Effect of Stocking Density Manipulation on Fugitive PM_{10} Emissions from Cattle Feedyards

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ABSTRACT

We conducted 16 ambient sampling events between August 1998 and August 1999 at a commercial feedyard in the Texas High Plains. We operated Federal Reference Method PM_{10} samplers and high-volume samplers upwind and at the downwind fence line of a 12-corral test area. Six of the corrals were stocked at a typical cattle spacing of 13.9 m^2 hd^{-1}, and the remaining six corrals were stocked at a nominal spacing of 7.0 m^2 hd^{-1}. Sampler locations were oriented with respect to the prevailing SSW winds so as to minimize the likelihood of cross-contamination. Sampling events spanned 6- to 24-hr intervals, as dictated by local weather conditions, in order to capture daily average effects and diurnal effects. We inferred the net emission of fugitive PM_{10} from the corral surface from the net (downwind-upwind) concentrations. The sampling data suggest that doubling the stocking density in cattle feedyards may reduce fugitive TSP and PM_{10} emissions from the corral surface by up to 29%, but average reductions of 5-20% or less are more likely in semi-arid climates. By itself, stocking density manipulation appears to have limited potential for control of particulate matter emissions from cattle feedyards, but it may represent a rational component of a dust-control regime involving additional management practices.

INTRODUCTION

The Southern High Plains region is the largest producer of beef cattle fed in confinement in the United States. Almost one-third of the cattle produced in confinement in the U. S. are fed within a 150-mile radius of Amarillo, TX. This semi-arid region, which averages only 350-600 mm of precipitation and approximately 1500-1700 mm of evaporation each year, is a major producer of feed grains (wheat, corn and sorghum). Because of the high concentration of Confined Animal Feeding Operations (CAFOs), however, the Southern High Plains must import from the Midwest much of the grain required to sustain the livestock industry. Ground water from the Ogallala aquifer in the Southern High Plains is generally of good quality, but its availability ranges from abundant to nonexistent so that production of feed grains is heavily dependent on irrigation.

The average one-time capacity of cattle feedyards in the Texas Panhandle is 40,000 head. In the typical, modern feedyard, livestock are maintained in corrals or pens surfaced with compacted, native clay or caliche. A concrete feed apron may extend 3 to 4 m from the feedbunk where hoof activity predominates, as well as around the water trough, but the corrals are seldom 100% paved. In a typical feedyard, the cattle are fed three times daily, beginning before dawn and ending in the early afternoon. The feeding period varies in length according to market conditions (100-150 days), but cattle are usually shipped to the feedyard at an average liveweight of 230-340 kg and fed to a finished weight of 450-550 kg before slaughter. Over the feeding period, a layer of compacted manure develops above mineral soil. When rainfall is sparse, this material becomes dry and, in excess, is friable and easily pulverized by hoof action.

The interaction of cattle behavior and the moisture of the manure pack is primarily responsible for the magnitude of dust emissions from the feedyard surface. Cattle tend to be sedentary throughout the mid- to late afternoon, reclining and ruminating randomly across the corral. In the early evening, however, the animals rise and play, wander to the feedbunk or water trough or engage in aggressive behavior with one another. This activity peak, when hoof action is most frequent and energetic, occurs just after the driest part of the day and often coincides with reduced atmospheric turbulence as temperatures and winds subside. The result is the well-known, evening dust peak that may persist near ground level until midnight or later. These dust events may temporarily impair cattle health (MacVean et al., 1986), impair visibility on nearby roadways or drift across nearby communities and create a nuisance. Although the figures are in considerable dispute (for example, see Parnell, 1994), the AP-42 emission factors (mass emitted per unit one-time capacity) for total suspended particulate (TSP) and PM_{10} from cattle feedyards are 127 kg $(1000\ hd)^{-1}\ d^{-1}$ and 32 kg $(1000\ hd)^{-1}\ d^{-1}$, respectively.

In a moisture-deficit region like the Southern High Plains or the Central Valley of California, the application of supplemental moisture to feedyard corrals during dry weather has been shown to reduce dust potential dramatically (Sweeten et al., 1999; Algeo et al., 1972). Most often, feedyard managers apply water actively through mobile tankers fitted with pumps and spray nozzles. Recently, solid-set sprinkler systems have been installed more frequently in new feedyards and expansions. Where ground water is deep and of excellent quality, like in the Southern High Plains, these capital-intensive systems are difficult to justify on the basis of dust suppression alone. However, prominent feedyard managers suppose that the localized, adiabatic cooling created by solid-set sprinklers improves feed-to-gain efficiency, reduces the prevalence and severity of bovine respiratory disease and increases feed intake (Schemm, 1998; Bork, 1998; Andre, 1985), all of which combine to improve cash flow.

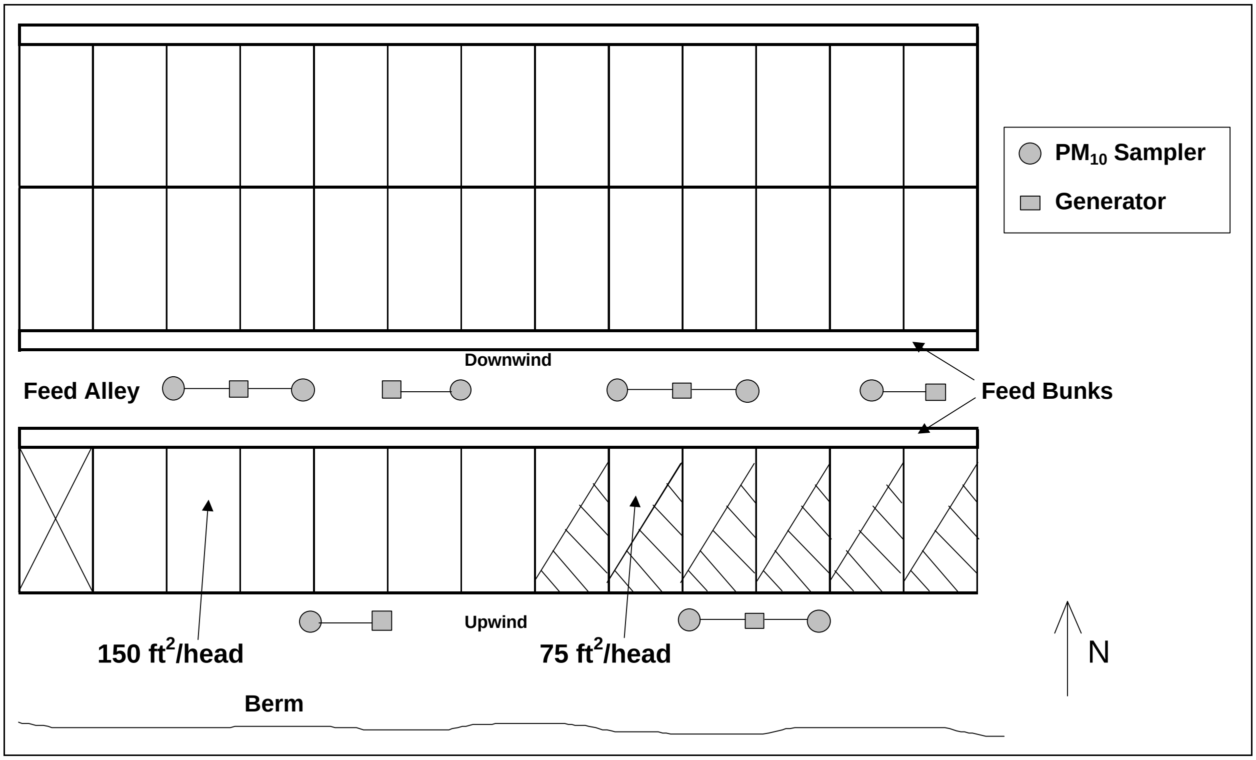
A more conservative approach to applying supplemental moisture is to increase the stocking density (or reduce the cattle spacing) across the feedyard. This passive approach uses the moisture excreted by the cattle for dust control by reducing the average area over which that moisture is spread, decreasing the localized moisture deficit and potentially maintaining higher moisture content in the manure pack. A single beef steer weighing 400 kg excretes, on average, 22.5 kg of water per day (ASAE, 1998). At a typical cattle spacing of 13.9 $m^2\ hd^{-1}$, and assuming uniform distribution across the corral, the excreted moisture is equivalent to an annual water depth of 540 mm. Doubling the stocking density, or reducing the cattle spacing to 7.0 $m^2\ hd^{-1}$, effectively doubles the depth of excreted moisture. When daily net evaporation from the corral surface is of the same order of magnitude, manipulating the stocking density may reduce dust emissions by maintaining a higher moisture content in the manure pack. In this study, we attempted to validate that hypothesis with ambient TSP and PM_{10} monitoring data.

EXPERIMENTAL METHODS

Configuration and Sampler Layout

We conducted our experiments at a large, commercial feedyard (>40,000 head capacity) in the Texas Panhandle. A recent feedyard expansion added 6,500 head of capacity in a set of rectangular corrals, with feed alleys and working alleys oriented E-W. Prevailing winds being from the S and SSW, the new corrals were ideally suited to segregating treatments with respect to upwind/downwind sampling (see Figure 1).

Figure 1. Plan view of the feedyard expansion, control and treatment corrals and sampler configuration for the March 1999 sampling event.



We placed the upwind samplers on a vegetated berm immediately to the S of the southernmost working alley. The downwind samplers were located along the centerline of the southernmost feed alley, and their E-W location was aligned with the centroid of each 6-corral treatment with respect to the anticipated wind direction. We also installed an automatic weather station (Campbell Scientific, Inc., Logan, UT) on the upwind berm to collect one-minute measurements of barometric pressure, temperature, precipitation, relative humidity, wind speed, wind direction and, as a summary over the sampling period, the avereage and standard deviation of wind direction.

The E-W length of the expansion was 792 m and spanned 13 identical corrals, each 61 m wide. We used only 12 of the corrals (#302, 304…324), leaving the corral at the W end (#300)for normal feedyard use. Because the main body of the feedyard was located to the W of the expansion, we elected to use corrals 302-312 as the control block, in which stocking density was maintained at the normal 13.9 m^2 hd^{-1}. Corrals 314-324 were assigned to the higher stocking density.

The increased stocking density was achieved through the use of permanent, diagonal cross-fences as shown in Figure 2. The diagonal fences were installed with three standard gates, spaced equally from corner to corner, that may be operated from horseback. Under wet conditions, the gates were opened to allow the cattle access to the entire corral area; when the corrals dried out, the cattle were returned to the feedbunk side of the diagonal, and the gates were closed.

Figure 2. Empty corrals modified with diagonal cross fences to reduce the cattle spacing by 50%. White fences are the existing corral perimeter; unpainted fence lies on the diagonal as shown in Figure 1.

Under the assumption that water excretion by livestock is approximately proportional to liveweight (ASAE, 1998), we adopted a modified basis (kg total liveweight per corral) for establishing stocking densities for the control and treatment corrals. Historical records and management targets indicated that the average liveweight of the newly received cattle was approximately 350 kg. Upon delivery of the young calves, cowboys processed the cattle through the squeeze chute to measure actual liveweight and assigned the cattle at random to each of the 12 test corrals. Animals were added to each corral until the total liveweight in each corral was 70,000 +/-175 kg. The resulting stocking densities, expressed in terms of liveweight per unit area, were 25 kg m^{-2} (control) and 50 kg m^{-2} (treatment). We made no attempt to maintain equivalent stocking densities beyond the initial allocation so that the cattle-feeding company would be able to detect differences in feed-to-gain performance.

Sampling Methods and Protocol

Our experimental design used net (downwind-upwind) PM concentrations as a surrogate for actual emissions from this area source. We installed Federal Reference Method PM_{10} samplers (Wedding and Associates, Inc., Ft. Collins, CO; and Graseby-Andersen, Inc., Smyrna, GA) upwind and downwind of the study corrals as indicated above. Gasoline-powered electric generators ranging from 4 to 6 kW powered the samplers. During the last two sampling trips, TSP samplers (General Metal Works, Inc., Smyrna, GA) were also installed to increase the information obtained and to obtain particle size distributions using the Coulter Counter Multisizer (Herber, 1988).

Sampling trips began in August 1998 1998 and continued sporadically until July 1999, producing 30 sampling intervals. Sampling trips occurred roughly every two to three months in order to capture seasonal variations and different livestock growth stages. Table 1 shows the dates of the sampling trips, the types of samplers used, and the number of samples taken. The arrangement of the samplers during each sampling trip varied according to the availability of samplers, generators, and favorable winds. Careful attention was given to wind direction in order to ensure that upwind and downwind samplers were labeled correctly. Labels for each sampling event consisted of the starting date and, for the 6-hour samples, the letters A, B, C and D, representing the portion of the day in which the sampling event took place (A = 2400 to 0600 hrs; B = 0600 to 1200 hrs; C = 1200 to 1800 hrs; D = 1800 to 2400 hrs). We used a similar labeling system during the June/July 1999 sampling trip with the following time changes: A = 0100 to 0800 hrs; B = 0900 to 1200 hrs; C = 1300 to 1600 hrs; D = 1700 to 2400 hrs.

Table 1. Overview of sampling trip information.

Date	**Number of Sampling Intervals**	**Sampler Types**[*]
August 1998	4	W&A
October 1998	4	W&A
December 1998	2	W&A
March 1999	6	W&A, TSP
June/July 1999	14	W&A, TSP, GA

*W&A – Wedding and Associates PM_{10}; GA – Graseby-Andersen PM_{10}; TSP – GMW Hi-Volume (total suspended particulate)

Filter Media and Preparation

The majority of the filters used in this study were EPA-approved, 203 mm x 254 mm microquartz filters (Whatman QM-A). During the March 1999 sampling trip, we used borosilicate and glass fiber filters having nearly identical penetration characteristics. During the June/July 1999 sampling trip, we used (a) glass fiber filters for gravimetric analysis and (b) polyweb filter media for determining particle size distributions using the Coulter Counter Multisizer.

The polyweb filters were cut into 203 mm x 254 mm (8 in x 10 in) sheets from a 254 mm roll. The filters were then placed on a clean sheet of copy paper and both the paper and filter were numbered using a felt tip marker. The filters were then folded twice inside the paper and placed inside numbered envelopes and stored in a cardboard box.

The gravimetric filters (microquartz, borosilicate, and glass fiber) were each numbered, folded, and placed in numbered envelopes. The envelopes were then placed inside sealed placed bags until conditioned and weighed. The filters were conditioned before weighing by placing them in a drying oven at 90°C for 24 hours to ensure that moisture differences would not create weighing errors. The filters were each weighed three times before and after exposure using an analytical balance (Mettler-Toledo, Model AG245) with a resolution of 0.1 mg. Filter pre-weights were recorded and logged according to filter number.

For the June/July 1999 sampling trip, the glass fiber filters were numbered, folded, and placed inside numbered anti-static bags. Unlike the previous sampling trips, the filters remained inside these anti-static bags throughout the conditioning and weighing procedures. These filters were conditioned in a climate-controlled environmental chamber for 24 hours according to 40CFR50 Appendix J (EPA, 1987). The filters were then weighed using the same procedure as previous sampling trips.

Filter blanks were collected during each sampling event to determine error associated with filter handling. These filter blanks were conditioned and handled in the same manner as the normal filters. During all sampling trips, the prepared filters were kept in plastic bags placed inside airtight, plastic containers until ready to be placed into filter cartridges and immediately after removal from cartridges. Filter cartridges were prepared in as clean an environment as possible, usually an area of the sampling trailer or in an air-conditioned room. Filters were always handled using latex gloves and tweezers on a clean surface. Prepared cartridges were placed within airtight, plastic tubs for transport to and from the samplers to avoid filter contamination. Following exposure, all filters were removed from the filter cartridges and placed in their corresponding envelopes. The filters were then returned to the lab, re-conditioned and weighed.

Sampler Calibration

In order to control the actual flow rate of the Graseby-Andersen PM_{10} samplers and the TSP samplers, we calibrated them using a laminar flow element (LFE) and assigned a K value used to determine flow rate using the following equation:

Equation 1. Flow rate calibration for the Graseby-Andersen PM_{10} and TSP samplers.

$$Q = 13.346\ K\ D_0 \sqrt{\frac{\Delta P}{r}} \qquad [1]$$

where:

Q = flow rate through the sampler (L min^{-1}),

K = orifice coefficient (dimensionless),

D_0 = orifice diameter (cm),

ΔP = orifice pressure drop (cm H_2O), and

ρ = density of the ambient air (kg m^{-3}).

The samplers were attached to a calibration unit consisting of a calibrated LFE, a Magnehelic gauge and a 5 hp centrifugal blower. The variac-controlled blower provided four different flow rates across the sampler orifice plate and through the LFE. Using the LFE, the flow rate through the sampler was determined and the pressure drop across the orifice plate was recorded. This was repeated at four different flow rates. The sampler's average K value was calculated using Equation 1. The K value was verified for the 1.13 m^3 min^{-1} flow rate needed for ambient sampling and placed on the samplers for quick reference in the field. Variacs and Magnehelic gauges were installed on all the TSP and Graseby-Andersen PM_{10} samplers to obtain the proper setpoints in the field.

The Wedding & Associates' PM_{10} samplers were calibrated *in situ* using a slack tube manometer or a digital manometer. Manometer readings and weather data were used to determine the actual sampler flow rate using published tables provided by Wedding & Associates (Wedding and Weigand, 1993).

Sampling Protocol

Prior to each sampling interval, we prepared a complete set of filter cartridges as described above and carried the cartridge tub, gasoline and oil to each sampler location. After replacing the exposed filter cassette with a fresh cassette, topping off the oil and gasoline reservoirs and recording the time, we re-started the samplers immediately, verifying the correct pressure drops as necessary and being sure to remain downwind of any samplers already operating. We then returned to the enclosed trailer to harvest and store the exposed filters and to reload the cassettes with unexposed filters.

At the end of each sampling event, we recorded the final pressure drops (as applicable), turned off the generators and recorded the stop time. We then returned to the enclosed trailer to pick up the cartridge tub and followed the cartridge-transfer protocol outlined previously. The overall duration of each event was less than the total sampling time (measured as the difference between start and stop times) due to (a) refueling the electric generators and (b) shutting off all samplers while feed trucks or water trucks were in the feed alley where samplers were installed.

RESULTS AND DISCUSSION

Data Processing

Average PM concentrations for each sampling interval were determined from the Equation 2.

Equation 2. Formula for computing time-averaged concentrations from gravimetric sampling data.

$$C_{\Delta t} = \frac{(W_f - W_i) \bullet 10^6}{Q_{std} \bullet \Delta t} \qquad [2]$$

where:

$C_{\Delta t}$ = the average concentration over the sampling interval (μg m^{-3})

Δt = the duration of the sampling interval (min)

W_f = the final filter mass (borosilicate, glass fiber or microquartz media only) (g)

W_i = the initial filter mass (g)

Q_{std} = the actual sampler flow rate, corrected to standard temperature and pressure (m^3 min^{-1})

Sampler flow rates were corrected to standard conditions using on-site weather data, the ideal gas law and the methods of Wedding and Weigand (1993), as applicable to the different sampler types. Net PM concentrations were computed from Equation 3.

Equation 3. Mathematical definition of "net PM concentration."

$$C_{\Delta t,net} = C_{\Delta t}^{D} - C_{\Delta t}^{U} \qquad [3]$$

where:

$C_{\Delta t,net}$ = net contribution of fugitive emissions to the time-averaged PM concentration (μg m^{-3})

$C^{D}_{\Delta t}$ = downwind PM concentration over the sampling interval Δt (μg m^{-3})

$C^{U}_{\Delta t}$ = upwind (background) PM concentration over the sampling interval Δt (μg m^{-3})

Where multiple samplers of the same type were associated with upwind, control or treatment locations, we averaged the net PM concentrations for those locations. Weights obtained from broken filters were not included in data analysis because of the potential error associated with the loss of fibers.

Data Completeness and Quality

Data Completeness

We completed a total of 30 successful sampling events of varying duration and during all four seasons (see again Table 1), yielding 276 exposed filters for gravimetric analysis. A total of 31 filter blanks, representing >10% of all collected filters, provided a basis for estimating measurement errors. Of the 276 exposed filters, 47 filters were rejected for filter breakage during handling or equipment failure during a sampling. Table 2 shows the breakdown of the sampling events and the number of filters taken, including all filter media.

Ranking Data Quality by Wind-Direction Criteria

Because of the wide variation in wind direction across all 30 events, we elected not to run statistical tests on the combined data set. Instead, we imposed an objective ranking scheme on the data based on the mean and variance of the wind direction. The main concern was any wind shift that would render the upwind/downwind designations ambiguous. In particular, any wind shift from southerly to northerly would result in 80% of the capacity of the feedyard expansion directly upwind of the test corrals. In that case, the test corrals would no longer be isolated from adjoining corrals, and heavy upwind loading would obscure any possible differences between the net concentrations assigned to the treatment and the control. (When northerly winds prevailed and upwind samplers were stationed in the feed alley, a wind shift to the southerly direction would smear the upwind/downwind distinction but would not result in the heavy filter loading). Consequently, any sampling intervals during which the 2-minute average wind direction shifted more than 90 degrees from the principal directions were to be discarded from final data analysis. (Later analysis revealed that a 45-degree wind test would further improve the quality of the data.)

The remaining events were ranked in terms of data quality according to the orthogonality of the winds to the E-W feed alley. Oblique wind directions were considered to reduce the isolation of the test corrals by introducing influence from the remainder of the feedyard. The ranking criteria for this wind test were twofold:

Table 2. Summary of event duration and wind direction data for all 30 sampling events (nr = not recorded).

Event Code	**Start**	**Stop**	**Duration**	**Wind Direction (x+/-1σ)**
	(mil)	**(mil)**	**(hrs)**	**(deg)**
081798	1210	1410	24	191±18
081898	1450	1230	20	172±16
081998	1252	1335	22	188±17
082098	1353	1310	22	252±18
101798-C	nr	nr	6	342±20
101798-D	nr	nr	6	324±14
101898-A	nr	nr	5	335±13
101898-B	nr	nr	6	266±17
120598-C	1210	1810	6	245±13
120598-D	1835	2430	6	240±20
031599-D	1710	2315	6	194±11
031699-A	100	705	6	218±13
031699-B	820	1445	6	226±21
031699-C	1520	2130	6	200±15
031699-D	2240	435	6	223±19
031799-B	550	1150	6	40±13
062699-C	1300	1800	5	141 ± 24
062699-D	1900	2400	5	140 ± 13
062799-A	100	800	7	203 ± 37
062799-B	900	1200	3	263 ± 20
062799-D	1700	2400	7	195 ± 25
062899-A	100	800	7	269 ± 37
062999-C	1200	1700	5	220 ± 14
062999-D	1800	2400	6	186 ± 20
063099-A	100	800	7	290 ± 103
063099-D	1900	2400	5	124 ± 16
070199-A	100	800	7	209 ± 107
070299-BC	900	1500	6	177 ± 9
070299-D	1700	2400	7	160 ± 8
070399-A	100	800	7	175 ± 9

1. Any events for which the mean wind direction deviated less from 180 (S) or 360 (N) was ranked higher than an event with a greater deviation from those principal directions.

2. When two events deviated equally from the principal directions, the event with the smaller standard deviation of wind direction was ranked higher.

Raw Data Summary

Compiling all the raw concentration data from the 5 sampling trips, upwind PM_{10} concentrations ranged from 0.00 to 1919.9 $\mu g\ m^{-3}$ with an average (n = 47) of 156.0 ± 331.7 $\mu g\ m^{-3}$. Downwind PM_{10} concentrations from the control group ranged from 0.24 to 1287.4 $\mu g\ m^{-3}$ with an average (n = 71) of 242.6 ± 238.2 $\mu g\ m^{-3}$. Downwind PM_{10} concentrations from the treatment group ranged from 2.31 to 1100.9 $\mu g\ m^{-3}$ with an average (n = 70) of 178.9 ± 209.9 $\mu g\ m^{-3}$. These global averages are not strictly germane to the research hypothesis, but the ranges and averages together do suggest that doubling the stocking density reduces net concentrations of PM_{10} from feedyard corrals. However, the global data set is confounded by serial correlation, seasonal climatic changes, intermittent precipitation throughout the 12-month sampling window and changes in total corral liveweight due to growth and shipment to/from the feedyard. No statistical significance should be inferred from this summary of the global data set.

Data Processing

The location-averaged PM_{10} concentration data (corrected to standard temperature and pressure), ranked according to the quality criteria listed above, are shown in Table 3. We also computed the % decrease in net PM_{10} concentration attributable to the increase in stocking density using Equation 4.

Equation 4. Formula for computing relative decrease in PM_{10} concentration attributable to increased stocking density.

$$R(\%) = 100 \bullet \frac{[C_{net}^{control} - C_{net}^{treatment}]}{C_{net}^{control}} \qquad [4]$$

where R is the relative reduction (%) in net PM_{10} concentrations attributable to the increased stocking density. In 5 of the 30 sampling events, the increased stocking density appeared to increase the net concentration (i. e., $R<0$) of PM_{10}, which was contrary to our hypothesis. The remaining events gave highly variable results, but 83% of the events followed our expected behavior. A frequency histogram of the entire (n=30) data set is shown in Figure 3. The mode of the n=30 histogram corresponds to a 20% reduction in net PM_{10} concentrations. Discarding the 11 sampling events that did not pass the 90-degree wind test, the mode of the frequency histogram (Figure 4) also corresponds to a 20% reduction in PM_{10} emissions.

Theoretically, the absolute value of R should never exceed 100%. $R>100\%$ implies that the treatment corrals somehow behaved as PM_{10} sinks (i. e., the net concentration for the treatment corrals is negative; see Equation 4), which seems rather unlikely. However, 6 of the sampling events passing the wind test resulted in $R>100\%$. Five of these 6 events were characterized by N

(101798-D), W (120598-C), SW (031699-A,C) or WNW (063099-A) average wind directions, which would have drawn upwind dust from the main body of the feedyard or the remainder of the expansion immediately to the north of the test corrals. In addition, winds from the WNW and SW would have forced the treatment and control samplers to sample virtually the same air. Four of the 6 events failed a more stringent wind test with a maximum deviation of 45 degrees from the principal direction, suggesting that the R>100% condition may have resulted from the interaction of non-orthogonal winds and relatively high variability in wind direction.

Table 3. Summary of PM_{10} concentration data, ranked by orthogonality of wind direction to the E-W feed bunk for all 30 sampling events. Concentration data are averages of collocated samplers.

Event Code	**C^U**	**C^D_{Ctrl}**	**C^D_{Trt}**	**$C_{\Delta t,net}$**	**R**	**Wind Deviation**
	(μg m^{-3})	**(μg m^{-3})**	**(μg m^{-3})**	**(μg m^{-3})**	**(%)**	**(deg)**
070299-BC	20.83	241.04	193.32	47.71	21.7	3
070399-A	21.14	120.69	108.35	12.35	12.4	5
062999-D	0.00	617.26	443.67	173.59	28.1	6
081898	28.16	138.78	133.42	5.36	4.8	8
081998	38.28	189.92	171.61	18.31	12.1	8
081798	14.57	131.69	193.70	-62.01	-52.9	11
031599-D	9.38	14.34	2.93	11.41	230.0	14
062799-D	5.10	301.25	132.94	168.31	56.8	15
101798-C	175.07	511.62	159.35	352.27	104.7	18
031699-C	48.93	88.53	15.65	72.88	184.0	20
070299-D	39.37	499.56	422.87	76.70	16.7	20
062799-A	9.96	31.40	23.52	7.89	36.8	23
101898-A	340.42	237.45	708.22	-470.77	457.2	25
070199-A	103.35	162.03	186.09	-24.06	-41.0	29
101798-D	1541.57	1287.36	780.33	507.03	-199.5	36
031699-A	43.51	69.34	11.26	58.08	224.9	38
062699-C	1.06	48.16	39.35	8.81	18.7	39
031799-B	200.92	265.12	49.39	215.73	336.0	40
062699-D	10.34	115.66	59.87	55.78	53.0	40
062999-C	11.63	292.43	205.63	86.79	30.9	40
031699-D	62.37	103.66	83.18	20.48	49.6	43
031699-B	226.93	4.31	59.00	-54.69	24.6	46
063099-D	22.85	748.93	257.37	491.56	67.7	56
120598-D	0.00	440.78	212.52	228.26	51.8	60
120598-C	234.47	148.32	97.46	50.86	-59.0	65
063099-A	72.24	168.23	68.98	99.24	103.4	70
082098	125.06	269.37	234.06	35.31	24.5	72
062799-B	25.24	136.88	54.70	82.18	73.6	83
101898-B	460.14	321.42	378.34	-56.92	41.0	86
062899-A	51.30	144.63	145.11	-0.48	-0.5	89

Figure 3. Frequency histogram (n=30) of the relative reduction in net PM_{10} concentration, R, attributable to doubling the stocking density.

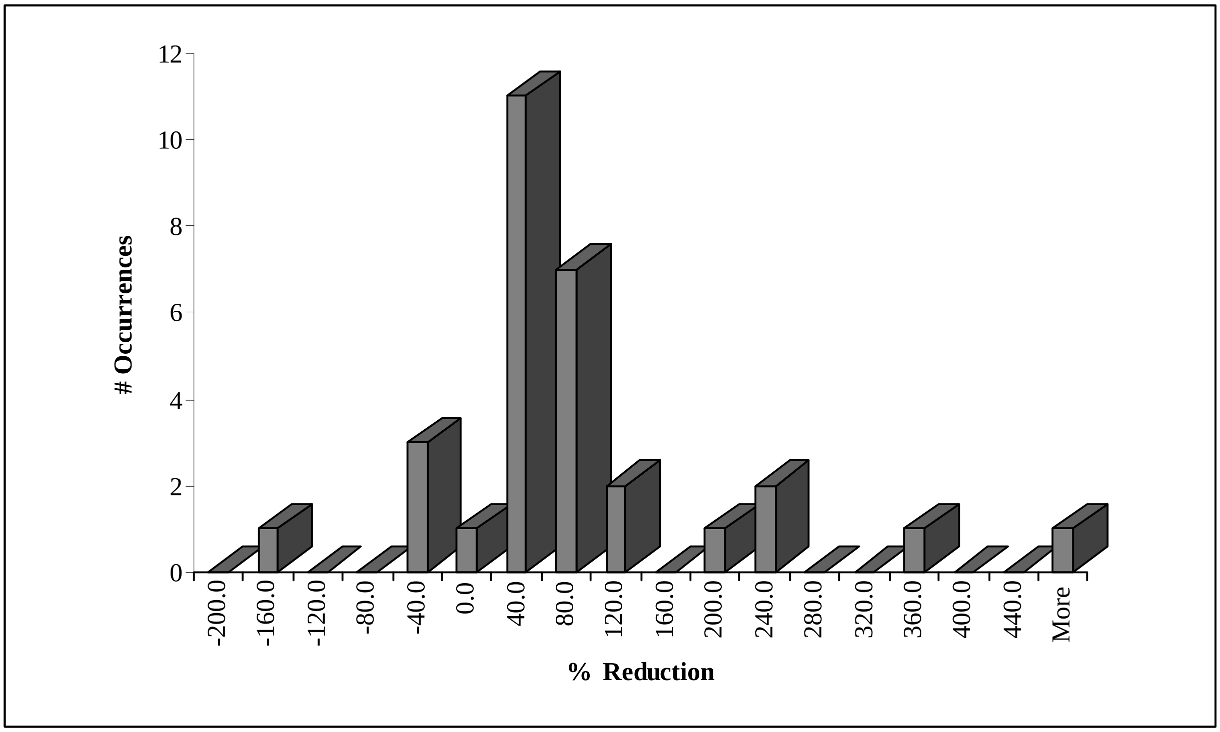
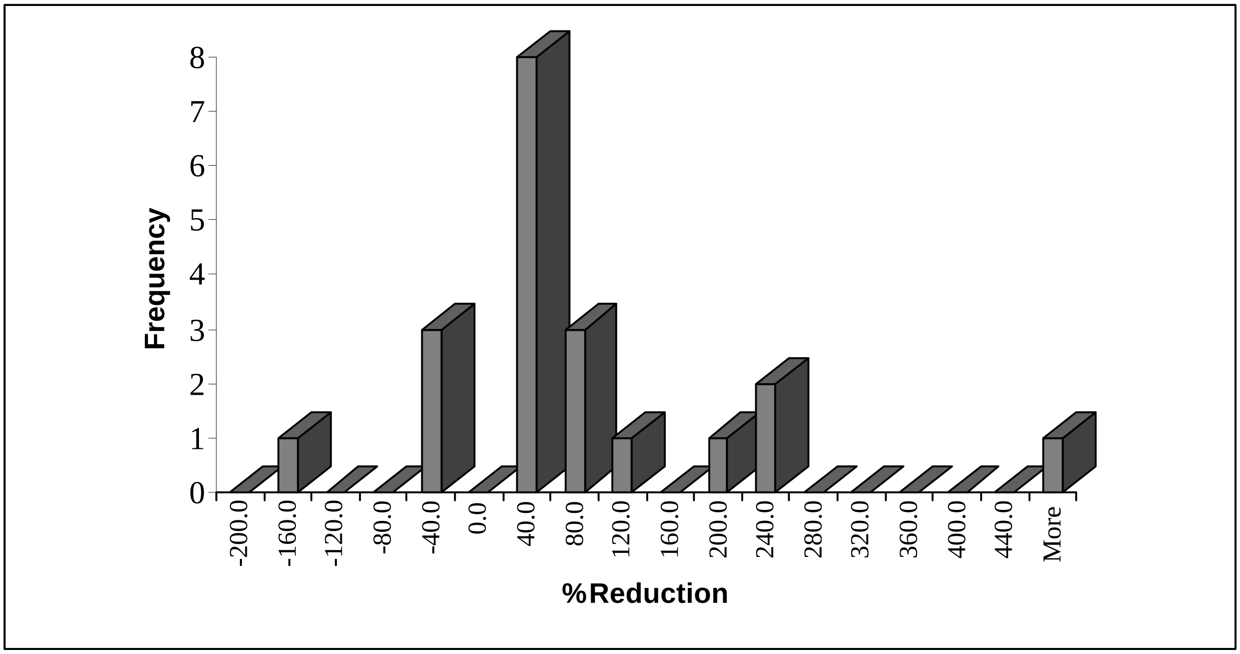


Figure 4. Frequency histogram (n=19) of the relative reduction in net PM_{10} concentration, R, attributable to doubling the stocking density. Events not passing the 90-degree wind test have been discarded.



Only 6 of the sampling events (070299-BC, 070399-A, 070299-D, 081898, 031599-D and 101798-D) passed the 45-degree wind test. Values of R for those 6 tests were 21.7, 12.4, 16.7, 4.8, 230.0 and –199.5%, respectively. Discarding the unrealistic events in which the absolute value of R exceeded 100%, the remaining 4 sampling events yielded an average R of 13.9%. It is perhaps more realistic to conclude that the highest-quality data suggested relative decreases of between 5 and 22% in the net PM_{10} concentration are potentially achievable with a 50% decrease in cattle spacing.

CONCLUSIONS

Of the 30 sampling events conducted in this study, only 4 yielded net PM_{10} concentration data of extremely high quality as evaluated on the basis of wind direction and its variation over time. The decreases in PM_{10} emissions attributable to decreasing the cattle spacing by 50% (or, alternatively, increasing the stocking density by 100%), represented by the variable R, ranged from 5% to 22% with an average of 14% for those 4 events. When all sampling data were included in a frequency histogram (n=30), the mode of the response variable R was on the order of 20%. Restricting the analysis to those sampling events that passed the most lenient wind-direction criterion (+/-90 degrees; n=19), the mode remained at about 20%. We conclude that doubling the stocking density in a feedyard located in a semi-arid climate has the potential to reduce net PM_{10} concentrations (and, by inference from classical dispersion-modeling theory, fugitive PM_{10} emissions) by up to 20%, but results are highly variable. Stocking density manipulation, by itself, is not likely to suppress PM_{10} emissions to an extent that justifies the expense and logistical difficulties associated with this management technique, but it may play an important role in a broader dust-management strategy involving frequent manure harvesting and active application of supplemental moisture.

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KEYWORDS

Cattle feedyards; PM_{10}; fugitive emissions; stocking density; TSP; particulate matter