studies support the suggestion that upland fields of Andosols inhibit the NH_3 volatilization loss compared to non-Andosols. The following were the key features of Andosols that might inhibit NH_3 volatilization: the relatively low soil pH; the relatively high effective cation exchange capacity even at a low soil pH; and the relatively high nitrification potential, signifying a high consumption rate of the applied ammonium.

1. Introduction

Field-applied nitrogen fertilizer is a major source of atmospheric ammonia (NH_3), in addition to livestock waste (Mosier, 2001; Galloway et al., 2004; Erisman et al., 2008). The emitted NH_3 results in nitrogen loads to ecosystems through its atmospheric transportation and deposition, which may impact ecosystems in various ways (Hayashi and Yan, 2010).

Hayashi et al. (2009a,b) reported that field experiments of the basal fertilization of chemical fertilizer and composted manure by surface incorporation or placement to upland fields of volcanic ash soils (Andosols) resulted in very weak volatilization losses of NH_3. The authors pointed out that the causes might be attributed to the high cation exchange capacity (CEC) and the relatively low soil pH that are general features of Andosols. Fueki et al. (2007) implemented incubation experiments using Andosol collected from an upland field in Hokkaido, northern Japan, to reveal the volatilization loss of NH_3 following the surface application of several types of nitrogen fertilizers at two temperature conditions (15 and 30 °C) and two soil pH conditions (5.9 and 7.0). The NH_3 volatilization losses at the representative values of temperature (15 °C) and soil pH (5.9) at the study area were 1.4% and 0.4% of the applied nitrogen for urea and ammonium sulfate, respectively. These values are remarkably lower than the existing emission factors of NH_3, 13% and 1.6% for urea and ammonium sulfate, respectively, at a temperature of 15 °C (Tier 2, European Environment Agency, 2009). However, the application methods used in these experiments (Hayashi et al., 2009a,b), surface incorporation or placement, induce less volatilization loss of NH_3 compared to surface application (broadcast) (e.g., Huijsmans et al., 2003). To date, there is no information on the NH_3 volatilization loss from broadcast nitrogen fertilizer at an upland field of Andosol.

Emission inventory of NH_3 is needed to evaluate anthropogenic nitrogen loads because a large portion originates from anthropogenic NH_3 emissions (Galloway et al., 2004). Accurate emission factors of NH_3 are indispensable for a solid emission inventory. Existing emission factors of NH_3 might overestimate the NH_3 volatilization loss from upland fields of Andosols if they have a universal feature of inhibiting NH_3 volatilization. Although Andosols have been described only in the volcanic zones of the world (Shoji et al., 1993), they account for approximately 50% of the upland soils in Japan (Takata et al., 2009). It is, therefore, important to elucidate the general features of Andosols in terms of the NH_3 volatilization loss.

The purpose of the present study was primarily to quantify the NH_3 volatilization loss from broadcast fertilizer at an upland field of Andosol. Specifically, the NH_3 volatilization was measured fol-

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lowing the broadcast supplemental fertilization with ammonium sulfate to winter wheat; the application was at the regrowing stage that occurred after the snowmelt at an upland field of Andosol in the Tokachi region in Hokkaido, northern Japan. A micrometeorological technique (i.e., the gradient method) was adopted to determine the exchange fluxes of NH_3 at the upland field. In addition to the soil surface, plants (young wheat in the present study) are also a possible emitter of NH_3 (e.g., Schjoerring and Mattsson, 2001). Thus, a dynamic chamber method with forced ventilation was tested to separate the NH_3 effluxes of the soil from the entire exchange fluxes determined by the gradient method. We also examined whether Andosols have a universal feature of inhibiting NH_3 volatilization loss by comparing Andosols with non-Andosols based both on previous studies and on the results of the present research.

2. Materials and methods

2.1. Site description

The study site (42°53′17″N, 143°4′26″E, 99 m ASL) was an upland field with an area of 1 ha (60 m × 167 m) located in the National Agricultural Research Center for Hokkaido Region (NARCH) in Memuro Town, Hokkaido Prefecture, Japan. The surroundings mainly comprised upland fields belonging to NARCH and local farmers. The ten-year means (1999–2008) of annual mean temperature and precipitation were 5.5 °C and 904 mm yr^{-1}, respectively. This region is usually covered with snow from December to early April and exhibits a boreal climate. The monthly mean temperature and precipitation in the study period (April 2009) were 4.9 °C and 71 mm $month^{-1}$, respectively.

The soil at the study site was volcanic ash soil classified as Silic Andosol (Bridges et al., 1998), which is an allophanic and low-humic soil (Fueki et al., 2004). The surface soil (a depth of 0–5 cm) had a texture of clay loam with a low soil pH (H_2O) of 5.6; a relatively high carbon content of 3.5% dry soil; and a relatively high CEC of 150 $mmol_c\ kg^{-1}$ dry soil (Hayashi et al., 2009a). These are all typical features of Andosols (Shoji et al., 1993). The bulk density of the soil changes with time and agricultural practices; the soil was relatively compact, with a bulk density of 0.95 $g\ cm^{-3}$ at the beginning of the study period when the snow season had elapsed, in contrast to a lower bulk density at the same site, 0.61 $g\ cm^{-3}$, immediately after tillage by a rotary cultivator (Hayashi et al., 2009a).

2.2. Fertilizer application and wheat cropping

Supplemental fertilization by surface application of ammonium sulfate to winter wheat (*Triticum aestivum* cv. Yumechikara) at the regrowing stage was conducted using a broadcaster in the morning of 20 April 2009, approximately three weeks after the snowmelt. The application rate was 300 $kg\ ha^{-1}$ (= 63.6 $kg\ N\ ha^{-1}$ as ammoniacal nitrogen). The plant height of the young wheat was 10–15 cm, and the spacing between successive rows of the wheat was 0.66 m, which is broader than the normal spacing in this region of 0.12–0.3 m.

2.3. Flux measurement by the gradient method

The air concentrations of NH_3 were measured using open-face filter holders (NL-O, NILU) (Hayashi et al., 2009a). The filter-pack set consisted of two stages: an upstream stage with a polytetrafluoroethylene membrane filter having a pore size of 0.8 μm (T080A047A, Advantec) that collects aerosols including particulate ammonium and a subsequent stage with a cellulose filter (51A, Advantec) impregnated with phosphoric acid that collects NH_3. The flow rate was approximately 8 $L\ min^{-1}$. The air concentrations were measured at heights of 0.5 and 1.5 m above the ground surface ($n = 2$ at each height).

The samplers of the filter pack were replaced at 9:00, 13:00, and 17:00; the sampling frequency was twice during the daytime (09:00–13:00 and 13:00–17:00) and once at night (17:00–09:00). The measurements of air concentration and meteorological conditions were carried out between 19 and 28 April 2009 at the east-west center of the site, 50 m from the northern border of the site. Ammonium collected on the filter was extracted by ultrasonic extraction using deionized water and then analyzed using a flow injection analyzer (AQLA-1000, Aqualab).

Fluctuations in the three-dimensional wind velocity and virtual temperature were measured at 10 Hz using a sonic anemometer–thermometer (81000, Young) installed at a height of 1.5 m. The air temperature and relative humidity were measured using a temperature–humidity sensor (HMP45A, Vaisala) installed at a height of 0.6 m. Ten-minute means were computed by and recorded on a data logger (CR1000, Campbell Scientific). The hourly rainfall and atmospheric pressure data were obtained from the NARCH weather station located approximately 100 m to the northeast of the point where the meteorological measurements were obtained.

As a micrometeorological technique, a gradient method was adopted to determine the exchange fluxes of NH_3 between the upland field and the atmosphere. The exchange flux is expressed as the product of the difference in the concentrations between the two heights by the diffusion velocity (D, $m\ s^{-1}$) (Hayashi et al., 2009a). D was calculated for 10-min intervals, and the mean value of D during the measurement interval of air concentration was used in the exchange flux calculation.

2.4. Flux measurement by the dynamic chamber method

There were two potential emitters of NH_3, the soil surface and the young wheat, in the upland field. Because it was desirable to evaluate the NH_3 volatilization loss from the Andosol alone, the contribution of the wheat to the NH_3 volatilization needed to be subtracted from the exchange fluxes at the upland field. A dynamic chamber method was utilized to determine the NH_3 effluxes from two types of plots, which encompassed only the soil between the rows of wheat (soil plot) and the soil with young wheat growing on it (soil + wheat plot) ($n = 2$ for each condition).

The dynamic chambers and their bases were cylindrical in shape and were made of transparent and colorless acrylic resin (Fig. S1 in supplementary data). The chamber had an inner diameter of 0.24 m and a height of 0.25 m, with a volume of 0.0113 m^3. The chamber base had an inner diameter of 0.206 m, with a base area of 0.033 m^2. There were two inlets of ambient air and two outlets of internal air at the top and near the bottom of the chamber, respectively. A battery-driven motor fan was affixed at the roof of the chamber to mix the internal air. A Y-branch was attached to each inlet: one end was to take in the ambient air, and the other was to connect to a dry NH_3 collector for the ambient air. The outlet was connected to another dry NH_3 collector for the exhaust from the chamber. A filter holder, consisting of two stages of inline filter holders (NL-I, NILU), was used as the dry NH_3 collector. The flow rate was approximately 8 $L\ min^{-1}$. The NH_3 effluxes were calculated according to Hayashi et al. (2009b).

The measurement frequency was twice in the daytime with sampling durations of 09:00–11:00 and 13:00–15:00. The sampling duration was shortened to 2 h to diminish the dew condensation inside the chamber because a portion of the NH_3 might have dissolved into the dew. Measurements for the air concentrations of NH_3 by the dynamic chamber method were carried out between