# A MECHANISTIC MODEL OF FUGITIVE EMISSIONS OF PARTICULATE MATTER FROM CATTLE FEEDYARDS, PART I: INTRODUCTORY EVALUATION

**Auvermann, B W.**[1]

## ABSTRACT

We present preliminary results of a bench-scale simulation of the mechanics of dust emissions from a cattle feedyard surface. The experimental apparatus simulated hoof action by dropping steel weights of standardized geometry onto an uncompacted layer of dried, sieved feedyard manure, varying the kinetic energy of the falling weight by adjusting the height from which it was dropped. The dust emitted by the impact of the falling weight on the uncompacted manure was captured on glass fiber filters, and its mass was determined by routine gravimetry. As expected, the mass of dust emitted by the hoof-action simulation was approximately proportional to the kinetic energy of the falling weight. In addition, for a given kinetic energy of a falling weight, the mass of dust emitted was influenced by the depth of the uncompacted manure layer onto which it fell, although the nature and physical meaning of that relationship are unclear. Additional experiments planned for the near future will illuminate the influence of bulk density and moisture content on the intrinsic dust susceptibility of the loose manure layer, as well as the relative contributions of anterior and posterior hoof action to the total dust emissions. The bench-top simulator provides a practical means of screening mulches and other surface treatments for their potential to suppress fugitive dust emissions from cattle feedyards and open-lot dairies.

**KEYWORDS.** fugitive dust, feedyards, emission factors, mechanistic model

## INTRODUCTION

The AP-42 emission factor (USEPA,1985) for fugitive dust from cattle feedyards, 127.3 kg $[1,000\ \mathrm{hd}]^{-1}\ \mathrm{d}^{-1}$ total suspended particulate (TSP), has been the object of considerable technical critique since the mid-1990s (Parnell et al., 1994; Grelinger and Lapp, 1996; Lesikar et al., 1996; Romanillos and Auvermann, 2002). Pursuant to the 1987 amendments to the Clean Air Act, the United States Environmental Protection Agency (EPA) replaced the National Ambient Air Quality Standard (NAAQS) for TSP with a new standard for $PM_{10}$, effectively requiring new emission factors for all PM sources including cattle feedyards. ($PM_{10}$ is defined as that proportion of suspended particulate matter having an aerodynamic equivalent diameter (AED) of 10 micrometers or less.) Using collocated TSP and $PM_{10}$ monitors near cattle feedyards in West Texas, Sweeten et al. (1988) determined that the $PM_{10}$/TSP ratio in feedyard dust is between 19% and 40%. This result led to the EPA adopting a standard value of 25%, which has been used routinely across the United States. Applying that ratio to the emission factor for feedyard TSP, the disputed emission factor for fugitive $PM_{10}$ from cattle feedyards is 31.8 kg $[1,000\ \mathrm{hd}]^{-1}\ \mathrm{d}^{-1}$.

Because cattle feedyards are large, spatially heterogeneous, irregularly shaped, area sources of fugitive dust, efforts to estimate the fugitive emission factor have traditionally relied on an indirect technique, inferring a spatially averaged source strength from downwind concentration data using a Gaussian dispersion model (e. g., Parnell et al., 1994). Recent estimates of the $PM_{10}$ emission factor using this method range from 2.3 kg $PM_{10}$ $[1,000\ \mathrm{hd}]^{-1}\ \mathrm{d}^{-1}$ (Parnell et al., 1994) to 9.1 kg $PM_{10}$ $[1,000\ \mathrm{hd}]^{-1}\ \mathrm{d}^{-1}$ (Parnell et al., 1999), but the validity of those estimates has been questioned (Consumers Union, 2001). In 2001, recognizing the thin scientific basis for the contested emission factor, EPA effectively withdrew it and elected not to replace it until scientists and engineers resolved the technical and statistical concerns with the more recent estimates. The inherent variability of the indirect, dispersion-modeling approach implies an ongoing need for a more direct method of estimating fugitive emissions from a heterogeneous, time-varying, area source such as the cattle feedyard.

In this paper a mechanistic model of feedyard dust emissions is proposed to replace the inverse method previously described. It is hypothesized that nearly all feedyard dust, as distinguished from road dust or other unrelated emissions, results from the mechanical shearing action of cattle hooves on a dry, uncompacted layer of manure on the corral surface. In the proposed model, the driving force for dust emission is a quantity known as the *hoof shear energy density* (kJ $m^{-2}$ $min^{-1}$), which is a time- and space-varying function of animal liveweight and behavior. That shear energy acts upon a surface having an *intrinsic susceptibility* to PM emissions (kg $kJ^{-1}$), which is a time- and space-varying function of the depth, bulk density and moisture content of the loose manure layer on the corral surface. The product of those two quantities is the instantaneous flux (kg $m^{-2}$ $min^{-1}$) of PM caused by the animals' hoof action.

The main objectives of this study were:

1. Confirm the hypothesis that the mass of dust emitted by the impact of a falling weight on a layer of loose manure is a monotonically increasing function of the kinetic energy of the falling weight.
2. Determine how the intrinsic dust susceptibility of a simulated feedyard surface changes with the depth of uncompacted manure.

## VARIABLE DEFINITIONS

*Indices and Generic Variables*

| | |
|---|---|
| i | Animal # within a corral |
| n | Number of animals within a corral |
| j | Day of year |
| k | Corral # |
| m | Number of corrals in the feedyard |
| t | Elapsed time since midnight (min) |

*Corral Properties*

| | |
|---|---|
| $\theta(x,y,t)$ | Moisture content of the loose manure layer, wet basis (kg $kg^{-1}$) |
| $\rho_b(x,y,t)$ | Dry bulk density of the loose manure layer (kg $m^{-3}$) |
| $L(x,y,t)$ | Mass loading of loose manure per unit corral area (kg $m^{-2}$) |
| $S(x,y,t)$ | Intrinsic PM susceptibility of the loose manure layer (kg $kJ^{-1}$) |
| $z(x,y,t)$ | Depth of the loose manure layer (m) |
| $x_m$ | Corral width (m) |
| $y_m$ | Corral depth (m) |

*Animal Behavior*

| | |
|---|---|
| $\{x(t),y(t)\}$ | Parameterized animal location as a function of time (m,m) |
| $P(t)$ | Rate of hoof shear energy imparted to the loose manure surface (kJ $min^{-1}$) |

*PM Emissions Quantities*

| | |
|---|---|
| $R(t)$ | Instantaneous emission rate of PM (kg $min^{-1}$) |
| E | Cumulative daily emission of PM (kg) |
| EF | Emission factor for PM (kg $hd^{-1}$ $d^{-1}$) |

## GENERAL MODEL DEVELOPMENT

The mechanistic model assumes that the instantaneous emission rate of fugitive PM, R(t), can be computed as the product of a susceptibility parameter, S, and a hoof energy density, P(t), or

$$R(t) = S \bullet P(t) \qquad [1]$$

The susceptibility term, S, is in general a spatially varying property of the loose manure layer on the feedyard surface, whose magnitude is a function of moisture content, $\theta$, dry bulk density, $\rho_b$, and spatial mass-loading rate, L, of the loose manure layer, all of which are nonuniform in space. Therefore, the generalized S becomes

$$S(x,y,t) = f(\theta(x,y,t), \rho_b(x,y,t), L(x,y,t)) \qquad [2]$$

Because animals move around corrals freely in response to social factors, feed availability and external stresses (e. g., weather phenomena, vehicle traffic, noise), the mechanistic model must account for the fact that dust-generating behaviors take place in different parts of the corral over time. One method of accounting for that phenomenon uses an animal-tracking approach that parameterizes the position of each animal over time within the corral {x(t),y(t)}, integrates each animal's contribution to the total dust emissions over the course of a 24-hour period and sums those contributions over all of the animals within a corral. The instantaneous PM emission rate attributable to the $i^{th}$ animal on the $j^{th}$ day of the year within the $k^{th}$ corral may be expressed as

$$R_{ijk}(t) = P_{ijk}(t) S(\theta(x_{ijk}(t_j), y_{ijk}(t_j), t_j), \rho_b(x_{ijk}(t_j), y_{ijk}(t_j), t_j), L(x_{ijk}(t_j), y_{ijk}(t_j), t_j)) \qquad [3]$$

The mass of PM emitted daily by the $i^{th}$ animal on the $j^{th}$ day of the year within the $k^{th}$ corral can be expressed as

$$E_{ijk} = \int_0^{1440} R_{ijk}(\tau)\, d\tau \qquad [4]$$

leading to an expression for the mean emission factor for the entire feedyard:

$$EF = \frac{1}{365\sum_{k=1}^{m} n_k} \sum_{j=1}^{365} \sum_{i=1}^{n_k} E_{ijk} \qquad [5]$$

Although further mathematical development is beyond the scope of this paper, it is likely that the parameter S and the hoof energy density P(t) should be generalized further into a tensor and a vector, respectively, to accommodate both vertical and horizontal components of the shearing action of a bovine hoof. Qualitative field observations strongly suggest that the vertical component predominates with respect to fore-hoof action and the horizontal component predominates with respect to rear hoof action. We have not presumed to validate the entire model in its most general form but have focused at the onset on validating the model's principal premise in the simplest geometry and with no time-varying component: pure vertical impact of a single hoof-action simulation. The simplified, governing model is R=S*P, with R representing the total mass (kg) of PM emitted by the impact of a falling weight, P the kinetic energy (kJ) of the falling weight and S (kg/kJ) the proportionality constant relating R to P.

Therefore, we restate our objectives in a mathematical form conducive to hypothesis testing:

Objective 1

Ho: The ratio S=R/P is indeterminate for fixed values of $\theta$, $\rho_b$ and L.
Ha: The ratio S=R/P is determinate and greater than zero.

Objective 2

Ho: The ratio S=R/P is not related to the loose manure depth, z (m), or its related quantity, the specific manure loading rate L (kg $m^{-2}$).
Ha: The ratio S=R/P has a measurable, functional relationship to z and/or L.

## EXPERIMENTAL METHODS

Initial investigation was at the bench-top scale under carefully controlled conditions using the apparatus shown in Figure 1. It consists of a wind tunnel 0.61m high, 0.61 m wide and 4.88 m long. The tunnel has three sections: (1) an upstream section 1.22 m in length and built of interior-grade plywood; (2) a downstream section 2.44 m in length and built of interior-grade plywood; and (3) a test section 1.22 m in length and fabricated from clear Lexan polycarbonate.

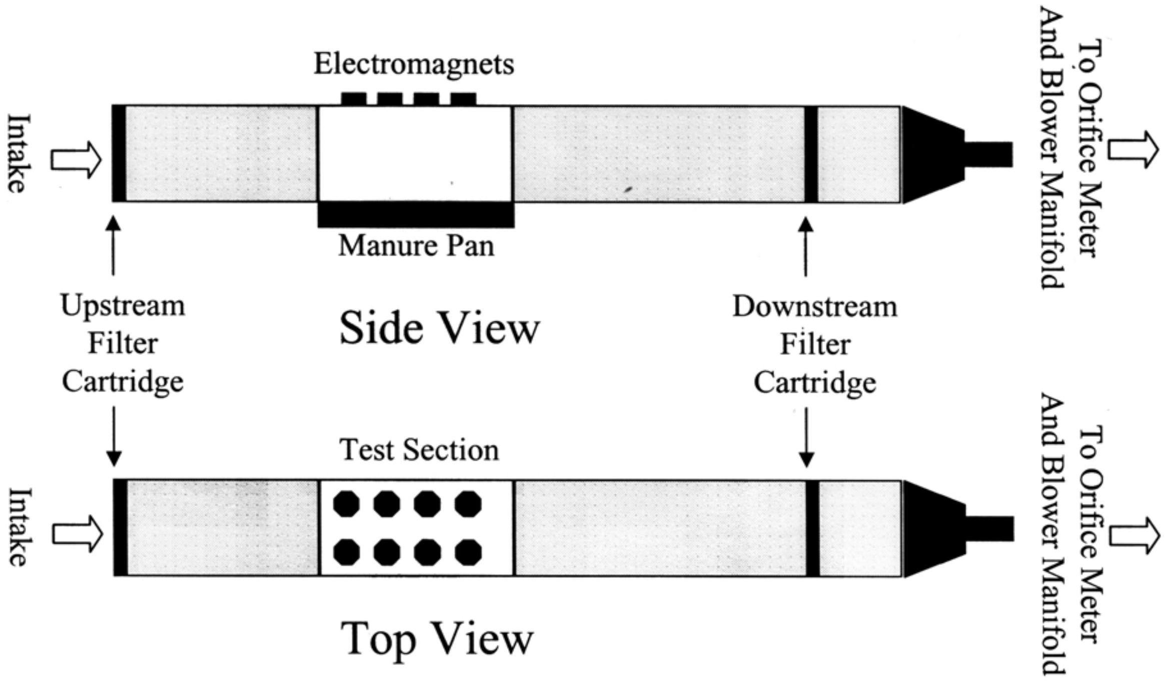

**Figure 1. Schematic top and side views of the weight-drop test chamber.**

The test section was open at the bottom and received a steel pan that holds the simulated feedyard surface, a layer of loose manure whose depth, moisture content and bulk density were varied according to the test being run. Irrespective of the depth of manure needed for the test, the surface of the loose manure layer was maintained flush with the interior, bottom surface of the upstream and downstream plywood sections using steel spacers between the pan and the polycarbonate. The three sections were held together by bolted flanges affixed to the exterior of each end of each section. Interior plywood surfaces were covered with Formica-style laminate. One wall of the downstream section was hinged and fitted with weatherstripping to facilitate access to the downstream filter cartridge while remaining air-tight during operation.

The upstream filter cartridge consisted of a square plywood frame (61 cm x 61 cm) with four (4) rectangular openings 20.3 cm wide and 25.4 cm long. A standard, high-volume air sampling cassettes (Graseby-Andersen, Incorporated, Smyrna, GA) was affixed to the plywood over each of the rectangular openings, and the cassettes were loaded with HEPA filtration media to reduce background concentrations of PM in the inlet air. The downstream filter cartridge was a similar plywood frame that could be inserted into any one of five slots in the downstream chamber section. The five slots were located at 0, 61, 122, 183 and 244 cm from the downstream edge of the test section and were designed into the chamber so that we can measure the effect of near-range particle settling on apparent emitted mass. To permit gravimetric determination of the mass of PM captured from each weight-drop event, preconditioned, glass-fiber filters were installed into the high-volume sampling cassettes bolted to the downstream cartridge. The filters were conditioned before and after exposure in a drying oven set at 90 C for 18 hours.

To suspend the steel weights above the simulated manure surface, an array of eight (8), 24VDC electromagnets (Magnetech Corporation, Novi, MI: model R-1007-24) having a nominal capacity of 11.8 kg (0.116 kN) each were installed in the ceiling of the polycarbonate test section. The electromagnets were controlled individually or as a group with a specially designed switching circuit based on a 24VDC power supply (Sola/Hevi-Duty, Skokie, IL; model SDP2-24-100). The weights were fabricated from 7.62 cm diameter steel stock, cutting the stock crosswise to a nominal thickness of 5.1 cm.

A set of three centrifugal fans in parallel (Cadillac Products, Chicago, IL; model HP-33A) provided air flow through the test chamber. All of the fans were controlled by variable-speed switches, and volumetric flow rate was measured during each test using a custom-designed, sharp-edged orifice meter built at the Texas Agricultural Experiment Station (TAES) machine shop in Bushland, TX. The orifice meter was calibrated three times in series with a NIST-traceable laminar flow element (LFE) (Meriam, Instrument, Cleveland, OH; model 50MC2-4) over a range of 0 to 8.5 $m^3$ $min^{-1}$. Pressure drops across the orifice meter and the LFE were measured by Magnehelic$^{TM}$ differential pressure gauges (Dwyer Instruments, Incorporated, Michigan City, IN; model 2010). The coefficient of determination for the polynomial function relating pressure drop across the LFE to pressure drop across the orifice meter was $R^2$=0.9996. Before each weight-drop experiment, the speeds of the individual fans were adjusted until the pressure drop across the orifice meter indicated a volumetric flow rate of 4.98 $m^3$ $min^{-1}$, equivalent to an average "wind speed" in the chamber of 0.223 m $sec^{-1}$ (0.5 mph). Each weight-drop test lasted 10 minutes.

The kinetic energy imparted to the simulated feedyard surface by a falling weight was computed as

$$P = mgh \qquad [6]$$

in which P is the kinetic energy (J) as defined above, m is the mass (kg) of the falling weight, g is the acceleration due to gravity (9.81 m $s^{-2}$) and h is the elevation of the bottom surface of the weight above the manure surface. To vary P and test the first hypothesis, m was held approximately constant and h varied by adjusting the length of the tubular shaft used to connect the main body of the weight to the cylindrical steel bearing whose flat end affixes to the electromagnet, as in Figure 2.

To date, twelve test sequences have been run varying (a) the depth of manure in the test section (nominally 2.54 cm, 5.08 cm and 7.62 cm), (b) the location of the downstream filter cartridge relative to the downstream edge of the manure pan (8.3 cm and 241.8 cm) and (c) the kinetic energy of the falling weights (L and H, for "lowest" and "highest," respectively). Within each of the twelve (12) permutations of those three variables, a series of seven (7) weight-drop tests were run with each generating four (4) downstream filters to be weighed before and after exposure. Each seven-fold test sequence involved two blanks, four 2-weight tests and an 8-weight test in the following order:

| Test # | Description | Weights Dropped |
|---|---|---|
| 1 | Blank | none |
| 2 | 2-wt | W1, W5 |
| 3 | 2-wt | W2, W6 |
| 4 | 2-wt | W3,W7 |
| 5 | 2-wt | W4,W8 |
| 6 | 8-wt | All (W1-W8) |
| 7 | blank | none |

The four 2-wt tests involved dropping an adjacent pair of weights simultaneously. (Each weight within a pair was located the same distance upwind from the downwind end of the test section.) Upon visual inspection, none of the pairs of weights disturbed the manure surface for any other pair, so the surface of the manure was reconditioned to its initial, smooth state with a fine-toothed hand rake only after tests 5 and 6.

**Figure 2.** **Standardized steel weights in a variety of shaft lengths used to vary the height from which the weights are dropped. The yellow segment at the top attaches directly to the contact face of the electromagnets.**

## RESULTS AND DISCUSSION

### *Related Measurements*

#### Manure Properties.

For the tests, the gravimetric moisture content and the dry bulk density of the sieved manure was $\theta$=7.5% (wet basis, wb), and $\rho_b$=752.4 kg $m^{-3}$, respectively, as loaded into the rigid pan beneath the test section.

#### Kinetic Energies.

Two kinetic energies of 0.5 J and 6.39 J per weight dropped were tested. The lowest kinetic energy resulted from the weight with the shortest drop height (longest shaft), ranging from 6.5 to 7.2 cm among the eight electromagnets in the weight-drop array. The average mass of the weights in the low-energy configuration was 1.599 kg. The highest kinetic energy was associated with the longest drop height (shortest shaft), which ranged from 44.2 to 44.8 cm. The average mass of the weights in the high-energy configuration was 1.463 kg.

#### Linear Dimensions.

The weight-drop pairs and downwind filter slots are located a fixed distance from the downwind edge of the control section as shown in the table below.

| Weight Pair or Slot # | Distance (cm) from Downwind Edge of Test Section |
|---|---|
| W1,W5 | 102.5, upwind |
| W2,W6 | 72.0, upwind |
| W3,W7 | 41.5, upwind |
| W3,W8 | 11.0, upwind |
| Slot 1 | 8.3, downwind |
| Slot 5 | 241.8, downwind |

### *Use of Test Blanks*

The two blanks in each set of seven tests were intended to gauge bias in the collected mass of PM resulting from wind scour, air leakage or other background sources not filtered out by the inlet filter cartridge. The bias in the five test measurements was computed as the arithmetic mean of the mass of PM collected in the two blank runs. The measured bias was subtracted from the collected PM mass from each of the five test runs to yield the corrected mass of PM collected in each run. The signal-to-noise ratio associated with this bias was greater when all eight weights were dropped at once than when two were dropped at a time, as shown in Table 1.

**Table 1. Sample of Raw and Corrected PM Mass Captured on Downwind Filters. (Signal-to-Noise Ratio is Computed as the Ratio of the Corrected PM Mass to the Mean Bias.)**

| Test # | Wts Dropped | Total Kinetic Energy (J) | PM Mass (g) | Mean Bias (g) | Corrected PM Mass (g) | PM Susceptibility (kg/kJ) | Signal/ Noise Ratio |
|---|---|---|---|---|---|---|---|
| 36 | blank | 0.000 | 0.0216 | 0.0144 | -- | -- | -- |
| 37 | W1,W5 | 12.784 | 0.0466 | | 0.0322 | 0.0025 | 2.2 |
| 38 | W2,W6 | 12.670 | 0.0399 | | 0.0256 | 0.0020 | 1.8 |
| 39 | W3,W7 | 12.796 | 0.0560 | | 0.0417 | 0.0033 | 2.9 |
| 40 | W4,W8 | 12.875 | 0.0366 | | 0.0222 | 0.0017 | 1.5 |
| 41 | W1-W8 | 51.125 | 0.2344 | | 0.2200 | 0.0043 | 15.3 |
| 42 | blank | 0.000 | 0.0071 | | -- | -- | -- |

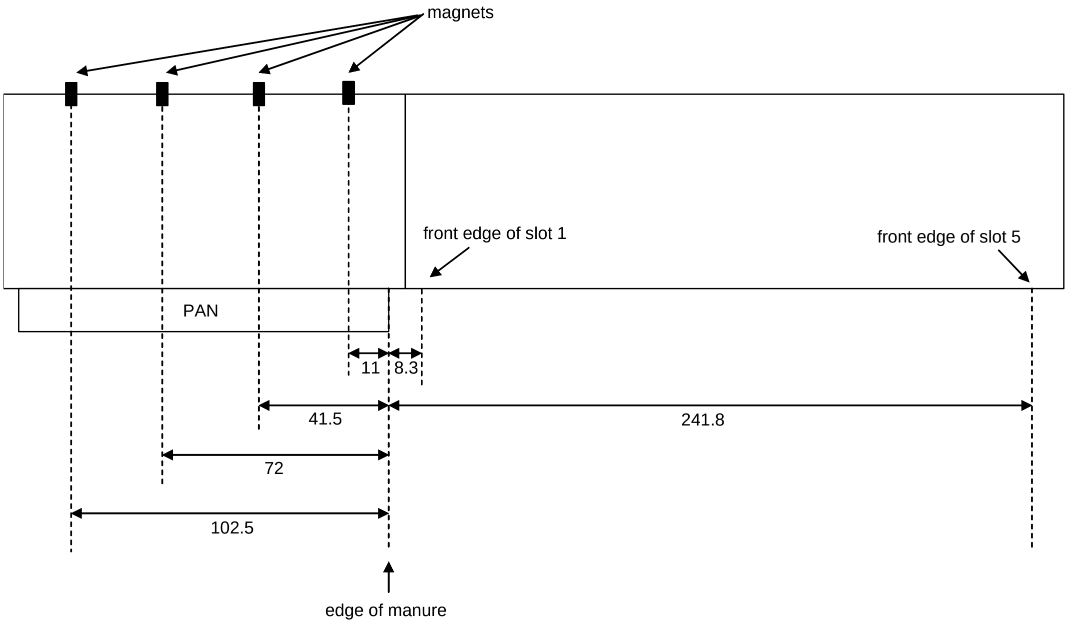

**Figure 3. Side-view schematic showing the locations of (a) the centerlines of the electromagnets and (b) the nearest and most distant downwind filter slots relative to the downwind edge of the test section. (All dimensions are in cm.)**

### *Hypothesis Validation*

Hypothesis 1 stated that the susceptibility parameter, S, is indeterminate. To test that hypothesis, a paired t-test (Microsoft Excel, 2002) was used to compare the mean, corrected mass of PM collected from the 8-weight drop tests for (a) low-energy (LE) runs 6, 20, 34 and 48 versus (b) high-energy (HE) runs 13, 27, 41 and 55. The one-tailed, paired t-test indicated that the mass of PM collected from the HE weight drop was always greater than that collected from the corresponding LE weight drop ($P<0.004$). That result does not yet prove that the relationship between emitted mass and kinetic energy is purely, monotonically increasing across the full range of possible kinetic energies, but it does lend credence to that component of the alternate hypothesis.

Hypothesis 2 stated that the susceptibility parameter, S, is independent of the manure depth. To test that hypothesis, the corrected PM mass was examined for the twelve, 8-weight tests among the three manure depths (Table 2). To eliminate measurements whose magnitudes were of the same order as measurement noise, data were arbitrarily selected for which the signal-to-noise ratio exceeded 10.0 (tests 13, 41, 48, 55 and 69). Examining only the values of S associated with high signal-to-noise ratios, it was observed that an exponential-decay relationship ($R^2$=0.99) existed between manure depth and susceptibility to vertical kinetic energy (see Figure 4). If that trend persists and is reproducible, it may represent an artifact of the test chamber wherein the greater depth of manure provides greater cushioning to the falling weights, dissipating kinetic energy in temporary compression of the manure column rather than in resuspension of PM in the air. Such a phenomenon would not be expected (a) if the geometry of the contact face of the falling weight were irregular like that of a bovine hoof and (b) in the horizontal, shear mode of dust emission.

**Table 2. Intrinsic dust susceptibility (kg $kJ^{-1}$) of the simulated manure surface in the vertical impact mode as a function of filter slot position and the depth of uncompacted, dry manure. The signal-to-noise ratios of the test data shaded in gray exceeded 10. Each of the tests in Table 2 involved dropping all eight weights simultaneously.**

| Test # | Filter Slot Position | Total Kinetic Energy (J) | Corrected PM Mass (g) | Mean Bias (g) | PM Susceptibility (kg/kJ) | Signal/ Noise Ratio | Manure Depth (in) |
|---|---|---|---|---|---|---|---|
| 6 | 1 | 8.377 | 0.0525 | 0.0185 | 0.0063 | 2.8 | 1 |
| 13 | 1 | 51.110 | 0.4073 | 0.0256 | 0.0080 | 15.9 | 1 |
| 20 | 5 | 8.402 | 0.0157 | 0.0129 | 0.0019 | 1.2 | 1 |
| 27 | 5 | 51.110 | 0.2211 | 0.0677 | 0.0043 | 3.3 | 1 |
| 34 | 1 | 8.402 | -0.0233 | 0.0181 | -0.0028 | -1.3 | 2 |
| 41 | 1 | 51.125 | 0.2200 | 0.0144 | 0.0043 | 15.3 | 2 |
| 48 | 5 | 8.402 | 0.0263 | 0.0016 | 0.0031 | 16.4 | 2 |
| 55 | 5 | 51.125 | 0.1908 | 0.0023 | 0.0037 | 83.0 | 2 |
| 62 | 1 | 26.337 | 0.00777 | 0.0071 | 0.0003 | 1.1 | 3 |
| 69 | 1 | 26.337 | 0.02689 | 0.0017 | 0.0010 | 15.8 | 3 |
| 76 | 5 | 51.162 | 0.00943 | 0.0025 | 0.0002 | 3.8 | 3 |
| 83 | 5 | 51.162 | 0.01915 | 0.0200 | 0.0004 | 1.0 | 3 |

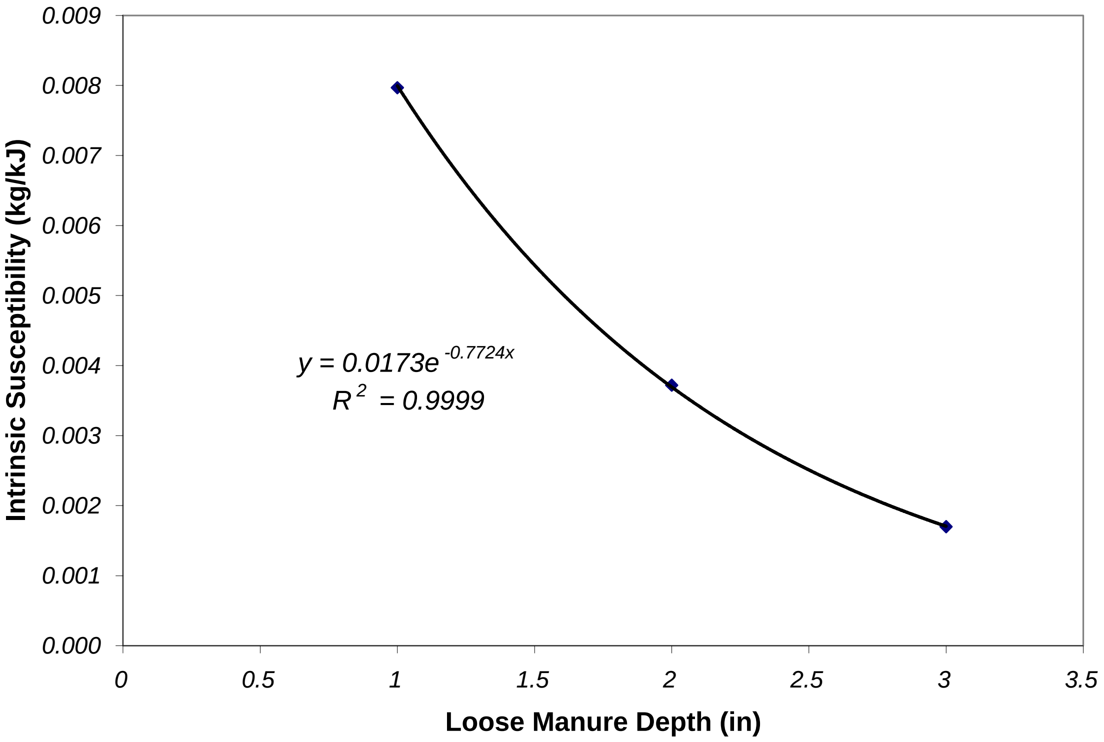

**Figure 4. Mean (n=3 for 2” depth; n=1 otherwise) intrinsic susceptibility of uncompacted manure (7.5% moisture by mass, wet basis) as a function of manure depth, showing an exponentially decreasing trend with depth. Mode of impact is vertical.**

## CONCLUSIONS

Clearly, a mechanistic method of estimating fugitive dust emissions from cattle feedyards will require much additional research. However, preliminary tests have confirmed the fundamental hypothesis: the mass of dust emitted by simulated hoof impact on a manufactured feedyard surface increases with an increase in the kinetic energy imparted to that surface. This has also begun to confirm the influence of certain manure properties on the intrinsic dust susceptibility of the loose manure layer, although measured trends were not statistically significant. Once the major factors influencing the susceptibility parameter have been described quantitatively in this simplified geometry, research will focus on developing instrumentation and analytical methods to measure the actual shear energy density imparted to feedyard surfaces by cattle. It was observed, for example, that the mode of hoof action on the loose manure layer has both normal (vertical) and horizontal components, and this investigation focused only on the normal component. Future bench-scale investigations will alter the design of the weight-drop mechanism to introduce a measurable, horizontal component to the impact of the weight on the loose manure layer. It is anticipated that susceptibility data from this testing procedure will be comparable to the "dust potential" data from the testing protocol described by Miller and Woodbury (2003). However, the method described in this study is likely to be less destructive (i.e., than the Miller and Woodbury procedure) to the structure of the loose manure layer as it develops *in situ*.

## ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial assistance of the United States Department of Agriculture under Project No. 2003-34466-11918. The Texas Legislature's biennial Special Legislative Initiative on Agricultural Air Quality, funded through the Texas Agricultural Experiment Station (TAES), provided additional funding for the project. The author is indebted to the "Posse," Kevin Heflin, Gary Marek, Chris Rogers, Shelley Howard and Arturo Romanillos, for their hard work in building and testing the weight-drop test chamber and collecting the laboratory data.

# REFERENCES

1. Consumers Union. 2001. Animal factories: pollution and health threats to rural Texas. URL: http://www.consumersunion.org/other/animal/animal3.htm.
2. Grelinger, M. A. and T. Lapp. 1996. An evaluation of published emission factors for cattle feedlots. Proccedings of the International Conference on Air Pollution from Agricultural Operations, Kansas City, MO, February 7-9.
3. Lesikar, B. J., B. W. Shaw and C. B. Parnell. 1996. Federal clean air act of 1990 implications for agricultural industries. Proccedings of the International Conference on Air Pollution from Agricultural Operations, Kansas City, MO, February 7-9.
4. Miller, D. N. and B. L. Woodbury. 2003. A simple protocol to determine dust potentials from cattle feedlot soils. Submitted to the *Journal of Environmental Quality* (in review).
5. Parnell, C. B., B. W. Shaw and B. W. Auvermann. 1999. Agricultural air quality fine particle project – Task 1: Livestock feedlot emission factors and emissions inventory estimates. Final report to the Texas Natural Resource Conservation Commission, Austin, TX.
6. Parnell, S. E., B. J. Lesikar, J. M. Sweeten and R. E. Lacey. 1994. Determination of an emission factor for cattle feedyards by applying dispersion modeling. Presented at the annual meeting of the American Society of Agricultural Engineers, Kansas City, MO, June 19-22. Paper No. 94-4042.
7. Romanillos, A. and B. W. Auvermann. 2002. Revisiting the emission factor for cattle feedyards and the effect of improved dispersion modeling. Presented at the annual meeting of the American Society of Agricultural Engineers, Chicago, IL, July 28-31. Paper No. 02-4213.
8. Sweeten, J. M. et al. 1988. Cattle feedlot dust emissions. Presented at the annual meeting of the American Society of Agricultural Engineers, Rapid City, SD. Paper No. 88-4047.
9. USEPA. 1985. Compilation of air pollutant emission factors: Volumes I and II. Office of Air Quality Planning and Standards, Research Triangle Park, NC.