AERMOD DISPERSION MODELING OF PARTICULATE MATTER EMISSIONS FROM CATTLE FEEDYARDS AND COTTON GINS

J. Bairy
R. McGee
C. B. Parnell Jr.
K. Steubing
Texas AgriLife Research
College Station, Texas
B. Auvermann
Texas AgriLife Research and Extension
Amarillo, Texas

Abstract

State Air Pollution Regulatory Agencies (SAPRAs) regulate the emission rates of Particulate Matter (PM) emitted from cattle feedyards, dairies, cotton gins, and grain elevators by permitting. The permitted allowable emission rates are determined by limiting modeled concentrations using the EPA preferred dispersion model to concentrations less than the National Ambient Air Quality Standard (NAAQS). In order to model regulated PM concentrations, an emission factor is required. In previous studies, PM emission factors were developed using concentrations measured with Federal Reference Method samplers. In this research, PM emission factors were developed using the concentration data from Tapered Element Oscillating Microbalance (TEOM) samplers. The goal of this research was to use reverse modeling and American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee's Dispersion Model (AERMOD) to generate regulated PM emission factors for cattle feedyards. TEOM concentrations for PM_{10} were compared with the predicted downwind PM_{10} concentrations from AERMOD for the same feedyard to find a correlation between the two. It was observed that TEOM sampler concentrations of PM_{10} were much higher than the concentrations from co-located FRM samplers. Three corrections were made to TEOM concentration measurements based upon previous research. These corrections were (1) TEOM vs. FRM, (2) FRM PM_{10} pre-collector oversampling and (3) evening dust peaks. Additionally, AERMOD modeling was used to predict PM_{10} and $PM_{2.5}$ concentrations for a hypothetical cotton gin located near Amarillo, Texas. Modeling was performed for property line distances of 50 and 100 meters and for 20, 40, and 60 bale-per-hour cotton gins. The results were evaluated for compliance with the NAAQS at the fence line and beyond. The PM_{10} and $PM_{2.5}$ 24-hr concentrations predicted by AERMOD exceeded the NAAQS at the property lines of the cotton gins for the emission factors used.

Introduction

The first federal legislation to addressing air pollution was the air pollution control act of 1955 (Cooper and Alley, 2002). Congress amended federal air quality legislation in 1963, 1967, 1970, 1977, and 1990. The Clean Air Act (CAA) amendments of 1970 provided the authority to create EPA and "put teeth into enforcement of air pollution regulation" The 1970 CAA amendments required EPA to establish National Ambient Air Quality Standards (NAAQS) and required states to submit State Implementation Plans (SIPs) to EPA. The NAAQS consisted of primary standards to protect public health with an "adequate margin of safety" and secondary standards to protect public welfare. The primary NAAQS were concentrations of air pollutants not to be exceeded in populated areas. States were required to monitor concentrations in community-oriented monitoring regions to insure compliance. Watson et al. (1997) described guidance for monitoring sites for compliance with the NAAQS as follows: "Community-oriented (core) monitoring sites are beyond the zone of influence of a single source, and should have neighborhood- to urban- scale zones of representation. The principal purpose of community-oriented monitoring sites is to approximate the short-term and long-term exposures of large numbers of people where they live, work, and play. A monitor placed at the fence line of an emissions source would not be considered to represent community exposures, even though there might be residences abutting that fence line." The current controversy associated with regulation of PM_{10} emissions from rural agricultural sources is the use of the NAAQS as a concentration not to be exceeded where no public reside. The current NAAQS for PM_{10} is 150 micrograms per cubic meter ($\mu g/m^3$) based upon a 24-hour average. Today, areas can be designated as attainment or non-attainment based on modeled or measured concentrations. If areas are classified as non-attainment, State Implementation Plans (SIPs) outlining plans to bring these areas into attainment are submitted to EPA.

Permitting with the NAAQS:

States have adopted an alternative use of the NAAQS for permitting purposes. Modeled or measured concentrations of PM_{10} must not exceed the NAAQS (150 $\mu g/m^3$) at the fence line and beyond or the facility is in violation of its permit conditions and subject to enforcement actions of the SAPRA. SAPRAs have utilized this "special use" of the NAAQS for permitting rural agricultural and industrial operations irrespective of whether the off-property concentrations impact public or are in locations where "large numbers of people live, work, and play". This special use of the NAAQS requires that the permit allowable emission rates of sources be limited so that modeled or measured downwind concentrations of regulated air pollutants not exceed the NAAQS. If the measured or modeled concentrations of PM_{10} or $PM_{2.5}$ exceed the NAAQS at the property line and beyond, the emitting facility may be in violation of its permit conditions. The consequences of a permit violation could be enforcement action and a mandate that the facility's emission rate be reduced. Modeled PM_{10} or $PM_{2.5}$ concentrations require emission factors that accurately represent emission rates. The emission factors used for predicting downwind PM concentrations using the AERMOD dispersion model must be accurate.

Emission Factors for Modeling:

In order to estimate PM concentrations using dispersion modeling, an emission factor is required. The emission factors listed in AP-42 Compilation of Air Pollutant Emission Factors are often used by EPA and SAPRAs to permit facilities (USEPA, 1993). The first AP-42 emission factor for cattle feedyards was first reported to be 280 lbs. of total suspended particulate (TSP)/ 1000 head-day which was the result of a study by Peters and Blackwood (1977), the study was funded by EPA. Peters and Blackwood (1977) used data reported by Algeo et al. (1972) and determine that the cattle feedyard TSP emission factor was 280 lbs per 1000 head-day. They used the infinite line source Gaussian model for back-calculating the emission factors. Sweeten (1988) used collocated FRM PM10 and TSP samplers at cattle feedyards and determined that 25% of TSP emitted by cattle feedyard consisted of PM_{10}. These findings resulted in EPA adopting an emission factor for PM_{10} of 70 lbs PM_{10}/ 1000 head-day. S.Parnell (1994) used the EPA recommended Fugitive Dust Model with measured FRM concentrations and Sweeten et al. (1988) data and recommended an emission factor of 10 lbs PM_{10}/1000 head-day. McGee (1997) used the EPA recommended Industrial Source Complex-3 Short Term (ISCST-3) and reported the emission factor for cattle feedyards was 20 lbs PM_{10}/1000 head-day. Parnell et al. (1999) found that Peters and Blackwood had made errors in their calculations and assumptions. Parnell et al., (1999) reported results of a state supported study to measure concentrations at a 60,000 head feedyard which was an emission factor of 15 lbs PM_{10}/1000 head-day which is currently being used by the regulators in Texas.

FRM vs. TEOM Concentrations Measurements – FRM/TEOM:

Cattle feedyard PM emission factors were developed using concentrations measured with Federal Reference Method (FRM) samplers (Parnell et al., 1999). The FRM sampling protocol for cattle feed yards consists of placing samplers in strategic locations around the yard and measuring the mass of PM collected on a filter as a constant flow of sampled air. The net mass of PM divided by the sampled air volume is the FRM concentration. FRM concentrations measurements are typically obtained for periods of 3 hours during the day and 9-10 hours at night. The resulting FRM concentrations are averages over time and do not show short term variations of concentrations that are common to TEOM concentration measurements. In contrast TEOM concentrations are reported measurements of five minutes or less and short term variations are clearly present in the concentration versus time plots. Skloss (2008) reported significant differences of PM_{10} concentrations measurements from co-located TEOM and FRM samplers downwind of cattle feedyards. Vanderlick et al., (2009) reported results of studying Skloss's PM_{10} downwind and upwind concentrations measurements from side-by-side TEOM and FRM samplers. He found that FRM downwind concentrations were significantly lower than the TEOM measurements. He also found that the upwind FRM and TEOM concentrations were not significantly different. This was also the finding that resulted when analyzing the data reported by Lambeth's (2008) study sampling 24-hour PM_{10} concentrations in urban areas with co-located FRM and TEOM samplers. It was concluded that PM_{10} sampling in locations with mass median diameters (MMD) are less than 10 µm and low concentrations (less than 100 $\mu g/m^3$); TEOM and FRM samplers are

not statistically different. However, in the presence of high concentrations measurements (greater than 100 μg/m^3) of PM_{10} with MMDs greater than 10 micrometers typical of PM emitted by agricultural sources, TEOM and FRM concentration measurements were not equal. The FRM/TEOM correction was FRM is equal to 60% of the TEOM measurement.

FRM vs. TEOM Concentrations Measurements – Over-Sampling:

The FRM sampler performance characteristics recommended by EPA are a cut point of 10 ± 0.5 μm and a slope of slope of 1.5 ± 0.1(USEPA, 2001). For a number of years, faculty in the Center for Agricultural Air Quality Engineering and Science (CAAQES) have reported that FRM sampling of PM_{10} in the presence of dust with large MMDs results in concentrations that are 2 to 4 times higher than the true concentration (Wang et al., 2005; Buser et al., 2006). This result was referred to as "over-sampling". The TEOM sampler used the same pre-collector as the FRM for PM_{10} and $PM_{2.5}$ sampling. An adjustment of the TEOM PM_{10} measured concentration was made by multiplying the TEOM measurements of PM_{10} by 0.5. This adjustment was referred to as the "oversampling" adjustment. The combined factor for both over-sampling and FRM/TEOM correction was 0.5*0.6=0.3. All TEOM measurements used to determine emission factors in this study were adjusted by multiplying the raw TEOM PM_{10} concentrations by 0.3.

FRM vs. TEOM Concentrations Measurements – Evening dust peaks (EDP):

Hamm, (2005) reported sharp spikes in concentrations measured with TEOM samplers. These were referred to as "evening dust peaks (EDP)". (EDPs usually occur in the evening.) Hamm hypothesized that EDPs were a consequence of meteorological conditions such as reduced mixing height, reduction in wind velocity, and a more stable stability class during this time period. Others have the opinion that EDPs are a consequence of cattle activity. If these EDPs are a consequence of cattle activity, the EDPs should be included in the correct determination of the emission factor. Previous research results EDPs significantly impact 24-hour concentration averages of TEOM data. It has been hypothesized that EDPs are a consequence of increased cattle activity and are not readily apparent in average FRM concentrations results. In an attempt to prevent the EDP from inflating the calculated emission factor, all concentrations between 6:00PM and 10:00PM were not included in the 24 hour average concentration used to produce the PM_{10} emission factor from TEOM data. This is referred to as the EDP correction.

Emission Factors for Cattle Feedyards

TEOM samplers were used by Auvermann (2010) to measure PM_{10} concentrations upwind and downwind at a cattle feedyard (CFY) in Panhandle Texas (See Figure 1). The data for this research were TEOM 5-minute PM_{10} concentrations measured from September 2010 through December 2010. Two TEOM samplers were located on opposite sides of the cattle feedyard to measure concentrations upwind and downwind based on the prevailing wind direction. The wind direction during sampling was not always in the prevailing wind direction. Five minute, TEOM PM_{10} concentrations along with meteorological data provided by Faulkner (2010) were used to estimate the daily 24-hour concentrations. AERMOD was used with the meteorological data and a ten pound per 1000 head-day (lbs/ 1000 head – day) emission factor was used to determine the 24-hour concentration referred to as the unit flux concentration. The adjusted acceptable TEOM PM_{10} concentrations were used with the CAAQES protocol to determine the emission factors. See Figure 3. Each of the five minute TEOM downwind concentrations were adjusted by applying the FRM/TEOM and over-sampling corrections. The EDP adjustments consisted of excluding the five-minute TEOM measurements between 6:00PM and 10:00PM each day from the average. The TEOM concentrations measurements that were not within the ± 45 degrees were also excluded. The remaining TEOM concentrations were averaged and assumed to be equal to the 24-hour concentration for that day. This procedure was followed for the months of September, October, November and December 2010.

AERMOD was used with the pre-processor AERMET to predict 24-hour downwind PM_{10} concentrations at the TEOM receptor locations. The meteorological data were processed by AERMET to generate boundary layer parameters. Grassland autumn values for the particular location were chosen for surface roughness, albedo and Bowen ratio. Missing data for cloud cover were borrowed from the EPA for that particular county (USEPA, 1992). The CAAQES protocol was used for developing emission factor using AERMOD. An emission factor of 10 lbs/ 1000 head – day is equivalent to a flux of 3.77 □ g/m^2-s.

Table 1. Adjustments (corrections) of measured TEOM five-minute PM_{10} concentrations to obtain 24-hour average concentrations. The potential number of five minute TEOM measurements per day was 240 with the 4 hour exclusion. The adjustments resulted in less than 140 measurements per day used to approximate the TEOM approximation of the 24-hour average.

	Concentrations ($\mu g/m^3$)	TEOM vs FRM	Ave TEOM 5-min PM_{10} Corrections
1	upwind	-	TEOM ave= TEOM meas.
3	Downwind	FRM/TEOM	TEOM ave =0.6*TEOM meas.
4	Downwind	Oversampling	TEOM ave =0.5*TEOM meas.
5	Downwind	EDP	Excluded 4 hours between 6:00PM and 10:00PM
6	Downwind	TEOM meas. for wind Outside of ± 45 deg.	Excluded

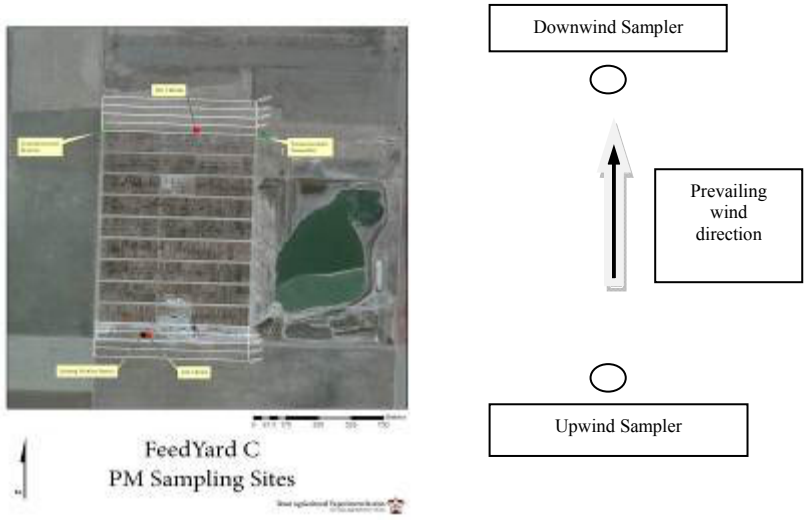

Figure 1: Cattle feedyard sampling layout. The sampler located on the north side of the yard was designated the downwind sampler due to the northerly direction of the prevailing wind.

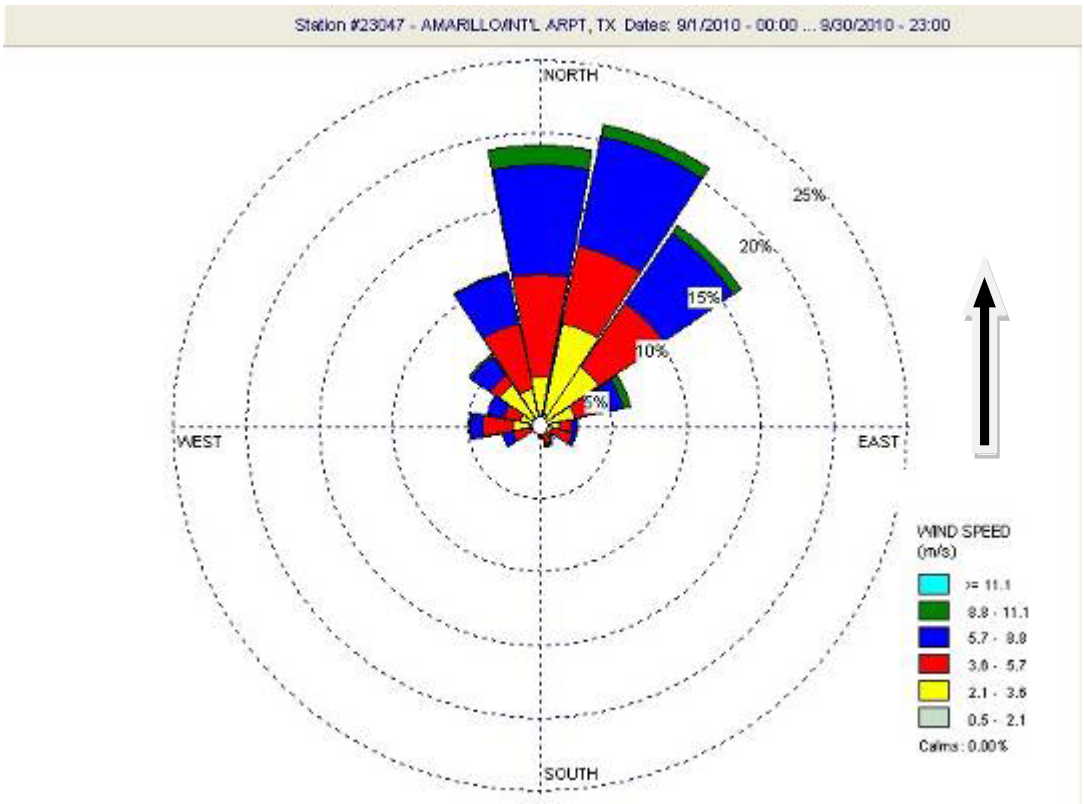

Figure 2: Wind rose for September 2010 generated from AERMOD pre-processor AERMET showing the prevailing wind direction towards North. The wind speeds recorded are in m/s.

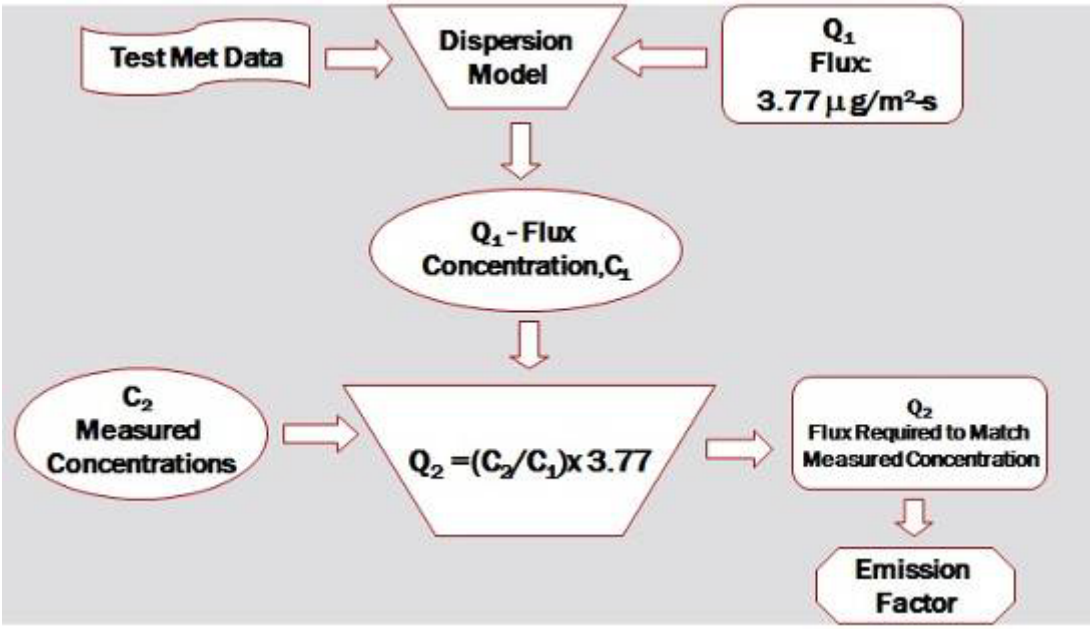

Figure 3: CAAQES protocol for deriving emission factor using dispersion model.

Results and Discussions

To obtain emission factors of cattle feedyards, TEOM concentrations measured for PM_{10} were adjusted with correction factors for TEOM vs. FRM concentrations, oversampling of FRM PM_{10} pre-collector and the removal of evening dust peaks. On the analysis done on the corrected TEOM concentration data, it was found that during the months of September and October, certain daily average concentrations were abnormally high. The reason for the spikes in daily average concentrations was that there were peaks in certain 5-minute TEOM data at times other than the evening dust peaks time-frame of 6:00 PM to 10:00 PM. To remove the bias to the daily concentrations from these dust peaks, the 5 minute concentrations which exceeded values that were thrice the standard deviation of the mean were removed from this study. (Steinbach et al., 1950) Subsequently, three 5-minute concentrations were removed from a total of 2743 5-minute data points for the month of September and seventeen 5-minute concentrations were removed from a total of 2107 5-minute data points for the month of October.

The daily average concentrations for PM_{10} at the cattle feedyard C from the corrected TEOM data were 169 $\mu g/m^3$ for September, 107 $\mu g/m^3$ for October, 43 $\mu g/m^3$ for November and 63 $\mu g/m^3$ for December. The average 24-hr downwind concentrations of PM_{10} predicted from AERMOD were 103 $\mu g/m^3$ for September, 119 $\mu g/m^3$ for October, 55 $\mu g/m^3$ for November and 84 $\mu g/m^3$ for December for CFY. The measured concentrations of PM_{10} exceeded the NAAQS at property line for September according to the adjusted TEOM concentrations while the concentrations were below the NAAQS for the months of October, November and December. The concentrations predicted by AERMOD were below the NAAQS for all the four months. Both the measured and modeled concentrations were well below the NAAQS for the months of November and December probably due to rain events. There were some days for which there were no sufficient 5-minute concentrations from TEOM. These data were excluded from the study since they did not represent the daily average concentration for the particular day.

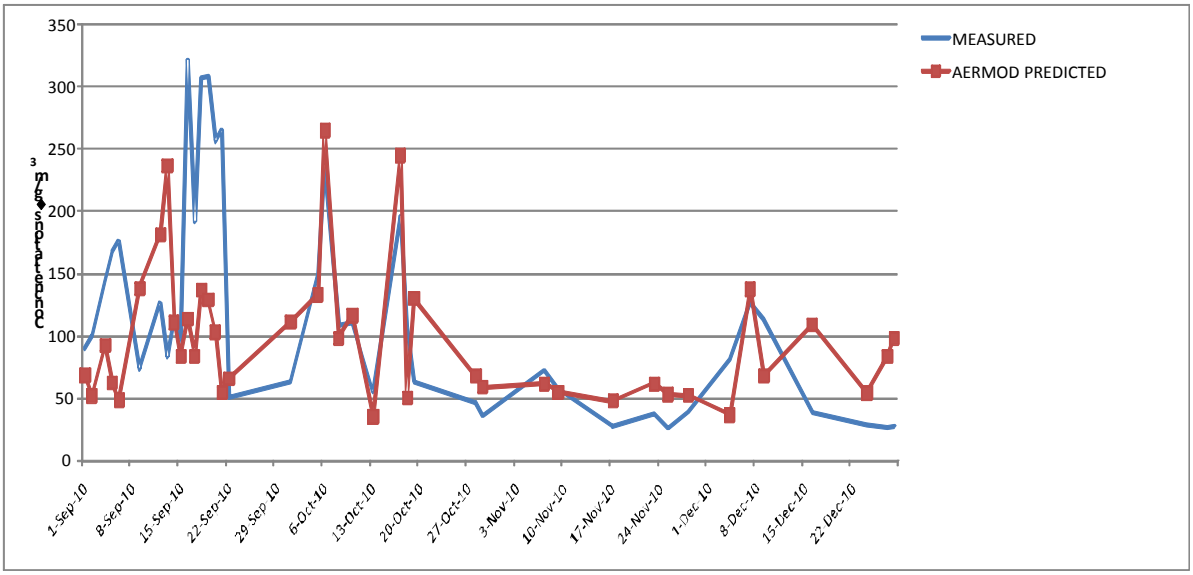

Figure 4. AERMOD predicted downwind concentrations compared to adjusted TEOM concentrations for September through December.

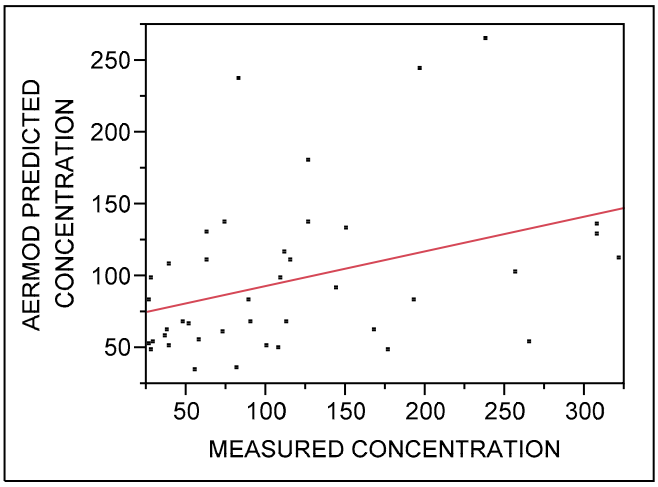

Figure 5: Regression analysis of AERMOD predicted 24-hour concentrations vs. corrected TEOM measured 24-hour PM_{10} concentrations.

Figure 5 illustrates the plot of calculated daily average measured concentrations of PM_{10} vs. the predicted downwind 24-hr concentrations using AERMOD. A regression analysis was performed to determine if there was a correlation between measured and modeled concentrations. The R^2 for this analysis was 0.14. The null hypothesis was that there was no relationship between the measured and predicted concentrations. The p-value was 0.0006 and t-ratio was 3.57. Hence, the null hypothesis was rejected.

Table 2. 24-hour PM_{10} emission factors for cattle feedyard using TEOM samplers and the CAAQES protocol.

MONTH	RANGE	PM_{10} EMISSION FACTOR (lb/1000 hd-day)
SEP	LOW	4
	HIGH	36
	AVERAGE	**19**
OCT	LOW	5
	HIGH	21
	AVERAGE	**10**
NOV	LOW	5
	HIGH	12
	AVERAGE	**8**
DEC	LOW	3
	HIGH	22
	AVERAGE	**9**

The emission factors for PM_{10} for cattle feedyard were computed for the 24-hr AERMOD and daily-TEOM average concentrations for the months of September to December. The low and the high emission factors for every month are recorded in Table 1. The emission factors ranged from 4 to 36 lbs of PM_{10}/1000 head-day for the month of September; 5 to 21 lbs of PM_{10}/1000 head-day for the month of October; 5 to 12 lbs of PM_{10}/1000 head-day for the month of November and 3 to 22 lbs of PM_{10}/1000 head-day for the month of December. The average emission factors were 19, 10, 8 and 9 lbs of PM_{10}/1000 head-day for the months of September, October, November and December, respectively. The relatively lower emission factors in November and December could be due to subdued cattle activity as a consequence of the colder climatic conditions. In general, the emission factors were in congruence with the emission factor of 15 lbs of PM_{10}/1000 head-day used by the TCEQ for PM_{10} regulation. The emission factors for PM_{10} were also in line with the emission factors developed by previous researchers at CAAQES (S.Parnell, 1994; McGee, 1997; Parnell et al., 1999).

Methodology for dispersion modeling using AERMOD to predict downwind concentrations at cotton gins

A hypothetical study was conducted to predict downwind concentrations of PM_{10} and $PM_{2.5}$ at a cotton gin at Amarillo Texas. The concentrations were measured at the property line of two distances, 50 m and 100 m. Three sizes of cotton gins were considered: 20 bales/hour, 40 bales/hour and 60 bales/ hour. An emission factor of 3.1 pounds/bale (USEPA, 2011b) was used for input in AERMOD. It was assumed that 20% of TSP comprised of PM_{10} and 5% of TSP was $PM_{2.5}$. Hence the emission factor assumed for PM_{10} was 0.6 pounds/bale and 0.15 pounds/bale for $PM_{2.5}$. There were four receptors located at east, west, north and south of the 50 m and 100 m property lines each. The meteorological data was the same as the cattle feedyard C at Amarillo. The cotton gin emission data was used from guidelines provided by North Carolina Department of Air Quality (NCDAQ, 2003). Accordingly, the stack height was 30 feet, inside diameter of stack was 4.3 feet, temperature of exit gases was 70° F and the volumetric flow rate was 3600 acfm; which was used to calculate the velocity of exit gases.

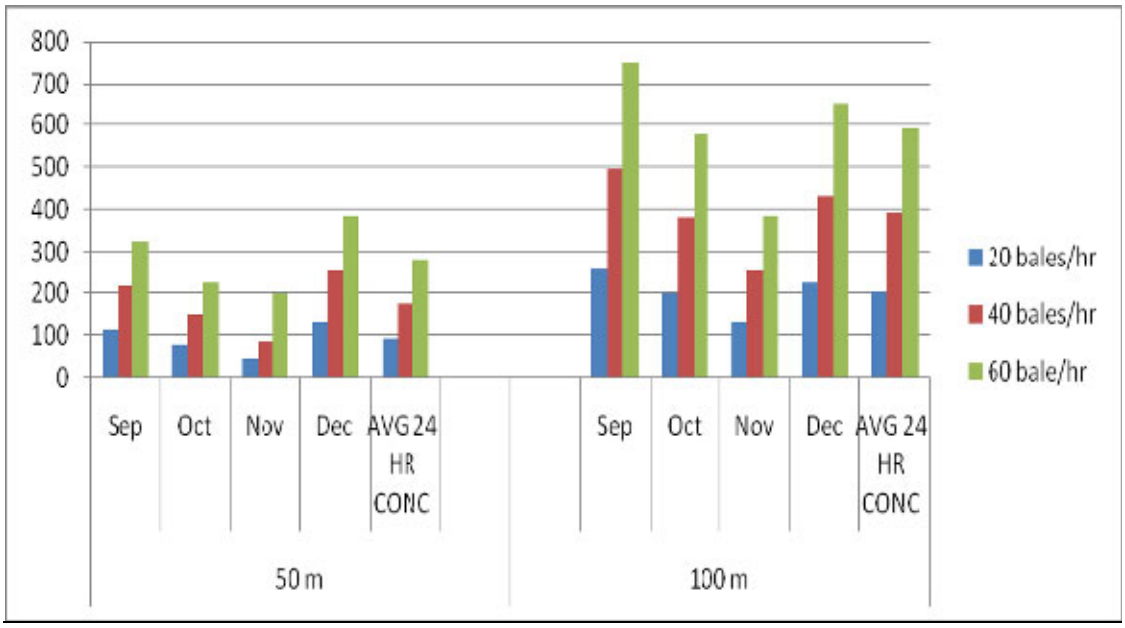

Figure 6: Predicted downwind concentrations of $PM_{10\ in}$ □g/m^3 for three different sized cotton gins of 20, 40 and 60 bales/hour, at property lines of 50 m and 100 m.

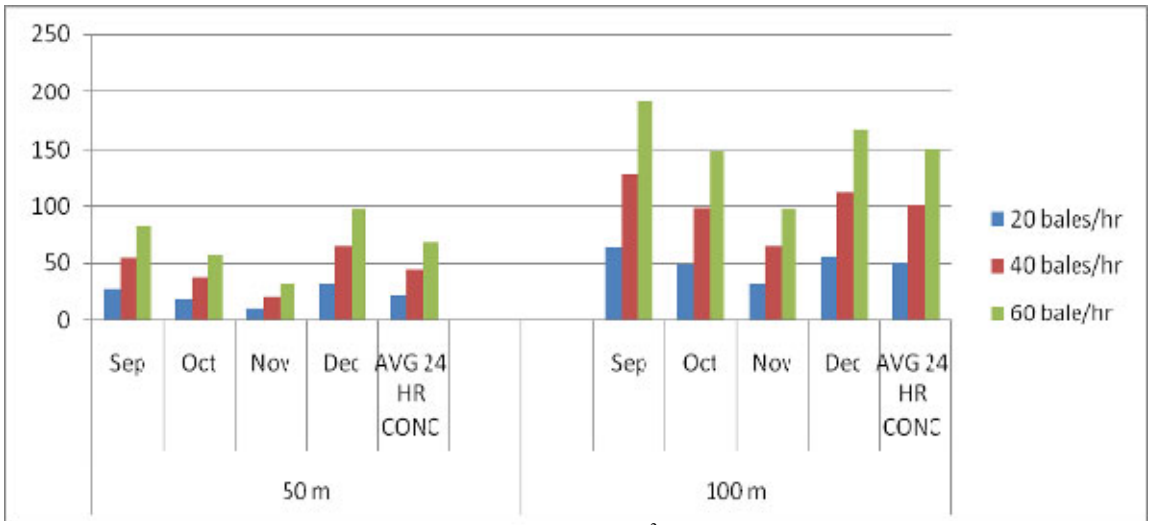

Figure 7: Predicted downwind concentrations of $PM_{2.5}$ in □g/m^3 for gins of 20, 40 and 60 bales/hour, at property lines of 50 m and 100 m.

Concentrations of PM_{10} and $PM_{2.5}$ were predicted using AERMOD for cotton gins for three different sizes. Figures 6 and 7 show the detailed average 24-hr concentrations for PM_{10} and $PM_{2.5}$ respectively. Based on the assumed emission factors and the fence line distances, the following results were obtained: For the property line at 50m it was observed that the 24-hr average concentrations for PM_{10} for September were below the NAAQS for the 20 bales/hour (bph) gin but exceeded the NAAQS for 40 bph and 60 bph gins. For the property line at 100m, all three gin sizes exceeded the NAAQS for all the months. A similar trend was observed for $PM_{2.5}$ predicted concentrations. As a consequence of these results, the cotton gins may be in violation of their permits. This shows that there is a need for the development of accurate emission factors for cotton gins. The predicted 24-hr downwind concentrations for the cotton gins increased as the property line distance increased from 50m to 100m. This was most likely a consequence of the plume passing over the 50m distance.

Summary

Concentrations measured using TEOM samplers should be adjusted with scientifically proven corrections. The CAAQES has developed a factor of 0.3 to be applied to TEOM measured downwind concentrations for PM_{10}. Hence, there should be adjustments provided for TEOM vs. gravimetric concentrations, oversampling due to PM_{10} pre-collector and evening dust peaks. The adjusted daily concentrations measured using TEOM at cattle feedyard C exceeded the 24-hr NAAQS for the month of September 2010. There were high peaks in the daily concentrations in September and October months. This was due to certain spikes in 5-minute TEOM concentrations greater than 3 times the standard deviation from the mean and these concentrations were removed from the daily average concentration. Based on the assumed emission factors for cotton gins, AERMOD predicted 24-hr concentrations at property lines which would exceed the NAAQS. This would have serious implications to cotton gins. If the modeled concentrations exceeded the NAAQS, the cotton gins may not be in compliance of their permits. Their permit may require the gins to reduce emissions by providing additional control technologies at the gins. If the emission factor used to predict the property line concentrations using a dispersion model such as AERMOD is not accurate for cotton gins, facilities could be inappropriately regulated. Hence there is a necessity to develop emission factors which are representative of the true PM emission factor values for cotton gins. Therefore the special use of the NAAQS wherein there is a requirement to model or measure 24-hr PM concentrations at or beyond property line will affect agriculture and there is a need to generate awareness amongst the concerned agricultural operations.

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