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Quantification of ammonia emissions from dairy and beef feedlots in the Jing-Jin-Ji district, China

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ABSTRACT

It is necessary to obtain accurate ammonia (NH_3) emission estimates from concentrated cattle operations to evaluate the contribution of emissions from dairy and beef feedlots in the Beijing-Tianjin-Hebei (or the "Jing-Jin-Ji") district of China to local dust-haze pollution such as fine particulate matter ($PM_{2.5}$) and the national animal NH_3 inventory. This study examines NH_3 emission rates from two dairy and two beef feedlots in four different seasons, which were measured using an inverse dispersion technique in combination with an open-path tunable diode laser. Ammonia emissions from both dairy and beef feedlots are characterized by a distinctive diel pattern with high emission rates during the middle of the day and low rates during the night, which is in good agreement with the diel variation in air temperature and wind speed. In addition, apparent seasonal difference in NH_3 emissions from dairy and beef feedlots were also observed, where the greatest emission occurred in summer followed by spring/fall and winter. Annual emission factors (EFs) for beef and dairy feedlots in the Jing-Jin-Ji district were estimated to be approximately 19.8 kg NH_3 head^{-1} yr^{-1} and 47.8 kg NH_3 head^{-1} yr^{-1}, respectively, accounting for 25% and 30% of the feed N inputs. The NH_3 emissions from beef and dairy cattle in this district were estimated to be 45.73 and 105.52 kt, respectively. In future, more field measurements on animal feedlots with various feed/manure management practices, stocking densities and weather conditions are highly requested to reduce NH_3 emission uncertainty and characterize the N cycling within animal feedlots.

1. Introduction

Atmospheric NH_3 is one of the major precursors of fine particulate matter. NH_3 readily reacts with acidic compounds, such as sulfate or nitrate, to form fine particulate matter (e.g. $(NH_4)_2SO_4$, NH_4NO_3 and brown carbon) with a mean aerodynamic diameter of 2.5 μm ($PM_{2.5}$). These compounds are respirable and contribute to elevated asthma morbidity, especially in rural areas (Todd et al., 2008; Loftus et al., 2015; Pavilonis et al., 2013; Updyke et al., 2012). In addition, dry and wet atmospheric NH_3 deposition is also a major cause of water eutrophication and acidic rainfall (Shen et al., 2011; Haruta et al., 2002).

Agricultural sources of NH_3 are the dominant contributor to the global NH_3 budget, with animal agriculture contributing the majority of NH_3 (over 50%–80% of agricultural emissions) (FAO, 2006; Zhou et al., 2015; Galloway and Cowling, 2002; Howarth et al., 2002). Increasing global concern regarding the environmental risks of atmospheric NH_3 has prompted countries to undertake periodic national NH_3 inventories. The inventory methodology has evolved from simply multiplying emission factors (EFs) by animal populations (Klimont, 2001) to assigning NH_3 EFs to each emission source based on the characteristics of feed nitrogen (N) flows on animal farms (Webb, 2001; Webb and Misselbrook, 2004). For example, inventory models based on the amounts of total ammoniacal nitrogen (TAN) in excreted manure from various emission sources and their TAN-based EFs are now being used worldwide (Webb, 2001; Webb and Misselbrook, 2004; Dämmgen and Hutchings, 2008; Chai et al., 2014; Sheppard and Bittman, 2013; Gao et al., 2013; Velthof et al., 2012; Misselbrook et al., 2000). However, the EFs of these models must be evaluated with high quality on-site measurements (Wood et al., 2015).

Generally, NH_3 emissions from concentrated animal feeding operations (CAFO) such as open lots are associated with large spatiotemporal variations, with coefficients of variation as large as 192% (Cole et al., 2007). Micrometeorological methods such as the flux-gradient method (Baek et al., 2006) have the potential to

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Table 1
Average feed intake and their compositions of the experimental beef and dairy feedlots during measurement period.

Items	Beef feedlots		Dairy feedlots	
	Cangzhou	Hengshui	Baoding #1	Baoding #2
Silage (DM, kg head^{-1} d^{-1})	5.68	4.80	5.84	8.60
Concentrates (DM, kg head^{-1} d^{-1})	4.48	4.31	12.12	6.93
Dry matter intake (DM, kg head^{-1} d^{-1})	10.66	9.11	17.96	15.53
Total feed N intake (kg head^{-1} d^{-1})	0.188	0.160	0.332	0.383
Measurement days (day)	18[a], 17[b], 15[c], 19[d]	20, 14, 17, 19	18, 15, 16, 19	17, 15, 16, 19

a, b, c and d represents the measurement days in spring, summer, fall and winter season, respectively at different feedlots.

provide emission rates over relatively large areas, but their utility is limited in complex situations such as animal operations because they employ highly simplified calculations. However, many studies have demonstrated that the inverse dispersion technique established by Flesch et al. (1995, 2004, 2007) can handle complex situations without a significant loss of measurement accuracy. For instance, Todd et al. (2015) measured NH_3 emissions from dairy feedlots, showing that the emission rates of 304 g head^{-1} d^{-1} for dairy feedlots accounted for approximately 41% of the feed nitrogen intake. van Haarlem et al. (2008) measured NH_3 emissions from beef feedlots during late fall, where the emission rate of 318 g head^{-1} d^{-1}accounted for approximately 72% of the feed nitrogen intake.

In China, haze-dust events (mainly $PM_{2.5}$) have been a frequent occurrence in recent years. These events pose a challenge to the synergetic development of the Beijng-Tianjin-Hebei region (also called the Jing-Jin-Ji district), and may largely derive from NH_3 emissions from animal production in the region because animal density in the Jing-Jin-Ji area is much higher than the national average (China Animal Industry Yearbook, 2013). However, few efforts have been made to estimate emissions from the CAFOs in this region, and the lack of directly measured EFs has hampered the establishment of a regional NH_3 inventory. Therefore, accurately estimating NH_3 emissions from animal production will allow researchers to build and complete regional NH_3 emission factors, update inventories and evaluate their direct impacts on the regional haze-dust pollution (Aneja et al., 2008).

Beef and dairy cattle that are mostly managed in feedlots (Zhu et al., 2013; Lin et al., 2015) are believed to be the major contributor to the atmospheric NH_3 in Jing-Jin-Ji district. Therefore, this study measured NH_3 emissions from two dairy and two beef feedlots in four seasons in this district, using an inverse dispersion technique in combination with an open path tunable diode laser (OPTDL) to: 1) characterize the diel and seasonal variations from these operations and provide annual emission factors; 2) evaluate emission intensities on the basis of feed N intake, milk production, and livestock weight units; and 3) estimate the NH_3 emissions from beef and dairy feedlots in the Jing-Jin-Ji district.

2. Materials and methods

2.1. Description of the experimental feedlots

In this study, we characterized the NH_3 emissions from two commercial beef feedlots (mainly Simmental cattle) located in Cangzhou and Hengshui and two dairy feedlots (mainly Holstein cattle) located in Baoding in the Jing-Jin-Ji district. There were no significant sources of NH_3 emission around the commercial feedlots.

During the entire measurement at the beef feedlot in Cangzhou (Beef #1), a restricted feeding strategy was applied. The beef cattle were fed twice a day at 0800 h and 1730 h; fattening cattle in stock ranged from 298 to 362 heads, corresponding to a stocking density of approximately 18m^2 head^{-1} during entire measurement period. The individual body weight ranged from 330 to 650 kg head^{-1} with an average of 485 kg head^{-1} and the average daily gain was approximately 0.75 kg head^{-1} d^{-1}. At the beef feedlot in Hengshui (Beef #2), a strategy of *ad libitum* feeding was employed during the entire measurement and feed was added to the bins at 0930 h and 1630 h. The cattle in stock varied from 1100 to 1200 heads, corresponding to a stocking density of 20m^2 head^{-1} during the entire measurement period. The individual body weight ranged from 350 to 630 kg head^{-1} with an average of 500 kg head^{-1}, and the average daily gain was approximately 0.68 kg head^{-1} d^{-1}. In both dairy feedlots, milking cows and heifers were fed three times a day, at 0630 h, 1330 h and 2030 h; they were milked twice a day at 0630 h and 1700 h. The average fat and protein corrected milk (FPCM) production of Dairy #1 was 23 kg cow^{-1} d^{-1} and it was 25 kg cow^{-1} d^{-1} for Dairy #2. The number of animals at dairy feedlots #1 and #2 during the study period was approximately 612 and 598 heads, respectively, with a stocking density of approximately 53 and 63 m^2 head^{-1}. Total mixed rations (TMR) were used for both dairy and beef feedlots; the average amounts of silage and concentrate intake in terms of dry matter and total feed N are shown in Table 1.

The feedlot floor in Cangzhou was earthen and manure was removed each day (i.e., there was a high manure collection frequency).The Hengshui and Baoding feedlots were paved with bricks, and feedlot manure was manually removed once a week (i.e., there was a low manure collection frequency). The collected manure was stored in the corners of feedlots and sold for crop and vegetable production in spring and fall.

2.2. Ammonia concentration measurements

Ammonia mixing ratios over the cattle feedlots were measured with an open-path tunable diode laser (OPTDL, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Hefei, China) at 1 Hz (Yang et al., 2013). We used the interior strategy proposed by Flesch et al. (2007), where the laser system was setup over the feedlots with a path length varying from 85 to 159 m and a measurement height varying from 2.4 to 3.0 m to provide a line-average concentration between the laser and a retro-reflector (Fig. 1). The NH_3 concentrations over each experimental feedlot were continuously recorded for 14–20 days in spring, summer, fall and winter measurement season, which met the requirement by Gao et al. (2009).[1] Laser signals were calculated to give 15-min average concentrations (C_L) along the laser line. Background concentrations (C_b) at the various experimental sites were measured prior to feedlot measurements; the background values were determined upwind of the cattle feedlots with laser path

[1] Gao et al. (2009) argued that the standard deviation of inversely modeled emission estimate was approximately 30%, therefore, it is forecasted that approximately 9 usable emission rates are needed to provide one hourly emission rate with a standard error of 10%. Given that the minimum ratio of usable to total hourly periods (15-min) of 40% at night is used, the minimum number of days required to achieve this threshold number can then be estimated to be 6 days.