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Ammonia losses and nitrogen partitioning at a southern High Plains open lot dairy

Richard W. Todd [a, *], N. Andy Cole [a], G. Robert Hagevoort [b], Kenneth D. Casey [c], Brent W. Auvermann [c]

[a] USDA -ARS Conservation and Production Research Laboratory, Bushland, TX 79012, USA
[b] New Mexico State University, Clovis, NM 88101, USA
[c] Texas A&M AgriLife Research, Amarillo, TX 79106, USA

HIGHLIGHTS

- Quantified ammonia emissions at an open lot dairy during summer in New Mexico.
- Almost half of the nitrogen fed to cows was lost to the atmosphere as ammonia.
- Almost all ammonia emissions came from the open lot area where cows were housed.
- Manure handling and animal housing affect the source and magnitude of ammonia loss.

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ABSTRACT

Animal agriculture is a significant source of ammonia (NH_3). Cattle excrete most ingested nitrogen (N); most urinary N is converted to NH_3, volatilized and lost to the atmosphere. Open lot dairies on the southern High Plains are a growing industry and face environmental challenges as well as reporting requirements for NH_3 emissions. We quantified NH_3 emissions from the open lot and wastewater lagoons of a commercial New Mexico dairy during a nine-day summer campaign. The 3500-cow dairy consisted of open lot, manure-surfaced corrals (22.5 ha area). Lactating cows comprised 80% of the herd. A flush system using recycled wastewater intermittently removed manure from feeding alleys to three lagoons (1.8 ha area). Open path lasers measured atmospheric NH_3 concentration, sonic anemometers characterized turbulence, and inverse dispersion analysis was used to quantify emissions. Ammonia fluxes (15-min) averaged 56 and 37 $\mu g\ m^{-2}\ s^{-1}$ at the open lot and lagoons, respectively. Ammonia emission rate averaged 1061 kg d^{-1} at the open lot and 59 kg d^{-1} at the lagoons; 95% of NH_3 was emitted from the open lot. The per capita emission rate of NH_3 was 304 g $cow^{-1}\ d^{-1}$ from the open lot (41% of N intake) and 17 g $cow^{-1}\ d^{-1}$ from lagoons (2% of N intake). Daily N input at the dairy was 2139 kg d^{-1}, with 43, 36, 19 and 2% of the N partitioned to NH_3 emission, manure/lagoons, milk, and cows, respectively.

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1. Introduction

Ammonia (NH_3) is a major trace gas emitted from concentrated cattle operations like dairies and beef feedyards (Hristov et al., 2011; Leytem et al., 2013; Todd et al., 2008, 2011). This fugitive NH_3 is a major pathway for reactive nitrogen (N) entering the atmosphere and subsequently being deposited to terrestrial and aquatic ecosystems. It is a precursor to $PM_{2.5}$ particulates that can negatively impact air quality (Hristov, 2010). It is also a precursor to the greenhouse gas nitrous oxide (N_2O) when deposited on land (IPCC, 2006). Dairies with more than 700 mature cows and that exceed the reportable quantity of emitted NH_3 (45.4 kg NH_3 d^{-1}) are required under the U.S. Emergency Planning and Community Right to Know Act (EPCRA) to report an estimate of NH_3 emissions.

Dairies are highly diversified in both animal housing design and management practices for handling manure. Housing for milk cows includes tie stall barns, freestall barns, bedded pack barns and covered or uncovered open lots (Hristov et al., 2011; USDA, 2010). Manure is generally handled intensively in dairies. Practices include daily scrape or flush manure removal systems, solids

* Corresponding author.
E-mail address: richard.todd@ars.usda.gov (R.W. Todd).

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separations, covered or uncovered wastewater lagoons, recycling and reuse of wastewater, frequent manure removal and mechanical grooming of open lot surfaces. The physical scale of dairies varies greatly, from smaller, more traditional dairies in the eastern U.S., to very large dairies of the drier western U.S. that can exceed 10,000 cows (USDA, 2010).

When animals are concentrated in feeding operations like dairies, excreted nutrients are also concentrated. For example, a 680 kg cow in mid-lactation requires from 20 to 30 kg of dry matter intake (DMI) each day and from 0.45 to 0.80 kg N d^{-1}, depending on factors such as milk production, diet composition, feeding behavior and weather (NRC, 2001). About 20–25% of N intake is used for milk production and the physiological needs of the cow, but from 70 to 80% of N intake is excreted (Hristov et al., 2011). Urinary N, mostly in the form of urea, is readily hydrolyzed to NH_3. The temperature-dependent process requires the enzyme urease, ubiquitous in dairy manure, and can be considered a fast pool source of NH_3. Nitrogen in feces is mostly in more complex organic forms that are transformed through slower mineralization processes into reactive compounds.

Ammonia emissions from feedyards general do not vary much across the beef-producing region of the U.S. Great Plains (Hristov et al., 2011; Preece et al., 2011), indicating a more common set of management practices. For example, manure is typically cleaned from a feedyard pen only once, at the end of a 150–180 day feeding period. Because manure handling is standardized, the most critical drivers of feedyard NH_3 emissions are temperature and dietary crude protein (Cole et al., 2005; Todd et al., 2011, 2013). Dairy NH_3 emissions on the other hand are quite variable from region to region and from practice to practice (Hristov et al., 2011; Moore et al., 2014). This diversity in emissions probably reflects the diversity in housing and manure management systems.

The southern High Plains of the southwestern United States has been a growing and major dairy producing region for over three decades. Production has centered in New Mexico, with milk cow population of 142,000 cows in three eastern High Plains counties in 2013 (USDA, 2014). Recent growth has occurred in seven southern High Plains counties in West Texas where the milk cow population has increased from 16,800 cows in 2000 to 209,000 cows in 2013 (USDA, 2014).

Ammonia emissions from open lot dairy production systems have been studied in California (Cassel et al., 2005a,b; Moore et al., 2014), Idaho (Bjorneberg et al., 2009; Leytem et al., 2011) and east Texas (Mukhtar et al., 2008), but not in the southern High Plains region. Our objective was to quantify NH_3 emissions at a commercial southern High Plains dairy farm. We focused on the two major sources of NH_3 volatilization, the open lot and the wastewater lagoon system. We also sought to build a nitrogen balance for the dairy that partitioned feed intake N, N retention in cows, milk N, volatilized NH_3–N, urinary N and feces N.

2. Materials and methods

2.1. Description of dairy

Research was conducted at a commercial dairy farm located in Curry County, New Mexico (USA) from 7 August 2009 to 15 August 2009 (day of year, DOY 219–227). Production practices at the dairy were typical of regional practices. The production facilities consisted of twelve open lot, manure-surfaced corrals (from 82 to 96 m by 225 m) with total area of 22.5 ha, and a nearby system of three wastewater lagoons (1.8 ha surface area); a fourth lagoon was unfilled (Fig. 1). A sun shade (7 m by 192 m) was located along the center line of each corral. Manure was not removed from corrals during the study, but the corral surfaces were groomed with a tractor-drawn harrow. A concrete-surfaced feeding alley was located on one long side of each corral. Feed was deposited just outside corrals in the feed alley and cows accessed the feed through stanchions while standing in concrete-surfaced flush lanes. The flush lanes were scheduled to be flushed twice a day using water recycled from the wastewater lagoons. However, operationally the flushing schedule was irregular and depended on whether dairy personnel were available, so that some days the lanes were flushed less than twice. The flush water removed and carried accumulated manure from the flush lane through a 700 m long canal that flowed into the first of the three lagoons; lagoons 1 and 2 were directly connected, lagoon 3 received overflow water (Fig. 1). Sediment from the bottom and near the inlet of the first lagoon was continually pumped to an adjacent solids separator; separated solids were stored at the separator for the duration of the study in a 10-m by 10-m stockpile.

Potential sources of ammonia at the dairy were the open lot, the lagoons, the canal that carried flush water to the lagoons, and the separated solids pile. We treated the open lot and lagoons as the major sources. However, this meant that any emissions from the canal would be included with open lot emissions when winds were southerly or south-westerly. We expected canal emissions to be very small and to make a negligible contribution to the open lot and total dairy emissions. It was not possible to discriminate lagoon emissions from emissions from the separated solids pile just to the east of the first lagoon. When wind direction was south-easterly, emissions from the solids pile and lagoon were combined, while at other times, the solids pile emissions were not included with lagoon emissions. Leytem et al. (2011) reported that NH_3 fluxes from dairy compost were similar to those from wastewater lagoons. If we take fluxes from compost as an approximation of fluxes from the separated solids, then emissions from the 100-m^2 solids pile would contribute little to emissions from the 18,000-m^2 lagoons.

2.2. Cow population, diets and milk production

Dairy management provided us with detailed information on the types and numbers of cows resident at the dairy during the study. Information on the composition of rations fed to the different cow classes was not available, but a representative ration in the region would include 30% corn silage, 30% rolled corn, 20% alfalfa hay, 10% dry distillers grains, 4% soybean meal, and 6% minerals and supplements. Dairy management was able to provide us with total dry mater intake (DMI) and diet crude protein (CP) content for each cow class, and total milk production. Cows were milked three times a day, however we did not have the times when individual pens were vacant.

2.3. Dairy nitrogen balance

A nitrogen balance for the dairy was calculated that included measured N feed intake, milk N and NH_3–N loss, and estimated values of N retained in cows and excreted N. For the estimated values, we used the empirical equations of Castillo et al. (2000), based on a meta-analysis of a database of 581 cows fed 91 different diets. Milk N was calculated by assuming that 3.31% of milk was crude protein and that 16% of crude protein was N. No off-farm manure N losses were considered, nor did we attempt to partition N between open lot and lagoons.

2.4. Inverse dispersion analysis

Ammonia emissions were quantified using inverse dispersion analysis (IDA; Flesch and Wilson, 2005). Inverse dispersion analysis has become a commonly used micrometeorological method to