Effects of sprinkling of pens to reduce particulate emissions and subsequent effects on ammonia emissions from open lot dairy facilities

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ABSTRACT

Air quality impacts of particulate matter 10 µm and under in aerodynamic diameter (PM_{10}) are leading to regulation of animal husbandry practices to control emission of primary PM_{10} and PM_{10} precursors. Water application has been suggested to mitigate emission of dust (primary PM_{10}), but the possibility of enhancing ammonia emission (a precursor of secondary PM_{10}) may effect adoption of this method. The efficacy of water application to reducing PM_{10} emissions and the impact of that treatment on ammonia emissions were measured on Holstein heifer corrals in summer in California. Micrometeorological mass balance methods were used to quantify the flux of both PM_{10} and ammonia for one week before and one week during daily water applications to corral surfaces. Fluxes of both compounds were highest during the 14:00 to 20:00 time period. Water applications significantly decreased PM_{10} fluxes. Ammonia fluxes increased at the initiation of water applications, but returned to levels similar to controls after the first 2 days of treatment.

KEY WORDS
Particulate matter, Ammonia, Open lot, Dairy

INTRODUCTION

The Clean Air Act establishes National Ambient Air Quality Standards (NAAQS) for six compounds. Two of these have been associated with open lot dairy production in California's San Joaquin Valley: Particulate Matter of less than 10 µm in aerodynamic diameter (PM_{10}) and ozone. Primary particulate matter (PM) has been found to make up as much as 55% of ambient PM_{10} in summer and fall, where as secondary particulate matter dominates in winter with as much as 36% of PM_{10} present as ammonium nitrate (Magliano, Hughes et al. 1999). The eight county region of central California known as the San Joaquin Valley (SJV) is currently in serious non-attainment of the NAAQS, recording daily average PM_{10} concentrations in excess of 150 µg/m^3 and annual averages above 50 µg/m^3. The SJV also houses approximately 800,000 dairy cattle and associated replacement stock. It is believed that cattle contribute soil and manure dusts to primary PM_{10} and ammonia emitted from the degradation of manure N contributes to secondary PM_{10} through the formation of ammonium nitrate.

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Dust from dry corrals is believed to contribute to primary PM in summer months. Rain does not typically occur between May and September. From June through September there are many days with maximum temperatures above 32 °C. Cattle movement tends to be minimal during the day with activity increasing at sunset. Corral housing design allows 37 to 55 m^2 per animal. Historically, the best management practice suggested to reduce dust in open lot feedlots was sprinkling the pens with water to keep manure and soil moist. Although this has been effective, there is increasing concern that the traditional mitigation practice for dust may adversely increase ammonia emissions and the potential for formation of the secondary particle ammonium nitrate.

Our objective was to evaluate the effect of pen sprinkling on primary particles and ammonia emissions in pens of growing dairy heifers.

MATERIALS AND METHODS

A commercial Holstein dairy was used. The dairy was selected to allow isolation of replacement heifers from lactating animals. The 900 replacement heifers were more than 425 m north east of the closest component of milking herd (dairy retention pond). West and South of the heifers was an alfalfa field. The field to the east was planted in corn for silage and it was more than 2 m in height at the beginning of the experiment. North of the heifers was an additional pen of heifers and alfalfa land. Approximately 900 heifers between four and 24 months of age were housed in 10 pens. Heifers were housed in groups by weight, sorted and moved from pen to pen once monthly depending on size. Two pens were used for bred heifers. These two pens had freestalls and corrals. Surface area of corrals was 15683 m^2 with an additional 3128 m^2 of feedlane space. Corrals were earthen base and scraped one week prior to the experiment. Average depth of dry manure on corral surfaces ranged from 0 to 6.5 cm. Animals were fed twice daily at 07:00 and 13:00.

Animals were excluded from the corner of one pen to accommodate the sampling tower and associated equipment (Figure 1). Prevailing winds were from the west-northwest. An upwind sampling station was located at the edge of an alfalfa field on a road that was used only by the irrigator during irrigation events. A meteorologic tower was located due west of the upwind station. Automated equipment recorded temperature, humidity, and wind speed and direction in 1 minute averages. Data were retrieved daily.

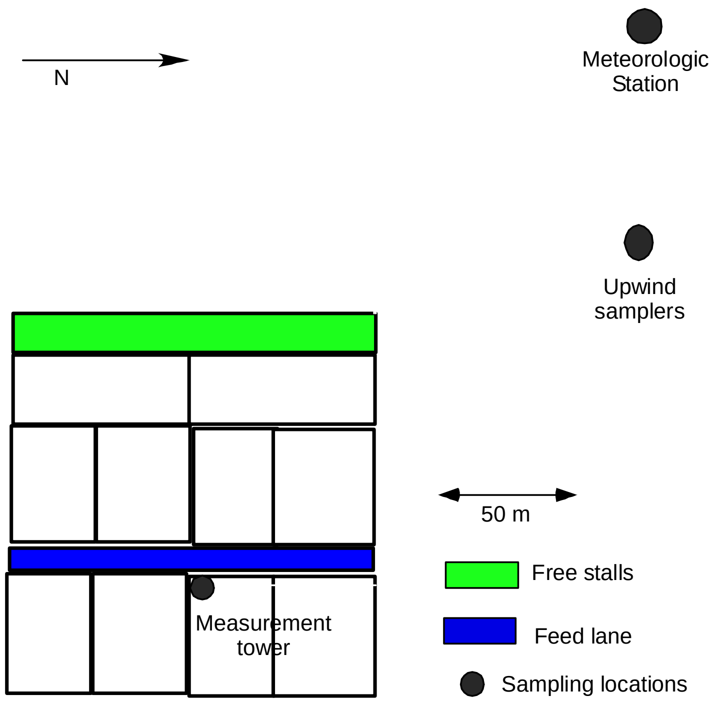


Figure 1: Scale drawing of study site showing free stalls, feed lanes, and open corrals with the relative positions of the measurement locations.

Upwind samples were collected at a height of 2 m, while sampling within the corrals was performed using a tower with samplers at 1, 3, 5, and 10 m heights. Interagency Monitoring of Protected Visual Environments (IMPROVE) aerosol samplers (Eldred, Cahill et al. 1988) were used to collect PM_{10} on 25 mm stretched Teflon filters weighed before and after sampling on a Mettler microbalance. Portable gasoline-powered generators placed downwind of the samplers provided power and EPA-approved Sierra Anderson inlets (Model 246b) produced the 10 µm size-cut. Bubblers with a total of 40 ml 3% H_3BO_3 were used to measure NH_3 concentrations. The samplers consisted of two 60 ml glass vials with Teflon lined rubber septa connected in tandem by 1/8 inch diameter Teflon tubing, approximately 50 cm long, with plastic diffusion stones on the submersed end and a 2 µm pore Teflon filter in a polypropylene holder at the inlet end. Flow rates recorded at the start and end of sampling using a magnehelic with a calibrated orifice were averaged to calculate the volume of air sampled. Particulate matter samples were analyzed gravimetrically and boric acid solutions were analyzed by selective conductivity for NH_4^+-N concentration after raising the pH of the sample, converting the NH_4^+ to NH_3(g) which passes through a semi-permeable Teflon membrane to a sensor.

Both PM_{10} and ammonia concentrations were computed as the total mass collected divided by the volume of air sampled. Net flux of each compound was calculated as the product of the upwind corrected concentration profile and the wind speed profile integrated over the height of the plume, which was generally below the top measurement height of 10 m.

Emission rate calculations were simplified by the placement of the sampling tower in the center of the heifer pens. Upwind fetch length and animal density was equal in an arc of approximately 180 degrees such that wind directions of due north through due west to due south produced similar exposure profiles to the sampling tower. Thus, net fluxes can be compared as rates without correction for fetch.

Sampling periods began at 08:00, 14:00, 20:00 and 02:00 with a one hour break for sample changes and flow measurements prior to 8:00 am. The experiment was conducted over a two week period. No water was applied during the first week and water was applied with a tanker truck during the second week. The protocol was to apply 56,000 l of water daily beginning at 14:00. During the first two days of water application the PM samplers were shut off and were turned on once the watering was complete. The initial idea was to apply .65 cm of water across the corral surface. This was quite unfeasible if applied via tanker truck. A reasonable application rate for the dairy producer would take less than 1 hr. Actual application rate was less than local evaporation rate. The tanker physically entered the corrals where bred heifers were housed. Water was sprayed from the front and back of the truck over the corral and a side sprayer was used to reach the west side of four other corrals. These corrals were sprayed on the east side from the feed lane. The eastern corrals were sprayed from the feed lane and the road to the east of the corrals. Water application was adjusted when corral conditions remained wet and appeared to be a greater habitat for flies. Unusual animal activity was anticipated during water application. During the last two days of water application PM_{10} samplers remained on even during water application. The ammonia samplers remained on throughout the entire collection period.

RESULTS AND DISCUSSION

Meteorological conditions were typical for the season during the entire two week study period (Table 1). Relative humidity was slightly higher in the second week, when the water treatment was applied, increasing also from the beginning to the end of that week. As the meteorological measurement site was over 100m upwind of the corrals, it is unlikely that the water application caused this change in measured humidity, though it may have been a local effect of irrigation events which were not logged as part of this study. Wind direction was very consistently from the Northwest, except for the early morning samples collected during the first week of the study (Figure 2). While the wind direction during those 3 tests was not ideal, the placement of the measurement tower within the corrals provided a similar source to the North and South as from the Northwest (Figure 1). Measurements made during the 02:00 to 08:00 period on 8/9/02, when the wind was from the East, are probably underestimates of true emissions due to the relatively shorter source fetch to the east of the measurement tower and the possible contamination of upwind samples.

Table 1: Sampling period averages of temperature and relative humidity during study period.

	Average Temperature (degrees C)		Average Relative Humidity (%)	
	week 1	week 2	week 1	week 2
02:00 - 08:00	13.53	14.76	80.58	88.77
08:00 - 14:00	25.15	24.51	44.01	58.11
14:00 - 20:00	28.78	29.93	33.90	44.03
20:00 - 02:00	18.07	18.73	61.01	73.54

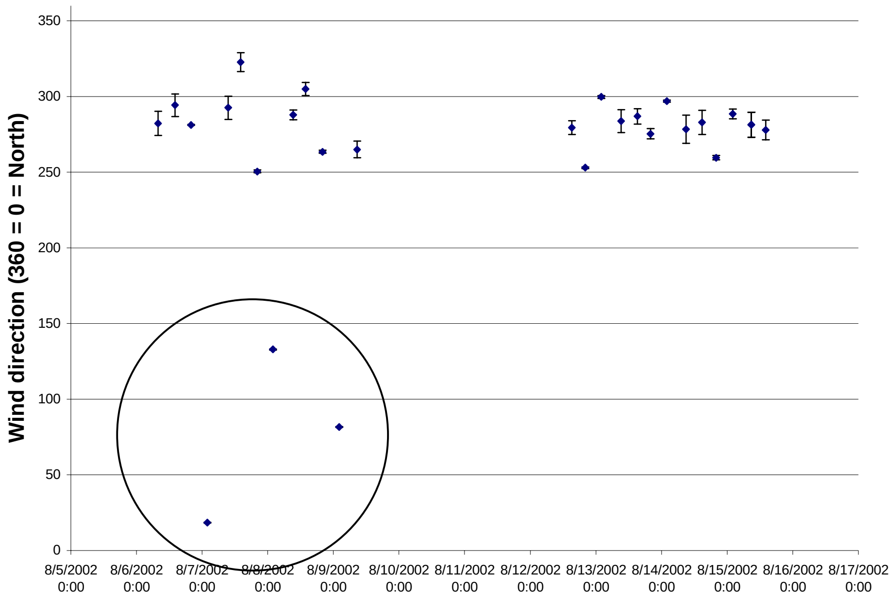


Figure 2: Average (points) and standard deviation (error bars) of wind direction during each measurement period during the two week study. Note the 3 circled points indicating samples collected between 02:00 and 08:00 on days 1, 2 and 3 of the study.

Ammonia and PM_{10} fluxes were computed for each of the sampling periods from concentration and wind speed profiles as described in Methods. The product of mass concentration (μg/m^3) and wind speed (m/s), integrated over the height of the plume (m) produces an emission rate in units of (μg/m.s) where the length variable (m) is in the crosswind direction. Typically, this would be divided by the upwind fetch length for units of (μg/m^2.s). But in this case we are assuming the upwind fetch to be similar for all periods and making a comparison on the base emission rate. The average emission rates of both ammonia and PM_{10} were greatest during the 14:00 – 20:00 time period during the entire first week (control period) of the study (Figure 3). Since this period had the highest emission rates and did not include samples collected under less than ideal wind direction conditions, it provides a good basis for comparing the effects of water application on ammonia and PM_{10} emission rates.

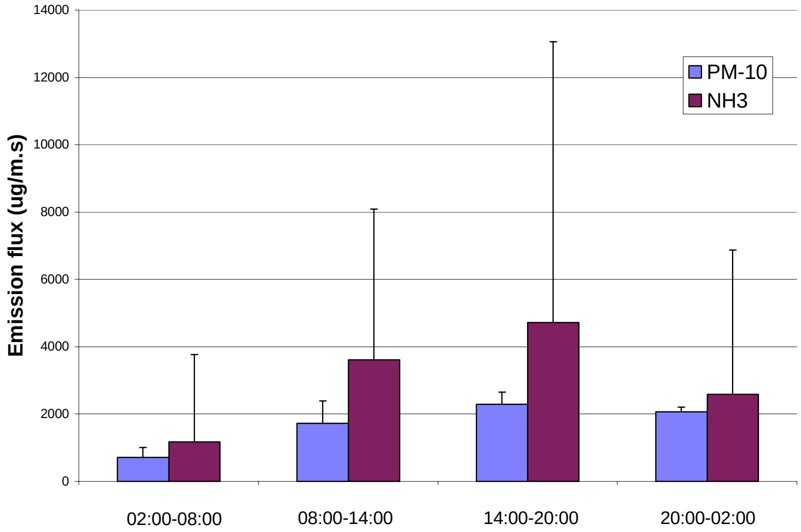


Figure 3: Average ammonia and PM10 emission fluxes for the four sampling period of the control (first) week of the study. Note the highest emission rates were recorded during the 14:00 to 20:00 period for both compounds. Error bars represent standard deviations of the averages.

PM_{10} emission rates measured from 14:00 to 20:00 indicate that daily water application was effective at significantly reducing PM_{10} emissions from dry lot corral housing of dairy heifers (Figure 4). The cattle responded to the presence of the water truck with increased activity, especially during the first two days of the water application. However, they quickly became accustomed to it and their behavior returned to close to normal by the end of the week. The decision to discontinue PM_{10} sampling during the application for the first 2 days was made to avoid biasing a 6 hours averaged data point with heightened animal activity occurring over a less than 1 hour portion of the sample. Once the animals were familiar with the procedure, sampling was continuous for both PM_{10} and ammonia during water application (second 2 days). Thus, the moderate increase in PM_{10} emission rates between the first 2 days and second 2 days of the experimental week (Figure 4) are most likely due to this experimentally introduced artifact.

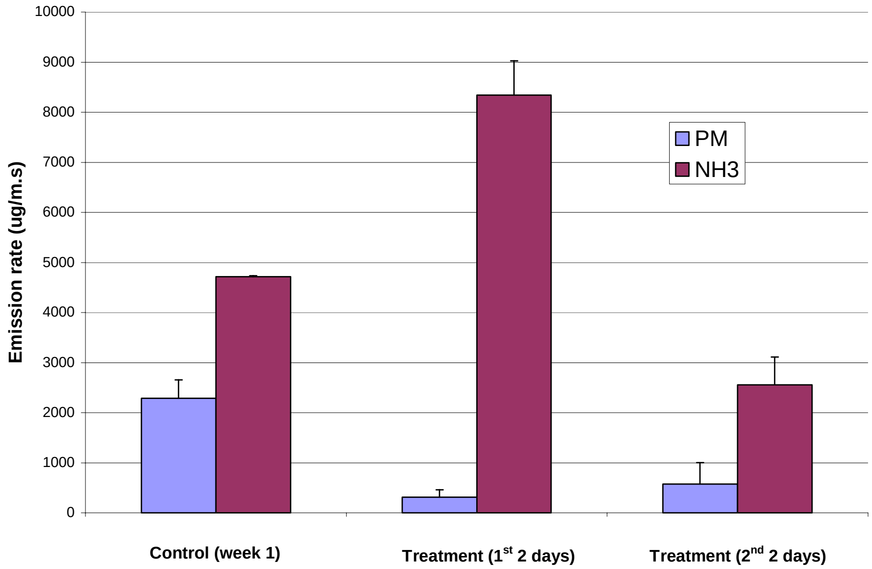
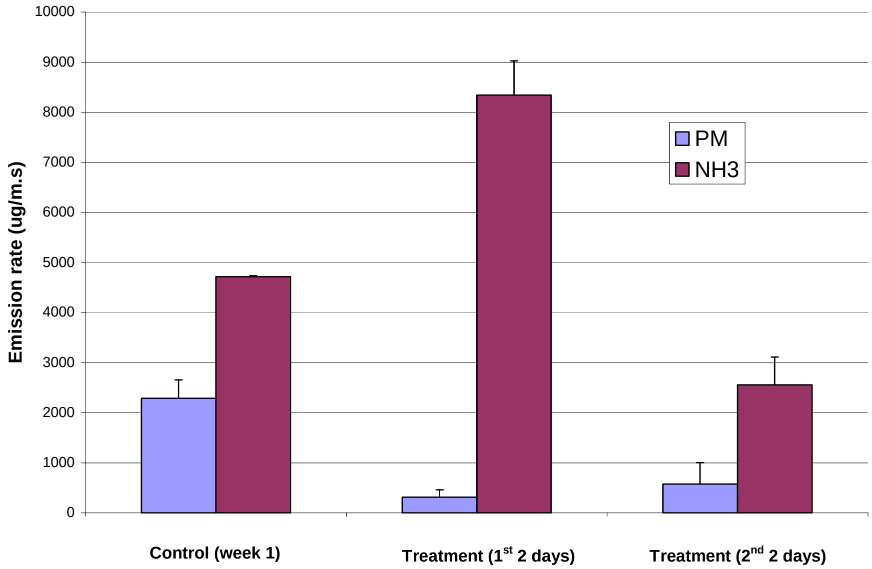


Figure 4: Average PM_{10} and ammonia emission rates for the time period 14:00 – 20:00. The four days of the first week (control) are presented with the average for the first 2 days and the second two days of the treatment week. Measured reductions in PM_{10} emissions were optimized by discontinuation of sampling during water application for the first 2 days of the treatment week (see Methods text).

Ammonia emission rates measured from 14:00 to 20:00 demonstrate an initial increase (first 2 days) followed by a return to the control conditions (second 2 weeks) (Figure 4). This observation may be due to the hydrolysis of urea suddenly solubilized with the addition of water and volatilizing as ammonia. These data indicate the potential for elevated ammonia emission when water is applied periodically, while consistent (daily) water applications may avoid such a response. It cannot be determined from the data available what periodicity of water application may be necessary to maintain a baseline ammonia emission rate or how long a corral must dry to recreate the "flush" of ammonia upon reapplication of water. Answers to these questions will be useful not only in judging the efficacy of water application to mitigating PM emissions from livestock but also in modeling the seasonal changes in emissions during Fall and Spring months when periodic rainfall may elicit the same emission patterns.



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