Ammonia deposition in the neighbourhood of an intensive cattle feedlot in Victoria, Australia

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Abstract
We conducted the first study in Australia to measure ammonia (NH_3) deposition within 1 km from a commercial beef feedlot in Victoria. NH_3 concentrations and deposition fluxes decreased exponentially with distance away from the feedlot. The mean NH_3 concentrations decreased from 419 μg N m^{-3} at 50 m to 36 μg N m^{-3} at 1 km, while the mean NH_3 dry deposition fluxes decreased from 2.38 μg N m^{-2} s^{-1} at 50 m to 0.20 μg N m^{-2} s^{-1} at 1 km downwind from the feedlot. These results extrapolate to NH_3 deposition of 53.9 tonne N yr^{-1} in the area within 1 km from the feedlot, accounting for 8% of the annual NH_3-N emissions from the feedlot. This high NH_3 deposition rate nearby the cattle feedlot had caused the increase of soil inorganic nitrogen content, especially for NO_3^- (from 33 mg N kg^{-1} at 1000 m from the feedlot to 124 mg N kg^{-1} at 50 m from the feedlot). Higher N content (4.0% to 5.7%) in the above-ground part of grassland species and high cover rate of single species (e.g. a cover rate of 31% to 42% at 50 to 200 m from the feedlot for *Cymbonotus lawsonianus*) were found in the grassland transect to the southeast of the feedlot. Our results suggest that NH_3 deposition is significant nitrogen (N) nutrient input for surrounding croplands and natural ecosystems.

Key Words
nitrogen deposition, dry deposition, soil nitrogen, plant response

Introduction
Cattle feedlots are large NH_3 hotspots. In Australia, annual emissions are estimated to be approximately 33,200 tonne NH_3-N based on an emission rate of 104 g NH_3-N $head^{-1}$ d^{-1} and 875,000 beef cattle across Australian feedlots (Denmead et al. 2014; Chen et al. 2015). However, little is known about the NH_3 deposition rate and its variance associated with the distance downwind of the feedlot. Furthermore, the effect of potential high NH_3 deposition on nitrogen contents in soil and plants are poorly understood. Our study aimed to 1) estimate NH_3 deposition rates downwind of a cattle feedlot in Victoria, Australia, and 2) identify the effects of NH_3 deposition from the feedlot on nitrogen contents in soils and plants around the feedlot.

Methods
The experiment was conducted at an intensive beef cattle feedlot, in the northeast of Victoria, Australia. The feedlot area was approximately 93 ha (1,230 m in the east-west direction and 760 m in the north-south direction) including cattle pens, manure stockpiles, bare soil or roads and effluent ponds. The feedlot held approximately 17,500 cattle during the study period. The area surrounding the feedlot was mainly cropland planted to wheat with sheep pasture lying to the northeast and grassland to the south (Figure 1).

The NH_3 deposition measurement was conducted during three 5 day sampling periods in 2015 (20-24 of April, 14-18 of May and 24-29 of June), with NH_3 concentration measured by a denuder system for long-term ammonia sampling (DELTA) (Sutton et al. 2001) and NH_3 deposition modelled using a bi-directional NH_3 exchange model. Four transects were selected for NH_3 collection. These transects were determined based on daily predominant wind direction and downwind of the centre of the feedlot. NH_3 was collected at five locations along a transect, with a distance of 50, 100, 200, 500 and 1000 m from the fence line of the feedlot (Figure 1). NH_3 samples were collected continuously at each location. The denuder trains were changed two times every 24 hours based on a day (8:00 am to 5:00 pm) and night (6:00 pm to 7:00 am the following day) cycle. The actual sampling duration for a sampling site was then recorded only when the site was located at downwind of the feedlot. The measured NH_3 concentrations were discarded if wind direction changed and the downwind sampling duration was less than 50% of the total sampling duration.

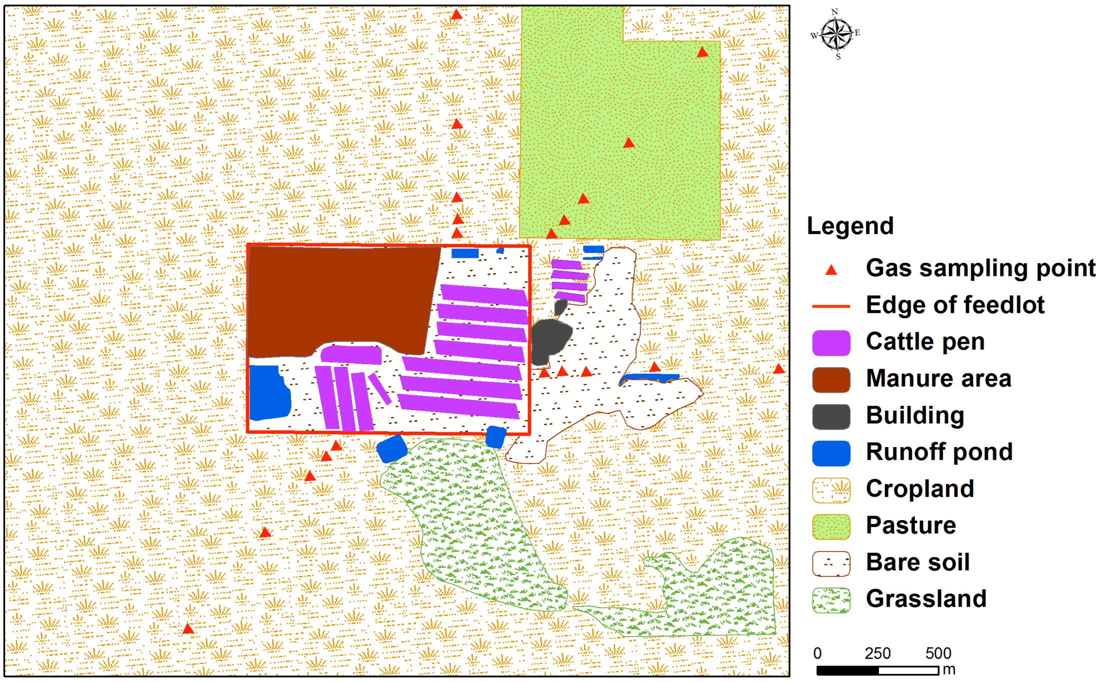

Figure 1. Land use types and locations of NH_3 samplers within 1 km of the feedlot. Map was drawn using ArcGIS (version 10.0, http://www.arcgis.com).

A weather station coupled with a three-dimensional (3-D) sonic anemometer (CSAT3, Campbell Scientific, Logan, USA) was set up at a height of 3.3 m above the ground located to the east of the feedlot. Fifteen-min averaged air temperature, wind speed, friction velocity, Monin-Obuhkov length and relative humidity were recorded at 10 Hz. The raw data was processed to hourly average data using SAS software (SAS 9.4, SAS Institute Inc., Cary, NC, USA).

A bi-directional NH_3 exchange model, which is called the two-layer canopy compensation point model (Massad et al. 2010), was used to estimate NH_3 dry deposition around the feedlot. Hourly NH_3 dry deposition flux was calculated based on the hourly meteorological data. As we did not measure hourly NH_3 concentrations, their values in a sampling event were assumed to be equal to the corresponding day or night NH_3 concentration measured.

Soil samples were collected along transects to the east, south, west, north, northeast, northwest, southeast and southwest of the feedlot. For each transect, normally 11 soil samples of 0-15 cm depth were collected at 50m and 100 to 1000 m from the fence line of the feedlot at distance of 100 m intervals. Soil samples were extracted with 1 M KCl solution (1:10) and then analysed to obtain ammonium and nitrate contents using the automatic analyzer (Skalar San plus, Netherland). Soil pH was measured based on a soil: water ratio of 1: 2.5 using the pH meter (TPS, Australia). Soil electrical conductivity (EC) was measured by extracting the soil samples with the high purity water at a soil: water ratio of 1:5 and then analyzing the EC of the extractant using the EC meter (TPS, Australia). Soil total nitrogen contents were measured using the mass spectrometer (SerCon, Hydra 20-20, UK).

Plant samples were collected on edge of a low hill on the south of the feedlot in a southeast transect across the grassland area (Figure 1) in June 2015. The sampling sites were located at 50, 100, 200, 500 and 800 m from the edge of the feedlot. All the sampling sites faced north and had similar elevation. Plant community components were identified and species (grasses: *Microlaena stipoides*, *Stipa nodosa*, herb: *Cymbonotus lawsonianus*) cover was assessed in three 2m × 2m plots at each sites. Typical grass and herb species were collected at each plot,dried at 70 ^{o}C for 24 h, ground and analyzed for total N using mass spectrometer (SerCon, Hydra 20-20, UK).

Results

The measured NH_3 concentrations showed large spatial and temporal variation. During the three sampling periods, the mean day and night (day/night) NH_3 concentrations were 300/370, 217/324, 117/245, 62/181 and

27/94 µg N m^{-3} at the distance of 50, 100, 200, 500 and 1000 m downwind from the feedlot, respectively. From 50 m downwind to 1 km downwind, NH_3 concentrations decreased by 74 - 97% during the day, and 60 to 87% during the night. Ammonia concentrations decreased exponentially with distance away from the feedlot. This indicates during the period of transporting NH_3 from the feedlot to the sampling sites NH_3 deposition and NH_3 dispersion might occur. Ammonia concentrations were the highest at night under stable atmospheric conditions and low dispersion of the NH_3 plume from the feedlot. The average NH_3 concentrations during the night were 1.1 - 6.0 times of those during the day. The ratio of NH_3 concentration during the night to that during the day increased with the distance away from the feedlot, due to the faster decrease of NH_3 concentration with distance away from the feedlot during the day than during the night. This suggests that sampling NH_3 concentrations separately during the day and night is preferred.

The NH_3 deposition fluxes also showed large spatial and temporal variation, ranging from 0.05 to 2.94, 0.03 to 4.34 and 0.03 to 4.34 µg N m^{-2} s^{-1} in April, May and June respectively. The NH_3 deposition fluxes decreased with the distance away from the feedlot. Higher ammonia deposition fluxes were generally found during the day than those during the night at 50 m site, but this trend was reversed at 200 m until to 1000 m site. This may be because that the differences of NH_3 concentration between day and night were relatively small at the 50 m site and therefore higher wind speed during the day resulting in lower aerodynamic resistance (R_a) has resulted in higher deposition fluxes during the day. But the much higher NH_3 concentration during the nigh than during the day at 200 m, 500 m and 1000 m sites made NH_3 concentration as the major affecting factor on NH_3 deposition fluxes.

We estimated the annual NH_3 dry deposition rates by assuming that the mean NH_3 deposition fluxes during April to June for cropland, grassland and pasture represented the annual average of NH_3 deposition fluxes. The estimated annual area-weighted NH_3 deposition rates around the feedlot were 614, 496, 322, 210 and 106 kg N ha^{-1} yr^{-1} at 50, 100, 200, 500 and 1000 m respectively, from the feedlot, provided that wind direction was constant. In fact, NH_3 deposition mostly occurred in the downwind areas of the feedlot in this study since the NH_3 concentration was very low or could not be detected in the upwind direction. Due to the frequent changes in wind direction in the studied region, we calculated the annual NH_3 deposition in the downwind areas of eight major wind directions by integrated the site-specific NH_3 dry deposition rates in the downwind transect (Shen et al., 2016). By summation, the estimated total NH_3 deposition in the areas within 1 km from the feedlot was 53.9 tonne N yr^{-1}, or 67.5 kg N ha^{-1} yr^{-1} as an area-weighted mean, which was calculated by divided the total NH_3 dry deposition around the feedlot by the total area (798 ha) within 1 km from the feedlot.

The mean soil nitrate contents at different distances from the feedlot across the eight transects ranged 124 mg N kg^{-1} at 50 m from the feedlot to 33 mg N kg^{-1} at 1000 m from the feedlot. The mean soil ammonium contents were measured with a range of 17 mg N kg^{-1} at 50 m from the feedlot and 5 mg N kg^{-1} at 1000 m from the feedlot. Both soil nitrate and ammonium contents showed a decrease trend with the increase in the distance from the feedlot.

Along the southeast transect through the grassland area species composition and plant cover rate varied (Figure 2). These differences are likely to reflect the differences in NH_3 deposition. For the three dominant species (grasses: *Microlaena stipoides*, *Stipa nodosa*, herb: *Cymbonotus lawsonianus*) in the grassland, the cover rate of the herb species decreased with distance from the feedlot. For example, cover rate was 42% at 50 m compared to 18% at 500 m. Conversely, the cover rate of grass species increased significantly with distance from the feedlot. For example, the cover rate of grass species was only 5% with the cover rate of herb species as high as 42% at 50 m from the feedlot. However, the cover rate of grass species increased to 88% with the cover rate of herb species decreasing to only 2% at 800 m. These results indicated that competition exists between the nitrophilous herb species (e.g. *Cymbonotus lawsonianus*) and the native grass species due to high NH_3 deposition.

The total N contents of both the grass (*Microlaena stipoides*) and herb (*Cymbonotus lawsonianus*) species were decreased with increased distance from the feedlot, indicating that NH_3 deposition is an important N source to the herb and grass species and increased of NH_3 deposition result in higher N contents of the grassland species. The total N contents from both herb and grass species showed significantly positive correlation with the NH_3 deposition rates. Plant leaf N content increased by 0.08% with an increase in NH_3 deposition of 10 kg N ha^{-1} yr^{-1}.

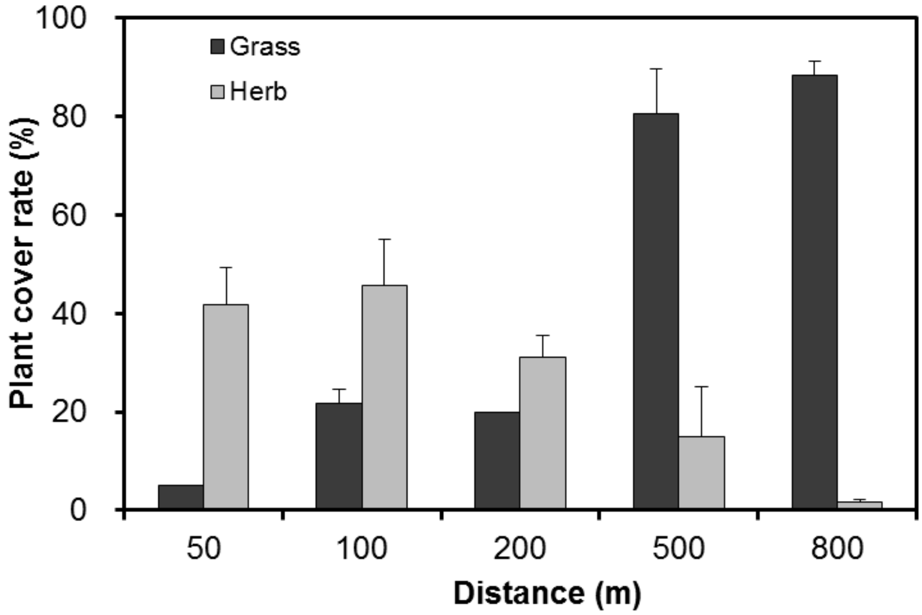

Figure 2. Plant cover rate at different distances from the feedlot along a southeast transect.

Conclusion

We estimated that the annual NH_3 dry deposition within 1 km from a commercial cattle feedlot was 53.9 tonne N yr^{-1}, accounting for about 8% of the emitted NH_3. The high NH_3 dry deposition around the feedlot indicated that the nitrogen input from NH_3 deposition nearby feedlots should be considered when making fertilizer recommendations to reduce N fertilizer input to croplands. The low fraction of NH_3 emitted from the feedlot that were deposited within 1 km of the feedlot suggests that NH_3 deposition in the area farther than 1 km from the feedlot need to be to be quantified. Long-term assessment of NH_3 deposition around the feedlot is required to account for seasonal variability in NH_3 deposition.

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