Vegetative Buffers for Swine Odor Mitigation - Wind Tunnel Evaluation of Air Flow Dynamics

T. Sauer[1], F. Haan, Jr.[2], J. Tyndall[2], G. Hernandez-Ramirez[1], S. Trabue[1], R. Pfeiffer[1], J. Singer[1]
National Soil Tilth Laboratory, Agricultural Research Service, USDA[1], Iowa State University[2]

Species:	Swine
Use Area:	Animal Housing
Technology Category:	Environmental Barriers
Air Mitigated Pollutants:	Ammonia, Hydrogen Sulfide, Volatile Organic Compounds, and odor

Description:

One of the most significant and persistent environmental concerns regarding swine production is odor transport from animal feeding operations and manure storage facilities. Odor constituents include ammonia, hydrogen sulfide, and various volatile organic compounds (VOCs), which may exist as individual gaseous compounds or adsorbed onto particulates (Zahn et al., 1997; Trabue et al., 2006; Tyndall and Coletti, 2006). Building type, facility management, animal diet, and climate affect the amount of potential odor constituents generated at production facilities. Local environmental conditions, especially wind speed and direction, vegetative cover, and topography determine the amount of odor constituents transported downstream from production facilities. Odor mitigation strategies may be designed to reduce either odor generation or transport or both.

As wind approaches a solid object such as a swine-housing unit without any protection upwind, the air accelerates around the sides and over the top of the building diverting air and disturbing the airflow downwind. This additional turbulence around confined swine feeding facilities may increase the downstream transport of odor constituents derived from the feeding facility or stored manure (lagoon, slurry tank, or deep pit). An upwind structure such as a vegetative buffer may protect buildings from excessive wind speed, reduce odor dispersion, and hence produce air quality benefits at a minimal cost.

Prevailing wind direction and speed are two driving factors of odor dispersion around confined feeding operations. Vegetative buffers planted upwind of confined swine facilities may modify air flow dynamics around buildings by decreasing wind speed, and hence diminishing transport of odor constituents. Vegetation is also capable of physically trapping particulates intersected as they flow through the plant canopy.

In addition to the potential mitigation of odor emissions and particulate transport from swine facilities, other benefits from using vegetative buffers include: tree products (e.g. firewood), aesthetics, snow control, wildlife habitat, buffers for extreme temperature fluctuations, soil C sequestration, and potential soil erosion control.

Mitigation Mechanism:

Vegetative buffers are one technique available for diminishing wind velocity, capturing particulates and reducing odor transport from swine production facilities (Malone et al., 2004; Tyndall and Coletti, 2006). Single or multiple rows of trees near swine feeding facilities can reduce odor transport by intercepting gaseous compounds and particulates. Vegetative buffers upwind of swine facilities may also reduce wind speed causing the odor constituents to be deposited on the land surface. Forest vegetation is an efficient natural air filter due to the large amount of surface area on leafy plants. Studies on urban woodland species found conifer trees to be more effective than broadleaf trees and hairy leaves more effective than smooth leaves in capturing particulates (Beckett et al., 2000).

Applicability:

Adding a vegetative buffer to a swine production facility has great potential to reduce air quality impacts and can be accomplished with a modest installation cost and a small increase in annual operation costs. Fig. 1 shows a model of the swine farm employed as a case study in our experiments including vegetative buffers in both north and south sides of the buildings.

Data from simulation studies (see details for wind tunnel study in implementation section below) show the extent to which the application of vegetative buffer technology can decrease wind speed around swine feeding operations (Fig. 2). These experiments showed definite benefits of vegetative buffers on air flow dynamics around swine facilities.

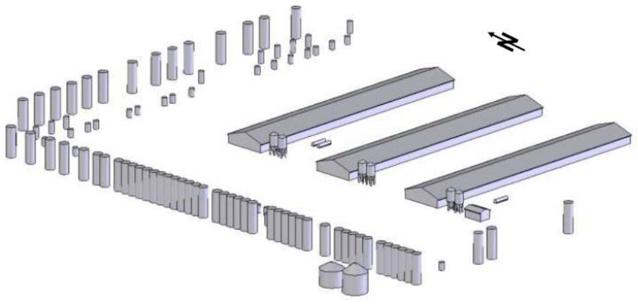

Figure 1. Model of a swine facility located in Boone County, IA. Prevailing wind direction from south west in summer and north west in winter. Cylinders west and north of the buildings represent trees (See description below in implementation section).

Limitations:

Swine confinement facilities should have an adequate air exchange with the surrounding atmosphere to assure proper animal growth and comfort. To reduce air flow around confined feeding facilities by improper planting of vegetative buffers (perhaps more than 3 dense rows) may limit the required heat exchange and compromise animal performance. Criteria for design and establishment of vegetative buffer (density, species selection, arrangement) should consider air circulation near and through buildings to promote animal comfort and development.

Field studies on air flow dynamics around confined animal feeding facilities are limited due to the large number of potential building arrangements, varying land cover, and topography. Therefore, studies on the transport of air quality constituents from buildings of various types have often been conducted in wind tunnels (Huber and Snyder, 1982; Huber, 1989). Low speed wind tunnels (LSWT) offer the advantage of being able to make detailed measurements with scale models of actual buildings under controlled environmental conditions. Some studies combine wind tunnel and field measurements (Mavroidis et al., 2003; Aubrun and Leitl, 2004b) and have generally shown that careful wind tunnel experiments provide an accurate and reproducible assessment of field conditions. Thus, scale model studies in a LSWT may offer a powerful cost-effective approach to assess numerous combinations of vegetative buffer and buildings as well as to develop general guidance for vegetative buffer design around swine confined facilities.

Our LSWT experimental setting facilitates comparative evaluation across diverse stable scenarios what would be very complex to complete in field studies. However, LSWT setting may impose few limitations to this study. Simulation scale models (1:150) of both vegetative buffers and buildings models may not be a precise representative of field conditions with respect to air flow dynamic. In addition, LSWT setting operates at constant wind direction and speed, while both direction and speed of wind are highly fluctuating in most field conditions. Nonetheless, wind tunnel simulations are appropriate proxies for relative comparison across diverse swine facilities scenarios, and it is a cost effective method to evaluate numerous combinations of vegetative buffer designs.

Cost:

The cost estimates for vegetative buffers around swine facilities encompasses site preparation, planting stock, establishment, maintenance (long-term management), and overhead. These costs were calculated for three different scenarios of vegetative buffers (Table 1) planted around a swine finishing facility employed as a case study (see model of the farm in Fig. 1) with the assumption that each scenario accepts the same level of investment risk, and over a period of 20 years with and without land rent factored in (Table 2).

Table 1. Vegetative buffer parameters by planting scenario.

	Scenario 1			Scenario 2	Scenario 3
Number of tree rows	3			1	1
Total trees	Row 1	Row 2	Row 3	113	113
	113	34	34		
Space between trees (feet)	9’	30’	30’	30’	30’
Species planted	Austree willow	Eastern red cedar	Jack pine	Austree willow	“Mixed hardwoods”[1]
Initial planting stock size	15” cutting	2-3’ potted	2’-3’ potted	15” cutting	1 year potted

[1] Native Iowa hardwoods: includes poplar, silver maple, hackberry, and black cherry.

Upfront costs (site preparation and establishment phase) were more than 50 % of the total costs to producers in each scenario (Table 2). These upfront costs were primarily due to costs of the planting stock. Costs of initial planting stock (sizes as described in Table 1) were 0.75, 18, 18, and 9 dollars for austree, eastern red cedar, jack pine, and hardwoods, respectively. Two additional upfront costs were planting operation ($1.00 per tree) and site preparation ($53.85 per acre). Site preparation included plowing, spraying, and disking. Other establishment costs were plastic mulch ($633/linear mile) and spraying ($20.25 per acre). Maintenance (weed control at $31 per linear mile, and replanting at 8 % mortality through fourth year) was also included in the financial analysis as well as overhead ($18 per year). Annual land rent was estimated as $100 per acre for tillable pasture.

For Scenario 1, the three row vegetative buffer system would cost a producer over a 20 year period just over $3,000, with just under $1,800 coming during the initial establishment phase. These costs translate to about $0.03 per pig produced. Scenario 2 featured a single row of Austree willow and would cost $460 over a 20 year period with half of the costs coming upfront; costs per pig are less than 1 cent per pig produced. Scenario 3 featured a single row of mixed hardwoods and would cost about $1,700 over a 20 year period with the vast majority (70 %) of the costs coming upfront; costs per pig come out to about $0.02 per pig (Table 2).

Table 2. Costs for each vegetative buffer scenario at 7% real alternative rate of return (RARR) and in 2008 dollars US.

	Planting Scenario		
Cost Presentation	1	2	3
Present Value Costs (without land rent)	$3, 039	$460	$1,682
Present Value Costs (with land rent)	$4,416	$1,074	$2,297
Upfront costs (site preparation and establishment only)	$1,786	$231	$1,180
Capital Recovery Costs (annual cost over 20 years)	$287	$43	$159
Total costs per pig[1] produced over 20 yr period	$0.03/pig	$0.005/pig	$0.02/pig

[1] It was assumed that each of the three hog finishing buildings holds 1,200 head and that there are 2.5 turns per year.

It should be noted that with these vegetative buffer scenarios, total costs are contingent upon the initial choice of planting stock, the comparative long-term health and maintenance of the system, and the choice of long-term weed control. With drier soils a drip irrigation system may be necessary and would add roughly $0.01/ per pig produced.

Implementation:

Information reported here concerning the effectiveness and feasibility of diverse vegetative buffer configurations to reduce odor and particulate transport downstream from feeding facilities is based on data from our LSWT studies (117 experimental runs) performed using scale models at wind speeds of 2, 5 and 10 m/s, and measuring of wind profile (2 to 400 mm above the floor of the wind tunnel) with a constant temperature anemometer equipped with a 1-D boundary layer hot film probe located downstream from the feeding operations at distances 1, 2 and 6 times the height of the buildings (1H, 2H and 6H, respectively) similar to Sauer et al. (2006). Measurements were done behind the buildings as well as midway between buildings. As described in the cost section above, three different upstream vegetative buffer configurations were evaluated: three rows of trees (first row of willow trees plus two rows of jack pine/eastern red cedar trees), and a single row of Austree willow trees or hardwood deciduous trees (both scenarios with equivalent total frontal area). All tree scale models (1:150) were constructed using 8 x 8 wire mesh (Aubrun and Leitl, 2004a). Both willow and hardwood models were 60 mm tall, while pine/cedar tree models were between 14 to 24 mm tall. To simulate differences in canopy among tree species, willow/cedar/pine models had a complete double mesh, while hardwood tree models had double mesh only in the upper one-third of the model.

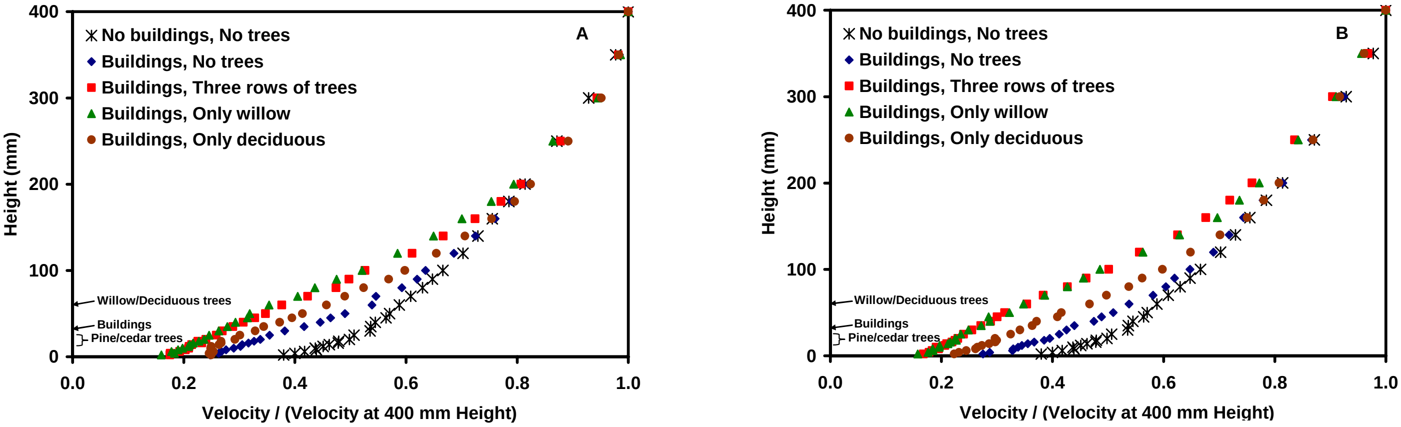

Figure 2. Wind velocity ratio profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions.

Our simulation study demonstrated the potential impact of vegetative buffers to substantially reduce wind speed. Fig. 2 shows how three rows of trees or a single row of willow trees can decrease wind velocity twice as much as the buildings alone from the ground surface to 50 feet (0 to 100 mm in our experimental scale).

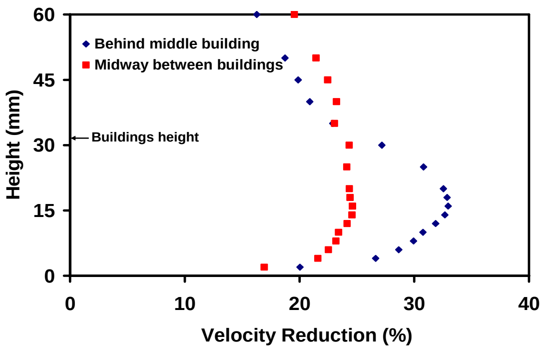

Figure 3. Wind velocity reduction due to building models with two sampling positions.

Buildings alone had a large impact on decreasing wind velocity (Fig. 3). At least 20 % of wind speed reduction was observed in our wind tunnel simulation studies. Measurements done behind the middle building (downstream of air flow) showed a wind speed reduction of about 10% compared to values measured midway between buildings (Fig. 3). However, those differences disappear at heights above the buildings (peak= 15.8 feet) indicating the definitive impact of buildings on air flow dynamic around swine confined feeding operations.

Contribution of windbreaks to wind turbulence (mixing) was found to be 15 to 20 % greater than the contribution by buildings (Fig. 4). In both cases (wind speed and turbulence) a single row of hardwood trees was intermediate between buildings alone and buildings plus three rows of trees or single row of willow trees.

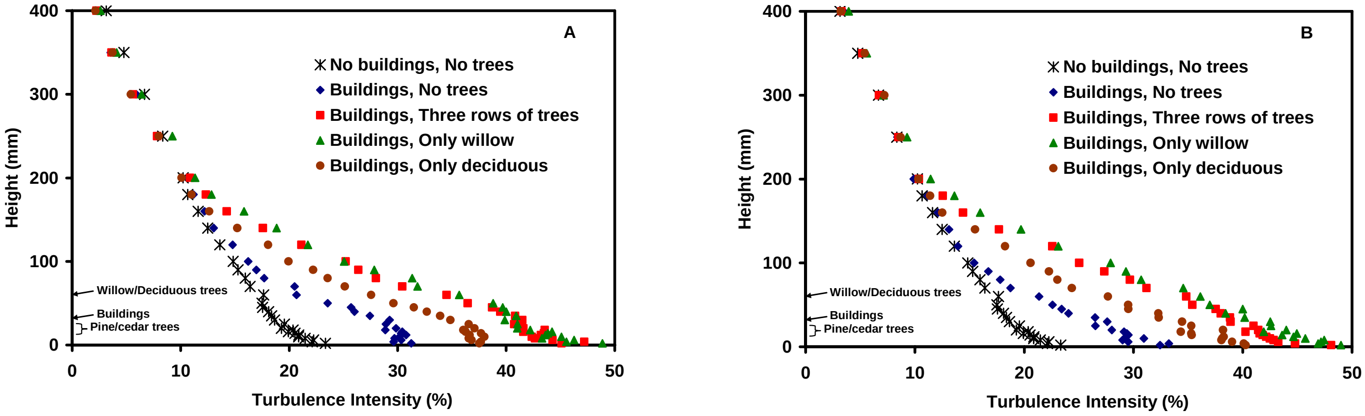

Figure 4. Turbulence intensity profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions.

In general, the effect of both buildings and trees on wind speed and turbulence (Fig 3 and 4, respectively) was observed in heights lower than 100 feet (200 mm in our experimental scale). Even more important, the impact of buildings on air flow parameters goes only to a height of 50 feet (100 mm in our experimental scale); however, the combined effect of buildings plus tree rows of trees persists until a height of 100 feet (200 mm in our experimental scale).

Results of these experiments suggest that implementation of vegetative buffers planted upwind can sharply decrease wind speed, and therefore they may reduce transport of odor constituents and particulates from a multiple buildings swine facility. In addition, it is remarkable that a vegetative buffer of a single willow tree row appears to have nearly the same effect as three rows of trees (1 willow + 2 cedar/pine). However, considerations with respect to vegetative buffer longevity and lifetime may justify the inclusion of cedar/pine together with willow trees in a vegetative buffer arrangement.

Additional Resources:

Windbreak and Odor Mitigation
http://www.forestry.iastate.edu/res/odor_mitigation.html

Windbreaks Function
http://www.ianr.unl.edu/pubs/forestry/ec1763.htm

Farmstead Windbreaks: Establishment, Care and Maintenance
http://www.extension.iastate.edu/Publications/PM1717.pdf

Acknowledgments:

We wish to thank Jadon Kool, Kevin Jensen and Dan West for their assistance in this study. Project support was provided by National Pork Board (Project 000).

References:

Aubrun, S., and B. Leitl. 2004a. Development of an improved physical modeling of a forest area in a wind tunnel. Atmospheric Environment 38:2797-2801.

Aubrun, S., and B. Leitl. 2004b. Unsteady characteristics of the dispersion process in the vicinity of a pig barn. Wind tunnel experiments and comparison with field data. Atmospheric Environment 38:81-93.

Beckett, K.P., P.H. Freer-Smith, and G. Taylor. 2000. Particulate pollution capture by urban trees: effect of species and wind speed. Glob. Change Biol. 6:995-1003.

Huber, A. H. 1989. The influence of building width and orientation on plume dispersion in the wake of a building. Atmospheric Environment 23:2109-2116.

Huber, A. H., and W. H. Snyder. 1982. Wind tunnel investigation of the effects of a rectangular-shaped building on dispersion of effluents from short adjacent stacks. Atmospheric Environment 16:2837-2848.

Malone, G., G. Van Wicklen and S. Collier. 2004. Efficacy of Trees to Capture Emissions from Tunnel Ventilated Poultry Houses. Proceedings to International Poultry Scientific Forum. Jan. 27, 2004.

Mavroidis, I., R. F. Griffiths, and D. J. Hall. 2003. Field and wind tunnel investigations of plume dispersion around single surface obstacles. Atmospheric Environment 37:2903-2918.

Sauer, T.J, J.L. Hatfield, F.L. Haan, Jr., and J. H. Prueger. 2006. A Wind Tunnel Study of Flow Characteristics near Model Swine Production and Manure Storage Facilities. Boundary Layers and Turbulence. 17th Symposium, San Diego, CA.

Trabue, S.L., K. Scoggin, F. Mitloehner, H. Li, R. Burns, and H. Xin. 2006. Volatile sulfur compounds associated with animal feeding operations. Atmospheric Environment (in review)

Tyndall, J.C. and J.P. Colletti. 2006. Mitigating Swine Odor with Strategically Designed Vegetative buffer Systems: A Review. *Agroforestry Systems*. Accepted August 1, 2006. **Published online**: **2**2 September 2006.

Zahn, J.A., J.L. Hatfield, Y.S. Do, A.A. DiSpirito, D.A. Laird, and R.L. Pfeiffer. 1997. Characterization of volatile organic emissions and wastes from a swine production facility. J. Environ. Qual. 26:1687-1696.

Point of Contact:

Thomas J. Sauer
National Soil Tilth Laboratory, ARS, USDA
Ames, IA, 50010
USA
515-294-3416
tom.sauer@ars.usda.gov
http://www.ars.usda.gov/mwa/ames/nstl

As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association
U.S. Pork Center of Excellence