Dust Emissions from Cattle Feeding Operations Part 1 of 2: Sources, Factors, and Characteristics

Air Quality Education in Animal Agriculture

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This publication discusses the sources, factors, and characteristics of dust emissions from cattle-feeding operations.

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With the trend toward larger and more concentrated animal feeding operations (CAFOs), particulate matter (PM) emissions from open-lot CAFOs are an increasingly prominent environmental issue. This is particularly true for CAFOs located in arid and semi-arid climates, where dry conditions favor dust emissions.

Particulate matter, or solid-phase aerosols, may be classified by aerodynamic diameter, which refers to the diameter of a spherical droplet of water that would have the same settling velocity in air as the aerosol particle in question. Fine particles with a mean aerodynamic diameter of about 2.5 micrometers ($PM_{2.5}$) or less may be respired deeply into the lungs. $PM_{2.5}$ is considered a threat to human health because it is associated with respiratory impairment and premature death. The so-called "inhalable" fraction of PM generally consists of particles having a mean aerodynamic diameter less than 10 micrometers (PM_{10}) and includes the $PM_{2.5}$ fraction plus a range of coarser particles, sometimes known as PMcoarse, PMc, or $PM_{10-2.5}$. The coarse fraction of inhalable PM generally is associated with reversible human health effects (e.g., allergic reactions) and quality-of-life factors. Fugitive PM from cattle feedyards also may reduce visibility and serve as a carrier for a range of malodorous compounds.

The provenance of aerosols may be classified as *primary* or *secondary. Primary* aerosols are generated directly by mechanical (e.g., grinding, scouring) or chemical (e.g., combustion) processes. On a cattle feedyard, the main sources of primary PM are hoof action on uncompacted manure, vehicle traffic on unpaved roads, feed pro-

Figure 1. Dust events generated by open-lot concentrated animal feeding operations may reduce ground-level visibility on nearby roadways. (Photo: S. Sakirkin)

Fugitive dust emissions from open-lot CAFOs are receiving increased regulatory scrutiny.

cessing (e.g., hay grinding, grain delivery), and combustion of natural gas, gasoline, and diesel fuel. The coarser, mechanically-derived particles are generally implicated in near-field to local environmental air pollution. The finer, chemically-derived particles tend to have environmental significance at the regional to national scale.

Secondary PM forms in the atmosphere as a product of acid/base or sunlight-mediated redox reactions. Secondary aerosols associated with CAFOs derive principally from gas-phase ammonia (a base), which dissolves into atmospheric moisture and there reacts with dissolved sulfate, nitrate, and/or chloride ions (all acids) to form fine particles. Because secondary PM tends to form fine to very fine particles, its environmental implications are regional to transnational.

Regulatory Matters

Fugitive dust emissions from open-lot CAFOs are receiving increased regulatory scrutiny, especially in the San Joaquin Valley of California and in southern Arizona, where PM concentrations characteristically exceed federal standards. Currently, odors associated with dust are regulated only under nuisance provisions, in which enforcement is driven either by complaints to the state regulatory authority or by nuisance litigation.

The National Ambient Air Quality Standards (NAAQS) establish threshold concentrations for certain *criteria pollutants* above which adverse human health effects may be expected in sensitive individuals. Particulate matter is one of those criteria pollutants. As of November 2011, these standards contain three independent, primary (i.e., directed at protection of public health) standards for PM. For PM_{10}, which was first regulated under the NAAQS in 1987, the only remaining standard is a 24-hour average concentration of 150 micrograms PM_{10} per cubic meter (μg/m^3). For $PM_{2.5}$, there are currently two standards, a 24-hour average concentration of 35 μg/m^3 and an annual average concentration of 15 μg/m^3. Any airshed in which PM concentrations exceed the NAAQS[†] for any criteria pollutant is classified as a nonattainment area (NAA). At present, southern Arizona and south central California are designated as nonattainment areas for PM_{10}, and central and southern California have a number of nonattainment areas for $PM_{2.5}$. In both states, the state implementation plan (SIP) for returning to compliance with the NAAQS prominently involves beneficial management practices (BMPs) for agricultural sources, including CAFOs.[‡]

State air pollution regulatory authorities administer and enforce air pollution regulations. Many states have established their own regulations, which are more stringent than those set by federal agencies. Several states administer programs to monitor ambient air quality, issue operating permits, and conduct compliance inspections and enforcement actions.

Emission Factors and Characteristics

High concentrations of fugitive dust from open-lot CAFOs result from three primary factors. The raw material for dust emissions is uncompacted manure (often mixed with soil) on corral surfaces. The drier that manure is, the more susceptible it is to emission as dust.[§] The mechanical energy required to emit the dust is either animal hoof action or wind scouring (Mielke et al., 1974), so elevated concentrations may occur during periods of increased animal activity or during high-wind events. Finally, and perhaps most important, relatively stable atmospheric conditions known as *inversions* may confine ground-level emissions to a shallow layer of air at the ground level rather than dispersing it to higher elevations through atmospheric turbulence.

Footnotes

[†]"Violation" of the standard does not mean a single instance of a measurement exceeding the numerical standard; rather, "violation" is defined statistically. In the case of the 24-hour PM_{10} standard, three measurements exceeding the standard within a three-year period constitute a violation of that standard. The statistical provisions for the two $PM_{2.5}$ standards are slightly more complicated.

[‡]See e.g., *http://www.azda.gov/ACT/CMPCostEff.pdf* (accessed 13 November 2011).

[§]See Razote et al. (2006), "Laboratory evaluation of the dust-emission potential of cattle feedlot surfaces," *Transactions of the ASABE* 49(4):1117-1124; and Guo et al. (2011), "Laboratory evaluation of dust-control effectiveness of pen surface treatments for cattle feedlots," *Journal of Environmental Quality* 40(5):1503-1509.

A diurnal pattern of dust emissions peaking shortly after sunset is commonly observed at many CAFOs in the semi-arid West. This phenomenon, commonly known as the evening dust peak (EDP), results from the temporal coincidence of the three primary factors. First, pen surface moisture is at its daily minimum in the late afternoon to early evening so that dry pen-surface conditions predominate (McCullough et al., 2001). Second, as the sun angle and daytime temperatures decrease, cattle become more active, and the increased hoof action suspends more manure particles in the air. Third, atmospheric stability increases, the boundary-layer mixing height decreases, and winds diminish, reducing atmospheric dispersion. When those three conditions coincide, the peak short-term concentration (e.g., 5- to 30-minute averages) may be 10 to 15 times higher than the 24-hour average (*Figure 2*).*

Many states monitor ambient air quality, issue operating permits, and conduct enforcement.

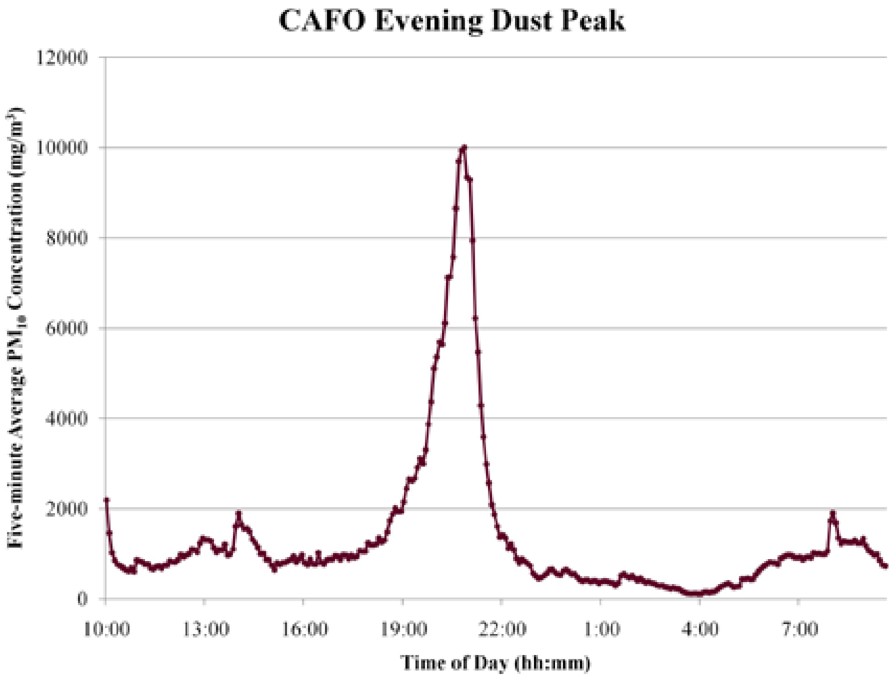

Figure 2. Five-minute average PM_{10} concentrations immediately downwind of the pen area showing the diurnal pattern of the evening dust peak typical of cattle feedyards in the West. Note that these data are not property-line concentrations.

Footnote

*These values of the peak-to-mean ratio are characteristic of open-lot beef feed-yards. For open-lot dairies, which feature significantly different patterns of animal behavior and increased shaded area as compared with feedyards, the peak-to-mean ratio is considerably smaller. See Auvermann (2011), "Texas/New Mexico open-lot research," Proceedings of the Western Dairy Air Quality Symposium, Sacramento, CA, April 20.

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Air Quality Education in Animal Agriculture

Dust Emissions from Cattle-Feeding Operations Part 2 of 2: Abatement

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This publication discusses dust abatement measures for cattle-feeding operations.

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Dust Abatement Measures

Dust abatement plans for cattle feeding operations encompass pen design and maintenance, feeding strategies, water application, and manure management. In general, dust-control tactics for concentrated animal feeding operations (CAFOs) are also effective at controlling odor emissions, particularly in the case of pen-surface management.

Manure Harvesting

Regular removal of uncompacted manure from corral surfaces is paramount to reducing dust emissions. Benchtop studies by Razote et al. (2006) have confirmed Auvermann's (2000) conjecture that the dust potential of a corral surface increases with increasing depth of uncompacted manure. The fundamental reason appears to be that the rear bovine hoof, which is characteristically dragged horizontally across the corral surface — as contrasted with the more vertical motion of the front hoof — accounts for most of the mechanical shearing that resuspends the manure as PM. As the rear hoof penetrates more deeply into uncompacted manure, the mass of manure resuspended in the air increases accordingly. Therefore, reducing the depth of uncompacted material limits the rear hoof's depth of penetration, limiting dust emissions.

The operational objective of manure-harvesting operations is to keep corral surfaces smooth, firm, and well-drained, maintaining a 1-2 inch thick surface layer of well-compacted manure and soil. A variety of machinery may be used to good effect, with paddle scrapers moving tremendous volumes of manure out of the larger pens and box scrapers collecting smaller volumes of looser, drier material more frequently. Machinery operators should be given a clear picture of the management objective and solid training in machinery settings and operation.

Attentively harvesting manure from pens containing cattle improves pen conditions with little reported effect on cattle performance or stress (Auvermann, 2009). Some feedyards in the southern Great Plains are operating manure-harvesting equipment continually across the yard regardless of the presence or absence of cattle in the pens (*Figure 1*).

Where the seasonality of farmer demand for manure presents logistical challenges to manure removal, and where pen slopes are sufficient to sustain good drainage without building manure mounds, a year-round composting operation provides an outlet for manure that otherwise would have to be stockpiled in the pens and compacted in place for longer-term storage. When mounds are used for seasonal manure storage and/or enhanced drainage, the manure should be moistened to 20-30 percent and compacted in place by a front-end loader or other wheeled machinery. Track-driven tractors will achieve somewhat less than the desired degree of compaction.

The upper limit on the amount of water that would need to be added to the uncompacted, harvestable manure to reach the 30 percent (wet basis) moisture content conducive to good compaction is about 650 gallons per acre of pen surface per inch of collectable manure depth.[†]

Regular removal of uncompacted manure from corral surfaces is paramount to reducing dust emissions.

Figure 1. Harvesting manure from populated pens improves pen conditions in feedyards with little reported effect on cattle health or performance. Note the pen surfaces in the background, which are hard, smooth, and well-drained. (Photo: B. Auvermann)

Manure Harvesting Frequency

The frequency of manure harvesting from pens is determined by pen conditions, cattle liveweight, feed intake and composition, and stocking density (or its inverse, cattle spacing). Accumulations of uncompacted surface manure should be minimized by frequent harvesting, but care should be taken to maintain a 1- to 2-inch layer of dense, compacted manure and soil above the underlying mineral soil. Harvesting manure too frequently or with poor technique — especially with "push" blades like front-end loader buckets — may damage the underlying layers. This can make future pen surface maintenance difficult, exacerbating odor and dust conditions, and decreasing the fertilizer and/or biofuel value of the harvested manure.

Economic and operational needs also determine the optimal frequency for harvesting manure. Operationally, it is easiest to harvest manure from empty pens rather than occupied pens. Open-lot dairies may have the opportunity daily to harvest manure when the cows head to the milking parlor, but daily manure harvesting is probably not necessary for most dairies.

Pens in beef feedlots, on the other hand, may be continuously occupied for 25 weeks or more. A common practice on many feedlots is to remove accumulated manure from pen surfaces only when cattle are shipped out of the pens. Monitor pen conditions and remove the uncompacted surface layer of manure before it accumulates too deeply — even if pens are occupied by animals. A reasonable threshold depth to trigger box-blade removal of uncompacted manure is 1.5-2 inches.

The depth to which manure is harvested from pens also affects the quality of manure for use as a fertilizer or biofuel. Most fresh manure contains at least 15 percent (dry basis) non-volatile solids (or *ash*). Over time, organic matter on the pen surface oxidizes to carbon dioxide, thereby increasing the remaining ash content; and hoof action, especially in wetter areas of the pen surface, may mix the manure with the mineral subsoil. In such cases, it is common to observe ash contents from 30 to 70 percent of dry matter in harvested manure (*Figure 2*).

Footnote

†For a more detailed treatment of water-based and corral-management tactics for feedyard dust control, see Auvermann and Casey (2011), "Feedyard dust control in an epic Panhandle drought, 2010-2011," Texas AgriLife Extension Service Bulletin SP-417, College Station, TX.

Ash content is undesirable because it adds weight to manure and decreases the average concentration of active ingredient(s): nitrogen, phosphorous, and potassium for fertilizer, and carbon, hydrogen, and oxygen for biofuel feedstocks. High ash indicates that mineral soil has been incorporated into the manure, which may occur if the machinery penetrates the manure/soil interfacial layer rather than skimming only the uppermost, primarily organic layers.

Manure Harvesting Equipment and Practices

Several kinds of manure removal equipment and different practices may be used to harvest manure from a pen surface. Examples are box blades, front-end loaders, elevating scrapers, and maintainers (followed by box blades and/or loaders). Some practices include scraping and removal; scraping and compaction for temporary in-pen storage; and building manure mounds to enhance pen drainage. The combination of

Figure 2. Although animal behavior and rainfall are the most obvious causes of wallows and holes like the one pictured here, these wallows may have been initiated by poor manure-harvesting techniques breaking into the underlying layers of the pen surface, exposing caliche or clay palatable to the animals, and creating areas from which rainfall runoff cannot drain. (Photo: S. Sakirkin)

Attentively harvesting manure from pens containing cattle improves pen conditions with little reported effect on cattle performance or stress.

equipment most commonly used in the Texas Panhandle — and apparently the cheapest to operate — is box blade, front-end loader, and dump truck (Bretz et al., 2010).

Manure harvesting equipment run by trained, skilled operators should be capable of leaving about 1 to 2 inches (2 to 5 centimeters) of hard, smooth, and evenly sloped manure/soil mixture over the underlying mineral soil. Different types of equipment vary in their effectiveness at ensuring rapid drainage and efficient manure removal. Machinery intended for digging or scooping, such as a front-end or bucket loader, may make it more difficult to avoid gouging the pen surface through the underlying compacted layers of manure and soil. Box blades, though having limited capacity and no means of manure removal, are pulled rather than pushed and can be more easily adjusted for penetration depth (*Figure 3*). Such features allow equipment operators to maintain an optimal pen surface more easily. Once the manure has been stacked by a box blade, a bucket loader is used to remove the manure from the pile.

The frequency of manure harvesting from pens is determined by pen conditions, cattle liveweight, feed intake and composition, and stocking density or cattle spacing.

Moisture Balance

The next significant dust-abatement strategy for feedyard surfaces is optimizing the moisture content of the surface manure. Dust predominates when moisture levels are low, and odor potential increases as moisture increases. However, feedyard dust is also associated with odors because some odorous compounds adsorb to the particles (*Figure 4*). The optimal moisture content for minimizing both dust and odor lies in the range of 25 percent to 45 percent on a wet basis (Sweeten and Lott, 1994).

Water can be applied to pen surfaces, alleys, and unpaved roadways by solid-set sprinkler systems, tank trucks, or water wagons. These systems should be capable of delivering a minimum of two-thirds of a centimeter (¼ inch) of water uniformly across the back 2/3 (i.e., the 2/3 furthest from the feed bunk) of each pen. A study found that solid-set sprinkler systems appear to reduce downwind PM concentrations by 55-80 percent (Bonifacio et al., 2011).

Figure 3. Box blades are effective at maintaining a smooth, hard pen surface without gouging the interfacial layer and exposing mineral soil. The manure being harvested in this photo will have a higher heating value of about 5,000 Btu/lb as collected and would be considered a relatively high-value biofuel feedstock. (Photo: S. Sakirkin)

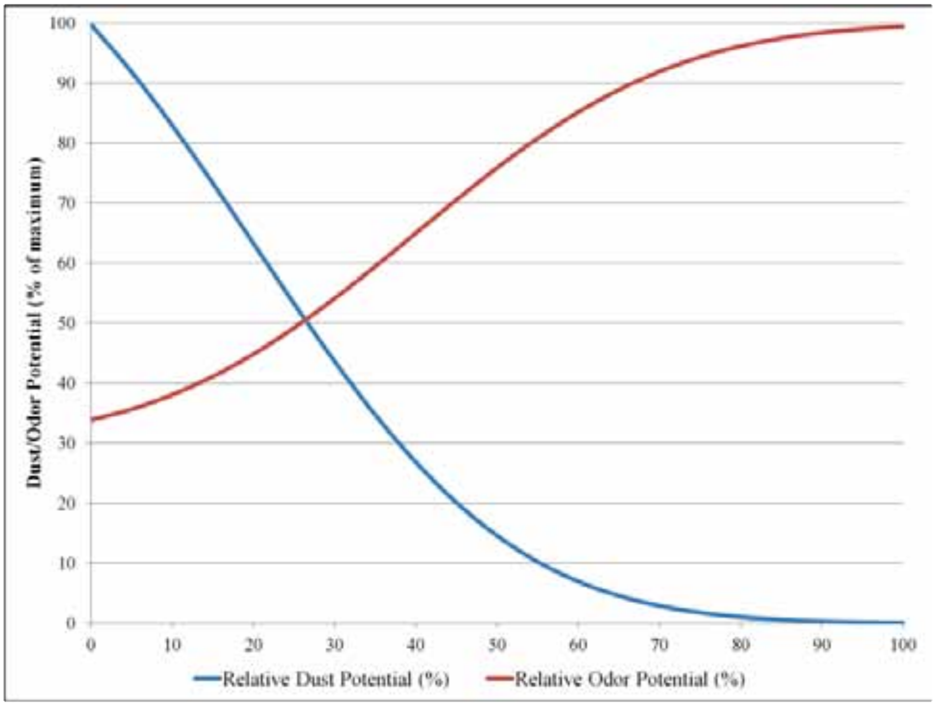

Figure 4. The semi-quantitive relationship between dust and odor potential as a function of manure moisture content on a feedlot pen surface (Auvermann, 2009).

A survey of 41 feedyards in the southern High Plains found that 54 percent of the feedyards applied water for dust suppression. The most common methods of applying water were water trucks and solid-set sprinkler systems with a couple of feedyards utilizing traveling gun systems. The initial investment, annual fixed, operational, total costs, as well as total cost per head marketed associated with solid-set sprinklers, reel-mounted traveling gun sprinklers, and water trucks for different sizes of feedyards, have been estimated (Amosson et al., 2006; Amosson et al., 2007; Amosson et al., 2008) and are summarized in *Table 1*. Solid-set sprinklers had the lowest operational cost and were easiest to use because they can be automated. However, they are capital-intensive, especially as a retrofit on existing feedyards.

Water trucks or wagons require less capital outlay and are more versatile for applying water to alleys or roadways, but have higher labor, fuel, and maintenance costs when compared to solid-set sprinkler systems.

A traveling gun system had the lowest total cost of the options analyzed but was less practical than solid-set sprinklers or water trucks. Traveling guns require more management, operate properly only on straight lines of travel, and can temporarily block alleys, interfering with other feedyard operations.

A survey of 41 feedyards in the southern High Plains found that 54 percent of the feedyards applied water for dust suppression.

Table 1. Estimated investment, fixed, operational, total annual costs, and total cost in dollars per head marketed for a solid-set sprinkler system, traveling gun, and water truck for different sizes of feedyards.

Head Capacity (x 1,000)	Initial Investment (x $1,000)	Fixed Cost $/hd Capacity	Operational Cost $/hd Capacity	Total Cost $/hd Capacity	Total Cost[1] $/hd Marketed
Solid-Set Sprinkler[2]					
10	307	3.63	0.46	4.09	2.05
30	649	2.56	0.40	2.96	1.48
50	1,015	2.40	0.39	2.79	1.40
Traveling Gun[3]					
10	45	0.62	1.05	1.67	0.83
30	96	0.44	0.94	1.38	0.69
50	151	0.41	0.95	1.36	0.68
Water Truck[4]					
10	155	1.97	1.80	3.77	1.89
30	310	1.32	1.74	3.06	1.53
50	464	1.18	1.72	2.90	1.45

[1]Assumes annual turnover rate of 2 head marketed per head of one-time capacity.
[2]Source: Amosson et al., 2006.
[3]Source: Amosson et al., 2007.
[4]Source: Amosson et al., 2008.

Additional Design Considerations

Good pen design can make manure harvesting and surface maintenance more effective and efficient, which in turn supports reduced emissions of both dust and odor. The shape of a pen should allow for complete manure harvest from edge to edge. Pen surfaces should slope uniformly away from feed bunks/aprons and water troughs at 3-5 percent. Wherever possible, pens should drain discretely into a runoff channel rather than into each other. Pen-to-pen drainage is undesirable because runoff exits the pen area more slowly and creates persistent wet conditions in downstream pens. Those conditions are even more pronounced as hoof action creates manure ridges beneath fencelines, further retarding runoff. Where pen-to-pen drainage cannot be easily avoided, special care should be taken to maintain maximum drainage capacity by eliminating ridges of manure where fencelines cross the drainage channel.

In-pen manure mounding can improve drainage in pens lacking adequate slope and provide livestock with dry areas to rest, reducing hoof traffic in low-lying areas susceptible to damage during wet conditions. In some cases, in-pen mounding may be more economical than stockpiling manure in a dedicated staging area prior to being land applied or composted.

Pen surfaces also may be paved with fly ash or crushed bottom ash[‡], concrete, or a soil/cement blend. Where mineral soil is unpaved, it should be evenly compacted to near Proctor density and should remain undisturbed by animal activity or machinery operations.

Footnote

‡Fly ash, crushed bottom ash, and hopper ash are combustion residues from coal-fired power plants. In general, these ash products have excellent cementing properties and good mechanical strength when installed properly, but they are not as durable as structural concrete. For more on paving feedyard pens with compacted fly or bottom ash, see Sweeten and Amosson (1996) and Pflughoeft et al. (2004).

Other Dust Mitigation Strategies

Other dust-mitigation options — some potentially effective but still experimental — include:

- Vegetative barriers, such as shelterbelts or windbreaks of one or more rows of tall trees, capture airborne particles and gases on leaf or needle surfaces. Shelterbelts provide the added advantages of reducing erosion and serving as an aesthetic visual screen.[§]
- Increasing stocking density may reduce dust emissions in some cases, but this effect is highly dependent on pen surface moisture and may negatively affect cattle performance (Auvermann and Romanillos, 2000). Still, where unallocated water resources are marginal and seasonal moisture deficits are not extreme, stocking density manipulation may be a cost-effective option to reduce direct water applications.
- Pen surface amendments, such as those effective for dust control on unpaved roadways (usually resins or oils), are being investigated for use on feedyard pen surfaces. This approach may not be cost-effective, because unlike roadways, manure is constantly being added to the pen surface, and any pen surface amendment would require frequent reapplication. In theory, other topical applications of crop residues (e.g., straw, hay, cotton gin trash, or peanut hulls) may reduce evaporation, absorb the energy from hoof action that would otherwise resuspend manure particles, reduce the amount of particulate matter picked up by air currents, and increase the quality of manure for land application or composting.[**]
- Feed-management techniques that may reduce dust emissions include (a) changing the time of day at which livestock are fed, and (b) changing the fat content in cattle diets. Delaying the last feeding of the day until late afternoon may reduce animal activity during the critical dust-peak conditions near sunset. Increasing fat in cattle diets may increase the cohesiveness of manure, making it more resistant to being pulverized by hoof action.[††]
- Unpaved roadways and feed mills are other sources of dust emissions found on feedyards. Vehicular traffic on feedyards may take the form of livestock, feed, water, and service trucks. Operating these vehicles at very slow speeds on dry, unpaved roads is helpful in reducing dust emissions. Regular watering of unpaved surfaces at the beginning of the day, prior to the start of heavy vehicular activity, is also useful. The application of resins or petroleum derivatives to caliche, dirt, or stone roadways may be more expensive than frequent watering, but has been shown to be effective at reducing dust emissions from vehicular traffic on feedyards (Gillies et al., 1999).

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Footnotes

[§]For a more thorough assessment of shelterbelt potential for trapping feedyard dust, see Li Guo, "Measurement and control of particulate emissions from cattle feedlots in Kansas," PhD dissertation, Kansas State University, 2011.

[**]Several of these surface amendments have been tested at the benchtop scale for efficacy in feedyard dust control. See Guo, "Measurement and control," pp. 90ff.

[††]Increasing dietary fat has not been evaluated on a large commercial scale and has several drawbacks, including (a) reduced feed intake or feed-to-gain performance, and (b) safety concerns for pen riders and their horses working on slick pen surfaces.

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AIR QUALITY

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