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Dust-Emission Potential of Cattle Feedlots as Affected by Feedlot Surface Characteristics

Edna B. Razote

Research Assistant, Department of Biological and Agricultural Engineering, Kansas State University, 141 Seaton Hall, Manhattan, KS 66506.

Ronaldo G. Maghirang

Professor, Department of Biological and Agricultural Engineering, Kansas State University, 145 Seaton Hall, Manhattan, KS 66506.

Bernardo Z. Predicala

Research Scientist, Prairie Swine Center Inc., P.O. Box 21057, 2105 8th Street East, Saskatoon, SK Canada S7H 5N9.

James P. Murphy

Professor, Department of Biological and Agricultural Engineering, Kansas State University, 234 Seaton Hall, Manhattan, KS 66506.

Brent W. Auvermann

Associate Professor, Texas A&M University Agricultural Research and Extension Center, Amarillo, TX.

Joseph P. Harner, III

Professor, Department of Biological and Agricultural Engineering, Kansas State University, 233 Seaton Hall, Manhattan, KS 66506.

William L. Hargrove

Director, Kansas Center for Agricultural Resources and the Environment, Kansas State University, 15 Waters Hall, Manhattan, KS 66506.

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Dust-Emission Potential of Cattle Feedlots as Affected by Feedlot Surface Characteristics

Abstract. *A laboratory chamber was developed for measuring the dust-emission potential of cattle feedlot surfaces as affected by surface characteristics. The chamber has cross section of a 0.61 m x 0.61 m and a length of 3.7 m. A feedlot surface is simulated by utilizing a layer of dry, uncompacted, sieved feedyard manure, either with or without a compacted soil layer underneath. The chamber simulated the vertical action of the cattle hoof by dropping a 4.5-kg weight onto the manure surface. The particulates emitted were collected with high-volume* PM_{10} *samplers. The effects of kinetic energy of the falling weight (9, 32, and 54 J), manure depth (2.5, 5.1, and 10 cm), degree of compaction of the manure surface (loose, slightly compacted), and manure moisture content (from 6 to 20% wet basis) were investigated. For each manure depth,* PM_{10} *emission potential was directly related to the kinetic energy of the falling weight. For each weight drop, little variation of* PM_{10} *emission potential was noted with change of manure depth. Additionally,* PM_{10} *emission potential was inversely proportional to the manure moisture content. Surface application of water decreased* PM_{10} *emission associated with the falling weight, but penetration of the wetted crust by the falling weight increased the emission potential for subsequent tests. Also, upon drying of the wetted surface layer,* PM_{10} *emission increased considerably, depending on the condition of the manure surface, as well as the amount of water applied.*

Keywords. Cattle feedyard, PM_{10} emission, fugitive dust, dust control.

Introduction

Particulate emission is one of the major air-quality concerns from open cattle feedlots and dairies. Particulate emission from open feedlots can reduce visibility, especially in the early- to mid-evening periods when the atmosphere is more stable and winds are light (Auvermann, 2003a). MacVean et al. (1986) linked the health and performance of feeder cattle to the onset and magnitude of dust events. Researchers (Donham, 1991; Schiffman et al., 1995) have linked adverse health responses of both workers and neighbors to air-pollutant emissions from swine confinement; for open feedlots, however, the effects of air pollutant emissions on workers and neighbors are largely unknown.

Major sources of particulate emissions from feedlots include the pen surface that becomes a padded mixture of soil and manure due to animal movement, as well as the feedlot roads and alleyways (Grelinger and Lapp, 1996). Increased emission is usually observed at night because of: (a) drier manure caused by exposure to wind and solar radiation throughout the day; (b) increased cattle activity due to feeding, drinking, and cattle playing, which result in pulverization and subsequent suspension of accumulated dry, loose manure by hoof action; and (c) stable atmospheric condition between dusk and midnight, resulting in the suspended particles remaining close to the ground (Alberta Cattle Feeders' Association, 2002; Auvermann, 2003a).

As more stringent air-quality standards are being developed, there is a need to characterize and reduce air-pollutant emissions from cattle feedlots. At present, limited research has measured air-pollutant emissions and/or evaluated abatement measures for mitigating air- pollutant emissions from cattle feedlots. Sweeten et al. (1988) measured an average net total suspended particulate (TSP) concentration of 410 $\mu g/m^3$ (ranging from 68 to 882 $\mu g/m^3$) for 24-h sampling periods at three Texas feedlots. For 4- and 5-h time intervals within the 24-h sampling periods, TSP concentrations ranged from 16 to 17,000 $\mu g/m^3$. In another study conducted by Sweeten et al. (1998), mean TSP and PM_{10} (particulate matter less than 10-μm aerodynamic diameter) concentrations measured from three Texas feedlots were 700 $\mu g/m^3$ (ranging from 97 to 1,685 $\mu g/m^3$) and 285 $\mu g/m^3$ (ranging from

11 to 866 μg/m^3), respectively. Auvermann (2003a) identified different methods to control dust from open feedlots, including manure harvesting, manure surface compaction, topical application of crop residues and chemical resins, and surface water application.

Further research is needed to understand the relationship between the rate of dust emission and the feedlot surface characteristics. Miller and Woodbury (2003) developed a simple protocol to test feedlot samples for their ability to produce dust under a variety of environmental conditions. They modified a blender to produce dust from a dried feedlot sample and collect airborne particles on glass fiber filters. They reported that sample moisture and organic matter content had the greatest effect on whether dust emissions were possible.

Auvermann (2003b) developed an experimental apparatus to simulate the mechanics of dust emission from a cattle feedyard surface. The apparatus simulated hoof action by dropping steel weights of standardized geometry onto an uncompacted layer of dried, sieved feedyard manure. Dust emission was proportional to the kinetic energy of the falling weight. Additionally, the depth of the uncompacted manure layer influenced the mass of dust emitted, although the nature of the relationship was unclear.

As an extension of the Auvermann's (2003b) study, this research was conducted to measure PM_{10} emission potential caused by the simulated vertical hoof action on the manure surface. Specific objectives were to determine the effects of the following factors on emission potential: (a) weight drop energy, manure depth, and presence of a compacted base soil underneath the manure layer; (b) moisture content of the manure layer; (c) degree of compaction of the manure layer; and (d) surface water application.

Materials and Methods

Weight Drop Test Chamber (WDTC)

An experimental apparatus, herein referred to as the weight drop test chamber (WDTC), was developed and instrumented (Fig. 1) for investigating the dust emission potential of cattle feedlot surfaces. The design was based on the chamber developed by Auvermann (2003b). The WDTC consists of 3.7-m long bench-top enclosure with a 0.61 x 0.61 m cross section, mounted over a simulated feedlot surface. Analysis of the sample at the KSU Soil Testing Laboratory according to standard laboratory procedures indicated that it had an organic-matter content of approximately 38% based on the total carbon content, and sand, silt, and clay contents of 62, 32, and 6%, respectively. Also, analysis of the particle size distribution by sieving (ASAE, 2002) resulted in a geometric mean diameter of 117 μm and a geometric standard deviation of 2.2.

The WDTC is equipped with five high-volume samplers for PM_{10} and a tapered-element oscillating microbalance (TEOM). Four of the PM_{10} samplers were used to collect the PM_{10} emission from the simulated feedlot surface; one PM_{10} sampler was placed at the inlet side of the WDTC to account for the background PM_{10} concentration. Each sampler ran at a sampling airflow rate of 1.13 m^3/min. The average velocity through the WDTC was approximately 0.2 m/s. An auxiliary exhaust fan was used for faster removal of suspended particulates inside the chamber before each test. Tests were conducted on a simulated feedyard surface without base soil (Fig. 1a) and with base soil underneath the manure layer (Fig. 1b). The base soil layer was used to verify possible experimental artifacts in the initial design of the WDTC (without base soil) and was used to further simulate actual ground conditions. The base soil layer was approximately 91 cm deep and consisted of 51 cm of compacted soil from the KSU feedlot and 40 cm of sand. Vertical hoof action was simulated by dropping a 4.5-kg cylindrical steel weight (8.6 cm diameter) on the feedyard surface.

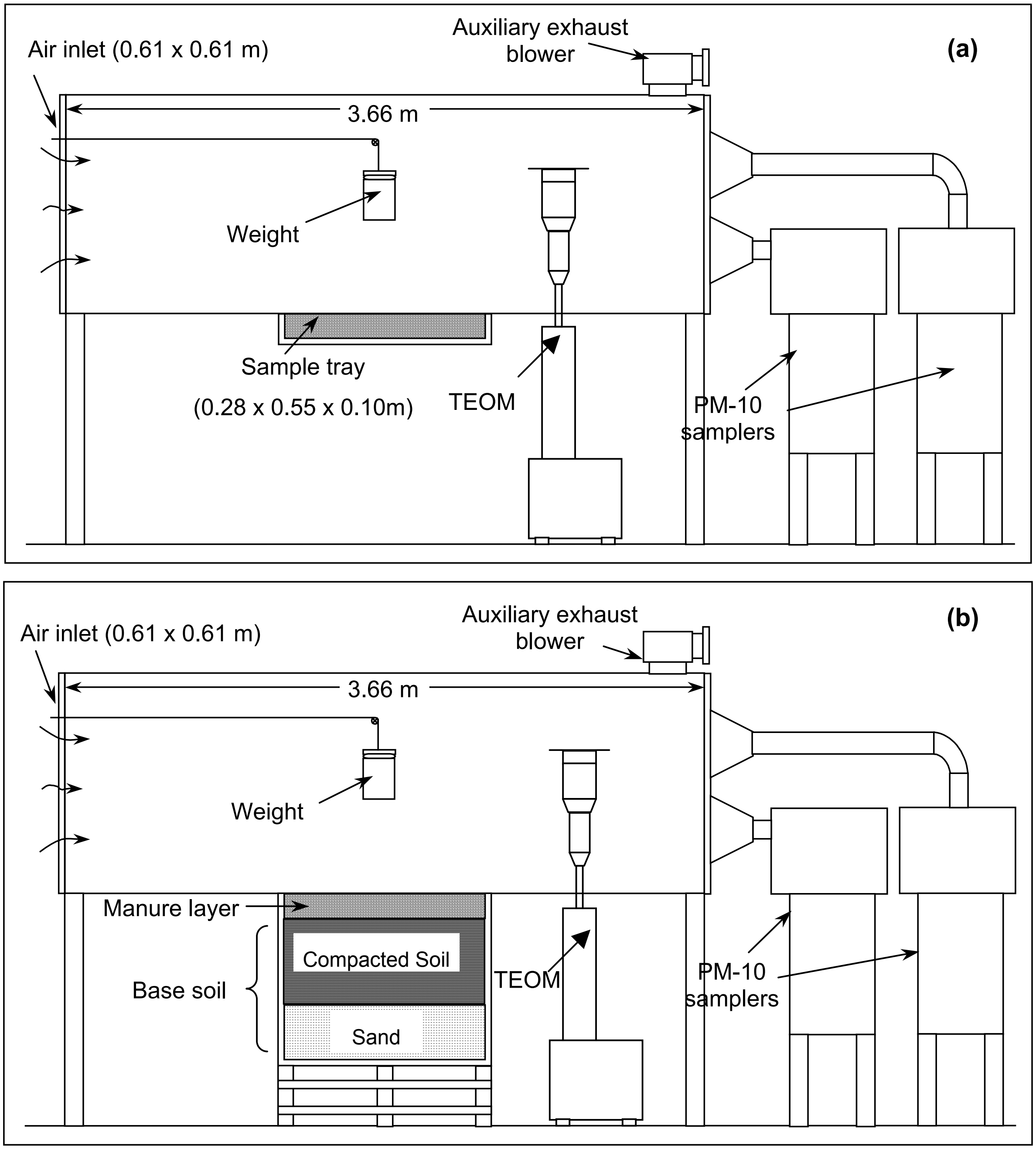

Figure 1. Schematic diagram of the weight drop test chamber without a base soil (a) and with a compacted base soil underneath the manure layer (b).

Experiments

The experimental parameters investigated in this study included drop height (or drop energy), depth of the loose manure layer, bulk moisture content (mc) of the manure surface, and degree of compaction of the manure surface. Preliminary studies were also conducted on surface water application to control PM_{10} emission. Table 1 lists the different treatment levels for these parameters. Tests 1, 2a, and 3 had three replicates for each treatment or treatment combination. Tests 2b and 2c had only one replicate for the intermediate mc levels.

Test 1 - Drop Energy, Manure Depth, and Base Soil

Test 1 considered the effects of weight drop energy, presence of a compacted soil underneath the manure layer, and manure depth on the emission from the dry, loose manure surface (mean moisture content of 6.6% wb). This test involved three manure depths (2.5, 5.1, and 10 cm) and three amounts of drop energy (9, 32, and 54 J). To achieve these amounts of energy, the 4.5-kg weight was dropped four times (from heights of 5, 18, and 31 cm, which were equivalent to drop energies of 9, 32, and 54 J, respectively). After each drop, the weight was raised carefully and moved approximately 6 cm (for those tests without base soil) and15 cm (for those tests with base soil) longitudinally over the sample tray so that the weight impacted on an undisturbed surface on each drop. After each test, the manure was restored to its loose and leveled condition before the start of a new test.

Table 1. Experimental parameters for the weight-drop experiments.

Test No.	Factors Investigated	Base soil depth (cm)	Drop energy (J)	Manure depth (cm)	Moisture content (% wb) or Amount of moisture applied (mm)	Degree of Compaction
1	Drop energy, manure depth, base soil	0, 91	9, 32, 54	2.5, 5.1, 10	6.6	Loose
2a	Bulk moisture content	0	9, 32, 54	2.5, 5.1, 10	6.1, 20.3	Loose
2b	Decreasing bulk moisture content:					
	sun drying	0	54	5.1	20.3, 17, 12, 6	Loose
	air drying	0	54	5.1	17, 15, 8, 3.8	Loose
2c	Increasing bulk moisture content	91	54	10	5.8, 12, 14	Loose
3	Degree of compaction of the manure layer	91	14	10	6	Loose, Slightly Compacted
4a	Surface water application	0	54	5.1	Amount of moisture applied: 0, 3.2, 6.4, 12.7, 19.1 mm	Loose
4b	Dry manure surface condition after water application	0	54	5.1	Amount of moisture applied: 3.2 mm	Loose
4c	Drying intervals after surface water application	0	54	5.1	Amount of moisture applied: 3.2, 6.4 mm	Loose

Test 2 - Manure Bulk Moisture Content

Tests 2a, 2b, and 2c evaluated the effects of the moisture content of the manure layer on the particulate emission. Test 2a considered two amounts of moisture content, 6.1 and 20.3% wb. The bulk mc of the manure sample was increased from 6.1% wb to 20.3% wb by placing the dry sample into a small concrete mixer and adding a known amount of water with a water spray-fogging system. The opening of the concrete mixer was sealed during water application to minimize loss of fine particles. Moisture was added in small increments to minimize sample agglomeration. Like Test 1, Test 2a had three manure depths (2.5, 5.1, and 10 cm) and three amounts of drop energy (9, 32, and 54 J).

Test 2b considered intermediate mc values, which were achieved by either sun drying or air drying a wetted manure sample. With air-drying, the wetted manure sample (initial mc of 20.3% wb) was spread on metal sheet and air-dried to achieve moisture contents of 17, 12, and 6% wb. With sun drying, the moist sample (initial mc of 17% wb) was dried to mc values of 15, 8, and 3.8% wb. Test 2b used a drop energy of 54 J on a manure depth of 5.1 cm with no base soil layer underneath.

Test 2c also considered intermediate values of mc (12 and 14% wb). The intermediate mc values of 12 and 14% wb were achieved by gradually adding moisture to the dry sample (5.8% wb) with the concrete mixer and spray-fogging system described earlier. Test 2c involved a manure depth of 10 cm with a compacted soil layer underneath. Like Test 2b, a drop energy of 54 J was used.

Test 3 – Degree of compaction

Test 3 compared the particulate emission from a loose manure surface (bulk density = 759 kg/m^3) and that from a slightly compacted surface (mean bulk density = 813 kg/m^3) by using a manure depth of 10 cm and a drop energy of 14 J. The slightly compacted surface was prepared by filling the sample tray with loose manure (approximately 12.5 cm) and gradually applying a uniform compaction force on the entire manure surface. The drop energy of 14 J was achieved by dropping the 4.5 kg weight once from a height of 31 cm above the manure surface.

Test 4 - Surface Water Application

To investigate the effectiveness of surface application of water (i.e., sprinkling) to control dust emission from cattle feedyards, a pre-determined amount of moisture was uniformly applied on the surface of the dry manure sample with a manual sprayer (Test 4a). After spraying, the sample was allowed to stand for approximately 30 min to allow the applied moisture to infiltrate into the sample before emission tests were conducted. A dry manure sample (approximately 6% mc wb) with no supplemental moisture served as the control. Three consecutive tests were conducted on each sample without restoring the manure surface; the weight was dropped on the same spot for each successive test.

After application of moisture on the surface, a wet layer of manure was observed on the surface of the sample. The wet layer solidified into a “crust” as the sample dried. To investigate the effect of the condition of the dry “crust” (i.e., disturbed vs undisturbed) on PM emission (Test 4b), two sample trays were prepared as for test 4a. Three consecutive drop tests were done immediately on the first sample tray (considered “disturbed”). The second sample tray was not tested and considered "undisturbed”. Both samples were then sun-dried for two days, forming a dried “crust” on the surface of both samples. After drying, three consecutive drop tests were conducted on each sample.

Preliminary emission tests were also conducted to investigate the change in PM_{10} emission potential at certain intervals after surface water application (Test 4c). Water was sprayed uniformly on the manure surface at two application rates (sample 1, ~3.2 mm; sample 2, ~6.4 mm) on two dry manure samples (depth 5.1 cm each). After spraying, the samples were allowed to stand for 30 min. A drop test was immediately conducted on the 2 samples by using a drop energy of 54 J, after which, the samples were sun-dried during the day and stored in the laboratory at night. Succeeding emission tests for each sample were then conducted approximately 4, 8, and 24 h after water application; for sample 1, an additional drop test was conducted after 28 h.

Particulate sampling and measurement and other ancillary measurements

The impact of the falling weight on the manure surface caused particulate emissions. The emitted particulates were collected on pre-conditioned 20 × 25-cm, type A/E, glass fiber filters (Gelman Sciences, Ann Arbor, MI) that were placed in four high-volume PM_{10} samplers downstream of the WDTC. Each individual sampler was operated at a sampling flow rate of 1.13 m^3/min. The combined flow rate of the four samplers generated an airflow within the chamber that was equivalent to approximately 0.8 km/h average wind speed. The samplers were run for 15 min, after which the filters were immediately removed from the samplers and placed in a conditioning container. The filters were conditioned in a constant-humidity container (25° C, 50% relative humidity) for 24 h before weighing, before and after sampling, to minimize the effect of humidity on filter weights. During each test, air temperature, humidity, and atmospheric pressure were monitored with a thermocouple, psychrometer, and barometer, respectively. The mc of the manure sample, before and after each test, was determined by using the ASTM D 2216-98 oven-drying method (ASTM, 2002).

Data Analysis

The General Linear Model and least square means were used to analyze the PM_{10} emission potential and determine the effects of different drop energies, manure bulk densities, and manure moisture contents (SAS v6. 12, Cary, NC).

Results and Discussion

Test 1 - Drop Energy, Manure Depth, and Base Soil

Figure 2 summarizes the measured PM_{10} emissions from the manure surface as a function of drop energy for each of the three manure depths, both with and without the base soil underneath the manure layer. For the case with no base soil, the highest drop energy (54 J) gave the greatest PM_{10} emission (range = 39.0 to 60.5 mg), followed by the 32 J drop energy (range = 32.1 to 44.2 mg), and then by the 9 J drop energy (range = 12.4-25.1 mg) (Fig.2). Similar to the results presented by Auvermann (2003b), PM_{10} emission was inversely related to the manure depth; PM_{10} emission was greatest for 2.5-cm manure depth (range = 25.1 to 60.5 mg) and least for the 10-cm manure depth (range = 12.4 to 39.0 mg) for all drop energies. The same trend was observed from the time-resolved measurements with the TEOM. At a drop energy of 54 J, the greatest peak PM_{10} concentration was measured for the 2.5-cm manure depth (722 $\mu g/m^3$) and the lowest peak concentration was measured for the 10-cm manure depth (485 $\mu g/m^3$) (Fig. 3). As indicated by Auvermann (2003b), this unexpected relationship between manure depth and dust emission can be attributed to the possibility of experimental artifacts in the test chamber, wherein the greater manure depth might have absorbed the impact of the falling weight.

With a 91-cm base soil, PM_{10} emission followed the same trend as that observed without base soil; the highest drop energy (54 J) had the greatest emission for all manure depths (range = 22.7 to 23.3 mg) compared with drop energies of 32 J (range = 16.2 to 17.6 mg) and 9 J (range = 10.0 to 11.7 mg) (Fig. 2). For each drop energy, however, the three manure depths did not differ significantly ($p>0.05$) in PM_{10} emission. Time-resolved measurements showed similar trends for drop energy. At the 54-J drop energy, the 10-cm manure depth gave the highest peak PM_{10} concentration (100 $\mu g/m^3$) followed by 5-cm manure depth (93 $\mu g/m^3$) and by 2.5-cm manure depth (52 $\mu g/m^3$) (Fig. 3).

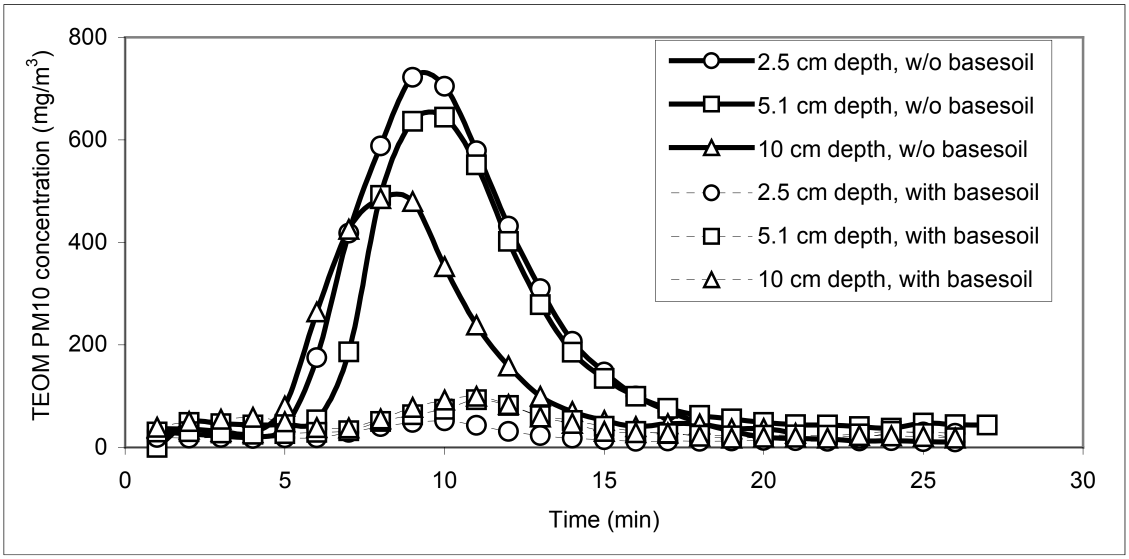

Figure 2. Mean PM_{10} emission from the manure surface, with and without base soil, as affected by drop energy and manure depth. Each data point is the average of three replicates; error bars represent 95% confidence interval.

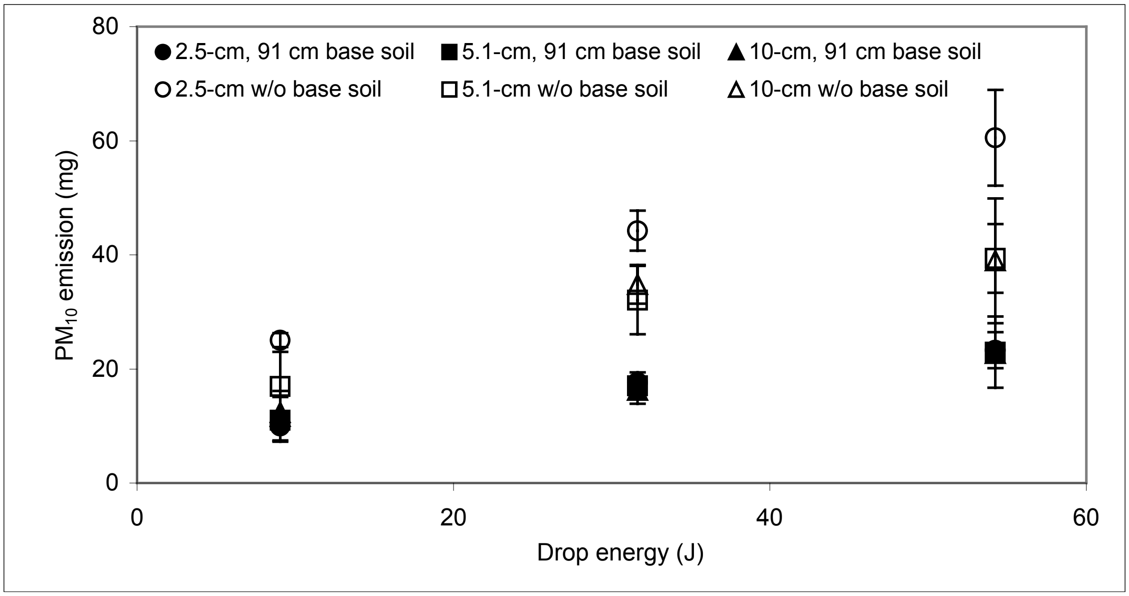

Figure 3. Time-resolved TEOM PM_{10} concentrations at different manure depths, as affected by the presence of a base soil underneath the manure layer. Drop energy used was 54 J. Each data point is the average of three replicates.

For a given drop energy and manure depth, PM_{10} emission was less from the manure surface with the 91-cm compacted base soil than from the manure surface without any compacted base soil underneath (Figs. 2 and 3). These results suggest that the base soil absorbed the extraneous impact energy, causing reduction in PM_{10} emission, and that manure depth does not affect PM_{10} emission for the range of the manure depths tested, at least for the vertical action mode of a falling weight.

Test 2 - Manure Bulk Moisture Content

As expected, for all drop energies and manure depths, the mean PM_{10} emission from the 20.3%-mc sample (ranging from negligible to 3.0 mg) was significantly ($p<0.05$) less than that from the 6.1%-mc sample (ranging from 12.4 to 60.5 mg) (Fig. 4) when the WDTC was used without base soil. Additionally, for the low-moisture sample (6.1% wb), drop energy (from 9 to 54 J) greatly affected PM_{10} emission. On the other hand, for the high-moisture sample (20.3% wb), drop energy had limited effect on emission. For the TEOM measurements, similar trends were observed; PM_{10} concentration was higher for the 6.1% wb mc than for the 20.3 % wb mc sample for all drop energies and manure depths.

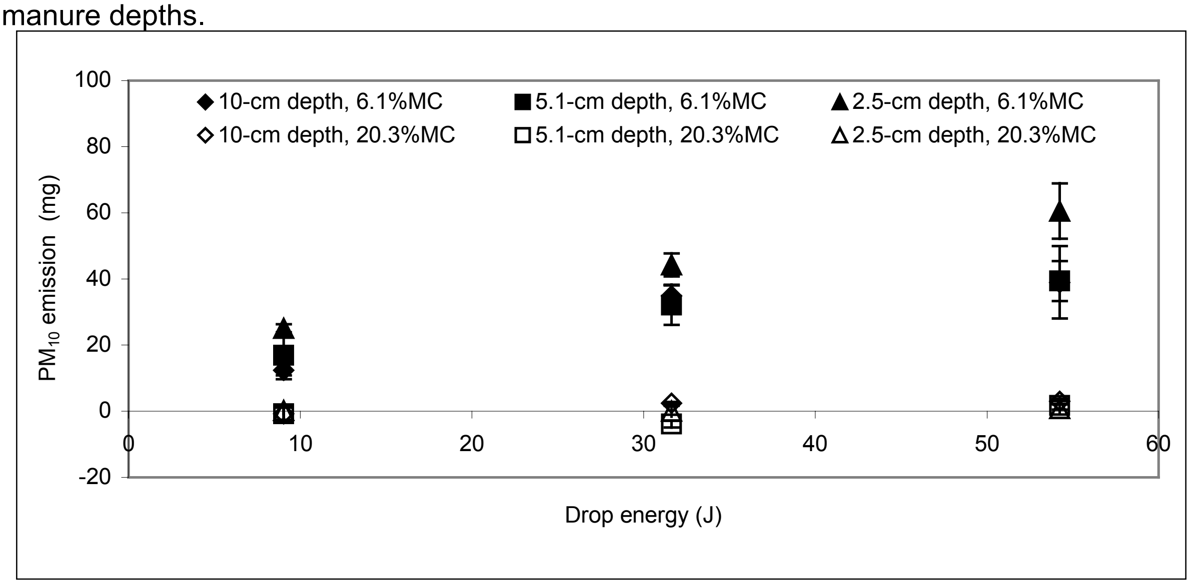

Figure 4. Mean PM_{10} emission for the 6.1%- and 20.3%-mc (wb) manure samples, as affected by drop energy and manure depth. Each data point is the average of three replicates; error bars represent the 95% confidence limits.

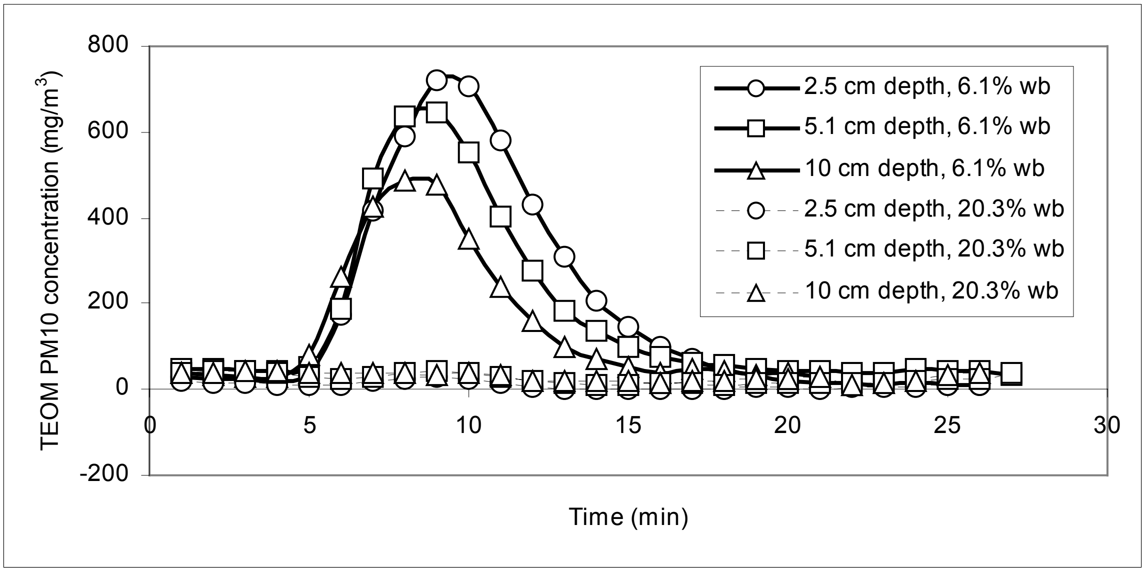

Figure 5. Time-resolved TEOM PM_{10} concentrations at different manure depths, as affected by manure bulk mc. Drop energy used was 54 J. Each data point is the average of three replicates.

The effects of intermediate values of mc were also investigated by using the WDTC, both with and without base soil. As mentioned earlier, for the WDTC without base soil, the high-moisture sample (20.3% wb) was reduced to 17%, 12%, and 6% wb by air drying. Measured PM_{10} emissions were small for all of these samples (range = 0.1 to 5.6 mg) (Fig. 6). Additionally, the mean PM_{10} emission for the sample that was air dried to 6% mc (5.6 mg) was considerably less than that for the original (i.e., before wetting) dry sample (PM_{10} emission of 39.4 mg). With sun drying, the 17% wb manure sample was reduced to 15%, 8%, and 3.8 % wb. The resulting samples exhibited the same trend in emission as the air-dried samples (Fig. 6). The sun-dried 3.8%-mc sample had considerably less PM_{10} emission (20.4 mg), compared with the initial dry (i.e., 6% wb) sample (33.1 mg). These results suggest that the fine particles in the wetted sample tend to remain agglomerated or bound to other particles even after drying to original mc.

To further investigate the effect of increasing mc on PM_{10} emission, the moisture of the dry sample was gradually increased from 6% to 12% and 14% wb by using the cement mixer and spray-fogging set-up. Drop tests in the WDTC with base soil showed that, for this range of sample mc, PM_{10} emission had an inverse linear relationship with manure bulk mc. The mean emissions for the 5.8%, 12%, and 14% mc wb manure were 26.6, 9.1, and 2.2 mg, respectively (Fig. 7).

Test 3 - Degree of compaction

Dust emission from a cattle feedyard is greatly affected by degree of compaction of the manure surface. Loose manure could potentially result in greater dust emission compared with a compacted manure surface; thus, it is recommended that dry, loose manure from feedyard surfaces be removed regularly while maintaining 2 to 5 cm of compacted manure to reduce dust emission (Lorimor, 2003; Alberta Cattle Feeders' Association, 2002; Auvermann, 2003b). In this study, mean particulate emission was significantly less (p>0.05) for the slightly compacted manure surface than for the loose manure surface (4.35 mg vs 6.10 mg) (Fig. 8).

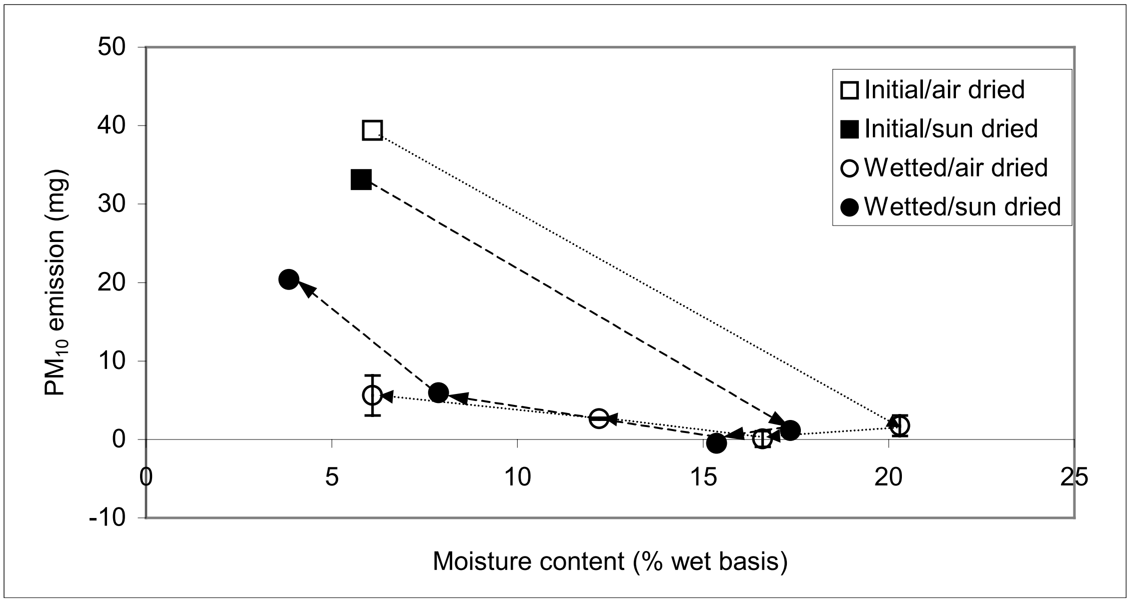

Figure 6. PM_{10} emission from the manure surface with no base soil, as affected by moisture content (mc) and drying method (drop energy=54 J, manure depth=5.1 cm). Arrows represent the "history" of the sample; dry manure sample (initial) was wetted with water and then either air dried (wetted/air dried) or sun dried (wetted/sun dried).

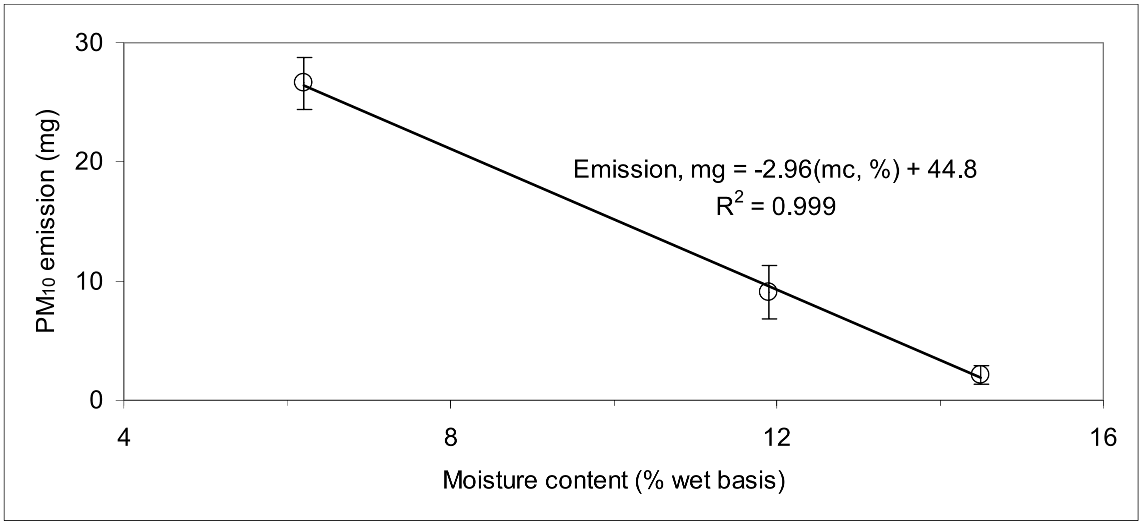

Figure 7. Mean PM_{10} emission from manure surface with 91-cm base soil underneath, as affected by manure bulk moisture content (drop energy = 54 J, manure depth=10 cm). Each data point is the average of three replicates; error bars represent 95% confidence interval.

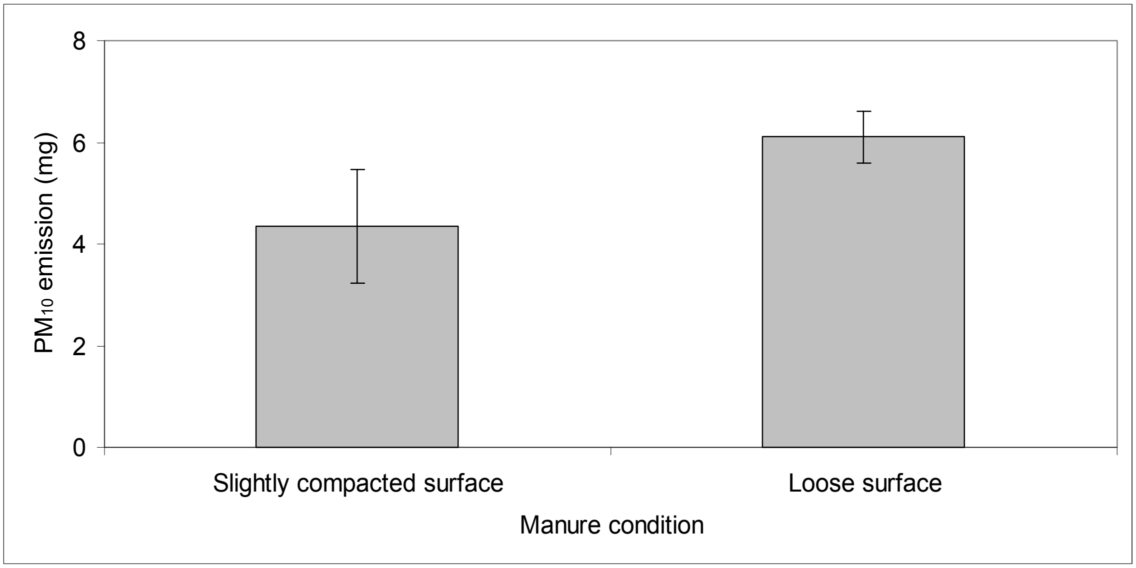

Figure 8. Comparison of PM_{10} emission between loose (759 kg/m^3 bulk density) and compacted manure (813 kg/m^3 bulk density) at 14 J drop energy and 10 cm manure depth. Each data point is the average of three replicates; error bars represent 95% confidence interval.

Test 4 - Surface Water Application

Surface water application greatly reduced the PM_{10} emission (range = negligible to 5.2 mg), compared with the control sample (range = 23.9 to 43.2 mg) (Fig. 9). But in the subsequent tests, in which the weight was dropped at the same location, PM_{10} emission increased. By dropping the weight in the same location, the weight penetrated through the wet surface layer, allowing dust particles to be released from the tray in the subsequent tests. For the first test, no difference in emissions was observed from the four samples with different amounts of surface water applied. In the subsequent tests, a slight increase in emissions was observed, which was inversely correlated to the amount of water applied. For the third tests, the sample with 3.2 mm of water added yielded a slightly greater emission (5.2 mg), followed by the sample with 6.4 mm water added (3.3 mg), although both of these emission levels were substantially less than that of the control tray (no water added), which yielded 43.2 mg. Results suggest that moisture application that does not penetrate throughout the vertical profile of the dry, loose manure layer will have limited benefits.

Drying of the manure sample with the wet surface layer resulted in the formation of a "dry crust". Emission from the surface with a "disturbed" crust remained relatively constant (mean of 23.9 mg) during the three tests (Fig. 10). On the other hand, the PM_{10} emission from the sample with "undisturbed crust" increased, from 5.0 mg for the first test to 25.4 mg for the third test. Emissions from both "disturbed" and "undisturbed crust" samples were considerably greater than that for the wet sample (mean of 1.3 mg).

Preliminary emission tests were also conducted to investigate the change in PM_{10} emission potential at various intervals after surface water application. Information from this study will help to determine the frequency of surface water application required to control PM_{10} emission. For both samples with different application rates, PM_{10} emissions were negligible immediately after surface water application and then increased considerably with time after water application (Fig. 11). For sample 1 (3.2 mm of water added), PM_{10} emissions were 23.8 mg after 8 h of sun drying and 45.5 mg 28 h after water application. For sample 2 (6.4 mm of water added), PM_{10} emissions were 3.1 mg after 8 h of sun drying and 22.4 mg 24 h after water application.

These results suggest that surface application of moisture on the feedlot surface reduces the PM_{10} emission potential; upon drying, however, the PM_{10} emission increases considerably, and the magnitude of increase is dependent on the condition of the surface, as well as the amount of surface water applied initially. Additional tests should be conducted to further establish the effects of frequency and amount of surface-water application on the PM_{10} emission potential from feedlot surfaces.

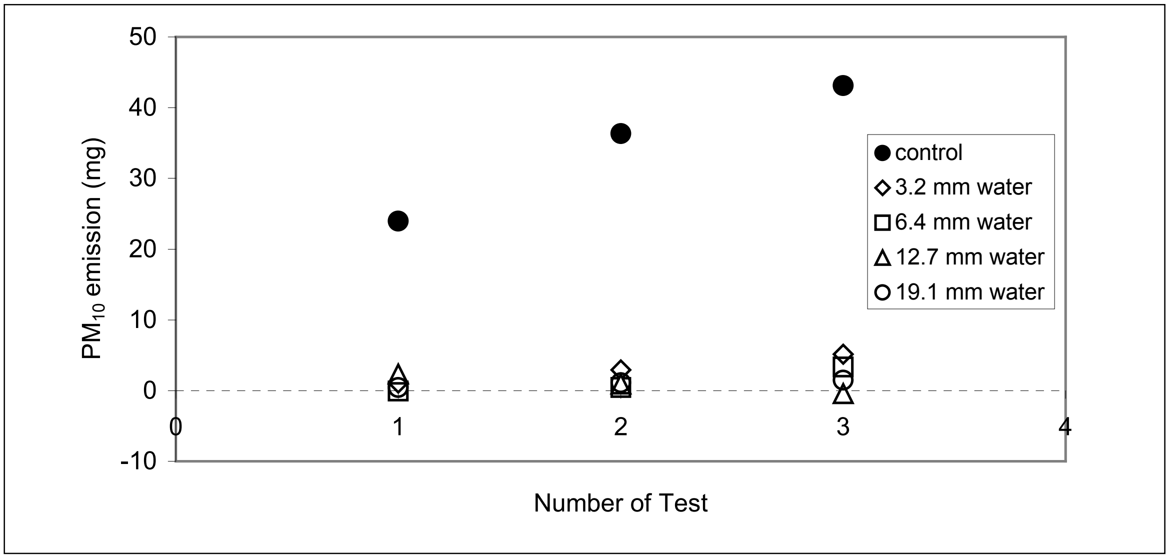

Figure 9. Effect of surface water application on PM_{10} emission. Emission tests were done with 54 J drop energy and 5.1 cm manure depth.

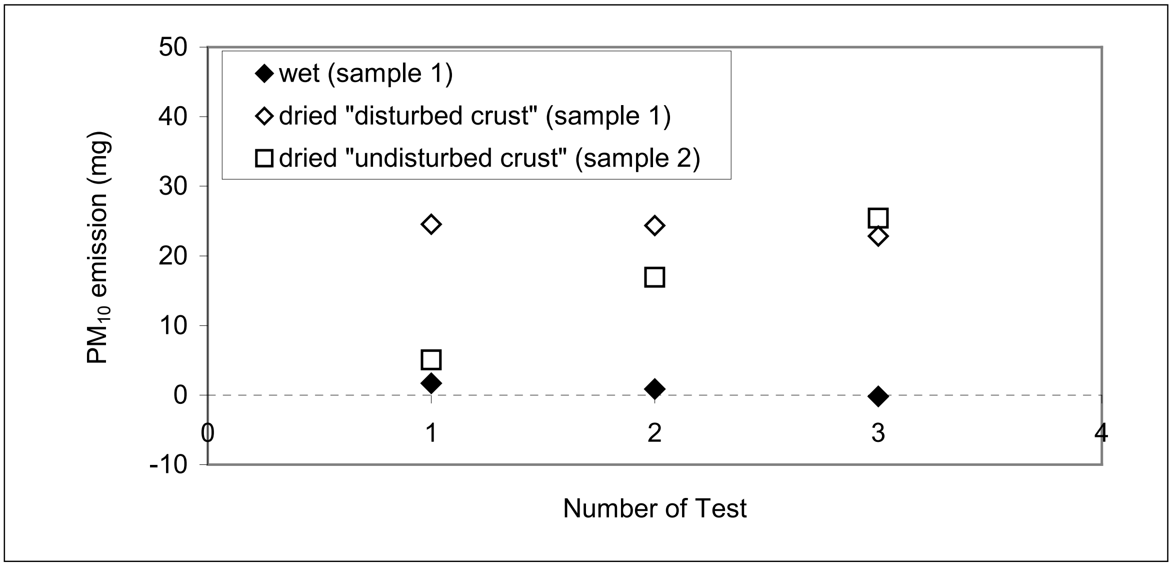

Figure 10. PM_{10} emissions of manure samples with disturbed and undisturbed dry crusts. Emission tests were done with 54 J drop energy and 5.1 cm manure depth.

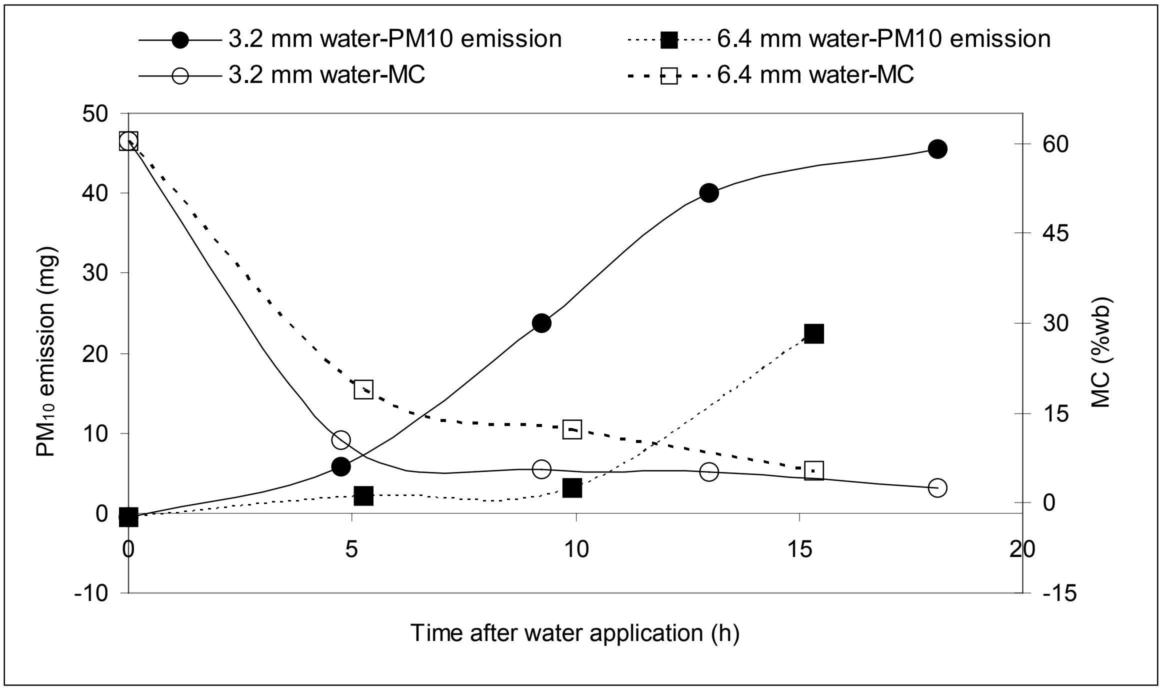

Figure 11. PM_{10} emissions at different intervals after surface water application. Samples were sun dried in between emission tests during daytime (8:00 AM to 7:00 PM) and air dried in the laboratory at night (7:00 pm to 8:00 AM). Emission tests were done with 54 J drop energy and 5.1 cm manure depth.

Conclusions

The following conclusions were drawn from this study:

- PM_{10} emission from the loose manure surface caused by a falling weight increased with increasing drop energy.
- PM10 emission potential from the loose manure surface with a compacted base soil did not differ significantly with different manure depths.
- PM_{10} emission potential associated with the impact of a falling weight decreased by more than one order of magnitude as the moisture content of the manure surface was increased from 6.1% to 20.3%.
- PM_{10} emission potential was greater for a loose manure surface (bulk density of 759 kg/m^3) than for a slightly compacted manure surface (bulk density of 813 kg/m^3).
- Surface application of moisture to the dry manure surface greatly reduced PM_{10} emission associated with the impact of a falling weight. But penetration of the wetted layer by the falling weight increased the PM10 emission potential.

This study simulated the vertical action of the cattle hoof on a feedlot surface. The resulting emissions are relative values and cannot be used to predict the actual emissions from cattle feedlots. However, these could be useful in assessing the relative effectiveness of dust abatement measures (e.g., water application) and/or the relative effects of feedlot surface conditions (e.g., moisture content, depth, degree of compaction).

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