RESEARCH REPORT

ENVIRONMENT

Title: Particulates, Ammonium Nitrate, and Ammonium Sulfate: Effects on Air Quality in Rural Iowa
NPB #06-098

Investigator: Richard Pfeiffer

Institution: USDA, ARS, NSTL

Date Submitted: 12/26/07

Abstract: The study involved both ambient air sampling at two sites and wind tunnel measurements dealing with the affects of buildings and trees on air flow. The ambient air sampling included sampling for particulate matter (PM2.5, PM10 and TSP), three vapor phase species (ammonia, sulfur dioxide and nitric acid), and two aerosol species (nitrate and sulfate). Particulate matter values ranged from 10ug/m^3 to 130ug/m^3. The values for the vapor phase species ranged from 0.1ug/m^3 to 2.1ug/m^3 for nitric acid, 0.1ug/m^3 to 4.5ug/m^3 for sulfur dioxide, and 1.5ug/m^3 to 105.0ug/m^3 for ammonia, however the ammonia concentrations are underestimated at the swine site due to saturation of the denuders. Values for the aerosol species ranged from 0.1ug/m^3 to 9.0ug/m^3 for nitrate and 1.5ug/m^3 to10.0ug/m^3 for sulfate.

A 1:150 scale model of the swine facility was constructed for placement in a wind tunnel. Trees and the feed bins made to scale were also included. Significant changes in wind velocity and turbulence occurred due to the buildings and even a poorly defined tree area. These changes in velocity and turbulence can alter the movement of particulates and other chemical species. Failure to address these changes when measuring concentrations of chemical species moving from the site can lead to a significant under or over estimation of the concentrations of those species.

Introduction: This project had two very different components: a wind tunnel and air samplers. The data obtained however, is related and both components are necessary for a complete understanding of the movement of particulates and chemical species from a swine facility. A scale model of the swine site including buildings and surrounding trees was constructed on a rotary platform. The model was subjected to differing wind speeds and directions. The resulting patterns were examined to better understand where samplers should be placed to accurately assess the emissions for chemical species from confinement facilities.

The air samplers used for this study were speciation samplers. They were used to collect three particulate size fractions (<2.5micron, <10 micron and < 500 micron) representing PM2.5, PM10 and TSP, respectively. The gaseous species included ammonia (NH_3), sulfur dioxide (SO_2), and nitric acid (HNO_3). The aerosol species included nitrate (NO_3) and sulfate (SO_2). Three samplers were used: one placed at a background site with no animal confinement operations within a 5mile radius, one 100 feet north of a 3000 head confinement operation and one between two buildings on the same site. The locations were chosen to measure background concentrations (background site), to measure total concentrations regardless of winds (between buildings), and the concentrations dependent on wind direction (north of site).

These research results were submitted in fulfillment of checkoff funded research projects. This report is published directly as submitted by the project's principal investigator. This report has not been peer reviewed

For more information contact:

National Pork Board, P.O. Box 9114, Des Moines, Iowa USA

800-456-7675, Fax: 515-223-2646, E-Mail: porkboard@porkboard.org, Web: http://www.porkboard.org/

Objectives: There were three objectives for this project. The two objectives for the measurement of the chemical species have been slightly changed since the original proposal to better describe the actual measurement that could be made with the speciation samplers. The objectives were:

1. Construct a scale model of the confinement facility to be used in the wind tunnel.
Measure the air flow under varying conditions to better understand how chemical species and particulates could move away from the site.
2. Use the speciation samplers to simultaneously measure particulate matter, ammonia, sulfur dioxide, nitric acid, nitrate and sulfate. The locations of the two samplers on the swine site were chosen to match those used in the wind tunnel.
3. Measure the same species at a site that represents rural Iowa, independent of any nearby confinement facilities.

Materials and Methods: Wind Tunnel

A 1/150th scale model of the confinement site was constructed for the wind tunnel simulations. The building models were constructed of wood with open sides to represent conditions with the side curtains down. Scale models of trees, grain bins, feed bins, pit fans, a propane tank, and storage building were also constructed and, with the building models, oriented to duplicate the field site conditions. A series of 63 wind tunnel experiments were completed. Air flow and turbulence measurements downstream from model arrays were completed using a constant temperature anemometer system (IFA 300, TSI Inc., Shoreview, MN) equipped with a 1-D boundary layer hot film probe (Model 1218). Measurements were made at 3 air velocities (0.5, 2, and 5 m s^{-1}), 3 wind directions (W, S, and SW), and 3 distances downstream from the building models (1H, 2H, and 6H where H is the building (peak) height = 15.8 ft (actual or field scale) or 32.2 mm for the models). Measurements were also completed with no tree models and with all scale models removed. Velocity measurements and turbulence statistics were calculated from 26 s of data collected at a rate of 10 kHz at each of 30 measurement heights from 2 to 400 mm above the floor of the wind tunnel.

Materials and Methods: Ambient Air Sampling

Two speciation samplers were located on a 3000 head swine confinement facility with one sampler placed between two of the three buildings and one approximately 100 ft north of the buildings on the site. A third sampler was placed on a site referred to as the background site since no confinement operations are located within a 5 mile radius of the site. Sampling was done on April 9th and 26th, May 11th and 25th, June 4th and 14th, and July 2nd and 17th

The annular denuder system (ADS) consisted of (1) an inlet with an impactor for particle size discrimination, (2) annular denuders to capture gaseous species, and (3) a filter pack to capture the particulates. For this study a Model 3500 Speciation Cartridge (Rupprecht & Patashnick, Albany, NY) was equipped with a 2.5u, 10u, or TSP impactor, three honeycomb denuders, and a 4-filter pack. The cartridges were placed in a Model 2300 Sequential Speciation Sampler (Rupprecht & Patashnick, Albany, NY). The Model 2300 Sampler was equipped to measure ambient temperature and pressure and then to automatically correct for changes in these parameters to maintain a constant volumetric
flow rate. Flow through the cartridges were turned on and off by the on-board computer system. During operation, ambient air is drawn through the size exclusion system, past glass denuders whose walls had been coated with citric acid or sodium carbonate solution to absorb the basic and acidic gaseous species, respectively. The air then passes through the filter pack equipped with a Teflon^{R} filter to trap particulate matter and aerosols. Additional filters placed downstream of the Teflon filter are coated with the same solutions as the denuders to capture any species resulting from breakthrough and/or evaporation. Following each run, the ADS system was removed, the ends capped, and brought back to the laboratory for extraction and chemical analysis. The denuders were extracted with deionized water and the extracts were analyzed for gaseous species using flow injection analysis (NH_3) and ion chromatography (SO_2 and HNO_3) at the NSTL Analytical Laboratory. The laboratory was equipped with a Lachat QuickChem FIA series 2000 (Loveland, Colorado) and a Dionex DX120 (Sunnyvale, California) for flow injection and ion chromatography, respectively. The filters were sealed in

individual containers and sent to the University of Iowa's Department of Occupational and Environment Health to be weighed for the determination of particulate mass. The filters were returned to NSTL, extracted with water using sonication and then the filter extracts were analyzed by ion chromatography for NO_3 and SO_4 by the NSTL Analytical Laboratory.

Results: Wind Tunnel

Air velocity profiles with varying wind direction were significantly different. Fig. 1 presents a typical case showing velocity profiles for experiments completed at a free-stream velocity of 5 m s^{-1} and measurements made at a distance of 2H downstream (32 ft at field scale). Note that the velocity profiles were standardized by dividing each velocity by the free-stream (400 mm) velocity to remove variation due to failing to achieve the 5 m s^{-1} target velocity. Turbulence intensity, the ratio of the standard deviation of the air velocity to the mean air velocity, is a measure of the "gustiness" of wind. Profiles of turbulence intensity for the experiments shown in Fig. 1 show progressively greater turbulence intensity with air velocity reduction (Fig. 2). It is clear that, although the buildings do block the wind, the air flow is much less steady and may affect how particulates and/or trace gases are transported from the facility. Due to the number of experiments, results were combined to enable generalizations on the observed air flow patterns (Figs. 3 & 4). Values of air velocity and turbulence intensity at the air sampler height (4 ft in field, 8 mm at model scale) were averaged for all measurements behind or between building models and with or without the tree models

Results: Ambient Air Analysis

Objectives 2 and 3 involve the same ambient air measurements, but at different locations. To facilitate the presentation of the results, the data and discussion for both objectives will be done together. A summary of the results for PM and aerosol (NO_3 and SO_4) are shown in Table 1. The results in Table 1 are the average values for each species, inlet, and locations over seven sampling periods. Those periods were April 9-13, April 26-30, May 11-15, June 4-8, June 14-18, July 2-6, and July 17-21. Shown in Figures 5-8 are the actual values for PM, SO_4, and NO_3, respectively. Those figures are included at the end of the report. The concentrations for the gaseous species, namely SO_2, HNO_3, and NH_3 are shown in Table 2. The results in Table 2 are the average values for each species and location averaged over five sampling periods. Those periods were April 9-13, April 26-30, May 11-15, May 21-25, and June 14-18. Note the asterisk(*) by the ammonia values. Due to the long sampling periods and high ammonia concentrations the denuders were saturated and thus the reported concentrations for ammonia at the swine sites are low. This was necessary in order to capture the other species at sufficient concentrations for analysis. Table 3 gives the average meteorological conditions during the sampling periods.

Discussion: Wind Tunnel

As expected Figure 1 shows that air velocity was reduced the most near the surface when the probe was directly behind a building model (W Wind, 2H Behind Building and S Wind, 2H Behind Building). However, nearly the same velocity reduction was observed when the probe was between building models (W Wind, 2H Between Buildings). Near-surface velocities for these three experiments were only about 25% of the velocity measured when no models were present. Finally, with a simulated SW wind (SW Wind, 2H Behind Building) the velocity reduction near the surface was about ½ of that for the S and W wind experiments. Another important feature is that, for all profiles, the effect of the models on reducing air velocity extended to a height of 150-200 mm or about 5 times the building model height (approximately 80 ft at field scale). Note that again the effects of the buildings models extend to a height of 200 mm, above which the models had no significant effect on turbulence intensity. Note also that below 25 mm the profiles were not always smooth, again indicating a highly turbulent zone near the surface in the wake of the building models as shown in Figure 2..

The data generated in these experiments (Figures 3 and 4) clearly demonstrate that trees had a dramatic impact by decreasing air velocity and increasing turbulence intensity. Air velocity at 1H and 2H behind or between buildings models with tree models present were only 20-30% of the velocity when no models were present. This contrasts with measurements between buildings when no trees were present when the air velocity averaged >70% of the velocity with no models. Conversely, turbulence intensity between the buildings with trees present was nearly 3 x's that when no models were present (Fig. 4).

Discussion: Ambient Air Sampling

Ambient air standards exist for particulate matter (PM), but changes have occurred in these standards during the past year. PM2.5 has an annual average of 15ug/m^3 and a 24-hour value of 35ug/m^3 and PM10 has an annual average limit of 150ug/m^3. Results from this study give average ug/m3 concentrations for PM2.5 of 19.75, 17.10, and 21.92 for the background site, between buildings, and north of the buildings, respectively. These values all exceed the PM2.5 annual standard, but not the 24-hour limit. However, examination of the values shown in Figure 5A-C seems to indicate a seasonal affect so the annual average may be somewhat lower. PM10 values did not exceed the standard however, the concentrations at the swine site were significantly higher that those at the background site.

The data for sulfate is rather interesting. On June 14 there was a large jump on sulfate concentrations at all three sites and all three PM fractions. Engine exhaust, both gasoline and diesel, contains sulfate so it is possible that the sites were mowed over the 4 day sample collection period, but no records were kept. Sulfate values differ very little from site to site or between PM fractions, except for the PM2.5 fraction where the average sulfate ug/m^3 concentrations for background, between buildings, and north of the buildings were 2.85, 1.73, and 2.56, respectively. The sulfate concentration between the buildings was actually less then ambient which is possibly due to the high flow rate of air from the fans serving to dilute the ambient concentrations. Due to high degree of variability within the data set, these values are not significantly different. These PM2.5 concentrations agree with values reported in North Carolina and Ohio (personal correspondence).

The concentrations for nitrate in the PM2.5 fraction were considerable lower than those for sulfate. The average ug/m^3 concentrations for background, between buildings, and north of the buildings were 0.67, 1.94, and 0.79. The average concentration between buildings is significantly higher than the other locations. The average concentrations of nitrate and the PM fractions differ with TSP > PM10 > PM2.5, but not statistically significant. These values are also in agreement with those from North Carolina (personal correspondence).

Ammonia concentrations were significantly higher at the swine site than at the background site even with the inefficient trapping at the swine site. The ambient concentration of ammonia at the background site was 3.3ug/m^3 (2.5ppb) which is what this investigator has found at other areas without significant animal confinement operations.

The sulfur dioxide levels were significantly higher between the buildings than north of the buildings or at the background. Reasons for this are not clear. The nitric acid concentrations were nearly identical at all three locations.

Lay Interpretation: Wind Tunnel

Overall, the major findings of the air flow measurements are that air velocity near the surface at a distance of 1H behind the buildings could be as low as ~25% of the velocity at the same height when no models were present. Air velocity at the same location but between buildings was reduced nearly as much by the presence of two rows of trees upwind of the buildings. The air velocity recovered with distance from the buildings and was less affected when the wind direction was at a 45° angle to the buildings. Turbulence intensity trends were opposite to those observed for air velocity as those situations with greater velocity reduction usually had higher turbulence intensities. These findings suggest that the trees and buildings, while reducing the mean air flow, also tended to increase turbulent mixing. The decrease in offsite transport of particulates and trace gases from the reduced velocity will likely be at least partially offset by the increase in turbulence intensity. In all cases, the effects of the buildings and trees were limited to a height of approximately 5 x's the building height. This represents the upper limit for deployment of air quality sensors in the near-wake environment behind the buildings.

Lay Interpretation: Ambient Air Sampling

Air quality has many components, one of which is PM2.5 and ammonium nitrate and ammonium sulfate are reported to be two of the major components. Swine confinement facilities generate significant quantities of ammonia which can combine with nitric acid and sulfur dioxide to form ammonium nitrate and ammonium sulfate. Nitric acid and sulfur dioxide appear to be the limiting factors. Results of this study indicate that swine production is not a significant source for nitric acid and sulfur dioxide to produce PM2.5.

Another component of air quality is particulate matter (PM2.5, PM10, and TSP). Data from this study indicates that swine production results in elevated concentrations of the larger particulates found in the PM10 and TSP fractions. The concentrations of small particulates that compose the PM2.5 fraction are nearly identical on the swine confinement site as on the background site.

TABLE 1: Aerosol and PM Summary Data

SITE	SPECIES	INLET (u)	MEAN (ug/m^3)	SE N=7
Background	NO_3	2.5	0.67	0.28
	SO_4	2.5	2.85	0.99
	PM 2.5	2.5	19.75	2.58
	NO_3	10	0.74	0.17
	SO_4	10	3.00	1.11
	PM 10	10	32.39	5.17
	NO_3	TSP	1.43	0.6
	SO_4	TSP	3.16	1.01
	TSP	TSP	42.5	7.51
Between Buildings	NO_3	2.5	1.94	0.71
	SO_4	2.5	1.73	0.21
	PM 2.5	2.5	17.10	4.25
	NO_3	10	1.58	0.37
	SO_4	10	3.16	1.04
	PM 10	10	52.23	8.78
	NO_3	TSP	2.55	0.84
	SO_4	TSP	3.30	0.96
	TSP	TSP	77.28	12.55
North of Buildings	NO_3	2.5	0.79	0.28
	SO_4	2.5	2.56	0.75
	PM 2.5	2.5	21.92	6.73
	NO_3	10	1.86	0.55
	SO_4	10	3.21	1.17
	PM 10	10	41.44	6.94
	NO_3	TSP	2.57	0.73
	SO_4	TSP	3.03	1.10
	TSP	TSP	49.23	8.16

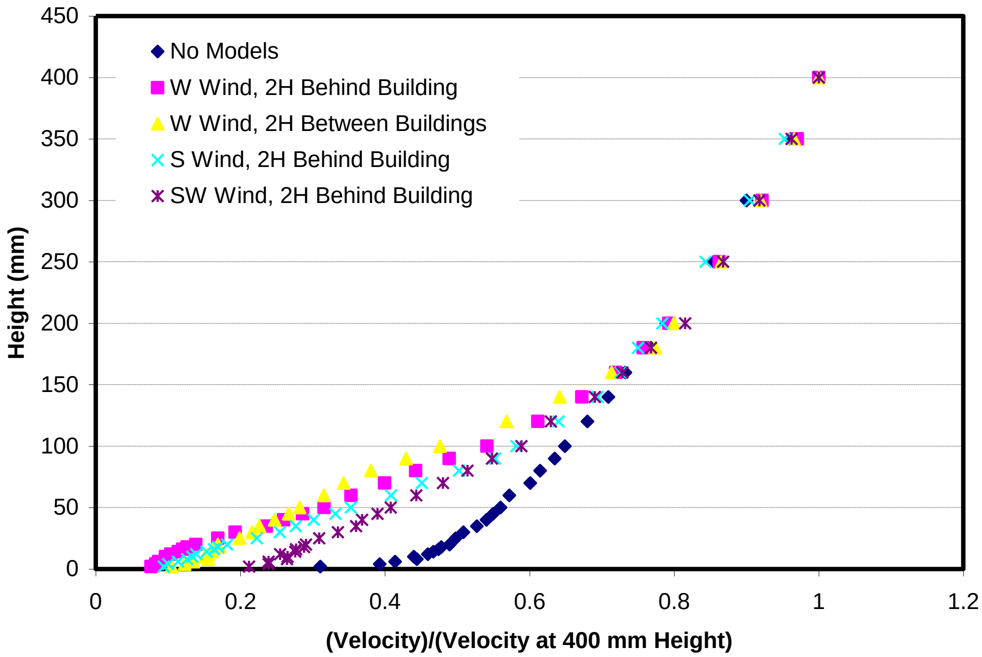
TABLE 2: Gaseous Species Summary Data

SITE	SPECIES	MEAN (ug/m^3)	SE N=7
Background	HNO_3	0.86	**0.37**
	SO_2	0.83	**0.32**
	NH_3	3.32*	**0.81**
Between Buildings	HNO_3	0.89	**0.33**
	SO_2	2.50	**0.89**
	NH_3	84.50*	**7.23**
North of Buildings	HNO_3	1.08	**0.36**
	SO_2	1.55	**0.53**
	NH_3	**54.10***	**12.9**

TABLE 3: Meteorological Conditions

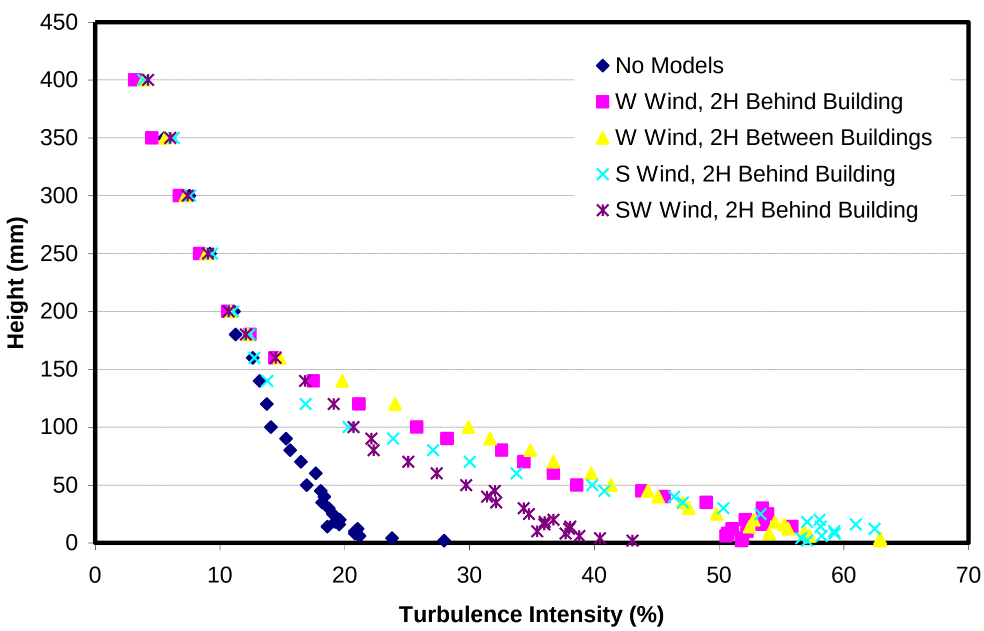
DOY Range	WD (Degrees)	WS (m/sec)	TEMP (^0C)	RAIN (mm)
103-107	190.1	1.7	10.0	0.0
116-120	223.2	2.6	17.3	0.0
131-135	187.8	2.9	20.9	0.0
155-159	231.0	2.5	20.5	3.3
169-171	204.6	1.3	22.3	45.2
187-191	211.4	0.9	25.4	11.7
198-202	148.9	1.8	22.1	0.00

FIGURE 1. Ratio of the velocity at each height to the maximum velocity at 400 mm at a distance 2H downstream from the building models at 5 m s^{-1} for different wind



direction

FIGURE 2. Profiles of turbulence intensity (ratio of the standard deviation of the air velocity to the mean air velocity) at a distance 2H downstream from the building models at 5 m s^{-1} for different wind



directions.

FIGURE 3. Average air velocity at air sampler height (4 ft in field, 8 mm in wind tunnel) as a proportion of the air velocity with no building or tree models present at distances of 1H, 2H, and 6H downstream

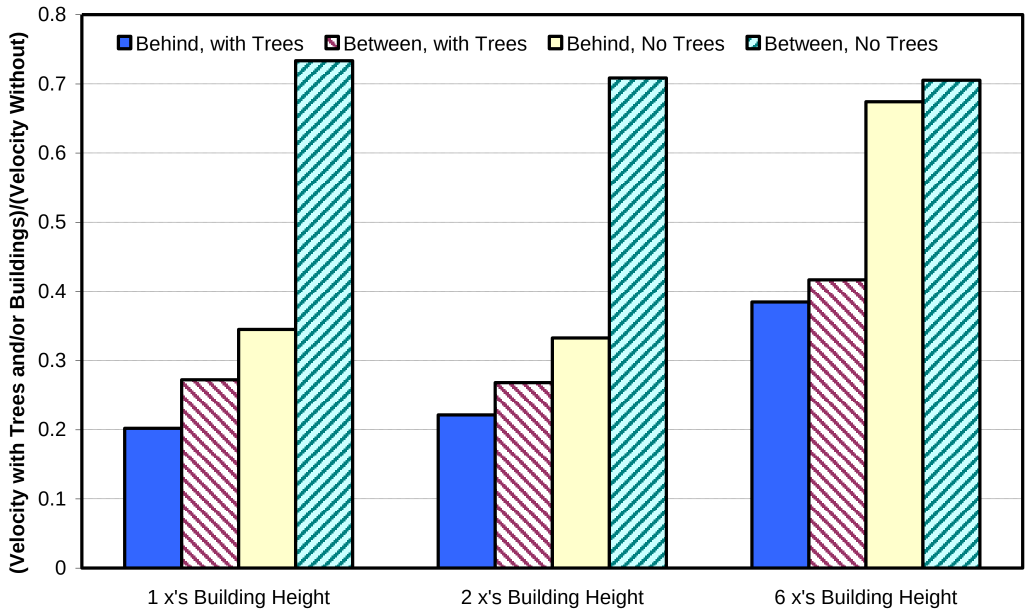
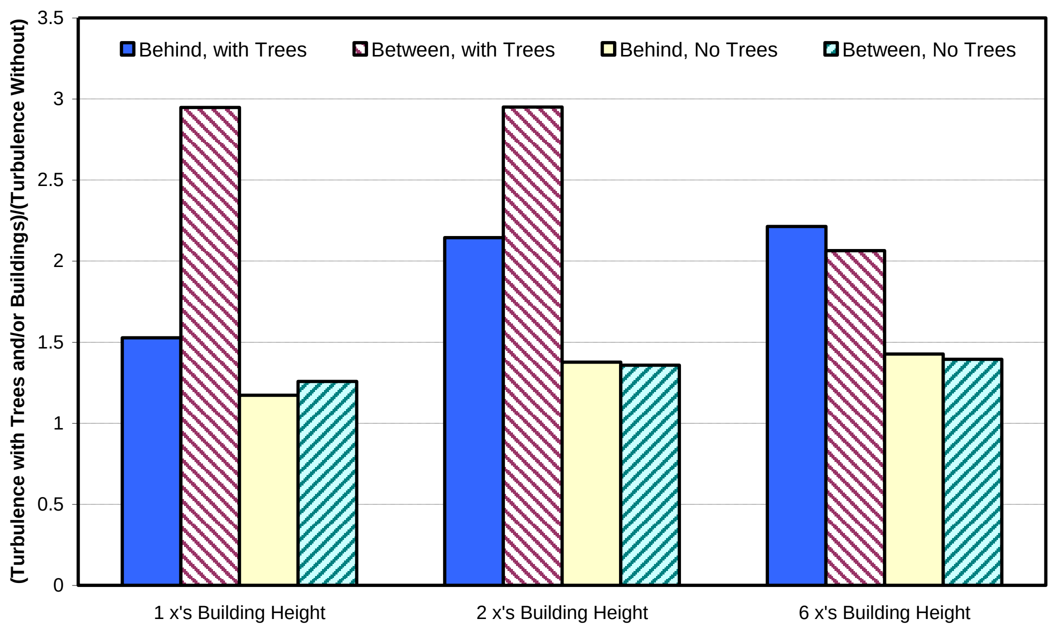
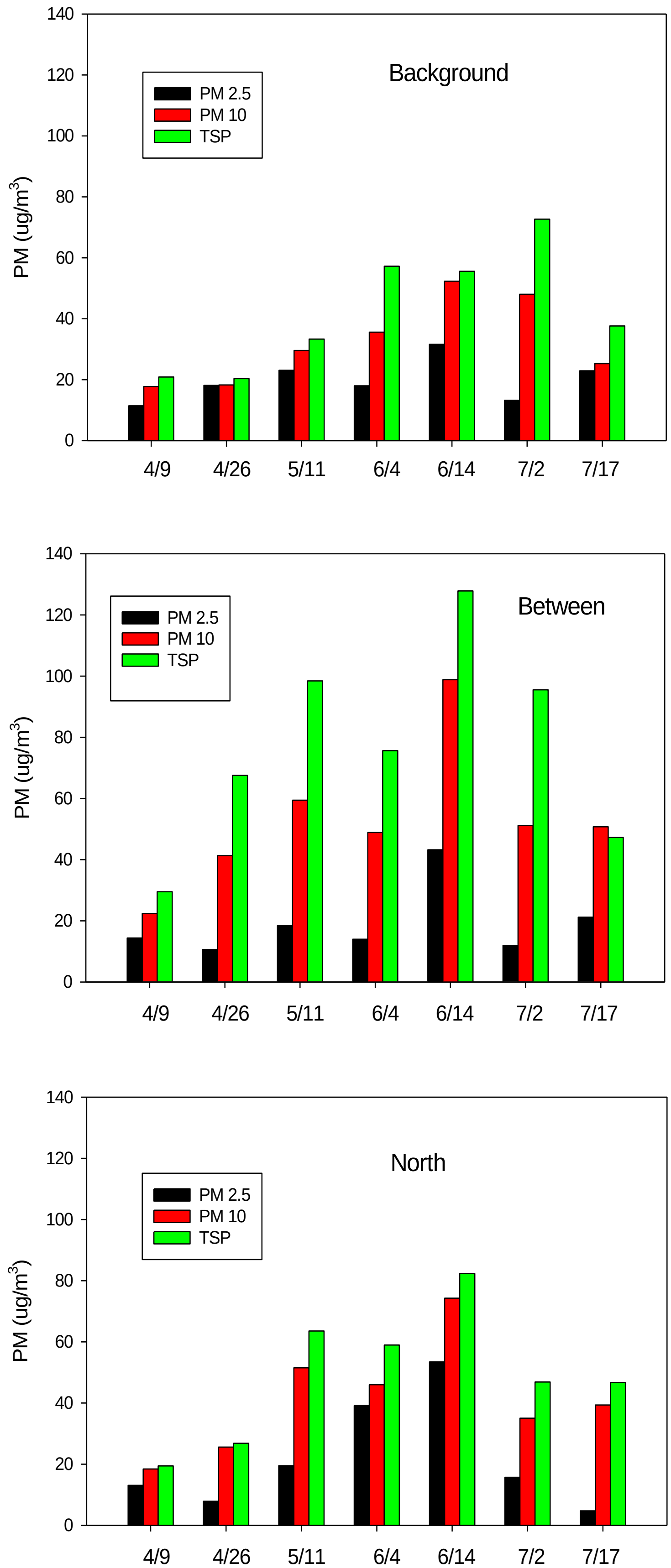


FIGURE 4. Average turbulence intensity at air sampler height (4 ft in field, 8 mm in wind tunnel) as a proportion of the turbulence intensity with no building or tree models present at distances of 1H, 2H, and



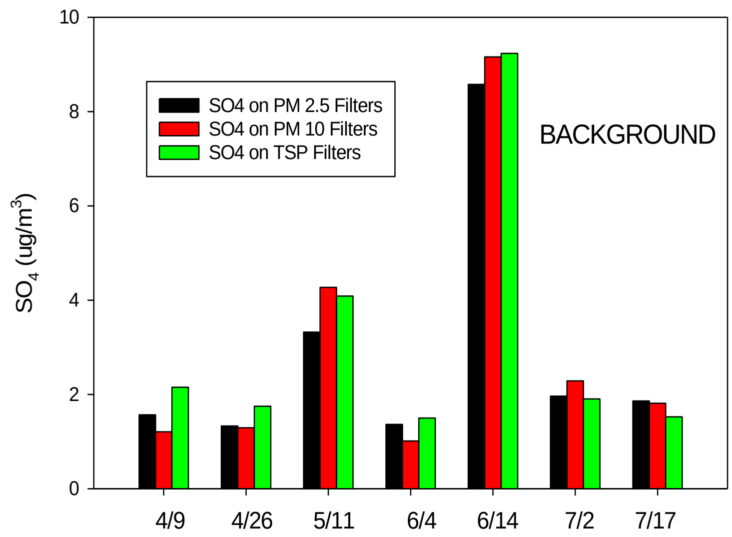
6H downstream.

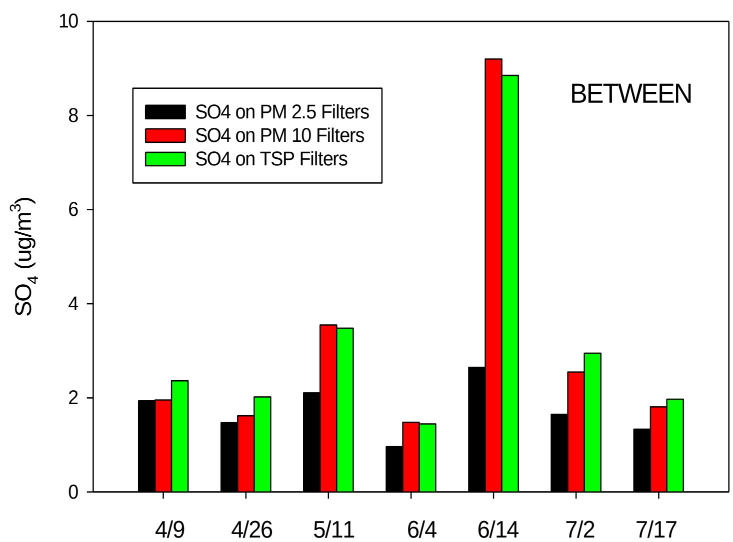
FIGURES 5A-C: PM Concentrations from Three Sites

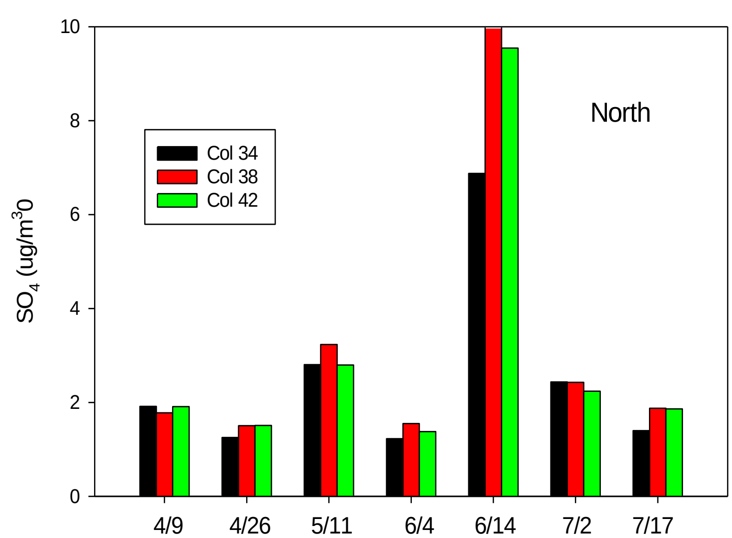


FIGURES 6A-C: Sulfate Concentrations on

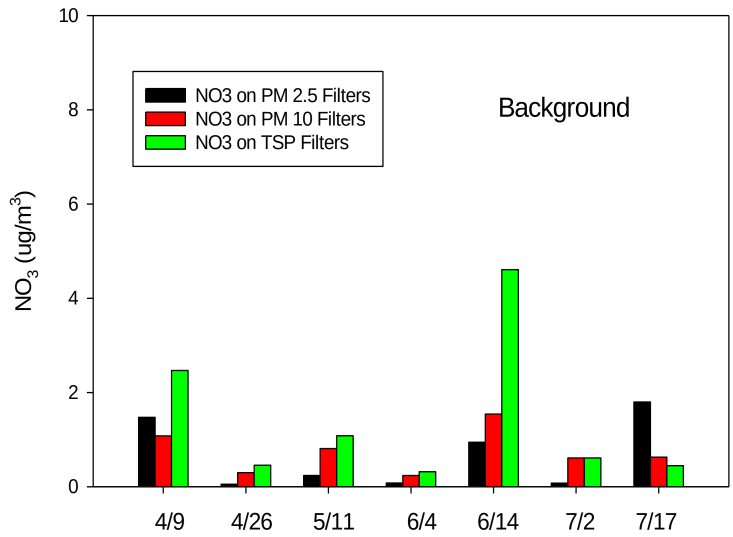
Filters from Three Sites

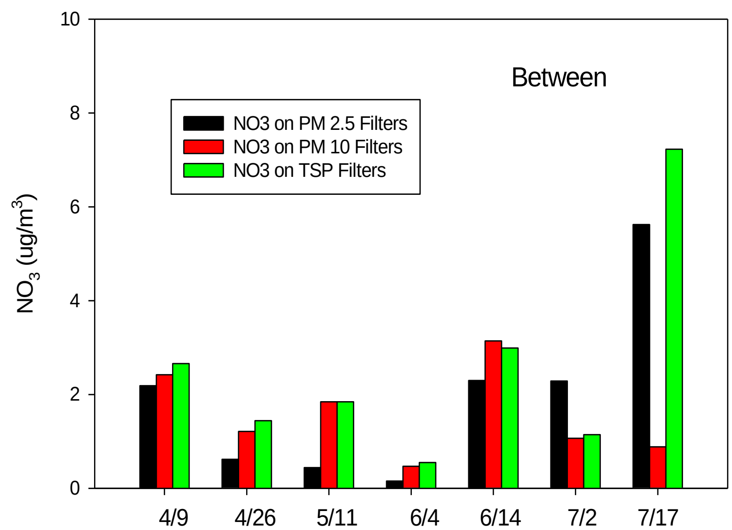


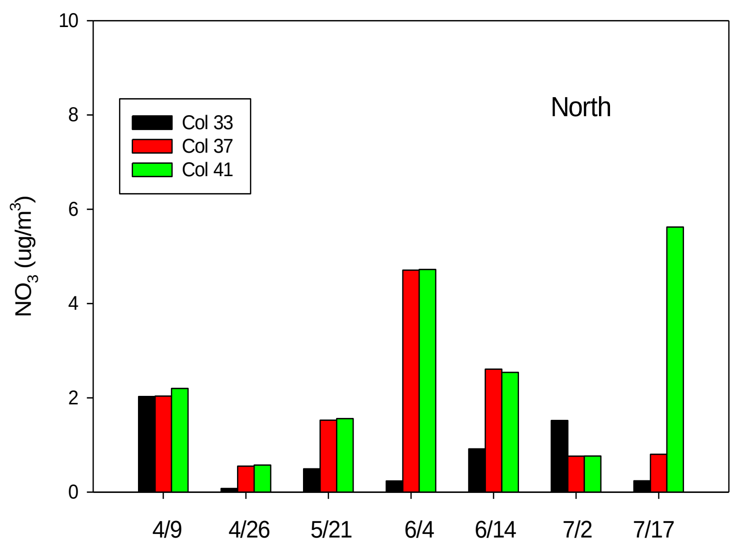




FIGURES 7A-C: Nitrate Concentrations on Filters from Three Sites







FIGURES 8A-C: Concentrations of Gaseous Species