Budget Estimates of Indoor Air Pollutants from Solid Biomass Fuels Used in India

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Abstract

In developing countries the most important indoor air pollutant are the combustion products of solid biomass fuels such as fuel wood, dung cakes, crop residues and charcoal. Almost 50% of the world's population and upto 90% of rural households in developing country rely on biomass fuels. It has been estimated that about half a million women and children die each year from indoor air pollution in India. The combustion of biomass release complex mixture of various species viz., NOx, SO_2, organic carbon (OC), elemental carbon (EC), Polycyclic Aromatic Hydrocarbons (PAH), Non-methane Hydrocarbons (NMHC) and Volatile Organic Compounds(VOC). Efforts have been made to study the emissions from solid biomass fuels to evaluate their emissions factors and derive budget estimates for India. An experimental setup has been built to carry out controlled burning of biomass fuels similar to the residential application (small cooking stoves and an open burning) in India. The emission factors for NOx, SO_2, OC, EC, PAH, NMHC and VOC have been evaluated. The preliminary budget estimates from biomass fuels in India for above species are 0.3, 0.8, 2.0, 0.7, 0.01, 2.8 and 1.4 Tg, respectively.

Introduction

Fuels used in residential sector of India is a major component of total energy use in India. Type of fuels used in residential sector in India varies with different environment and availability of the local fuels and also by way of cooking food in the open fires or in the rural cook stoves (Earthen Chulas). Out of residential fuels, 70 to 80% of the energy needs in rural India are met with the use of biomass in the form of fuel wood, dung cakes, charcoal and agricultural residue. Burning of biomass from all these sources is well known to be associated with the emission of smoke/plumes consisting of particulate and gaseous species as these are not energy efficient processes and thus the fuels are not burnt completely. The species emitted and their concentrations depend on the nature of the source of biomass and other factors including the physical parameters associated with the consumption of the biomass.

Poor kitchen ventilation i.e., lack of properly designed and installed chimneys or exhaust, is common in rural areas in India. This together with the low efficiency cookstoves and large amount of fuels used results, in many cases, in serious indoor air pollution. High concentration of CO, NO2, PM and benzopyrene were found indoors with the highest values at standing breathing level in the kitchen when dungcake, fuelwood and coal were burning (Kandpal et al., 1995a and 1995b). Personal exposure to the toxic air pollutants thus may greatly increase due to the high emission from domestic use. WHO asserts a “Rule of 1000”, which states that a pollutant released indoors is one thousand times more likely to reach people’s lung than a pollutant released outdoors (WHO, 1997). In recognition of the need to identify and develop cleaner domestic combustion systems, this study aims at providing an initial assessment of total emissions from indoor combustion in the rural sector of India.

Comprehensive studies to evaluate the emission factors for OC, EC, SO_2 and NO_x for biofuels used as energy source in rural residential sector have been carried out to arrive at reliable budgets estimates. PAH, NMHC and VOC’s are of special interest due to their toxicity, carcinogenicity and ubiquitous presence in the environment. Thus the studies are being carried out on some important PAH, NMHC’s and VOC,s and would be presented at the workshop.

Experimental

The experimental setup consisting of a U-shaped chimney (see Firgure-1) to carry out biofuel burning in the laboratory with all the plumes passing through the High Volume Sampler (HVS). A Whatmann 8×10 sq. inch GF/A filter is fixed on the support for the collection of particulate matter. The other end of the chimney is about 25 cm above the ground. Known quantity of fuel is burnt below the chimney and the plumes pass through the HVS. The chimney is fixed tight on to the HVS to ensure complete deposition of the particulate matter emitted during the burning of the fuel sample. Part of the plumes are routed through the impingers in series for the sampling of SO_2 and NO_X. They are evaluated by wet chemical methods. The particulate matter deposited on the filter paper is analysed for EC and OC. For the determination of PAH, VOC and NMHC from the emissions studies are being conducted. A known amount of fuel is kept on a firebrick support with an electric filament mounted on it to initiate the burning of the fuel. Fuels emit smoke as a result of pyrolysis in the initial stage. When the temperature rises enough it burns with vigorous flames for some time and ends up in smoldering for a few minutes. The three stages i.e., pyrolysis, flaming and smoldering, together are referred to as combustion. The fuels studied are fuel wood, dung cakes, agricultural residue and charcoal. This burning setup is very similar to the style of cooking or residential heating adopted in rural sector or small-scale industries except for the difference that instead of the electric heater plate some stand is used, which keeps the fuel a little risen above the ground. Sometimes in residential cooking the fuel is burnt on the ground between two bricks or in a three sided fire place i.e., a typical Chulha (an earthen stove used for cooking in villages) or in cylindrical fire place with raised hearth made of a steel mesh and having provision for air inlet beneath it. The details of the experimental setup are described in the earlier papers (Gadi et al., 2003, Parashar et al., 2005).

Results and Discussion

Emission factors of SO_2, NO_X , OC and EC as determined in the laboratory have been given in table 1. The emission factors are based on experiments which resemble a typical burning/cooking process. There is a degree of natural variability in fuel quality depending upon region and seasons, which has led to a range for each emission factor. It is seen that emissions of SO_2 are highest from dungcakes and low from agricultural residue and charcoal, but NO_X emissions from bagasse are almost double those from fuelwood and charcoal. The emission factors for OC and EC are highest for dungcakes and lowest for charcoal. Emission factors for bagasse have been used for evaluation of emissions from agricultural residues. The emissions depend upon the combustion characteristics and would be smaller with the increase in burning efficiency. The annual consumption of Fuelwood, dungcakes, agricultural residue and charcoal are 281 Tg, 62 Tg, 36 Tg and 3 Tg respectively (Venkataraman et al., 2005 and TEDDY, 2001/2002).

Table 1. Emission factors for SO_2, NO_X, OC and BC from biomass fuels used in India

Bio-Fuels	SO_2 (g/kg)	NO_X (g/kg)	OC (g/kg)	BC (g/kg)
Fuelwood	0.7± 0.6	2.2± 1.0	3.5± 1.9	1.1± 0.5
Dung cakes	1.4± 0.9	0.8± 0.6	12.6± 4.5	4.4± 2.2
Agri. Residue	0.5± 0.5	3.3± 0.9	3.9± 3.4	1.3± 1.1
Charcoal				
Production	-	0.1± 0.1	18	1.4
Consumption	0.5± 0.3	2.1± 0.5	0.9± 0.6	0.4± 0.2

Using the emission factors given in Table 1 and the annual consumption of various biomass fuels in India, the budgets of SO_2, NO_X , EC and OC are estimated (Table 2). The major contributors of the emissions are fuelwood and dungcakes due to their high annual consumption in the rural residential sector.

The experimental work on the estimation of PAH, NMHC and VOC is being carried out. The preliminary budget estimates based on the emission factors from literature (Oanh et al., 1999 and Andreae and Merlet, 2001) for PAH, NMHC and VOC are 0.01, 2.8 and 1.4 Tg respectively. Further work is in progress to improve the reliability of all the emission estimates by conducting experiments on different biomass fuels being used as a fuel in the residential sector for cooking purposes in different regions of India.

Table 2. Budget estimates for SO_2, NO_X, OC and BC from biomass fuels used in India

Bio-Fuels	SO_2 (Gg)	NO_X (Gg)	OC (Gg)	BC (Gg)
Fuelwood	197±169	618±281	984±534	332±151
Dung cakes	87±56	50±37	781±279	273±136
Agri. Residue	18±18	119±32	140±122	47±40
Charcoal				
Production	-	0.3±0.3	54	4.2
Consumption	1.5±0.9	6.3±1.5	2.7±1.8	2.4±1.2
Total	304±244	794±352	1962±937	659±328

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Environmental and Management Drivers of Nitrous Oxide Emissions in Australian Agro-ecosystems

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Abstract

Australian climate, soils and agricultural management practices are significantly different from those of the northern hemisphere nations. Consequently, experimental data on greenhouse gas production from European and North American agricultural soils and its interpretation are unlikely to be directly applicable to Australian systems. A program of studies at five sites of nitrous oxide greenhouse gas emissions from agriculture has been established by the Co-operative Research Centre for Greenhouse Accounting. The study is designed to reduce uncertainty of non-CO_2 greenhouse gas emissions in the Australian National Greenhouse Gas Inventory and provide outputs that will enable better on-farm management practices for reducing nitrous oxide greenhouse gas emissions. As part of this study are experiments with both chamber and micrometeorological emission measurement techniques which focus on process based studies of emissions and paddock scale emissions respectively. As well there are parallel studies on emission modelling and good practice. The systems being examined and their locations are irrigated pasture (Kyabram Victoria), irrigated cotton (Narrabri, NSW), irrigated maize (Griffith, NSW), rain-fed wheat (Rutherglen, Victoria) and rain-fed wheat (Cunderdin, WA). The field studies include treatments with and without fertilizer addition, stubble burning versus stubble retention, conventional cultivation vs. direct drilling and crop rotation to determine emission factors and treatment possibilities for best management options. The data to date indicate that nitrous oxide emission factors (the nitrogen lost as nitrous oxide as a fraction of the fixed nitrogen applied) for inorganic nitrogen fertiliser and urine from animals are profoundly affected by the climatic variations in soil water status and soil temperature. The emission factors are much lower than previously used for rain-fed wheat and significantly higher for irrigated maize with stubble burning. Application of nitrogen fertilizer at different rates to irrigated cotton indicates the non-linear growth in nitrous oxide emissions when nitrogen application exceeds plant uptake requirements. These new emission factors are applied to produce the spatial distribution of nitrous oxide emissions in Australia. There are substantial changes to the distribution of emissions compared to the spatial distribution of nitrous oxide emissions obtained using the IPCC default emission factors. The good practice management options that have been identified so far include stubble retention (in maize), crop rotation in cotton, and matching the nitrogen applied to the crop nitrogen requirements.

Efficacy of a Lagrangian and a Gaussian Model for Back Calculating Emission Rates from Feedyard Area Sources

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Abstract

Emissions of odor, gases and particulates from animal and crop production systems are an expected by-product of the systems. With the decrease in traditional setbacks, increasing community expectations and increasingly stringent federal and state air pollution regulations, agricultural operations have had to rethink traditional operating procedures.

As a part of this "rethink," baseline data on emission rates is needed to establish generic or even site-specific emission rates. The way in which emission rates (ERs) from lagoons and feed pads are determined is subject to debate. The two most commonly used styles are referred to as direct and indirect techniques. Direct methods involve placing enclosures on the surfaces to measure the emissions. Indirect methods refer to taking downwind samples on or near a source and calculating an emission rate using mathematical formulae. Indirect techniques offer the advantage of being able to process relatively large sources, such as lagoons and feedyard pens, and provide a spatially integrated emission rate. A possible disadvantage to using back calculation techniques is that there may be variation between the emissions derived using different types of indirect techniques.

Hydrogen sulfide emission rates were determined at two feedyards using two indirect back techniques, the Lagrangian WindTrax model and the Australian Gaussian plume model, Ausplume, which is based on the USEPA ISC model. Both models were run using the same data set and default dispersion settings. This was undertaken as to provide a comparison of the models as used with default values. Between 24 and 33 points were modeled at each site, providing an average emission rate over time. Each data point consisted of upwind and downwind concentrations, wind speed, wind direction and atmospheric stability data.

At present it is unknown which of the models provides a "true" estimate of emissions from area source. However, the models compared very well for the data sets. For feedyard A the relationship between the models was $y = 0.9x - 0.1$, $r^2 = 0.98$ for the pond, and $y = 0.9x - 1$, $r^2 = 0.99$ for the pens. A similar relationship was observed for feedyard C with $y = 1.2x - 0.8$, $r^2 = 0.99$ being observed for the pond data. As shown by the similarity of the gradients, the average emission rate and standard deviation of the predicted concentrations was similar.

Differences in the modeled predictions were identified as a function of distance from the source to the measurement point and subtle differences in the models. The results show that the WindTrax and Ausplume (ISC) models provided very similar emission rates for three real world data sets. This indicates that emission rates derived using one model can be used within other models with a reasonable degree of confidence.

Introduction

Emissions of odor, gases and particulates from animal and crop production systems are an expected by-product of the systems. With the decrease in traditional setbacks due to urban encroachment, increasing community expectations and increasingly stringent federal and state air pollution regulations, agricultural operations have had to rethink traditional operating procedures and even traditional areas of operation.

Area sources, including feedyards, are amongst the most difficult sources from which to estimate gaseous emission rates (Watts 2000). This is due to the fact that there is no way of directly measuring or sampling the emission. Therefore, indirect methods must be used where the emissions are sampled after they have mixed with the air stream (Watts 2000). Currently a number of methods are available to determine emissions from area sources; however, it is important to note that in these techniques there are a number of inherent uncertainties.

At present, there are two broad areas used to determine emission rates from area source. These are indirect, also known as back calculation, or direct, such as wind tunnels and flux chambers. Many studies have been undertaken using flux chambers, wind tunnels and back calculation techniques, however it is hard to define which of the techniques actually provides a realistic emission rate.

If the end use of the data is dispersion modeling (i.e. predicting concentrations away from a source using computer models) it is essential that the direct techniques would provide the same emission rate, i.e. those derived using a model using downwind concentrations would be the same as a direct technique used at the same time. The advantage offered by back calculation is that it can provide a spatially averaged emission rate (Harris *et al.*, 1996; Smith and Kelly, 1996) rather than a single point sample of a source based upon the limited footprint of an enclosure technique. A number of assumptions must be made when using Gaussian or other models to estimate emissions. Some of the assumptions detailed by Harris *et al.* (1996), which are relevant for this work include:

- the ground is a barrier to vertical mixing and is represented as a flat surface reflecting the plume back into turbulent air flow;
- the emission is neutrally buoyant – this assumption implies that the temperature at which the gas is released equals the ambient air temperature;
- the gas does not degrade after release (conservation of mass);
- gas source emissions do not vary within the averaging time used in the model; and
- gas source emissions do not vary spatially.

In this study, two models, the Australian Gaussian model Ausplume (Lorimer, 1986) and the Lagrangian model WindTrax (Flesch *et al.* 2005a, 2005b) were run on identical real world data sets to derive hydrogen sulfide emission rates at two large feedlots in Texas.

Methods

Sample Sites

Both beef cattle feedyards were located in the Texas Panhandle, in a semi-arid region with average annual rainfall of 500 mm. The feedyards were open-lots with earthen-surfaced pens. Pen slopes ranged from 1 to 5%.

Feedyard A had a one-time capacity of 18,000 head, while Feedyard C had a capacity of 55,000 head. Both had average stocking densities of one animal per 14 m^2 (150 ft^2). Animal weights ranged from 180 to 550 kg, with an average of about 340 kg. Cattle in both feedyards were fed a 90-92% concentrate diet consisting primarily of steam-flaked corn with 7-10% roughage consisting of ground alfalfa. The diets contained Rumensin® and Tylan®. About 15% of the steam-flaked corn was replaced with corn gluten feed in Feedyard C.

Meteorological Data Collection and Analysis

A 2 meter stationary meteorological station (Unidata America, Lake Oswego, OR) was located at each site, and recorded wind speed, wind direction, net solar radiation, and air temperature at a time step of two minutes. The stations were located on the edge of each feedlot approximately 100 meters (300 feet) from the feedlot pens in a field surrounded with low grass. Wind direction was scalar averaged for a 6 minute time period (2 minutes before and 2 minutes after) to obtain a representative wind speed and direction for modeling. Solar radiation and temperature were averaged over a 10 minute period to provide a representative radiation measurement.

Atmospheric Stability

Atmospheric stability was calculated using the solar radiation/delta-T (SRDT) method as detailed in USEPA (2000). The method uses the basics of Turner's (1964) method while negating the need for observations of cloud cover and ceiling. The method uses the wind speed (measured at or near 10 m) in combination with measurements of total solar radiation during the day and a low-level vertical temperature difference (DT) at night (USEPA 2000).

As 10 meter wind speed and direction data was unavailable, , the SRDT method was modified so that the wind speeds detailed in Table 6-7 in Meteorological Monitoring Guidance for Regulatory Modeling Applications (USEPA 2000) were useable with 2 meter data . To achieve this, the power law (Equation 1) was used to adjust the wind speeds from 10 to 2 meters based on the stability class in the table. The values for atmospheric stability class based on the new values for wind speed are shown in Table 1.

$$U_Z = U_{ref}\left(\frac{Z}{Z_{ref}}\right) \qquad \text{Equation 1}$$

where U_z is the wind speed at a height of Z (m) above the ground; U_{ref} is the wind speed at anemometer height Z_{ref} ; a is the wind profile exponent, and is a function of the stability class.

Table 1: Adjusted wind speeds for SRDT determination

	Solar radiation (W/m^2)						
Wind speed at 2 meters (m/s)	≥925		925-675		675-175)		<175
<1.8	A	<1.8	A	<1.8	B	<1.6	B
1.8-2.7	A	1.8-2.7	B	1.7-2.6	C	1.6-2.4	D
2.7-4.5	B	2.7-4.5	B	2.6-4.3	C	2.4-3.9	D
4.3-5.1	C	4.3-5.1	C	3.9-4.7	D	3.9-4.7	D
≥5.1	C	≥4.7	D	>=4.7	D	≥4.7	D

The Ausplume Model

Ausplume is the accepted regulatory Gaussian plume dispersion in Australia and New Zealand and is based on the ISC model of Bowers *et al.* (1979). It is designed to predict ground level concentrations or deposition of pollutants emitted from one or more sources including area sources, volume sources or stacks.

Recently the model was upgraded to incorporate a numerical integration approach for area sources. This allows standard and irregular shapes (such as polygons) to be modeled with more accuracy close to the source. This option was used for the modeling. An example of the output from the model is shown in Figure 1.

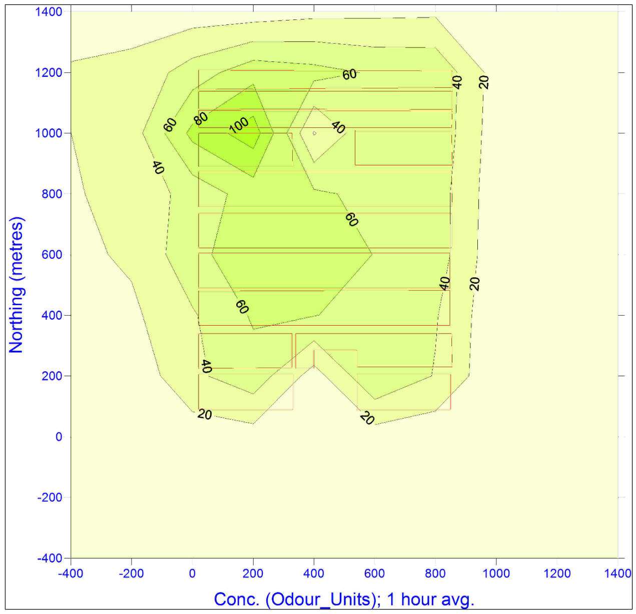

Figure 1. Example of pen alignment in Ausplume

Modeling was undertaken using an arbitrary constant emission rate of 1 ug/m^2.sec and using the default Pasquill Gifford dispersion curves for averaging periods of 1 hour. As an arbitrary emission rate was used, the emission rate had to be scaled to match the measured concentration thus providing an accurate estimate of the real emission rate. This was achieved using Equation 2.

$$ER = \frac{ER_{const}}{C_{\text{mod}}} \times C_{meas} \qquad \text{Equation 2}$$

Where ER is the emission rate µg/m^2.sec, ER_{const} = the arbitrary emission rate (1 µg/m^2.sec), C_{mod} is the average modeled concentration at the receptor during the sampling period (µg/m^3) and C_{meas} = measured concentration at the receptor. The measured concentration was calculated as the downwind H_2S concentration minus the upwind H_2S concentration in µg/m^3.

The WindTrax Model

WindTrax version 2 (see Flesch *et al.* (2005) or Flesch and Wilson (2005) for details) was used to determine average emission rates.

WindTrax is a backward-time Lagrangian stochastic (BLS) dispersion model that calculates emission rates of gas from a source area based on measured wind speed and gas concentrations. WindTrax uses a Lagrangian (particle-following) model to simulate atmospheric dispersion. The model releases a large number of computational particles from a set location and follows their trajectories as they float passively through the surrounding air. To imitate the turbulent nature of the atmospheric surface layer, random forcing terms in the equations governing their motion disturb the particles. Although the path taken by each particle is therefore random, the average motion of the entire group closely matches that of the real atmosphere.

When a particle's trajectory causes it to bounce off the surface within an area source, it is assumed to represent the tracer emitted from the source. The more times a particle touches down within the source area, the greater will be its contribution to concentration measured downwind. WindTrax keeps track of these touchdowns and uses them to calculate the relationship between emission rate and concentration: if either is known, the other can be predicted.

When modeling emissions from area sources, it is generally much more efficient to follow particles backward through time from the measurement location back to the area source rather than predicting where a particle will go as it flows after being emitted from a source. This is because an area source represents a much larger target than does a point sensor; a given particle is much less likely to reach any specific detection point located downwind of its source than to have originated somewhere within an upwind area source, given that it ended up at the detector.

Prior to running version 2, version 1 of WindTrax was run. Both versions provided identical emission rate estimates. The location and size of the pens were defined with data taken from a scaled aerial photograph of the site. The inputs required by the model are similar to those described for Ausplume above. WindTrax was run using 1,000,000 particles to ensure good coverage of the source. The model provides the user with an emission rate in μg/m^2.unit time. An example of the pen shown in Figure 1 as set up in WindTrax is shown in Figure 2.

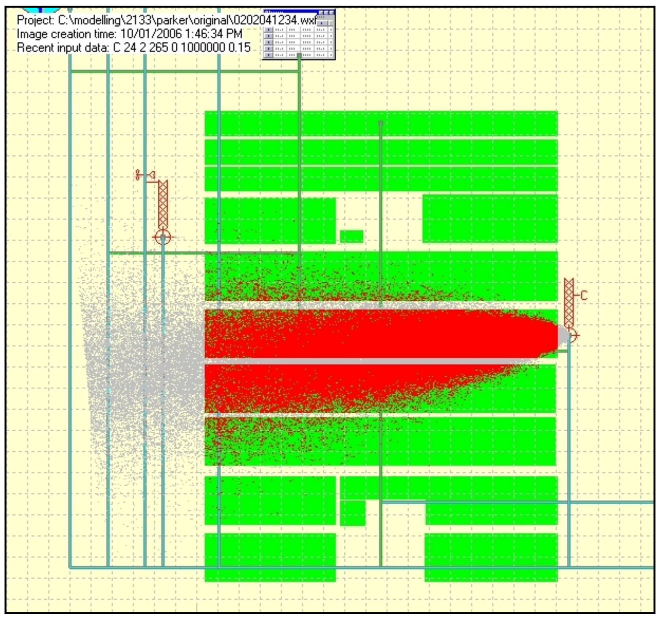

Figure 2. Example of pen alignment in WindTrax

Surface Roughness

Roughness height allows the modeler to represent the presence of features in the surrounding area. Generally, the higher the surface roughness the higher the back calculated emission rate. Therefore, variation in this parameter makes it important for dispersion modeling. Kelly *et al.* (1994) investigated the aerodynamic roughness of an Australian feedlot in the 1990s by examining surface roughness using vertical temperature and wind speed profiles.

When applying the 1/10th rule of thumb, they expected a 15 to 20 cm surface roughness: in reality they found that the cattle and fences did not overly influence the surface roughness of the feedlot. Their work found the surface roughness to be 1.16 ± 0.3 cm. Based on their findings, the modeling was undertaken using a surface roughness of 5 cm in an attempt to compromise between the work of Kelly *et al.* and the 1/10th rule of thumb. Therefore, the results of the model predictions should fall within the range of this maximum and minimum expected surface roughness. As the primary focus of this work was to compare the models, the influence of surface roughness would remain the same provided both models used the same surface roughness values.

Data Used for Modeling

Dispersion models in general have a basic set of data required to run them. As a general rule the more complex the model, the more data required. In this case the data required was:

- Wind speed;
- Wind direction;

- Pasquill Gifford stability class;
- Surface roughness;
- Feedyard dimensions including pen dimensions;
- Sampling location and height; and
- Upwind and downwind concentrations in µg/m^3 (upwind concentration was subtracted from the downwind concentration).

Both models were run using the same data set and conditions with the exception that in Ausplume the pens were set as to have a 10 cm height above the surrounding area and an initial mixing height of 0.5m both of which are was not required to model using WindTrax.

Results and Discussion

The model was run on two feedlots for pen emissions and for a sedimentation pond at one of the feedlots. The results of the model comparison for the pen and pond data are shown for Feedyard A in Figure 3 and Feedyard C pond in Figure 4. Additionally, the combined data for both Feedyards A and C are presented in Figure 5.

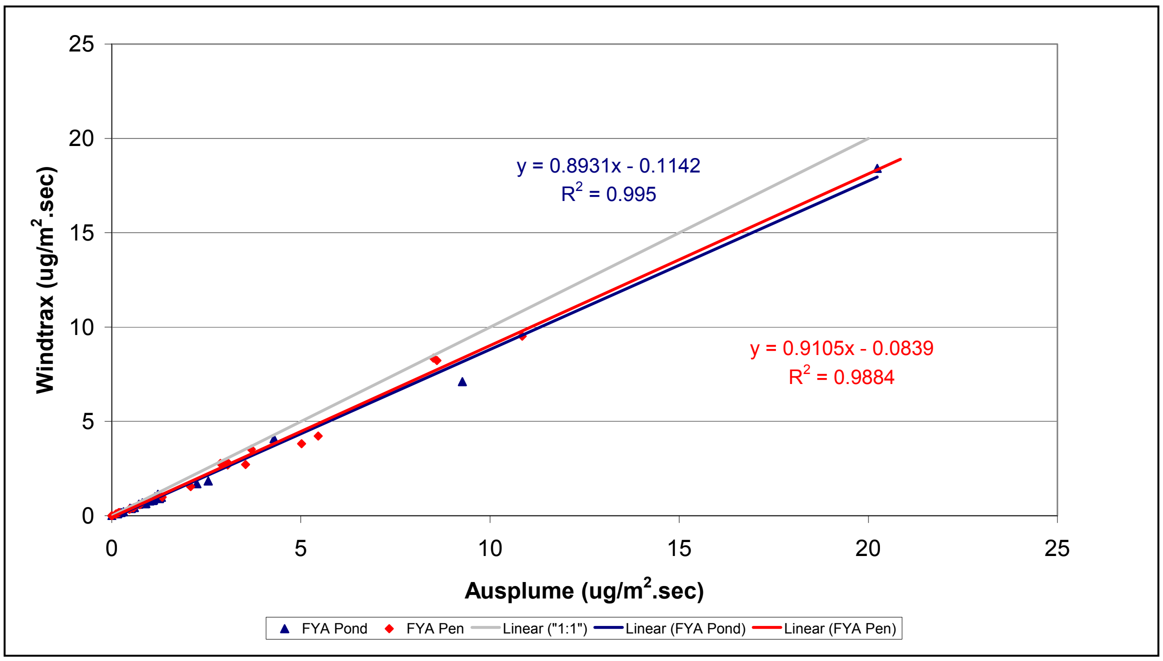

Figure 3. WindTrax and Ausplume derived emission rates: Feedyard A

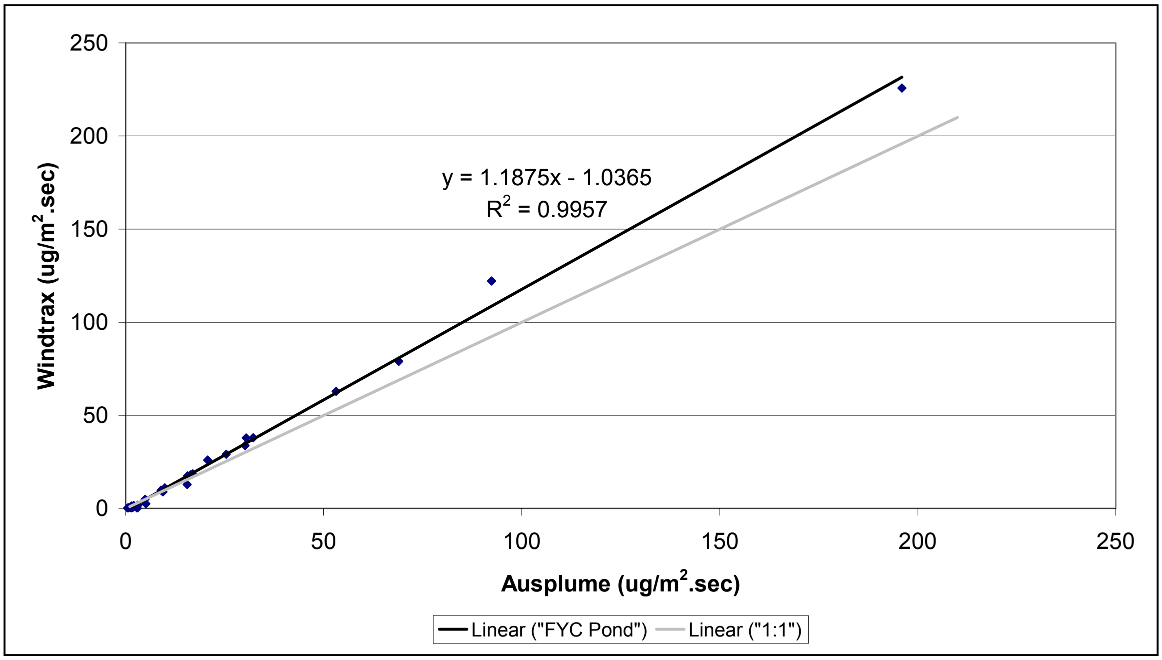

Figure 4. WindTrax and Ausplume derived emission rates: Feedyard C Pond

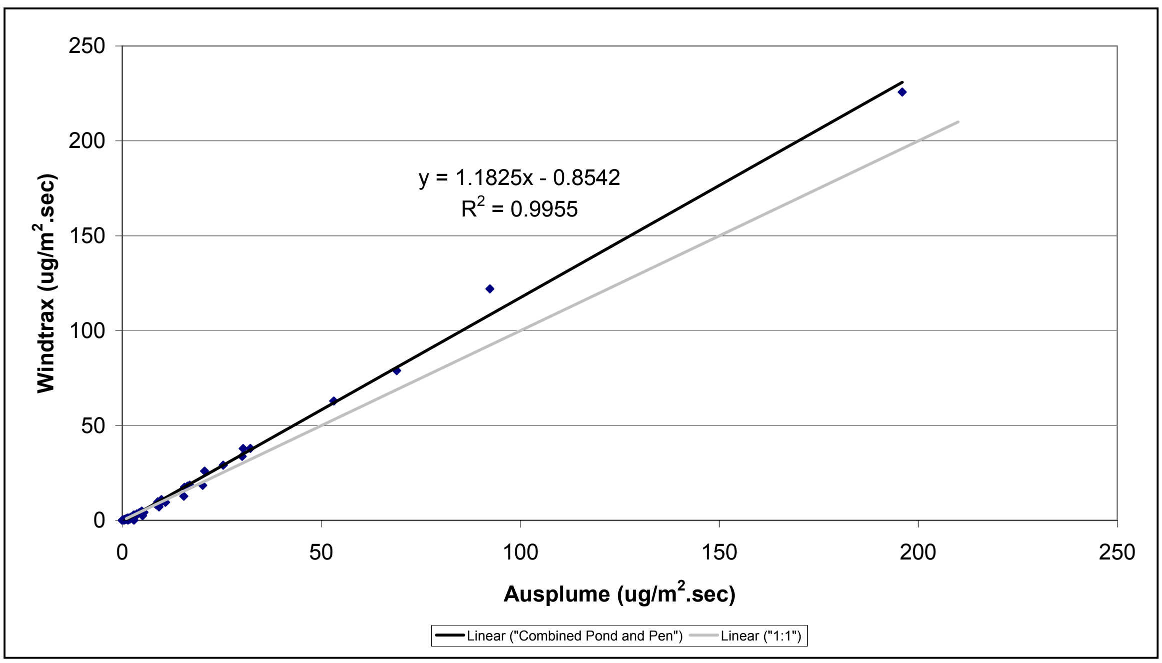

Figure 5. Combined data

It should be remembered that the Ausplume model, like all plume models is based on the Gaussian approximation, which assumes that a plume will disperse according to the normal distribution. In contrast to this the WindTrax model is a largangian model that follows randomly traveling particles in the air to simulate atmospheric dispersion. Thus, it is expected that there will be some differences between the models. Taking this into account, and inputting the same data into them, it would be expected that they would provide a similar if not identical response (i.e. 1:1, WindTrax : Ausplume). A good correlation was observed between the emission rates derived using the two models for both pond and pen data. This is similar to the work of Sommer *et al.* (2004) who found that the Theoretical Profile Shape (TSP) model and WindTrax correlated well.

The emission rates derived for Feedyard A via modeling (Figure 3) showed that the models predicted similar emission rates for both the pen and pond data sets (i.e. both had similar equations and r^2 values). However, Ausplume predicted slightly higher emission rates compared to WindTrax. Additionally, when all pond and pen data for both feedyards was combined (Figure 5), the data again showed a good correlation between the Ausplume and WindTrax derived emission rates. However in this instance, WindTrax predicted higher emission rates compared to Ausplume. When all of the data was combined the data was dominated by the higher emission rates derived for the Feedyard C pond which in turn had an influence in the derivation of the overall equation as shown in Figure 5.

Whilst a good correlation was expected the amount of deviation from the theoretical 1:1 line was not expected to be in the order of 20 %. This was unexpected as the two methods are essentially the same in that both derive an emission rate using a mathematical formula, which is linked to the input data. Previous studies have undertaken sensitivity analysis with regards to the effect of varying the model inputs. Important inputs for both models include wind speed, stability class, wind direction and surface roughness.

For each model run, both models used the same data, thus differences in with regard to difference the input data can be ruled out. The way in which the models process the data is therefore an obvious area for further investigation as the two models are different and thus will treat the data differently.

As shown in Figure 3 above, both models compared well irrespective of source size (pens maximum upwind fetch was approximately 3000 ft, ponds up to 2400 ft), thus source size may not have a direct influence in this instance. Possible reasons for the discrepancies between the models are discussed further below.

Stability class is an important input in modeling. An analysis of all of the data points showed that of the modeled data points, stability class A occurred 1 % of the time, class B 23 %, class C 28 % and Class D 49 % of the time. Thus neutral conditions occurred at approximately half of the sampling events. The data when correlated according to stability class is shown in Figure 6.

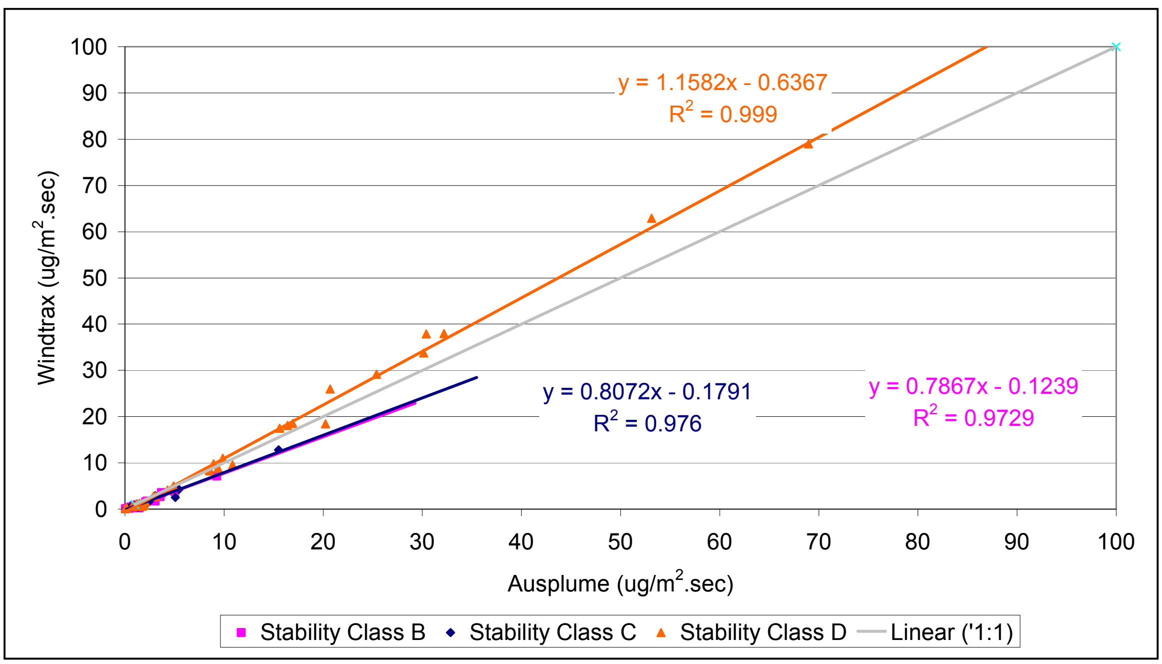

Figure 6. Emission rates as a function of Atmospheric Stability

Figure 6 shows that good correlations were observed between the models for the different stability class conditions. Interestingly, the results for stability class B and C events (unstable conditions) were very similar, however those for neutral conditions (Class D) resulted in higher emission rates (some emission rates were greater than 20 μg/m^2.sec) which may simply be a function of the amount of gas emitted from the source. Thus, from the data it can be concluded that under unstable conditions Ausplume tends to over predict emissions, whereas under neutral conditions Ausplume appears to under predict emissions compared to WindTrax.

Trinity Consultants (2000) concluded that ISC (upon which Ausplume is based) does not model unstable atmospheric conditions accurately. Whilst the emission rate data derived under neutral conditions was much higher than those under unstable conditions, the correlation between WindTrax and Ausplume was very good indicating that the models (including ISC) would provide similar estimates under neutral conditions. Further examination of the data in Figure 4 where WindTrax over predicted emissions compared to Ausplume showed that the emission rates derived were not a function of neutral conditions as only 32% of the dataset consisted of stability class D events meaning that a factor other than stability class is likely to have resulted in the difference in the predictions of the two models.

The modeling was undertaken as using a scaling factor (Equation 2) to enable back calculated emission rates to be derived using Ausplume. It is important to note that the meteorological data covered a period of approximately 6 minutes. This is handled well in WindTrax as in effect, it assumes that the data is all collected over the same averaging period. Additionally WindTrax uses the Monin-Obukhov Similarity Theory (MOST) for the Profiles in the atmospheric surface layer which is suitable for short time periods (Flesch *et al.* 2005 b). Ausplume uses the Pasquill Gifford dispersion curves that were developed from 10 minute averaged experimental data and are more commonly used for hourly averaged data.

It is likely that the comparison between the models could be improved by incorporating sigma theta (standard deviation of wind direction) data in Ausplume where an averaging time that is approximately the same as the time over which the data was measured (Environmental Protection Agency, 2000). However, the aim of the exercise was to compare the models using default dispersion settings thus future work should examine the improvement in emission estimation as a function of more representative dispersion curves in both models.

An easily identifiable difference between the Feedyard data sets is the distance from the source to the measurement locations. For Feedyard A (pens and ponds), most of the measurement sites were located within 50 feet of the source (pens and pond), whereas for the Feedyard C pond, the measurement locations were located more at distances greater than 60 feet (up to 400 feet) from the source.

The near field (close to source) over prediction by Ausplume (Figure 3) may be a function of the initial vertical spread (sigma z) as set by the user (0.5 m). The value was based on an initial height as to represent a source where the height of the cattle or the banks of the sedimentation basins will influence the initial vertical spread. The growth of the initial spread with fetch (plume growth with distance from the source) was not modeled in this exercise. Whilst it may be less of an issue with ponds, it could be significant with pens that have large fetches. The similarity between the pond and pen data in Figure 3 indicated that the increase in initial mixing height with distance across the source may not be very significant. Whilst the selection of the overall value of sigma z is likely to be the cause of the over prediction in the near field, adjusting this value is likely to exacerbate the under prediction in the far field. Future work is required in this area to further assess the reasons why the models differ when run for measurement points close to a source.

Conclusions

An assessment of emission rates derived using the Gaussian Ausplume and largangian WindTrax model indicated that the emissions rates derived using the models correlated well irrespective of the type of source (r^2>98%). Without direct measurements it is difficult to define which model provides the most accurate estimate of emissions. Work such as that of Sarkar and Hobbs (2003) and Galvin *et al.* (2004) has shown that dispersion models can correlate well with certain direct measurement techniques The models are inherently different and thus some difference was expected. Whilst the correlation between the two models was excellent there was consistent variation in the order of 20 % between the emissions predicted by the models and the theoretical 1:1 line. This did not appear to be a function of the size of the source. The data indicates that with sufficient knowledge of the models, the emission rate data derived using one model can be interchanged with the other models with confidence. Whilst not fully proven, it would appear that the way in which the models handle dispersion close to the source and thus distance to the source are important factors when back calculating emissions from area sources. To back calculate emissions from a source, a trade off may need to be made with respect to inaccuracies in the models near the source and the ability of the measurement technique to measure the species in question as it dilutes with distance from the source.

Future work should further investigate the use of improved meteorological parameters and the selection of initial mixing heights for emissions derived close to areal sources. Additionally thought should be given to the location of the downwind sampling point.

Acknowledgements

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Monitoring System Design for the Southeastern Broiler Gaseous and Particulate Matter Air Emissions Monitoring Project

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Abstract

Air emissions data proposed to be used as representative data for southeastern U.S. broiler operations in the national Air Compliance Agreement is currently being collected by Iowa State University and The University of Kentucky. Two mechanically ventilated commercial broiler houses located in western Kentucky are being monitored for one year. This study includes the quantification of building emissions for ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), non-methane hydrocarbons (NMHC), total suspended particulates (TSP), particulate matter less than 10 microns in diameter (PM_{10}) and particulate matter less than 2.5 microns diameter ($PM_{2.5}$). This paper describes the continuous air pollutant monitoring system developed for use in this study. Two mobile air emission monitoring units were designed and fabricated at Iowa State University during the summer of 2005. Monitoring system installation was completed in fall 2005, and monitoring for all pollutants was initiated in January 2006. The mobile air emission monitoring units include a system to quantify pollutant concentrations within the broiler houses and a system to quantify the volume of air exhausted from each broiler house by the ventilation fans. Ammonia, carbon dioxide, methane and total hydrocarbon concentrations are measured using INNOVA 1412 photoacoustic multi-gas monitors. Hydrogen sulfide concentrations are measured using Teledyne API 101E pulsed fluorescence analyzers. Total hydrocarbons, non-methane hydrocarbons and methane are also measured using VIG-200 gas chromatographs. Continuous measurement of air flow from each house is accomplished by measuring building static pressure and the operational status of each ventilation fan. The fan operation status in conjunction with building static pressure is applied to in situ fan curves developed for each fan using FAN Assessment Numeration System (FANS) units built by the University of Kentucky. Compact Field Point data acquisition hardware is utilized in conjunction with a custom data acquisition program written in Labview 7. Details of the monitoring system components are outlined in this paper.

Introduction

Accurate quantification of pollutant emissions from AFOs including commercial broiler production systems are needed to develop improved emissions inventories and emission factors, as well as to determine if certain regulatory reporting requirements of emissions are required. A concern for the US poultry industry as well as for regulatory agencies is to ensure that reasonable estimates of emissions from broiler production systems are used. Currently, estimates based on continuous emission data for multiple air pollutants are lacking for these systems. The mass of a pollutant emitted from a facility is the product of source concentration of a pollutant and the air exchange rate through the source following proper unit conversions and correction for temperature and barometric pressure effects. It is a challenge to reliably quantify pollutant concentration and airflow in broiler production housing on a continuous basis. The use of intermittent ventilation by cycling of the ventilation fans off and on, especially when the birds are young, makes it necessary to coincide the in-house pollutant concentrations to the periods of fan operation in order to calculate emissions that are representative of those exhausted from the production housing. The pollutants of interest in this study include ammonia (NH_3), carbon dioxide (CO_2), total suspended particulate matter (TSP), particulate matter 10 microns or less (PM_{10}), particulate matter 2.5 microns or less ($PM_{2.5}$), hydrogen sulfide (H_2S) and non-methane hydrocarbons (NMHC). This project will quantify emissions from two commercial broiler production houses over a one year measurement period. Data from this project is proposed to be used to represent air emissions from southeastern U.S. broiler houses in the Air Quality Compliance Agreement (ACA), which will have regulatory significance to future enforcement and decisions made by the EPA in regards to air emissions from animal agriculture. Instrument selection for each pollutant of interest is shown in Table 1.

Table 1. Monitoring Equipment Selection by Pollutant of Concern

Pollutant	Monitoring Instrument
NH_3	Innova 1412, Innova AirTech Instruments A/S, Denmark
CO_2	Innova 1412, Innova AirTech Instruments A/S, Denmark
H_2S	UV Fluorescence Hydrogen Sulfide Analyzer Model 101E, Advance Pollution Instrumentation, San Diego, California
NMHC	Model 200 Heated Methane/Non-Methane/Total Hydrocarbon Analyzer, VIG Industries, Anaheim, California
NMHC	Innova 1412, Innova AirTech Instruments A/S, Denmark
TSP	Tapered Element Oscillating Microbalance (TEOM) Series 1400a with TSP inlet head, Thermo Electron Corporation, East Greenbush, New York
PM_{10}	PM_{10} - Tapered Element Oscillating Microbalance (TEOM) Series 1400a with PM_{10} inlet head, Thermo Electron Corporation, East Greenbush, New York
$PM_{2.5}$	$PM_{2.5}$ - Tapered Element Oscillating Microbalance (TEOM) Series 1400a with PM_{10} inlet head in conjunction with a 2.5 micron cut cyclone, Thermo Electron Corporation, East Greenbush, New York

Project Description

Two broiler houses associated with Tyson Foods broiler operations in Western Kentucky are being monitored in this extensive field monitoring study. The monitored broiler production houses use tunnel ventilation and box air inlets along the sidewalls which is representative of typical southeastern U.S. broiler production practices in terms of housing style and production management

Each broiler house has its own environment-controlled Mobile Air Emissions Monitoring Unit (MAEMU) that houses air pollutant and fan flow monitoring systems and provides an environment-controlled instrument area as shown in Figures 1 and 2. Air samples from the house sampling points (representing the exhaust air streams) to the MAEMU will be protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. Building airflow will also be monitored continuously. A real-time data acquisition (DAC) program developed using LabVIEW 7 software (National Instruments, Corporation, Austin, TX) is used to acquire data, automate sampling location control, display real-time data, and deliver data and system operation status as shown in Figure 2.

Figure 1. The Mobile Air Emissions Monitoring Unit (MAEMU).

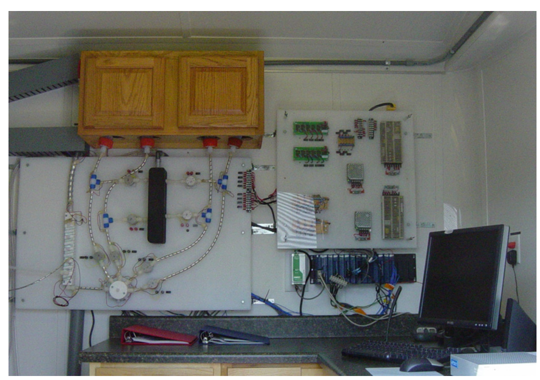


Figure 2. The MAEMU Gas Sampling Control System.

Each MAEMU will house a gas sampling system, gas analyzers, environment-monitoring analyzers, a computer, DAC system, and other equipment needed for the study (Figure 3). Each broiler building will be sampled continuously for 12 months. The 12-month duration assures this project will meet the objectives of characterizing long-term emissions and to respond accurately to the need for annual emission factors from animal facilities by regulatory agencies and others. Long-term measurements allow the recording of variations in emissions due to seasonal effects, animal growth cycles, and diurnal variations. The two broiler houses, each 13.1m x 155.5m (43 x 510 ft) will be monitored at two different sites, 40 miles apart.

The houses use four 91-cm (36-in) diameter sidewall exhaust fans spaced about 120 ft apart, and ten 123-cm (48-in) diameter tunnel fans for ventilation.

Experimental Design

The use of intermittent ventilation by cycling of the single-speed fans off and on, especially when the birds are young, makes it necessary to correlate the in-house pollutant concentrations to the periods of fan operation in order to calculate emissions that are representative of those exhausted from the production housing. Broiler house minimum ventilation exhaust fans are typically operated in five minute duty-cycles with a 30 second minimum run-time. For example, a fan could operate for two minutes and then turn off for three minutes during a five minute duty-cycle. Higher stage ventilation fan operation is based on temperature set points, which still result in intermittent fan operation. The determination of ventilation rates through the animal housing, based on manufacture supplied fan performance curves, is difficult due to the large number of fans involved and the inherent variation among them. As such, each fan is calibrated in situ to reflect the actual operating conditions in the field. For in situ calibration, the FANS method is used (Gates et al., 2004). During FANS testing, the fans operation status is tracked in conjunction with building static pressure to develop fan curves for each unit.

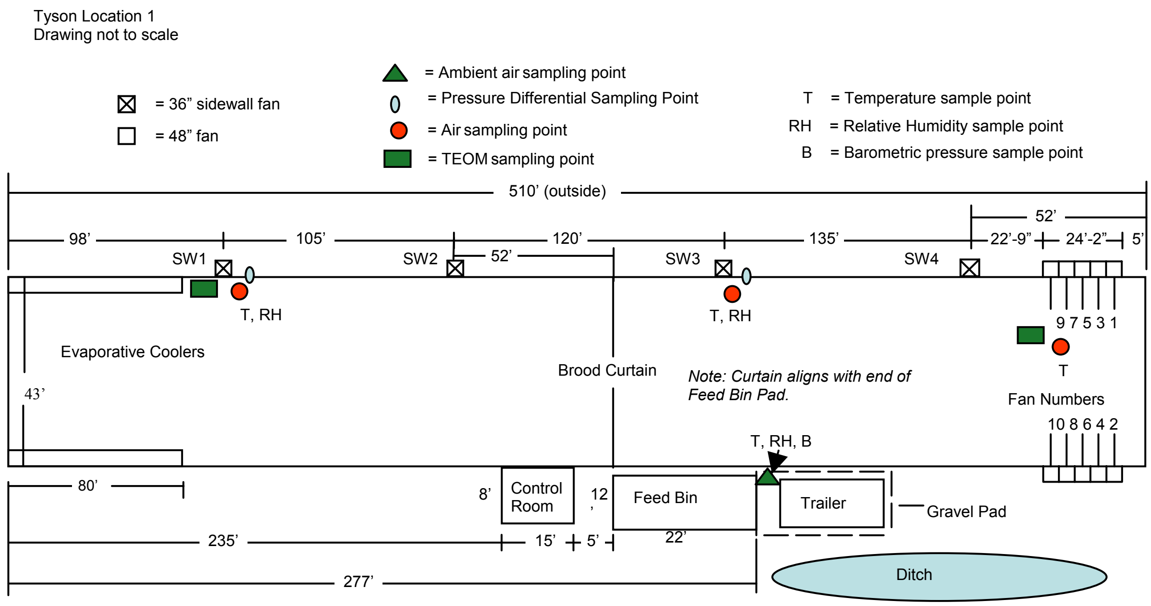
Air samples are drawn from three locations in each house (Figure 4 and 5), as well as from an outside location to provide ambient background data. One is located near the primary minimum ventilation (36-in) sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location is near the fourth sidewall (36-in) exhaust fan (SW4) (non-brooding end). The third location is at the tunnel end for the first and higher stage of tunnel ventilation mode. In addition, an ambient air sample from outside the broiler house, near the eave between inlet boxes on the house sidewall that does not have exhaust fans will be taken at 2-hour intervals to provide a background concentration level. The background quantity will be subtracted from the exhaust quantity in calculating the pollutant emissions from each house. Air samples will be collected via 0.95-cm (3/8-inch) o.d. and 0.64-cm (¼-inch) i.d. teflon tubing (Fluorotherm FEP tubing). Sampling locations and placement of the sampling ports were chosen to maximize representation of the air leaving the houses. Each sample inlet point is equipped with two paper pleated dust filters to keep large particulate matter from plugging the sample tubing as well as a 20 micron *Teflon* filter to remove smaller particulate matter (Figure 4).

Figure 3. Gaseous emission monitoring instruments in MAEMU.

Figure 4. Gaseous emission in-house sample intake line with filters.

Individual supply pumps (with all internal wetted parts teflon coated) are used to continuously draw air from each of the sampling locations. The sampling train is designed such that a sample will be drawn from all four sampling points continuously and when a sample point is not being analyzed the flow will be bypassed at the instrument trailer. This arrangement is designed to greatly reduce sample-to-sample purging time. When analyzing each of the in-house air samples, four 30-second measurement cycles by the multi-gas (NH_3, CO_2, H_2O, and NMHC) analyzer will be performed to ensure attainment of 97% or better of the actual gas concentration values. Minimum time interval between samples is experienced when all fans are operational at all three sampling locations. This minimum time interval of a complete sampling cycle is 360 s (120 x 3 = 360 s). To account for potential concentration changes during this period, linear interpolation between the two adjacent readings of the same location is performed to determine the concentrations in between. If SW4 and/or TF1 fans are not operating, their sample analysis is skipped, and the sampling returns to SW1 or fresh/background air. Airflow rates corresponding to the measured concentrations are used in the calculation of the overall house emission rate. Since compositions of the background air are much more stable than the house air, the background is sampled once every 2 hours. Due to the larger step change in ammonia concentration between the in-house air and background air, a longer sampling time (i.e. 5 minutes) is used to allow full stabilization of the analyzer readings. Only the concentration readings at the end of the sampling cycle are considered as valid measurements.

Figure 6 shows the TEOMs in place inside the broiler facility. Placement of the TSP, PM_{10}, $PM_{2.5}$ TEOMs is as follows: while the brooder curtain is closed all TEOMs are places adjacent to the sidewall 1 fan. When the brooder curtain is opened the TEOMs will be relocated to the tunnel end of the house as shown in Figure 5. TEOM sampler location was determined following collection of dust concentration and air velocity data near the SW1 and tunnel fans. This data was used to identify areas where dust concentrations were representative of the concentrations being exhausted through the sidewall and tunnel fans.



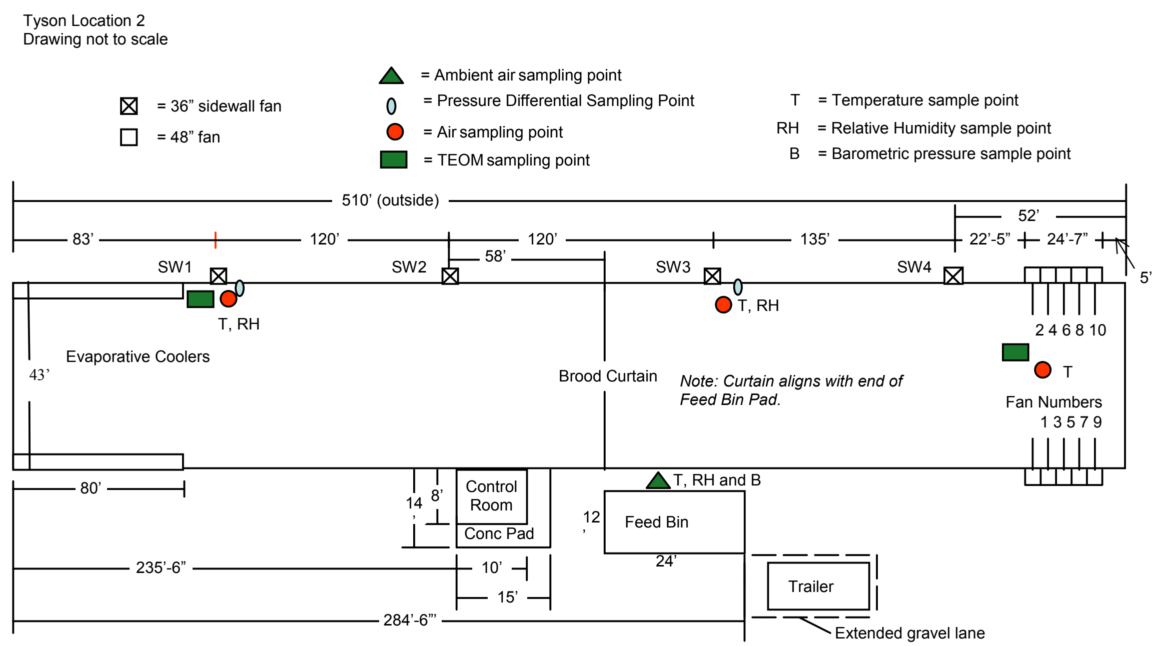


Figure 5. Schematic layout of Tyson Location 1 and 2.

Figure 6. In-house particulate matter monitoring instruments for PM_{10}, $PM_{2.5}$, and TSP.

Summary

The main objective of this study is to determine and report emissions of ammonia (NH_3), carbon dioxide (CO_2), total suspended particulates (TSP), particulate matter 10 microns or less (PM_{10}), particulate matter 2.5 microns or less ($PM_{2.5}$), hydrogen sulfide (H_2S) and non-methane hydrocarbons (NMHC) based on continuous pollutant concentration and fan flow data over a one year period from broiler houses representative of commercial broiler production in the Southeastern United States. The primary concern for this study is the establishment of reliable and accurate methods for determining pollutant concentration and ventilation rates in broiler houses for emission rate determination. Initial instrumentation and method testing began in the 3rd Quarter of 2005. Data collection began in the 1st quarter of 2006 and will conclude at the end of the 1st quarter of 2007. Results will be reported during the 3rd quarter of 2007. Because the harsh nature of the sample air, high humidity and high concentrations of the pollutants is beyond the operational limits of many analytical instruments, it is a challenge to reliably quantify concentration and airflow in animal production housing on a continuous basis (Xin et al., 2003). As the project is proposed to represent the southeastern U.S. broilers in the Air Quality Compliance Agreement, extreme caution is being taken to obtain the most representative and highest quality data.

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Quality Assurance Project Plan (QAPP) Implementation for the Southeastern Broiler Gaseous and Particulate Matter Air Emissions Monitoring Project

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Abstract

Air emissions monitoring at the sites proposed to provide data representative of southeastern broiler operations to the national Air Compliance Agreement is being conducted cooperatively by Iowa State University and The University of Kentucky. Monitoring system installation was completed in fall 2005, and monitoring for all pollutants was initiated in January 2006 at two mechanically ventilated commercial broiler houses located in western Kentucky. The aerial emissions from the broiler houses quantified in this study include ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), non-methane hydrocarbons (NMHC), total suspended particulates (TSP), particulate matter of ≤ 10 µm diameter (PM_{10}), and particulate matter of ≤ 2.5 µm diameter ($PM_{2.5}$). This paper describes the Quality Assurance Project Plan (QAPP) developed and implemented for this study, including the key components of Project Management, Data Generation and Acquisition, Assessment and Oversight, and Data Validation and Usability.

Introduction

In January 2005, the US Environmental Protection Agency (EPA) announced a plan, after negotiating with representatives of the animal agricultural industry, to collect scientifically credible data concerning air emissions from livestock and poultry facilities. This effort is titled the Air Compliance Agreement (ACA) (Copeland, 2005). Monitoring work performed as part of the ACA will have regulatory significance to future enforcement and decisions made by the EPA in regards to air emissions from animal agriculture. As such, projects within the ACA are required to operate with a Category 1 Quality Assurance Project Plan (QAPP) (US EPA, 2001).

The QAPP as defined by the EPA is a tool for project managers and planners to define the type and quality of data needed for environmental decisions, and to describe the methods for collecting and assessing those data. The QAPP integrates technical and quality control aspects regarding planning, implementation, and assessment for a project. The goal is to insure that the results of a project are of the type and quality needed and expected by the EPA. The four components of the plan are Project Management, Date Generation and Acquisition, Assessment and Oversight, and Data Validation and Usability (US EPA, 2001).

In the fall of 2005, Iowa State University and The University of Kentucky began implementing monitoring at the sites proposed for use as the ACA study for southeastern broiler operations. This segment of the study will monitor air emissions from two mechanically ventilated commercial broiler houses in western Kentucky. The study includes the quantification of emissions of ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), non-methane hydrocarbons (NMHC), total suspended particulates (TSP), particulate matter of ≤ 10 µm diameter (PM_{10}) and particulate matter of ≤ 2.5 µm diameter ($PM_{2.5}$) from the broiler production facilities. The following section describes the development and implementation of key quality assurance and control components for the project's Category 1 QAPP as required by the EPA (US EPA, 2001).

QAPP Development and Implementation

Development and implementation of the QAPP for the Southeastern Broiler Gaseous and Particulate Matter Air Emissions Monitoring Project are discussed below by plan component.

Project Management

This component addresses the background and objectives for the project, the basic management of the project, and the responsibilities of the participants. All individuals participating in the project were identified and assigned tasks pertaining to their areas of expertise and participation level. Contact information for the participants was also included in this section. Project objectives and a brief summary describing the project were provided. A biosecurity plan was added to this component of the QAPP to outline the steps that should be taken by members of the project team when visiting the broiler facilities.

Data Generation and Acquisition

This component of the plan is key to identifying project design and steps for implementation. Methods identified here ensure appropriate methods for sampling, measurement and analysis, data collection, and quality control (US EPA, 2001). In the plan, this component clearly defines the experimental design, equipment selection and set-up, sampling methods, and quality control for the southeastern broiler air emissions project.

As compared to air emissions monitoring for the commercial manufacturing and industrial sector, air emissions monitoring for agriculture is a more recent concern. Also, as compared to the industrial setting, monitoring of air emissions for agriculture is a small sector of the monitoring equipment economy. As such, while many types of analytical equipment and sampling methods are available, few have been standardized for agricultural situations. A primary concern for this study is the development of reliable and accurate methods for determining pollutant concentration and ventilation rates in the environment of a broiler house for the determination of pollutant emission rates. It is a challenge to reliably quantify concentration and airflow in animal production housing on a continuous basis (Xin et al., 2003). The harsh nature of the sample air, high humidity and high concentrations of the pollutants is beyond the operational limits of many analytical instruments.

Unique to broiler housing is the use of intermittent ventilation through intermittent operation of the single-speed fans to provide minimum ventilation, especially when the birds are young. At the same time, the system must have sufficient ventilation capacity to meet the needs of market-size birds under warm conditions. The use of intermittent ventilation by cycling of the fans makes it necessary to correlate in-house gas and particulate matter concentrations to periods of fan operation. Emission calculations will then be representative of those exhausted from the production housing. Broiler house minimum ventilation exhaust fans are typically operated in five minute duty-cycles with a 30 second minimum run-time. For example, a fan could operate for two minutes and then turn off for three minutes during a five minute duty-cycle. Higher stage ventilation fan operation is based on temperature set points, which also result in intermittent fan operation. Consequently, the use of continuous, real-time analyzers with fast response times is critical for measuring emission concentrations from exhaust air in broiler houses. Two other critical issues for accurate emission rate calculation are location of sample intake within the facility and accurate determination of ventilation rates. The following is a list of analytical instruments selected for measurements of pollutant concentrations in this project.

- NH_3 – Innova 1412, Innova AirTech Instruments A/S, Denmark
- CO_2 - Innova 1412, Innova AirTech Instruments A/S, Denmark
- H_2S – UV Fluorescence Hydrogen Sulfide Analyzer Model 101E, Advance Pollution Instrumentation, San Diego, California
- NMHC – Model 200 Heated Methane/Non-Methane/Total Hydrocarbon Analyzer, VIG Industries, Anaheim, California , and Innova 1412, Innova AirTech Instruments A/S, Denmark
- TSP – Tapered Element Oscillating Microbalance (TEOM) Series 1400a with TSP inlet head, Thermo Electron Corporation, East Greenbush, New York
- PM_{10} - Tapered Element Oscillating Microbalance (TEOM) Series 1400a with PM_{10} inlet head, Thermo Electron Corporation, East Greenbush, New York
- $PM_{2.5}$ - Tapered Element Oscillating Microbalance (TEOM) Series 1400a with PM_{10} inlet head in conjunction with a 2.5 micron cut cyclone, Thermo Electron Corporation, East Greenbush, New York

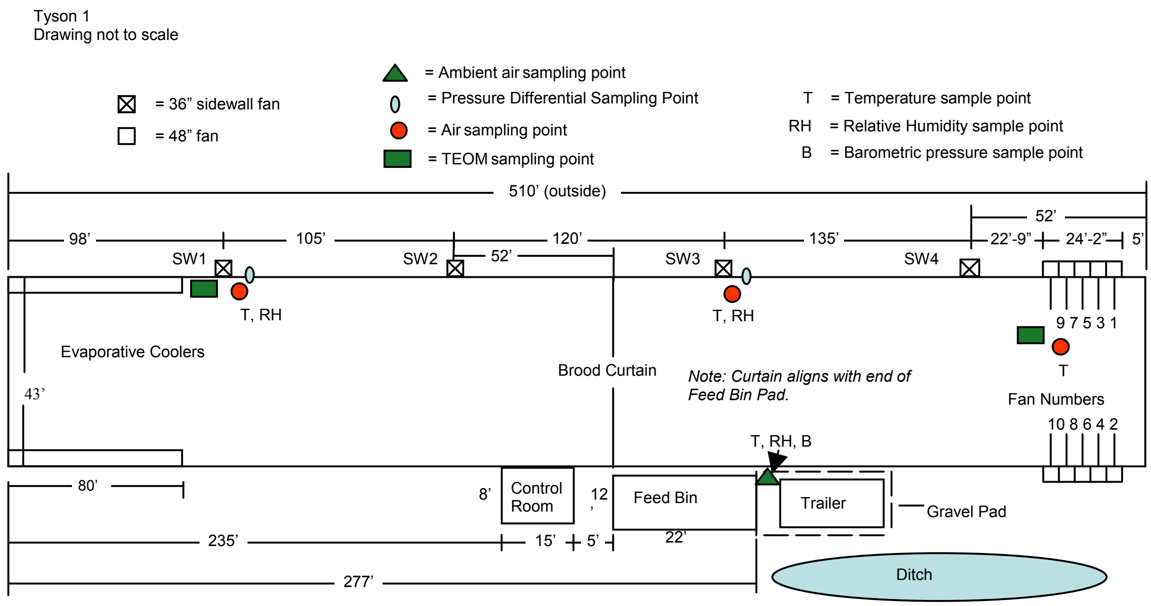
After analytical instruments were selected for the project and prior to placement of each instrument at the monitoring sites, experiments were performed in the laboratory. Laboratory processing for all analytical instrumentation included initial calibration, verification and setting of analysis cycle time, assessment of dynamic response, accuracy and real-time interfacing with the data logging program and software. Prior to on-site analysis and data collection, field testing of the equipment was performed to ensure proper operation and placement.

For the gaseous emissions, four sample locations were identified, with three locations for in-house concentrations and one for outside ambient concentrations (Figure 1). Sampling from these locations is based on real-time fan operational status. For instance, if only one fan is operating then sampling repeats at that location, but if multiple fans are operating sampling will be sequenced repeatedly among these locations. A sample line delivers the sample air from each location to the environmentally controlled Mobile Air Emissions Monitoring Unit (MAEMU) (Figure 2) where the instrumentation is housed and the air sample is provided through a manifold to the three instruments.

Of particular importance for on-site testing was the determination of TEOM placement within the broiler house. Because the three TEOMs could not be placed at triplicate locations (due to budget limitations) as is the case with the gaseous sample lines, a best case placement was determined. Through on-site testing and air velocity profile measurements within the house, two locations were identified. During the brooding period, the TEOMs are placed beside sidewall fan 1 (SW1). When the brooding curtain is raised, the TEOMs are moved and placed near the tunnel end (Figure 1).

Accurate determination of ventilation rates is critical to proper calculation of air emission rates. Initially, all the exhaust fans were calibrated in situ, individually and in combined operation stages, with a Fan Assessment Numeration System (FANS) to obtain the actual fan performance curves (airflow rate vs. static pressure) (Gates et al., 2004). Once the actual airflow curves are established for all the exhaust fans and their combinations, runtime of each fan is monitored and recorded continuously by sensing ON/OFF state of the current switches (CR9321, CR MAGNETICS, INC, St. Louis, MO) driven by the current flow through the fan power supply cord. Concurrent measurement of the house static pressure is made with differential pressure sensors (Model 264, Setra, Boxborough, MA). Summation of airflows from the individual fans during each monitoring cycle or sampling interval yields the overall house ventilation rate. This method of determining dynamic ventilation rates of mechanically ventilated animal confinement has been successfully used in recent AFO air emission studies in the United States (Gates et al., 2005, Wheeler et al., 2006).

In addition to describing the steps taken to implement the project and verifying accuracy of the results, this component of the QAPP also provides explicit details for project duration quality control. Recalibration triggers and schedules are described. Moreover, standard operating procedures (SOPs) for handling all instruments and systems components are included as Appendices.



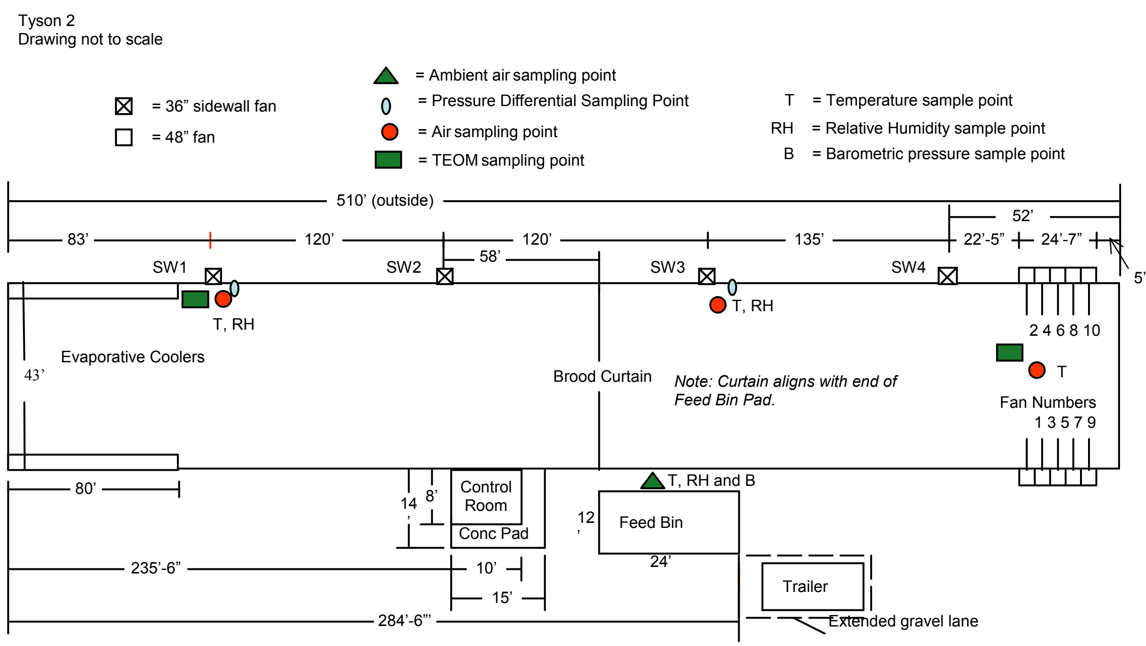


Figure 1. Schematic layout of Tyson 1 and Tyson 2.

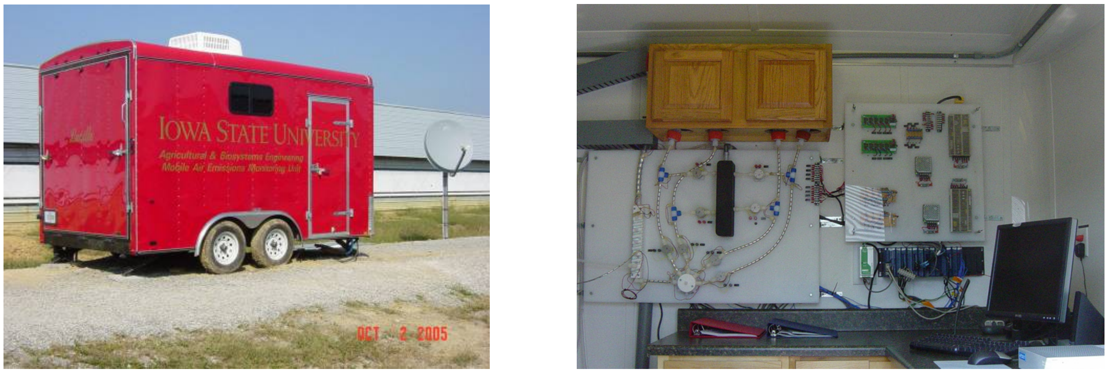


Figure 2. Inside and outside views of the Mobile Air Emissions Monitoring Unit (MAEMU).

Assessment and Oversight

This section of the plan addresses the required activities for assessing the effectiveness of the quality assurance and quality control activities associated with implementing the plan. A combination of remote surveillance, on-site surveillance, internal technical systems audits, external technical systems audits and out of range data flagging/review is used to provide project assessment.

Remote surveillance is conducted on a daily basis via a high-speed internet connection to each MAEMU. Using a web-based remote interface, all pollutant monitoring readings can be viewed in real time as well as individual fan operational status, pressure differential, temperature, relative humidity and dew point conditions at all four sampling points. A complete on-site surveillance of the monitoring system is conducted weekly at each monitoring site. During weekly visits to each site project personnel perform a visual check on all system components including in-house sampling points, TEOMs and fans, the ambient monitoring point, and all instruments and components located inside the MAEMUs. During this visit paper element filters and the 20 micron teflon filters are replaced, and the TSP, PM_{10} and $PM_{2.5}$ TEOM heads are exchanged for clean heads (TEOM heads are exchanged twice per week due to the high dust conditions encountered in the broiler houses). A report detailing assessment observations and any required response actions is prepared following the visit and emailed to team members.

Internal technical system audits are performed between flocks. The broiler houses are empty for approximately ten days following the removal of each flock of birds. During this ten day period, ISU and UK project personnel conduct an internal technical systems audit at both monitoring sites. This audit includes a visual inspection of all system component, and a flow check at each of the four sample points to confirm pump flows are maintaining a 15 liter per minute flowrate. A flow-audit is conducted on each TEOM during the audit. Leak checks of the GSS and supply lines are conducted by calibrating an additional INNOVA 1412 with the INNOVA 1412 located in the MAEMU and then placing the second INNOVA 1412 at each sample point inside the broiler house and confirming matching ammonia readings. This provides a confirmation that no dilution air is entering the system, and thus that no leaks are present.

An external technical systems audit team has been established and will conduct an audit following final acceptance of the project QAPP. The external audit team members are nationally recognized experts in AFO air emissions monitoring who have no association with the project. The external auditors will make a visit to each site and will include a review of calibration and QC measures.

All data is reviewed for out of range data using a computer program. The data processing program automatically flags out of range data and project personnel will review flagged data on a weekly basis and confirm that the data is invalid, or override the flag if data is determined to be valid. Flagged data is not used in emissions calculations. A record of data review and any removal of data following review is maintained. The response action to data flagged as out of range is to investigate and document the reason that the data was flagged and to follow-up with a site visit if any data flags were the result of equipment malfunction and correct the problem.

Data Validation and Usability

This component describes the activities that occur after the data collection phase of the project. Because this project involves a long period of intensive data collection, steps for continuous review and validation of the data are necessary. To improve the ease with which data are reviewed, real-time emission calculations are performed on site by the PC as data are collected and recorded. However, all raw data are also recorded. All data are reviewed within two business days after having been recorded.

Summary

While a requirement of considerable time and energy in developing a detailed Quality Assurance Project Plan (QAPP), the QAPP is a very useful planning tool when implementing and managing projects of this size and importance. The US EPA provides in-depth descriptions of what is necessary for a QAPP to address the four plan components (Project Management, Date Generation and Acquisition, Assessment and Oversight, and Data Validation and Usability). The information detailed in the QAPP, will help ensure collection of scientifically credible data concerning air emissions. Because analytical equipment for air emission monitoring is not specifically made for the conditions encountered in some agricultural settings, a primary concern for this study is the establishment of reliable and accurate methods for the determination of emission rates. Laboratory and on-site testing that occurred prior to the start of emission data collection verify the effectiveness of the instruments and methods chosen for this work. The team participating in the Southeastern Broiler Gaseous and Particulate Matter Air Emissions Monitoring Project feels that the steps detailed in the project's QAPP are conducive to assuring the quality of the methods and results.

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Measurement, Analysis, and Modeling of Inorganic Fine Particulate Matter in Rural, Ammonia-Rich Areas in Eastern North Carolina

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Abstract

Gaseous emissions of ammonia from confined animal feeding operations (CAFOs) in eastern North Carolina have become an environmental issue of concern. These emissions cause an impact in eastern North Carolina in many different ways such as human health, and increased fine particulate formation on a local and regional scales. To study these impacts, acidic gases and inorganic fine particulate matter ($PM_{2.5}$) concentrations were measured at a hog farm in eastern North Carolina, and at a down wind site ~10 miles away. This analysis showed slight seasonal differences in both gas and PM concentrations and the insights into the gas/particulate interface. To study the regional impact, an analysis of fine particulate data in eastern North Carolina was conducted in order to investigate the impact of the hog industry and its emissions of ammonia into the atmosphere. This fine particulate data is simulated using ISORROPIA, a thermodynamic model that simulates the gas and aerosol equilibrium of inorganic atmospheric species. The observational data analyses show that the major constituents of fine PM are organic carbon, sulfate, and ammonium, nitrate, and elemental carbon. The observed $PM_{2.5}$ concentrations ares positively correlated with temperatures but anti-correlated with wind speeds. The correlation between $PM_{2.5}$ and wind direction at some locations indicates the impact of the emissions from hog facilities on $PM_{2.5}$ formation. The modeled results are overall in good agreement with observations, with slight better agreement at urban sites than at rural sites. The predicted total inorganic PM concentrations are within 5% of the observed values under conditions with median initial total PM species concentrations, median RHs, and median temperatures. The ambient conditions with high PM precursor concentrations, low temperature, and high relative humidity favor the formation of the secondary PM.

A PM_{10} Emission Factor for Free Stall Dairies

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Abstract

Ambient concentration measurements of total suspended particulate (TSP) were made at a commercial dairy in central Texas during the summers of 2002 and 2003. The facility consisted of both open pen housing and free-stall structures to accommodate approximately 1840 head of milking cows. The field sampling results were used in the EPA approved dispersion model Industrial Source Complex Short Term version 3 (ISCST-v3) to estimate emission fluxes and ultimately develop a seasonally corrected emission factor for a free stall dairy.

Ambient measurements of TSP concentrations for sampling periods ranging from 2 to 6 hours were recorded during the summer of 2002. The mean upwind concentration was 115μg/m^3 with a maximum of 231μg/m^3 and a minimum of 41.4μg/m^3. The mean net downwind TSP concentration was 134μg/m^3 with a maximum of 491μg/m^3 and a minimum of 14μg/m^3. Field sampling at this same dairy in the summer of 2003 yielded significantly more 2 to 6 hour TSP concentration measurements. The mean upwind TSP concentration was 76μg/m^3 with a maximum concentration of 154μg/m^3 and a minimum of 36μg/m^3. The mean net downwind TSP concentration was 118μg/m^3 with a maximum of 392μg/m^3 and a minimum of 30μg/m^3.

The particle size distributions (PSD) of the PM on the downwind TSP filters was heavily influenced by the PSD of PM upwind of the dairy source. This is a consequence of the relatively low PM concentrations downwind versus upwind. The respective mass of PM in the different size ranges utilizing the upwind PSD and measured concentrations were subtracted from corresponding mass of the downwind PSD and measured concentrations, and were used to produce a net PSD that is attributed to the source. The result of this process was a representative dairy PM PSD. The mathematical representation of the dairy PSD is a lognormal distribution with a mass median diameter (MMD) of 15μm and a geometric standard deviation of 2.1. With this dairy PSD, PM_{10} concentrations can be determined from a measured TSP concentration by multiplying by 0.28. In other words, the average percent mass of TSP emitted by dairies corresponding to PM_{10} is 28%.

The reported PM_{10} 24-hour emission factors were 5.0 kg/1000hd/day for the free stall areas of the facility and 15 kg/1000hd/day for the open pen areas of the dairy. These emission factors were uncorrected for rainfall events. Corrections for seasonal dust suppression events were made for the San Joaquin Valley of California and the panhandle region of Texas. Using historical rainfall and ET data for central California, the seasonally corrected PM_{10} emission factor is 5.0 kg/1000hd/day for the free stalls, and 11.2kg/1000hd/day for the open pens. For Texas, the seasonally corrected emission factors are 5.0 kg/1000hd/day for the free stall areas and 11.3 kg/1000hd/day for the open pens.

Unlike cattle spacing on cattle feedyards, the dairy cattle spacing is significantly different for the open lot areas versus free-stall areas. Using a free stall spacing of 9.29square meters per cow (m^2/cow) located in the free stall area and 46.5m^2/cow located in the open lot area fluxes can be calculated and/or emission factors can be calculated. The seasonally corrected PM_{10} emission factors for California of 5.0kg/1000hd/day for the free stalls, and 11.2kg/1000hd/day for the open pens correspond to fluxes of 6.2μg/m^2/s and 2.8μg/m^2/s for free-stall and open lot areas, respectively. The seasonally corrected emission factors for a Central Texas Dairy are 5.0kg/1000hd/day for the free stall areas and 11.3 kg/1000hd/day for the open lot areas corresponding to fluxes of 6.2μg/m^2/s and 2.8μg/m^2/s for free-stall and open lot areas, respectively.

These emission factors represent drastic reductions from those used by many regulatory agencies. The past emission factors attributed to dairies were reported to be as high as 61.4 kg/1000hd/day PM_{10}. This is due to the historical use of the former AP-42 beef feed yard emission factor as a starting point for determining dairy emissions. Due to the numerous errors in the development of the former AP-42 beef feed yard emission factor and the drastic differences between the dairy and beef facilities, it is not appropriate to use that emission factor for dairies. This work clearly displays that not only it is correct in theory but actual field sampling and emission factor development also showed that adapting a beef feed yard emission factor for use on dairies is a gross misuse of AP-42 emission factors.

Update on the National Air Emissions Monitoring Study

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Abstract

The National Air Emissions Monitoring Study is designed to provide quality-assured air emission data from representative swine, egg layer, dairy and broiler production facilities in the U.S. Following sound scientific principles and using accepted instrumentation and methods, this project will collect new data from 10 to 25 farms across the country to form a database to which additional studies of air emissions and effectiveness of control technologies can be compared. These benchmark data and accompanying analysis and interpretation will allow U.S. EPA and livestock and poultry producers to reasonably determine which farms are subject to the regulatory provisions of the Clean Air Act and reporting requirements of CERCLA and EPCRA. The study involves air emissions from both barns and open waste storage facilities over a two-year period—capturing the variation in emissions with time of year, stability of the atmosphere, and changes in facility operation. Gaseous emissions (NH_3, H_2S, some VOCs) from open waste storage facilities (lagoons and waste basins) and open feedlots will be made at many farms using open path optical remote sensing in conjunction with micrometeorological measurements and various plume modeling techniques. Gaseous and aerosol emissions (NH_3, NO_X, H_2S, CO_2, total VOCs, TSP, PM_{10} and $PM_{2.5}$) from barns at many farms of varying character will be determined by measuring exhaust concentrations and airflow while closely monitoring internal processes.

Vegetation Management and Competition in Future Ozone Climates

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Abstract

Vegetation management to reduce crop-weed competition in agroecosystems is heavily reliant on non-renewable energy for cultivation and/or synthetic chemicals. Both have air quality implications in direct proportion to the magnitude of infestation and the difficulty of controlling the competing weed species. The magnitude of weed infestation is a function of competition with the crop itself, and of biotic and abiotic environmental conditions, including air quality. The difficulty of controlling a weedy species, in many modern production systems, may be a simple function of its resistance to herbicides. The present work considers the potential interaction between rising concentrations of tropospheric ozone and (1) the competitive interactions between common crops such as cotton and tomato with weeds such as nightshade (*Solanum nigrum*) and nutsedge (*Cyperus esculentus*). We have investigated these interactions across a range of exposures to ozone. Exposures have been administered in field exposure chambers. In the case of cotton or tomato competition with yellow nutsedge, competitive outcomes in vegetative plants were predicted by the relative sensitivities of the pairs of species. In the case of cotton and nightshade, both crop and weed were sensitive to ozone but the combined impact of weed pressure and ozone resulted in the near elimination of cotton from the combined system. We conclude that ongoing climate change, including increasing tropospheric ozone concentration, will alter best management practices for common weeds in many cropping systems. In many cases additional vegetation management interventions will be required to maintain current yields. In addition to these direct effects, the changes will also have indirect effects on air quality, increasing emissions of NO_x and VOC from vehicles involved in the additional cultivation procedures and emissions of VOC from the applied herbicides.

Introduction

The San Joaquin Valley of California (SJV) is a highly productive agricultural region in which crops absorb considerable O_3 from the atmosphere (Grantz et al., 1994). As a consequence, yields of cotton (*Gossypium spp*.) and tomato (*Lycopersicon esculentum* Mill.) are reduced substantially (Brewer et al., 1986; Oshima et al., 1979; Temple et al., 1985, 1988), particularly cultivars of long-staple Pima cotton (*G. barbadense* L.) selected elsewhere (Olszyk et al., 1993). The older Pima cultivar, S-6, exhibits considerable physiological and yield sensitivity to current ambient concentrations of O_3 (Grantz, 2003; Grantz and Yang, 1996, 2000; Grantz et al., 2003), with yield losses approaching 20% (Olszyk et al., 1993), though recent cultivars selected in the SJV are reported to be more tolerant. Yield losses in tomato of over 24% were observed in the SJV in cv. 'Murrietta' (Temple et al., 1985).

Continued productivity of both cotton and tomatoes in the SJV is increasingly threatened by rising ambient concentrations of ozone. Ozone is increasing regionally and globally even as it declines in some urban areas (NARSTO, 2000).It appears to be an aspect of ongoing climate change that is likely to have substantial near-term impacts on native and cultivated vegetated systems (Davison and Barnes, 1998; Heck et al., 1988; Krupa et al., 2001; Lefohn, 1992; Fuhrer, 2003; Patterson, 1995).

In the SJV and elsewhere, economic crop production is also challenged by weed pressure. Weeds continue to account for substantial economic costs and crop yield losses globally (Buhler, 2003). Vegetation management is a major cost of production. Herbicide is applied to approximately 60% of the land area under cotton cultivation in the SJV (DPR, 2002), increasing yields by an estimated 2.5-fold (NCFAP, 2002). Herbicides are applied to 99% of the tomatoes grown in California, increasing yields by an estimated 20% (NCFAP, 2002).

Yellow nutsedge (*Cyperus esculentus* L.) is a particularly difficult weed to control, particularly in irrigated row and vegetable crops (Holm et al., 1991; Mulligan and Junkins, 1976). Yellow nutsedge reduces yield of tomatoes through both above- and below-ground competition (Morales-Payan et al., 2003). It is a major pest in cotton under irrigated SJV conditions. As a C_4 species, it is well adapted to hot, dry climates. Reproduction is largely or entirely by below ground production of vegetative tubers.

Black nightshade (*Solanum nigrum*) is a C_3 plant that has become a problem in both cotton and tomato in California (DeFelice, 2003), and in the presence of an established seed bank is quite difficult to control (Perez and Masiunas, 1990; Keeley and Thullen, 1991). It reproduces copiously by seed production, and exhibits canopy characteristics very similar to both crops, competing with both mainly for light interception.

While O_3 impacts on competitive interactions are potentially quite significant, little is known of interspecific interactions under elevated O_3 (Fuhrer and Booker, 2003; Ziska, 2002). The relative ozone tolerance of competing species may not predict competitive outcomes in the presence of O_3 exposure. Under open top chamber (OTC) exposure conditions, for example, blackberry (*Rubus cuneifolius*) came to dominate an early successional community previously dominated by sumac (*Rhus copallina*; Evans and Ashmore, 1992), despite the great sensitivity of blackberry to O_3. Grass-legume pasture communities (e.g. *Lolium perenne* L.-*Trifolium repens L., Festuca arundinacea-T. repens,* and *Phleum pratense* L.-*Medicago sativa* L.) have tended to simplify toward pure grass during O_3 fumigation in both open air and chamber facilities (Nussbaum et al., 1995; Rebbeck et al., 1988; Wilbourne et al., 1995; Johnson et al., 1996). The degraded performance of the legumes and increasing competitiveness of the grasses may be explained by O_3 inhibition of biomass allocation to storage roots of the former.

In many weedy species, short life cycles and prolific seed production and dispersal will accelerate adaptation to high ambient O_3 concentrations. In others, abundant production of reproductive vegetative tubers may limit the rate of such adaptation.

Methods

Competition experiments with yellow nutsedge and cotton or tomato were conducted in open top field exposure chambers (Heagle et al., 1973) at the University of California, Kearney Research and Extension Center, Parlier, CA. O_3 was generated by corona discharge from purified oxygen (Model G22; Pacific Ozone Technology, Brentwood, CA; Model AS-12; AirSep Corporation, Buffalo, NY), 24 hours per day, 7 days per week. The low O_3 regime was charcoal filtered, achieving approximate 12 hour mean exposures of 12 nL L^{-1}). The medium O_3 regime was charcoal filtered with O_3 added to approximate a local diurnal profile of a polluted day (Grantz et al., 2003), with nominal maxima of 140 nL L^{-1}. The high O_3 regime was 1.5-fold greater than the medium.

Juvenile individuals of yellow nutsedge (*Cyperus esculentus*; single tuber; shoot approximately 6 cm tall; 2-3 leaf blades) were collected in the eastern SJV and transplanted, cotton (*Gossypium barbadense*; cv. Pima S6; J.G. Boswell Co., Corcoran CA) was planted as seed, and tomato was obtained as 3 wk old nursery stock (15-cm tall; cv. HD 8892 or cv. EMP 113) and transplanted. Plants were grown in 9 L (45 cm deep x 18 cm diameter) polyethylene pots in 6-40 mesh sintered clay (Quicksorb, A & M Products, Taft, CA). Cotton or tomato were planted or thinned to one uniform plant pot^{-1} and nutsedge to 0, 1, 2, or 3 plants pot^{-1}. Additional pots contained single plants of nutsedge, alone. Pots were drip irrigated and well fertilized.

Competition experiments with black nightshade (seed collected in the western SJV) and cotton (*cvs.* Pima S6 and S7; data pooled) were performed in closed-top field exposure chambers (Musselman et.al., 1986) at the University of California, Riverside, CA. Chambers had teflon walls to reduce heat load and ozone reactivity. A range of ozone (O_3) concentrations was delivered to the chambers by mixing charcoal filtered air with unfiltered ambient air (Musselman et.al., 1986), with 100, 80, 60, 40, and 0 % ambient air, 24 hours per day, 7 days per week. 0% ambient chambers achieved approximately 25 nL L^{-1} 12-hr seasonal mean.

Plants were grown in the ground, which had been excavated and replaced with a uniform soil mixture(U.C.Soil Mix II) pre-fertilized with 82 g of 16-20-0 (equivalent to 28 kg N/ha). Seed of Pima cotton (cv. S-6) were spaced 0.076 m within rows and 0.75 m between rows oriented N-S. Seed of nightshade were planted within the row at 30 cm intervals. The crop was dominated by weeds in the first year and the planting was destroyed. Measurements were taken in the following year, when cotton was replanted and volunteer nightshade appeared at similar densities in all chambers. Plants were drip irrigated weekly.

O_3 exposures differed between experiments and repetitions within experiments. Averages (12 hour means across all reptitions) are indicated in the figures.

Results and Discussion

We use data from several systems to explore the possible effects on vegetation management of increasing ozone in rural areas. The cotton-nutsedge and tomato-nutsedge experiments have been described elsewhere (Grantz and Shrestha, 2006; Shrestha and Grantz, 2005). The cotton-nightshade experiments have not been described previously.

Black nightshade is an economically important weed in cotton and tomato, exhibiting a similar canopy morphology. At very high weed density it completely shaded out the cotton at all concentrations of ozone (not shown, data from the first year after planting). At the more moderate densities achieved in the subsequent year, cotton competed well, developing an approximately 6.8-fold superiority in shoot biomass over nutsedge at low ozone concentration (cf. Fig. 1B,C). At higher ozone concentrations, however, cotton was nearly out-competed, with its shoot biomass advantage reduced to about 2.7-fold. Total above ground biomass of the system was reduced by ozone by 41% (Fig. 1A), while nightshade biomass increased by 26% (Fig. 1B). This reflected the reduced competition, particularly for light, exherted by the cotton (Fig. 1C) as its shoot biomass declined by 49%.

In this study we do not have measurements of the ozone sensitivity of the two species grown alone. In the mixed system, the impact of ozone on this crop-weed system was to inhibit cotton directly, as shown in previous studies, and to creat a competitive opening which nightshade was able to exploit. Nightshade was not particularly tolerant of ozone. The main impact in future atrmospheres may be the increased competitiveness of nightshade and an increased seed bank following high ozone years due to this enhanced performance.

Yellow nutsedge is also an economically important weed in cotton and tomato, but one which does not exhibit a similar canopy and does not compete effectively with the crop for light. In cotton grown without competition (Fig. 2A), shoot biomass was reduced by ozone by about 25% at the near ambient ozone concentration and by about 75% at elevated ozone. In cotton grown with nutsedge competition, cotton biomass was reduced significantly by about 50% over all levels of nutsedge competition (Fig. 2A).

The presence of just one nutsedge plant (1:1) reduced shoot biomass of cotton at all levels of O_3 (Fig. 3A). The effects of ozone and nutsedge competition were additive, with an overall reduction at the highest ozone and with nutsedge competition (Fig. 2A) of 87% in shoot biomass productivity. This interaction was not significant, but the significant linear relationships at all levels of O_3 between 1/biomass and competition intensity (Passini, 2003) clearly distinguished the effect of competition at low and medium ozone from that at high ozone (Fig. 3B). Exposure to O_3 at the higher than ambient concentration altered the competitive interaction between cotton and nutsedge.

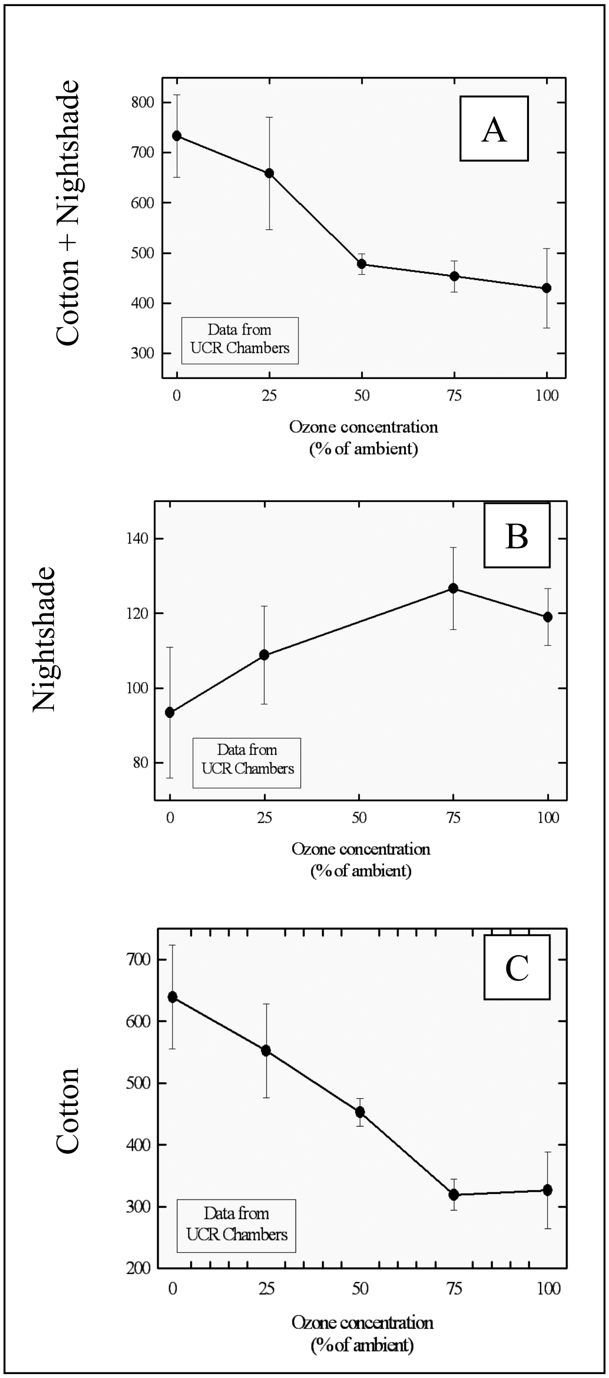

Figure 1. Competition between black nightshade and Pima cotton over a range of ozone exposures. Effect of ozone on shoot biomass (g/m row) of (A) both species pooled, B) nightshade, and (C) cotton.

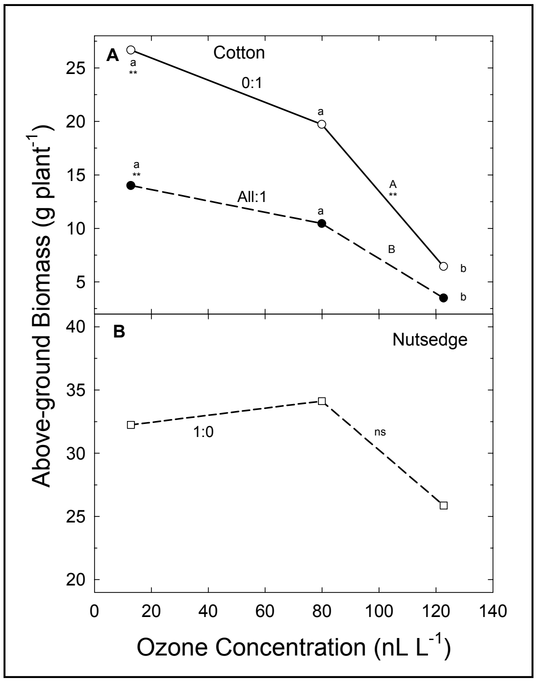

Figure 2. Effect of ozone exposure on above-ground biomass productivity of cotton (A) and nutsedge (B). Open symbols represent each species grown alone; closed symbols represent the average of all levels of nutsedge competition. Inset presents the effects of nutsedge competition on shoot growth at each level of O_3 exposure. Statistical differences between means within a line are indicated by different lower case letters and symbols indicating the level of significance. Statistical differences between lines are indicated by upper case letters.

In nutsedge grown alone (Fig. 2B), above-ground biomass (shoot minus rhizomes and tubers) was not significantly impacted by O_3, but consistently (cf. Fig. 2B, 5B) exhibited maximal shoot biomass at medium ozone and declined at high ozone by 24%.

Root production in cotton grown alone (Fig. 4A, circles) declined with increasing exposure of the shoot to O_3. At the highest ozone concentration root biomass was reduced by approximately 85%, similar to previous results (Grantz and Yang, 1996, 2000). The root:shoot (R:S) biomass ratio of cotton was reduced by O_3 exposure (not shown), particularly at high ozone relative to low and medium ozone, despite the large O_3-induced reduction observed in above ground biomass. Reduced allocation of photosynthate to sink tissues and the associated inhibition of root development are commonly observed following exposure to ozone (Cooley and Manning, 1987; Reiling and Davison, 1992; Grantz et al., 2006).

Reduced allocation to shoot tissues such as stolons (Wilbourn et al., 1995; Barnes et al., 1998) has also been observed following exposure to ozone. Below-ground biomass of nutsedge contains both shoot and root vegetative tissues as well as shoot-borne reproductive tubers. Nutsedge grown alone produced considerably greater below ground biomass than did cotton (Fig. 4A). The two root systems could not be separated quantitatively when grown together. The combined root biomass decreased with increasing O_3, and increased marginally with increasing nutsedge density. The two species inhibited each other to a similar extent below ground, since the 1:1 root mass fell midway between 0:1 and 1:0 (Fig. 4A; triangles), particularly at near ambient ozone.

Allocation below ground was not significantly affected by O_3 in nutsedge grown alone (Fig. 4A), though in our experiments it has consistently declined at medium (near ambient) ozone concentrations relative to clean air concentrations and recovered (often increased) at high ozone (cf. Fig. 6). The nearly opposing responses of above and below ground biomass (cf. Figs. 2B, 4A) resulted in a substantial reduction in the below:above-ground biomass ratio at medium ozone, but a complete recovery at high ozone (not shown). Total tubers per plant was generally maximal at medium ozone exposure (Fig. 4B).

In the tomato-yellow nutsedge system the presence of nutsedge (averaged across all population ratios) caused a decline in tomato shoot biomass over all O_3 concentrations imposed (Fig. 5A). Increasing O_3 concentrations also reduced shoot biomass of tomato, whether grown with or without nutsedge. In tomato grown alone, shoot biomass declined by 31% between low and medium ozone concentrations, but with little further reduction at elevated ozone (Fig. 5A, open circles).

Shoot biomass (above-ground excluding rhizomes and tubers) of nutsedge grown alone (1:0) increased at moderate ozone exposure (Fig. 5B), but declined significantly, by 42%, at high relative to medium ozone (Fig. 5B).

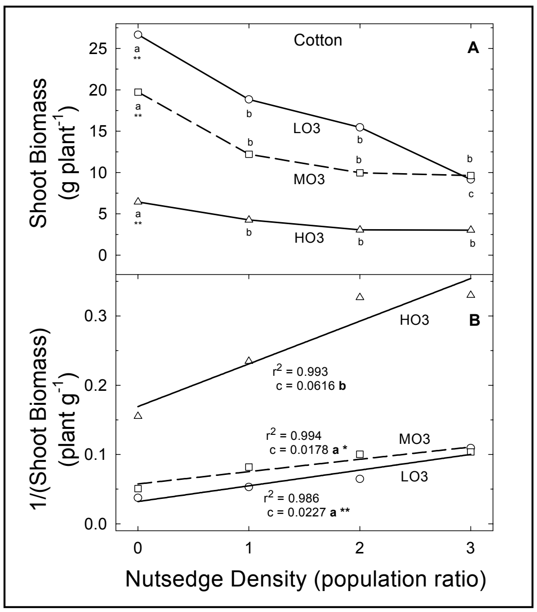

Figure 3. Effect of nutsedge density on shoot biomass (A) and on the inverse of shoot biomass (B) of cotton at each level of ozone exposure. In (B) the slope of each line is interpreted as a competition coefficient.

Shoot biomass of nutsedge was more impacted by tomato than it was by ozone (Fig. 5B). At each concentration of O_3, the addition of a single tomato plant to a nutsedge plant substantially reduced the shoot biomass of nutsedge (Fig. 5B). Even a 3:1 population advantage did not increase shoot biomass of nutsedge to the level observed in the absence of tomato competition (Fig. 5B). In previous studies (Morales-Payan et al., 2003) shoot production of nutsedge was reduced by 33% when grown in competition with a tomato plant. Our findings support the earlier conclusion (Santos et al., 1997) that nutsedge is a relatively weak inter-specific competitor (e.g. for light), but a strong intra-specific competitor.

Tomato root biomass declined nearly linearly with ozone concentration (Fig. 6; open circles). Root biomass was approximately 25% lower at MO3 and 44% lower at HO3, relative to LO3.

The effect of competition from nutsedge on tomato root biomass was difficult to evaluate, as it was for cotton, because the two root systems could not be separated quantitatively. The combined root biomass of tomato and nutsedge (grown at 1:1) was similar to that of tomato alone (0:1), but substantially less than that of nutsedge alone (1:0), at all concentrations of ozone. Thus, tomato inhibited nutsedge productivity more than nutsedge inhibited tomato. In previous studies, measurements of reduced-NO_3 in tomato sap when grown in the presence of nutsedge (Morales-Payan et al., 2003) indicated that significant competition between these species may take place belowground.

The root:shoot biomass ratio of tomato was reduced by O_3 concentration, particularly at high relative to low ozone concentration (not shown). This reflected the nearly balanced decline in both root and shoot biomass as O_3 exposure increased (Fig. 5A, 6; open circles).

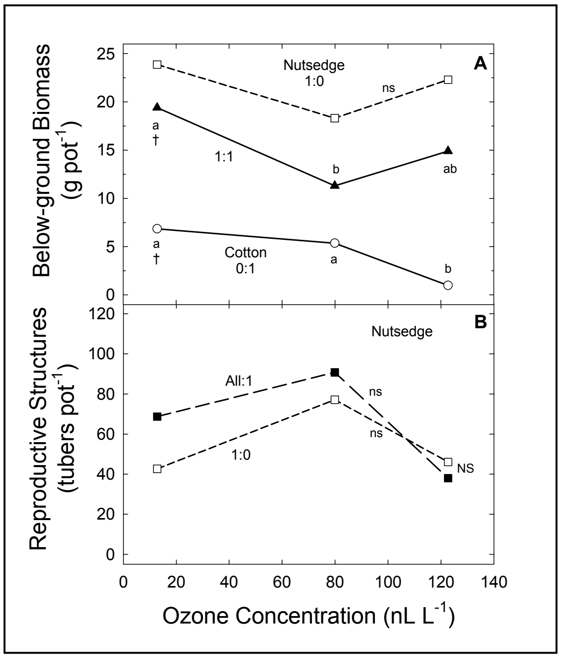

Figure 4. Effect of ozone exposure of the shoot on (A) below-ground biomass productivity of cotton (circles) and nutsedge (squares) grown alone and on the combined biomass of one plant of each species grown in direct competition (solid triangles) and (B) on the reproductive effort of nutsedge grown alone (1:0; open squares) or averaged over all population ratios (All:1; solid squares), expressed as number of reproductive structures per plant (B). Mean separation as in Figure 1.

Below-ground biomass of nutsedge grown alone was not affected by O_3 (Fig. 6; squares). However, the below:above-ground biomass ratio , a more sensitive parameter, was significantly affected by ozone, with a decline at medium and increase at high ozone concentration, reproducing the pattern observed, above, in the cotton system.

The number of tubers produced by the nutsedge plants increased with the number of seedlings initially planted in each pot (Fig. 7). However, the presence of a tomato plant reduced the number of tubers relative to nutsedge grown alone at all ozone concentrations (Fig. 7), as observed in previous studies (Morales-Payan; 2003).

When grown alone, aboveground productivity of tomato was more sensitive to moderate O_3 concentration than was that of nutsedge (Fig. 5A). However, at HO3 the relative sensitivities of the two species were quite similar. In these studies, tomato exhibited a distinct competitive advantage over nutsedge in light interception, confirming earlier results (Santos et al., 1997). Exposure to O_3 further established this aerial dominance, as nutsedge shoots were more erect in the LO3 and MO3 treatments than at HO3. At the highest O_3 exposure nutsedge shoots appeared less rigid, and exhibited a more prostrate growth habit, and even visibly healthy leaves were often observed hanging over the edge of the pots.

Below-ground productivity was also more sensitive in tomato compared to nutsedge (Fig. 6) as below-ground biomass of tomato declined with increasing O_3, whereas nutsedge increased slightly due to stimulated allocation to reproductive tubers. Overall, nutsedge was more tolerant to moderate O_3 concentrations than was tomato, with a substantial shoot response and enhanced allocation to tubers observed only at high ozone, whereas tomato responded progressively to increasing ozone concentration (Fig. 5,6).

Thus, in cotton any increment of ozone concentration, above that of charcoal filtered air, weakened cotton more than it did nutsedge and shifted the competitive advantage to the weed. In tomato, in contrast, this was true only at medium ozone and was reversed at high ozone, where nutsedge was the more sensitive species.

In the tomato system, exposure to high ozone stimulated biomass partitioning into reproductive structures (tubers), relative to the medium regime. Enhanced allocation to reproduction is a commonly observed plant stress response.

Tuber production in our studies has consistently appeared to be stimulated by O_3, though generally not significantly. As enhanced tuber production would lead to greater distribution and persistence of this weedy species in cultivated and other systems, this is a serious concern.

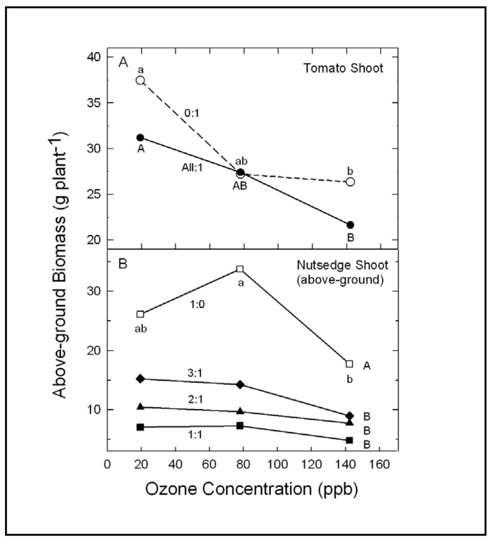

Figure 5. Effect of ozone exposure on development of above-ground biomass of (A) tomato (shoot) and (B) nutsedge (shoot minus rhizomes and tubers). Open circles represent each species grown alone. Closed symbols represent the levels of competition specified as population ratio of nutsedge:tomato.

The situation was similar for the critical root to shoot biomass ratio (R:S). This parameter and its associated leaf area-specific root hydraulic conductance (Grantz and Yang, 1996), are critical indicators of plant response to ozone.

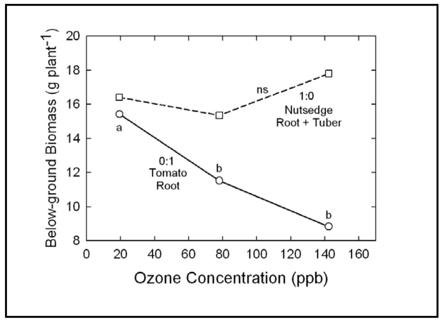

Figure 6. Effect of ozone exposure on development of below-ground biomass of tomato (circles; roots) and nutsedge (squares; roots plus rhizomes and tubers) grown alone.

Conclusion

Rising tropospheric ozone concentrations in rural, agricultural, areas has the potential to cause substantial changes in the management of weedy species in croplands. Similar changes may occur in vegetation management programs along highway and canal banks, and other non-agricultural settings. The specifics of ozone impacts on competition appear to be crop species specific. Further mechanistic details regarding competition above and below ground will be required to allow prediction of such competitive outcomes in future atmospheres. The frequently cited direct effects of ozone on crop yield loss represent only one important aspect of the general impact of changing ozone exposure patterns on crop production.

Acknowledgements

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Agricultural Pesticides as Sources of VOC Precursors of Photochemical Ozone

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Abstract

This project investigates the photochemical tropospheric ozone (tO3) formation potential of Volatile Organic Compounds (VOCs) from agricultural pesticide applications. One class of pesticides, emulsifiable compounds, is often formulated with highly volatile solvents as carriers. These solvents, in addition to the pesticidal chemicals themselves, are VOCs potentially contributing to ozone formation. A common formulation of chlorpyrifos accounts for a substantial portion of the highly reactive solvents used in the San Joaquin Valley (SJV) of California, where compliance with tO3 concentration limits remains a persistent challenge. This project investigates the volatility characteristics of each component of the selected chlorpyrifos formulation under ideal conditions to establish the relative volatility of the carrier solvent and longer half-life of the chlorpyrifos. Time courses of emission rates of both chlorpyrifos and the carrier solvent are then measured following field application of the pesticide formulation. The resulting data are used to speculate on the effectiveness of shifting the timing of pesticide application away from peak tO3 hours for mitigating tO3 concentrations in the SJV.

Rationale

Almost all past research on pesticides in air has been done on the "active ingredients", or AI. In contrast, the AI portion of chlorpyrifos pesticide formulations PF is presently low priority for two reasons: (a) it is known from past studies, that the AI is of sufficiently low volatility, such that its maximum incremental reactivity (MIR) cannot or will not be determined*; (b) without supporting information such as MIR, any data generated on the AI would be of no use for ozone formation estimations. Even though chlorpyrifos is referred to as a 'semi-volatile' in terms of laboratory analysis, this is relevant for a gas chromatograph operating at temperatures above 200C, which is very greatly in excess of ambient temperature maximums (including all-time records in California or elsewhere) of about 50C. Therefore, the main chemicals in our present study are the solvents used in the chorpyrifos PF, of which a major group are xylenes that have well-established MIRs.

Because ALL past research appears to have been performed on the semi-volatile AI and NONE on the rest of the PF (e.g. xylenes), we have determined that: (a) past research on chlorpyrifos, whether using the AI alone or as the PF, have no data on non-AI volatiles and therefore no information regarding the xylenes; (b) almost none of the past methods are useful for determining the emission of VOC (e.g. xylenes) from crop applications.

The disconnect in methods arises because the chlorpyrifos is designed for retention in the crop zone or canopy, while VOC such as xylenes are selected for providing solubility and for dissipation, in part to minimize harm to plants. The vastly different physico-chemical properties between AI and VOC means that different methods must be used for xylenes.

It is probable that air sampling methods for AI can't be used for xylenes, so we must evaluate such basic steps in the research. AI-based methods such as Teflon sheets for application rate/loss/overspray will almost certainly produce erroneous information for xylenes.

An extensive literature search has turned up NO methods for xylenes in PF applications. The first phase of our research is to develop a viable air sampling method that meets our analytical needs. This is currently underway. Only when we have a viable analytical method, can we turn to an initial field trial, which is in the planning stages now.

Method Approach

Ideally, a circular plot will be defined within which natural variation of terrain, plant stand, soil characteristics, etc. is limited. The plot will be large enough to be sprayed using conventional (industry typical) application equipment and small enough for application to be completed within a couple of hours at most. A tripod with a tall (30 foot) mast will be erected in the center of the plot so that the width of the pesticide-applied swath is equal in all directions. Since the sampling height must greatly exceed the plant canopy, cotton or alfalfa are preferred over orchard crops. Under this scenario, wind from any direction will provide the samplers on the mast equal concentrations of VOC assuming homogeneous volatilization from all points in the plot. Sampling will begin immediately upon completion of PF application plus anchoring of the second pair of guy-wires and will only be interrupted for changing the sampling cartridges. Personnel will wear appropriate protective clothing and ventilation for the required initial period – 24hours, perhaps.

A similar plot near the experimental plot but far enough away to avoid being impacted by the spray activity (a couple of miles) will be identified for background sampling. A single sample will also be collected 50 meters downwind of the downwind edge of the plot during application (beginning at the start of application and ending when application is complete for a time integrated sample of the entire operation). If wind speed and direction are adequate for dispersion modeling, concentrations measured upwind and downwind of the plot during application will be used to estimate emission rates during application. If wind speed is below 0.5 meters per second, the downwind sample may still provide an estimate of the relative importance of drift.

Site parameters

A circular plot such as that described above is agronomically atypical. Ideally, a square field can be found isolated from fields where the PF of interest is going to be applied during the experiment and where the corners of the field can miss an application without creating great hardship for the farmer. The site must also be isolated from significant structures or tree canopies that would create a wind shadow (no buildings or orchards within a half mile). The mast will be constructed in the center of the field and erected, creating a footprint of about 10 ft^2. As soon as application is complete, sampling will begin. Sampling can then continue until measured concentrations reach background and/or until neighboring fields require an application of either chlorpyrifos or other product containing the VOC -- which eliminates the required ambient background.

Experimental parameters

Sampling medium which has been bench-tested to be quantitative for all of the compounds of interest (AI and VOC) will be deployed at 5 heights from 0.5 to 9 meters above ground on the mast. A low (0.1-2.0 L/min) flow rate through the media will be maintained using battery operated pumps. The flow rate will be measured using an mass flow meter at the start and end of each sampling period for use in calculating total air volume. The pumps will be powered with rechargeable batteries which will be changed as needed and/or supplemented with solar panels. Upwind sampling will be accomplished with similar hardware but, assuming much lower concentrations to be present, several sampling periods on the mast may be integrated by time to one period at the background location (e.g. the background may run one time integrated sample for the first 24 hours while the samples on the mast are changed every 4-6 hours).

Model Calculation Results

Finally, our initial results from model calculations suggest that evening application of xylene based pesticides may result in 50% reduction of VOC (by chemical reaction during the night) before sun-light can commence photo-chemical production of ozone in the morning. However, under common rural conditions, there is still ample VOC for the same level of ozone to be reached in the course of the day.

* Personal communication from M. Benjamin, CARB.

Predicting Dust Concentrations Downwind from Eroding Sites

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Abstract

Soil erosion is a process of detaching and moving soil particles. The process is driven by energy transfer to the soil surface from flowing air or water and as well as particles such as raindrops or saltating soil grains impacting the surface. Suspension occurs when vertical fluctuations of the fluid exceed the settling velocity of the detached particles. Depending on the settling velocity and hence particle size, concentrations decrease vertically moving away from the source at the surface.

During the wind erosion process, the movement of soil along the surface rapidly increases with length of the eroding site because saltating particles enhance the return of detachment energy to the surface. This erosion process produces a line source potential for dust suspension that varies with length along the eroding site. Above the line source, a dust plume develops which increases in height as a function of site length. Dust concentration depends on both the mass of dust in suspension and the volume of air in the plume through which the dust is suspended. Dust concentrations, thus, vary both vertically and horizontally above the eroding site.

When the dust plume leaves the eroding site, it continues to grow until it reaches a height limit in the atmosphere, such as a temperature inversion or edge of front. Suspended particles settle out from the plume and are not renewed by the erosion process downwind from the erosion site. Thus, dust concentrations continue to change after leaving the eroding site and rapidly decrease because of the growth in plume height. When the plume reaches it maximum height, dust concentrations slowly decrease as an exponential decay function of length of travel. An overview of the concepts used to develop mathematical functions that describe this process and the changes in dust concentration as a function of height and distance downwind from dust sources is presented.

Background and Introduction

The accurate prediction of dust concentration downwind from eroding sites depends primarily on an accurate description and prediction of the detachment or erosion process. While many models exist that predict soil erosion by wind, one of the most accurate methodologies has been developed at Texas Tech University. This method is known as TEAM (Texas Tech Erosion Analysis Model) (Gregory et al., 2004). TEAM predicts the rate of soil movement as a function of the length of the eroding area, soil type and conditions, soil cover, wind speed, and relative humidity. Currently, it is assumed that the rate of soil movement is that predicted by the TEAM model. TEAM has successfully been used for both agricultural and industrial settings and defaults to a maximum transport equation when soil conditions approach that of sands found in desert regions. It is, thus, a very robust model in terms of variations in soil conditions over which it can be applied.

Dust concentration at ground level at any point along an eroding site can be calculated by dividing the predicted rate of soil movement per unit width by the volume of air containing the soil mass. The volume of air containing the soil mass is defined as the depth of wind containing the mass times a unit width times the average wind velocity in the horizontal direction in this cross section. Most movement associated with the wind erosion process is in the mode of saltation: a process of detachment then a return of the detached particle to the land surface where new detachment occurs from the kinetic energy of the incoming particle and the wind driving the particle. On the average, particles moving in saltation move only a few centimeters above the surface. A few particles may reach a height of 0.5 meters above the surface, but the main mass is very near the surface. This process is easily observed in snow or sand movement across roads. For this work, the average height of saltation is used as the height for estimating wind velocity in calculation of the air flow containing the detached soil. Twice the average height of saltation is used herein to define the depth of wind containing the material. Experiments in a wind tunnel (Wilson, 1994; Singh,

1994) indicate the distribution of soil particles to be very non-linear in this zone. Nevertheless, the present definition of dust concentration is a reasonable approximation of the average dust concentration just above ground level.

Suspension is a totally different process from detachment and movement by saltation. Unless particles are rotational, they have balanced forces acting above and below. There is a drag force that moves the particle downwind but no net upward force to lift the particle higher. Suspension occurs when the local air mass or eddy containing the particle moves up and carries the particle or particles with it. For this to occur, the particle must have a settling velocity less than the upward velocity of the eddy. Hence, small diameter and low density particles (aggregate particles compared to solid particles) move up and large diameter particles tend not to move into suspension. Based on conservation of air mass, the volume of air that moves up must be offset by an equal volume of air that moves down. Even though there is no net movement of air mass, there can be a net upward movement of suspended particles because the air near the surface has a higher concentration of particles than the air higher in the atmosphere associated with the downward movement of air masses. Even if the air masses above and below start with the same dust concentration, the system would redistribute the dust concentration to produce high concentrations near the surface and lower concentrations away from the surface. In the upward movement step, the rate of movement is the eddy velocity minus the settling velocity. In the downward step, the rate of movement is the eddy velocity plus the settling velocity. Thus, particles will move downward more readily than up. At steady state conditions, the rate of downward movement of dust equals the rate of upward movement. Equations to describe this process will be presented in a more detailed paper to follow and will be used to generate dust concentration variations with height and particle size. The objective of this paper is to present an overview of the system in which these suspension equations operate.

Dust Plume Limit

The height of the dust plume is one major limit or boundary condition affecting to the suspension of dust particles. This limit is visually detectable above eroding areas and downwind from eroding sites. Plume height is near zero at the beginning of the field or more technically at the beginning of the surface roughness conditions associated with the eroding site. It then increases in height with length downwind. Dust concentration (recognized as darkness or opaqueness in the plume) increases at ground level as the length of the eroding site increases. This observation matches the increase in predicted soil movement with length from the TEAM model. The top of the dust plume is often irregular revealing up eddies or gust of wind moving sediment upward. Nevertheless, there is a general shape of dust plume associated with length along the eroding site. This observable height of plume is the upper limit to the suspension process. Thus, to accurately predict dust concentrations above and downwind from eroding sites, this upper boundary must be included as part of the system.

This upper boundary or dust-plume boundary is best viewed as a boundary within a boundary. Surface winds that drive the wind erosion process are produced as a boundary condition from air movement over the land surface. Thus, the whole wind system is a boundary layer that produces an average wind velocity with height that follows a logarithmic or power equation distribution as a function of height. Horizontal winds increase at a decreasing rate with distance above the land surface. Equations that govern this process can be found in most fluid textbooks that deal with open channel flow or flow in the atmosphere. When a new surface condition is encountered by the wind, it starts to shape the wind velocity profile producing a different set of characteristics from the previous surface condition. The difference between the old and new conditions is detectable, increasing in height as a function of fetch length, length downwind from the beginning of the new surface conditions. The literature defines this change in wind profile conditions as an internal boundary layer (Elliott, 1958). Elliott (1958) has shown this internal boundary layer not to be a function of wind velocity but is a function of surface roughness conditions.

It appears that the same process creating the internal boundary layer is also involved in creating the dust plume above eroding sites. If true, then knowledge and equations developed to predict the internal boundary layer can also be used to describe the upper limit for the suspension process. Elliott (1958) provides a relatively simple empirical equation to predict the height of the internal boundary layer. Elliott's equation, however, is too simple to match the boundary conditions for the upper conditions in the atmosphere or for long distances downwind from the eroding site. An alternative equation to Elliott's equation is used in the current dust concentration models. The alternate matches the required upper boundary conditions and produces results that closely match Elliott's equation near the surface. The equation used to predict the height of the internal boundary layer and, thus, the height of the dust plume above and downwind from eroding sites is a saturating exponential function with independent variables of fetch length and height of the boundary layer in the atmosphere. The typical heights for the boundary layer during wind erosion events are about two thousand meters for frontal events and four to five thousand meters for events produced by down mixing of winds from aloft.

There is some question about what to do when the dust plume leaves the eroding site. In theory, a new surface condition is encountered and a new internal boundary layer begins. The new internal boundary layer should produce a clean air boundary below the dust plume similar to clean air below a plume downwind from a smokestack. We, however, do not see this condition downwind from eroding sites. Instead, we see dust. In fact, there have been major car accidents downwind from eroding sites because of the reduced visibility near ground level downwind from eroding sites.

It appears that the new internal boundary layer that should form due to the new surface condition is masked by sediment and heaver sediment-laden air settling and mixing into the lower less dense layer. Thus, we continue to grow the old internal boundary layer as the upper limit for the dust plume and the upper limit for the suspension process.

It should be noted that predicted dust concentrations and observed visibilities rapidly change with distance downwind from eroding sites because the same amount of sediment is now distributed in an increasing volume of air as the dust plume grows in height. This rapid decrease in dust concentration and increase in visibility continues until the dust plume reaches the height of the boundary layer producing the wind. After the dust plume depth reaches the height of the boundary layer, dust concentration decrease at a much slower rate as a function of loss of sediment and widening of the plume.

Loss of Sediment

As the dust plume moves downwind from the erosion site, sediment particles may drop out and not become re-detached. The rate of this sediment mass loss is a function of dust concentration in the zone immediately above the land surface and the settling velocity of the sediment. Sediments with large particle sizes settle out more rapidly than sediments with small diameters. Once the dust plume height has reached its maximum height, the loss of sediment and loss in dust concentration becomes an exponential decay function of distance traveled by the plume. This relationship is verified by observations that monitored dust concentrations which began in China and traveled across the Pacific (Arimoto, 1989).

There are other processes that can remove sediment from a dust plume. Rain, hail, or snow all can trap sediment particles and quickly move them to ground level. Dust laden rain, hail, and snow have all been observed in West Texas, sometimes on the same day. These methods of sediment removal are not considered in the current model, however, they are part of nature's way to filter air and improve air quality.

Summary of Modeling Process

In the current model, the concentration at ground level is estimated from the erosion process with TEAM. Next, the upper boundary for dust concentrations is estimated with an equation for internal boundary. The third step is to remove sediment from the lower boundary of the dust plume by settling particles across the lower boundary. The total sediment at a specified distance downwind is then redistributed from ground level to the maximum height of the plume. The redistribution is performed for each particle size of interest. Generally, the particle size distribution of the soil is used to establish five to seven size classes of particle. The masses from each of these particle size redistributions are summed to get total mass of sediment at heights of interest. The total sediment concentration at a given height is then determined by dividing the mass of sediment by the volume of air containing the sediment. The process is feasible but tedious—a good use of computer technology.

The current model uses representative particle sizes with deterministic equations to describe a system of continuous particle size distributions and random or stochastic variations in vertical wind speeds to make calculations. The solution is only approximate. However, it is built on known relationships in the literature and relationships that can be derived from physical principles. This leads to a relatively robust process-based model that describes the soil erosion and dust generation processes caused by wind.

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Release and Measures to Reduce Generation of Dust in Fattening Pig Houses

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Abstract

The mass balance of dust as well as the efficiency of different dust reducing measures in fattening pig houses have been investigated and analysed.

Investigations showed that the generation of dust is influenced by the number and the weight of the pigs. Settling of dust is a more important mechanism in the mass balance of dust than ventilation rate. A major part of the generated dust settles on different surfaces inside the buildings. The settling rate of dust is affected by the concentration of dust in the air. The settled amount of dust also stands in relation to the floor area of a stable.

An increased ventilation rate has a limited effect on the concentration of total dust due to the importance of the settling of the dust. However, it has been observed that the type of ventilation technique may influence concentration of respirable particles. Also the type of housing system influence the generation of dust. One factor which has a strong influence on the concentration of dust is the activity in the buildings.

Dust reducing measures as electrostatic air cleaning of the air and removal of dust with vacuum cleaners had limited influence on dust concentration.

Automatic spraying of small droplets of water reduced the dust concentration with two types of spraying nozzles. For another type of nozzle the generation of dust increased due to an ultra sound which created an increased activity of the pigs. Spraying with a mixture of rape seed oil was also effective with manual spraying as well as with an automatic spraying system. The oil seemed to have an effect on the generation of dust from the skin but also to function as a dust binding agent for settled dust.

Introduction

The presence of dust in pig houses may create working environmental problems (Donham, 1987; Tielen et al., 1995; Takai and Iversen, 1990; Larson et al., 1993; Malmberg et al., 1993) as well as depressed health status of the animals (Donham, 1991; Robertson et al., 1990; Robertson, 1993; Hamilton et al., 1993). Measures to reduce the contamination of the air in swine confinement houses are therefore urgent. The purpose of these investigations has therefore been to analyse the mass balance of dust but also the effectiveness of different dust reducing measures.

The major part of swine house dust is organic. Originally, the dust was considered to origin from feedstuffs. However, investigations (Hartung, 1992) have indicated that there are also other components of the dust as particles from skin, hair and faeces. Investigations (Angst, 1984; Hartung., 1992) have shown that the composition of settled dust and feedstuffs in pig houses differ considerably regarding crude protein and crude ashes.

The major part of the number of dust particles are respirable (Nilsson, 1982). However, it should be observed that the major part of the weight of the dust is not respirable. Donham (1986) reported that 7 % of the total weight of the dust was respirable.

A considerable proportion of the dust seems to originate from the pigs themselves. Nilsson (1982) found that the type of feed (dry or wet) had limited influence on the daily averages of total dust concentrations in growing-finishing pig houses. However, both in cases with wet and dry feed the dust concentrations increased during the feeding time due to an increased activity.

Several investigations (Nilsson, 1982; Gustafsson, 1994; Pedersen, 1993; van't Klooster et al., 1993) have proved that the activity in swine houses has a strong influence on the concentration of dust in the air. The concentration normally increases during periods when the activity is high, such as during feeding, weighing of the pigs, etc. The influence of feeding technique on the activity of the pigs may have an indirect effect on the dust concentration (Robertson, 1992). Pedersen (1993) has shown that the number of dust particles in the air varies with the same pattern as the signal from an activity sensor.

There is little consensus among investigations about the influence of ventilation on dust concentration. However investigations (Bundy and Hazen, 1975; Bundy, 1984) about the influence of ventilation rate on the number of dust particles have shown a decrease in number of dust particles at increasing air flow rate. The influence of ventilation rate on total mass concentration of dust in the air has been less pronounced (Nilsson, 1982; Gustafsson,1994). Investigations have also indicated influence of different ventilation techniques on dust concentrations (van't Klooster et al., 1993).

Theory

The mass balance of generated dust can be described as:

$$V\frac{dC_{av}}{dt} = p - q(C_o - C_i) - SA - G \quad (1)$$

where: V is the building volume in m^3 ; C_{av} is the average dust concentration; C_o and C_i are the total dust concentrations in outlets and inlets in mg/m^3 ; t is time in h; p is the production of dust in mg/h; q is the ventilation rate in m^3/h; S is the settling rate of dust in mg/ m^2 h; A is the area of the floor in m^2; and G is the amount of dust removed by air cleaning devices in mg/h.

The settling of dust may be described by:

$$S= v \; C_{av} \quad (2)$$

where v is a value depending on the properties of the dust in m/h.

If stationary conditions are maintained, is it possible to determine the generation of dust from:

$$p = q\ (C_o - C_i) + S\,A + G \quad (3)$$

The fraction removed by air cleaning devices is described by:

$$G = \theta \;\; q \;\; \eta \;\; C_{av} \quad (4)$$

where θ is the relation between the air flow rate of an air cleaner and the ventilation rate of a barn and η is the air cleaning efficiency of an air cleaning device. The concentration in the inlet of the air cleaner is assumed to be the average dust concentration in the air C_{av}.

Material and Methods

Buildings and Equipment

The investigations were carried out in three piggeries for growing-finishing pigs at the research station Alnarp Södergård.

The influences of the following factors in the building environment were investigated, namely: number and weight of pigs; activity; settling of dust; ventilation rate; ventilation technique; and animal housing system.

The following methods to reduce the generation and concentration of dust were also investigated, namely: electrostatic air cleaning; dust removal by vacuum cleaning; humidification of the air with different spraying nozzles; and oil treatment.

Measurements

The efficiencies of different treatments were analysed by: gravimetically measurements of the amount of total dust in mg/m^3 with 37 mm diameter dust filters (Millipore) located in the middle of the barn at 1.5 m height but also in the exhaust air; gravimetically measurements of the amount of respirable dust (mg/m^3) with dust filters (Millipore) after separation of particles larger than 5 µm with a cyclon (SKC cyclon) at the same locations as for total dust; counting the number of particles of different sizes with an optical particle counter (Rion) which counted the number of particles of sizes larger than 0.3, 0.5, 1.0, 2.0 and 5.0 µm; weighing settled dust on five 0.230 m^2 settling plates located at a height of 2.0 m with the collected amount of dust measured by weighing the plates on a balance; measuring the ventilation rate with a hot wire anemometer (Alnor) in exhaust air ducts.

Each measurement was carried out over a period of 3-4 days in order to collect enough dust on the settling plates. Different treatments were compared to reference values measured before and after the treatments.

Analyses

Different measures to reduce the generation and concentration of dust were analysed by using the following properties in the mass balance Eqn (1): averages of total and respirable dust concentrations C_{av} measured in the middle of the barn and in the exhaust air; average of settling rate of dust on settling plates S; generation of dust p as defined by Eqn (3); relation between settled amount of dust and dust concentration S/C_{tot}; and fraction of respirable dust C_{resp}/C_{tot}.

Measurements of the number of particles were mainly used to get a picture of the particle size distribution and influence of activity and ventilation rate.

Results and Discussion

The influence of number of pigs on production of dust was investigated by changing the number of pigs when their average body weight was in the range of 86 – 98 kg. The measurements showed that the generation of dust is proportional to the number of animals (Figure 1).

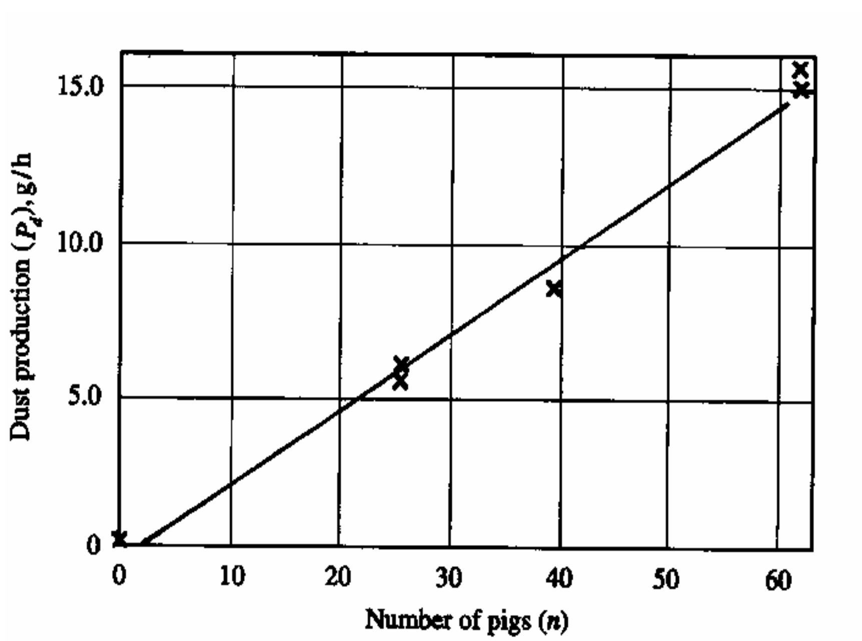

Figure 1. Relation determined between the production of dust and the number of pigs.

The influence of pig weight on dust production was also investigated during 14 production batches with growing finishing pigs. The production of dust increased with the body weight in all batches.

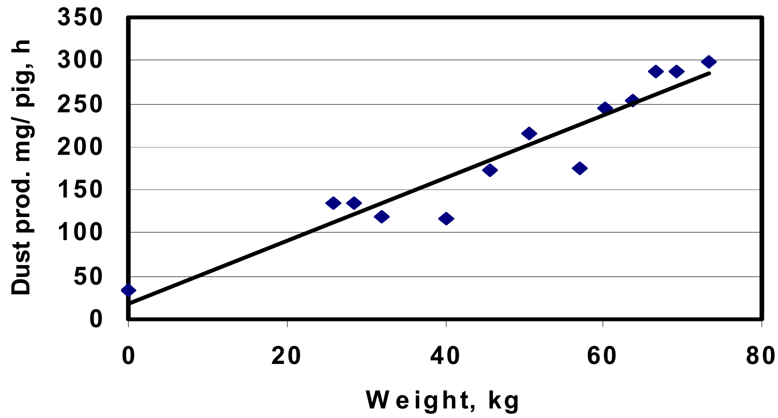

Figure 2. Relation between dust production and weight of pigs

The settling rate of dust varied to a large extent between different locations inside the buildings. However, it was also found that the variations in the settling rate followed the same pattern over the entire production periods. This fact indicates that the air flow patterns inside the buildings could have an influence on the dust conditions.

An example of relation between settling rate *S* and the total dust concentration C_{tot} is presented in Figure 3. Determinations indicate that the settling rate of the dust is influenced by the concentration of dust in the air.

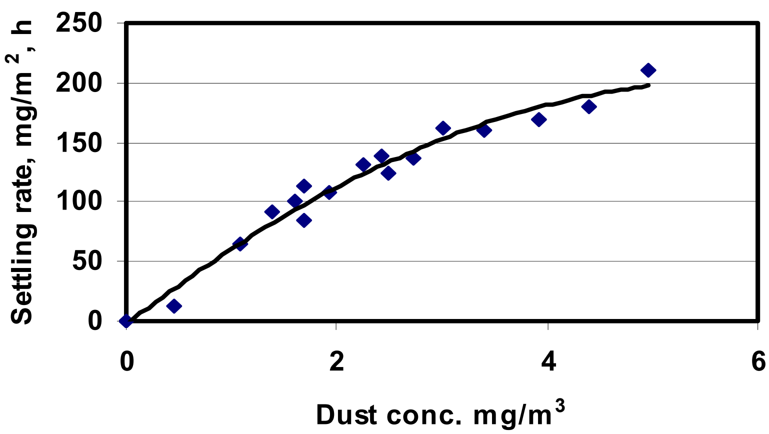

Figure 3. Relations determined by linear regression between the settling rate and the concentration of total dust during a production batch with growing- finishing pigs.

Increased ventilation rate is often recommended as a method to reduce the concentration of air pollutions in buildings. Unfortunately, the ventilation rate has a limited diluting effect on dust at those ventilation rates recommended for insulated pig houses in temperate areas. The reason is that the settling of dust on different surfaces is a more important mechanism to remove dust particles from the air than the ventilation rate in pig houses. The major part of the dust settles on different surfaces inside the buildings. Figure 4 shows an example of the limited effect on total dust concentration at different ventilation rates. The dilution of the dust by increased ventilation will increase the heating requirement in temperate regions.

The fraction of the generated dust which is exhausted by the ventilation air is presented in Figure 5. The fraction of the dust which is exhausted is limited at those ventilation rates which occur in swine confinement houses in temperate areas. The low fraction of exhausted dust shows that the settling of dust is more important than ventilation rate in the mass balance of dust.

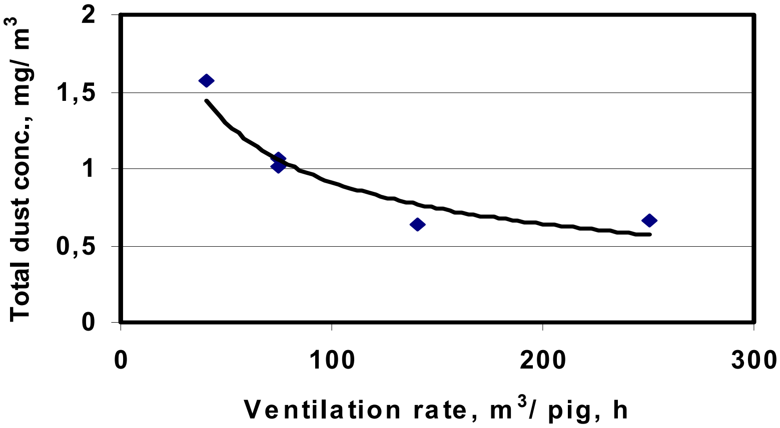

Figure 4. Example of influence of ventilation rate on total dust concentration.

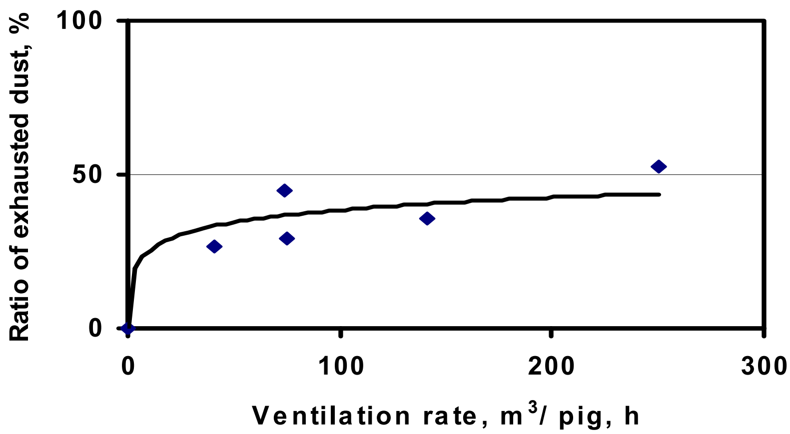

Figure 5. Ratio of dust extracted by the ventilation system to dust production.

The influence of ventilation rate on the number of dust particles of different sizes when air was supplied with a high speed recirculating air inlet is presented in Figure 6. The ventilation had a diluting effect mainly on particles larger than 1.0 µm. The ventilation rate had no effect for particles smaller than 1.0 µm for this particular ventilation system.

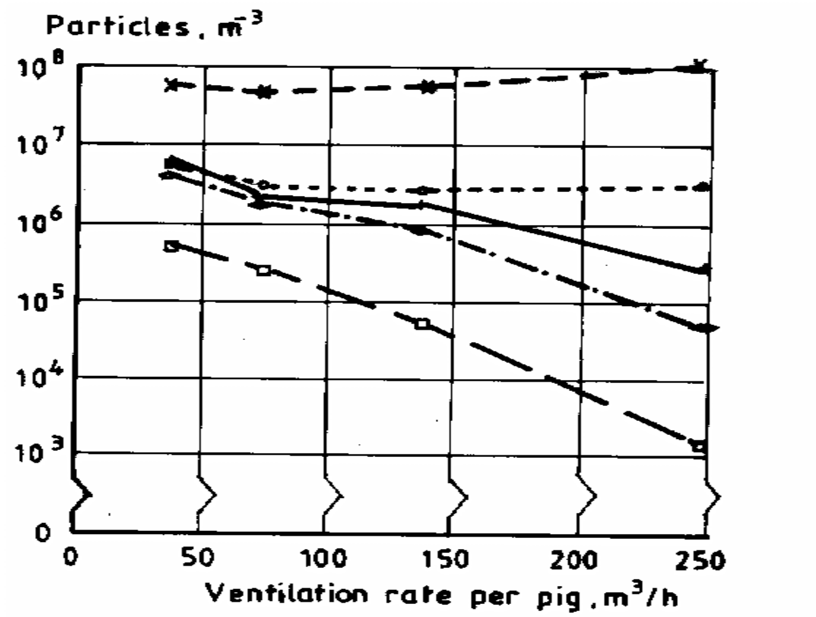

Figure 6. Influence of ventilation rate on the number of dust particles of different sizes;
x ___ ___ x, 0.3-0.5 μm; o _ _ _ _ o, 0.5 -1.0 μm; +_______+, 1.0- 2.0 μm;
♦ __ . __ ♦, 2.0- 5.0 μm; ____ ____, > 5.0 μm

Two very different ventilation principles were compared, namely: high speed recirculating air inlets in combination with an exhaust fan located at roof level (high exhaustion); and a porous ceiling as the air inlet in combination with manure gas ventilation (low exhaustion).

The recirculating air inlets create considerable air mixing and air movements in the stable while the air movements from the porous ceiling are extremely small.

Experimental data for dust concentration and production, settling rate, ratio of respirable dust and fraction of exhausted dust are presented in Table 1. Significant differences ocurred regarding respirable dust concentration C_{resp} and S/C_{resp}. These results indicate that the ventilation technique (mainly air velocities and air movements) may have an influence on small particles.

Table 1. Total and respirable dust concentration C_{tot} and C_{resp}, dust production, ratio between settling rate S and total and respirable concentrations, ratio of respirable to total dust concentration and fraction of exhausted dust at two different ventilation techniques.

Parameter	High speed air inlet + high exhaustion			Breathing ceiling +low exhaustion			Difference,	
	x	s.d.	n	x	s.d.	n	%	
Total dust conc., mg/m^3	1.29	0.57	10	1.14	0.32	7	+13	NS
Resp. dust conc., mg/m^3	0.26	0.095	6	0.15	0.061	4	+77	*
Dust prod. per pig, mg/h	253	104	11	322	116	6	-21	NS
S/C_{tot}, m/h	86	41	11	69	12	7	+24	NS
S/C_{resp}, m/h	392	86	6	535	80	4	-27	*
Ratio of resp. dust, %	18.8	3.5	6	14.2	4.8	4	+32	NS
Exhausted dust, %	25.9	7.3	9	21.0	6.0	5	+23	NS

x, average; s.d., standard deviation; n, number of batches; N.S., non-significant difference;
*, significant difference 0.05 >p >0.01

Two different housing systems were compared namely: climate controlled confinement in an insulated piggery; and cold confinement in an uninsulated piggery with straw bedding and natural ventilation.

In all investigated batches except one, significant differences occurred between the different piggeries, see Table 2. The presence of dust was much lower in the uninsulated stable with straw bedding. The reasons to the large differences between the different systems are difficult to explain. Possible explanations may be more moisture in the cold environment with straw bedding, and very high ventilation rates during spring, summer and autumn in the uninsulated stable.

Table 2. Total and respirable dust concentration C_{tot} and C_{resp} and settling rate of dust S at five comparative production batches with growing-finishing pigs in two different housing systems.

		Insulated and climate controlled			Cold confinement with straw bedding and natural ventilation			
Property	Trial	x	s.d.	n	x	s.d	n	Δ
Total dust conc.	1	1.26	0.57	10	0.19	0.06	15	-75 ***
mg/m^3	2	1.91	0.82	17	0.91	0.22	11	-52 ***
	3	1.00	0.40	14	0.39	0.1	14	-61 ***
	4	0.787	0.35	17	0.62	0.41	7	-21 NS
	5	1.37	0.59	23	0.45	0.15	23	-67 ***
Resp. dust conc.	2	0.30	0.23	5	0.096	0.087	10	-68*
mg/ m^3	3	0.09	0.05	11	0.034	0.036	13	-62 **
	4	0.14	0.07	16	0.215	0.146	6	+53 NS
	5	0.15	0.063	23	0.059	0.015	7	-61 ***
Settling of dust	1	67	22	21	30	20	20	-55 ***
mg/m^2, h	2	72	27	17	45	29	9	-38 *
	3	55	24	15	30	8	14	-45 ***
	4	63	25	17	63	25	20	0 NS
	5	71	22	23	52	21	22	-27 ***

x, average; NS, non-significant difference; s.d., standard deviation; n, number of batches;
Δ, difference %; *, significant difference 0.05 >p >0.01; **, significant difference 0.01 >p >0.001;
***, significant difference 0.001 >p

The use of an electrostatic air cleaner had a limited effect on the dust concentration in the air, although it was proved that the equipment removed a large fraction of the particles in the air which passed through the device. Considering the mass balance of the dust, it is obvious that air cleaning devices need large airflow capacities if the dust concentration in the air should be affected. The airflow through an air cleaner has the same influence on the dust concentration as an equally large increase in ventilation rate in the building.

The use of a vacuum cleaner designed for industrial purposes, as well as a central vacuum cleaning system, were investigated. Both devices were used to clean floor surfaces but also other surfaces such as pipes, etc. at different cleaning intervals. Although most surfaces looked cleaner after the treatments, no significant effect could be measured regarding total and respirable dust concentrations, settling rate or generation of dust.

Three types of spraying nozzles were investigated in an automatic spraying system namely: high pressure (ultra sound) nozzles; flat fan nozzles; and full cone nozzles. The nozzles were operated automatically in short sequences. They were operated twice per hour from 8 a.m. until 6 p.m. and once per hour during the rest of the day.

Spraying water droplets have given different results depending on the type of nozzles which were used. The use of ultra sound nozzles which created droplets in the size range between 5 and 10 μm resulted in a significant increase of both total and respirable dust concentrations during nine comparative trials. The reason for the increased dust concentrations was probably the ultra sound (frequency 30 kHz) created by the nozzles. This sound was outwith the human hearing range. However, observations of the pigs clearly showed that the pigs reacted in an abnormal way the first times the nozzles were in operation. The increased dust concentrations may only be explained by an increased activity of the pigs due to the ultra sound.

The use of the flat fan nozzles operated with a pressure of 0.35 MPa gave a reduction in both total and respirable dust concentrations. In these trials, each pen was equipped with four (horizontal spraying direction) flat fan nozzles in combination with a full cone nozzle (orientated downwards).

The use of full cone nozzles operated at 0.3 MPa pressure also reduced both total and respirable dust concentrations. The settling rate and the generation of dust were also affected. The efficiency was improved with increasing amount of water, see Figure 7.

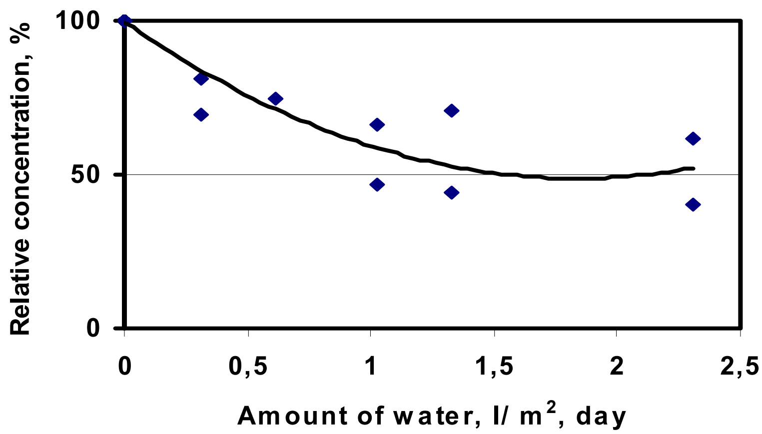

Figure 7. Relative change in dust concentration in % when different amounts of water were supplied with full cone nozzles.

It has earlier been proved by Takai et al. (1993) that the spraying of mixtures of oil and water in pig houses will give a significant reduction in dust concentrations. However, it has not been verified whether the reduction of dust is due to less generation of dust from the pigs skin surfaces or if the oil functions as a dust binding agent on different building surfaces.

In these investigations, 10% rape seed oil in a water solution was used. The mixture was applied in two different ways namely: manually spraying directly on the pigs with a knapsack sprayer; and automatically with a spraying system with full cone nozzles parallel to the feeding troughs. In the latter case, the oil mixture was applied once per day during the feeding time.

The manual treatment affected all the parameters measured. In order to see if the oil affected the release of dust from the skin, one treatment was carried out outside the building so that no oil should cover any building surfaces. In this treatment, the total dust concentration was reduced to 84% of the reference level. The treatment had a significant reduction on settling rate (63% of the reference level) and generation of dust (72% of the reference level). It can be concluded that the treatment with oil reduced the generation of dust from the skin to some extent but also that the oil treatment functions as a dust binding agent on surfaces in the building.

An automatic system for spraying of oil was also investigated. The automatic spraying system consisted of two full cone nozzles per pen located parallel to the feeding troughs. The oil mixture was sprayed over the pigs back once per day during the feeding of the pigs. The reduction on total dust concentration at different amounts of oil is presented in Figure 8. The treatments resulted in a considerable reduction in total dust concentration. Reduction levels in the range of 75-80% has earlier been reported by Takai et al. (1993) with a high pressure spraying system.

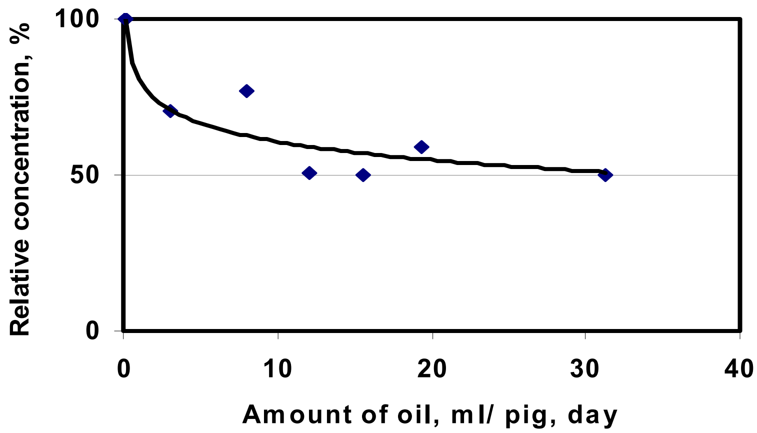

Figure 8. Relative change in total dust concentration in % when different amounts of oil were supplied with full cone nozzles.

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