Title: Field and Wind Tunnel Evaluation of Vegetative Buffers for Particulate Trapping and Odor Reduction Near Swine Production Facilities **(NPB #07-048)**

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Industry Summary:

Growing number of swine operations have turned to natural buffers (also called shelterbelts or vegetative buffers) as part of their odor mitigation strategy. However, there is little to no data on the effectiveness of these buffers and little to no guidance on metrics that should be used to determine the performance of a buffer. This study was designed to measure the effectiveness of buffers in lowering odor from a swine facility by measuring odor indicators. These indicators included particulate concentrations and odorous compound concentrations emitted from a swine facility. The facility monitored was a finishing unit with a tree buffer system on the north and west sides of the operation. Samplers were positioned to measure particulates and odorous compounds when the winds were from the south, blowing over the buildings and samplers.

For particulates, there was a 44% reduction in concentration load when comparing samplers before the buffer and samplers placed behind the buffers. In terms of particulate sizes, 94% of the particles on the north side of the buffer were in the range of 0.3-0.5 μm compared to only 88% on the south side of the buffer (i.e., building side). For 0.5-1.0 μm size particles, the building side contained 10% compared to 4% on the north side of the buffer. The tree buffer appeared to consistently filter out the larger particles with a greater proportion of 0.3-0.5μm particles detected at the sampler outside the buffer.

For odorous compounds, the effectiveness of the buffer is a little more complicated. The results show that shelterbelt removed compounds from the air stream just not the most odorous compounds (phenols and indoles) as effectively as less odorous compounds (volatile fatty acids, VFAs). There was a 50% reduction in the VFA concentrations comparing samplers before and after the buffer. Leaves taken from 8 ft had significantly higher amounts of the odorous VFAs, phenolic, and indole compounds sorbed as compared with samples taken from either 2 or 4 ft. This may indicate that as the shelterbelt grows in height their effectiveness for lowering odor increases; however, more research is needed to confirm these findings.

A random sample of existing hog confinements throughout Iowa was used to design buffer systems for each production site. The full costs of establishing and managing these shelterbelt systems were calculated. The effects of a cost share program were then examined. Individual farm level costs were averaged regionally and aggregated by county to estimate the total investment needed by the Iowa hog industry to utilize shelterbelt systems for air quality purposes and to get a baseline understanding of potential cost share program outlays. Across all of Iowa the total costs for the buffer per pig produced (over 20 years) came to $0.036 per pig. Overall, cost sharing reduces total 20 year costs by 18% and upfront costs by just under 50%. Per pig costs are

lowered by almost a penny per animal.
The presence of a vegetative buffer at the study site reduced the amount of particulates and some odor compounds by approximately one half. The estimated cost for establishing and maintaining a vegetative buffer was $0.036 per pig produced over 20 years. Although more research is needed, the effectiveness and cost of this practice should encourage wider adoption.

Scientific Abstract:

The purpose of this study was the measure the effectiveness of a tree buffer in reducing particulate and odor movement from a swine confinement operation and an economic analysis of costs associated with establishing and maintained vegetative buffers around swine confinement facilities in Iowa. Optical particle counters (OPC) were used to measure the number of particles within and outside the tree buffer and group them into 8 size fractions. When the winds were from the south there was an overall reduction of 44% in particulates due to the tree buffer. Large particles (> 10 microns) contributed less than 0.1% of the total. Differences were observed for 4 of the 6 size fractions. For the 0.3-0.49 micron fraction, the values were 94.3% and 88.9% for OPC 3 and OPC 2, respectively, indicating a larger proportion of small particulates in the north side (away from building) of the buffer. For size fractions 0.5-0.69 microns, 0.7-0.99 microns, and 1.0-5.0 microns there was an increase in the percentages for OPC2 versus OPC 3.

The buffer was effective for removing VFAs with peak concentrations occurring at 5:00-7:00 pm (18:00:00) and concentrations reduced by over 50% in both the August and September samplings. While this is a positive result, the odor threshold concentrations for these compounds (VFAs) are significantly higher (less odorous) than for the aromatic compounds (i.e., phenol and indole compounds) so removing these compounds from air stream will not have the same effect as removing the aromatic compounds. The more odorous compounds represented by 4-methylphenol (p-cresol) indicate that the buffer had mixed results with the August sampling showing little to no difference between the north and corn field samplers, and September sampling showing that levels of this compound are reduced when comparing the different field samplers. There results show that buffer removed aromatic compounds from the air stream just not as effectively as for the VFAs.

The wind tunnel experiments indicated that the effect of both buildings and trees on wind velocity and turbulence was observed at heights lower than 100 feet (200 mm in our experimental scale). The impact of buildings perpendicular to air flow parameters was greater than for tree models further downwind. The lower wind velocity and greater mixing near the trees should enhance particulate trapping and odor sorption to the tree tissues.

By taking a random sample of existing hog confinements throughout Iowa (n=60), site specific shelterbelt systems were designed for each production site. Assuming each shelterbelt was designed as a retrofit system, the full costs of establishing and managing these shelterbelt systems were calculated for each facility. The effects of the Environmental Quality Enhancement Program (EQIP) were then examined. Individual farm level costs were averaged regionally and aggregated by county to estimate the total investment needed by the Iowa hog industry to utilize shelterbelt systems for air quality purposes and to get a baseline understanding of potential cost share program outlays.

Examining first the low cost scenarios (based on seedling prices for planting stock), producers in SE Iowa would experience the lowest average costs of $3,896 total for establishing and managing a shelterbelt system over a 20 year period. Producers in SW Iowa would face the highest costs of $4,500 per site. In terms of upfront cost only there is just a $229 difference between high and low costs ($1,671 versus $1,447). Across all of Iowa the total costs per pig produced (over 20 years) comes to $0.036 per pig. Overall, EQIP reduces total 20 year costs by 18% and upfront costs by just under 50%. Per pig costs are lowered by almost a penny per animal. As yet another way to think about costs, with the low cost situation the total costs come to about $1.40 per linear foot of shelterbelt.

IV. Introduction:

One of the most significant and persistent environmental concerns regarding swine production is odor transport from animal production 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, 2007). 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 from* production facilities. Odor mitigation strategies may be designed to reduce either odor generation or transport or both.

Vegetative windbreaks or buffers are one technique available for 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 animal production facilities can reduce odor transport by intercepting gaseous compounds and particulates and by reducing the wind speed and causing the odor constituents to be deposited on the land surface. 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). Adding a vegetative buffer to a swine production facility has great potential to reduce air quality impacts and can likely be accomplished with a modest installation cost and a small increase in annual operation costs. Further research is needed, however, to evaluate the relative effectiveness of different species and arrangements, to develop criteria for vegetative buffer designs that will optimize odor and particulate trapping, and to estimate costs associated with this odor mitigation strategy.

Due to the large number of potential building arrangements and varying land cover and topography, 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). Wind tunnels 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, 2004) and have generally shown that careful wind tunnel experiments provide an accurate and reproducible assessment of field conditions. Thus, combining field measurements of odor and particulate transport at a swine production facility with a vegetative windbreak with scale model studies in a wind tunnel offers a powerful combination of approaches to develop general recommendations for vegetative buffer design.

Very little is known about the financial requirements for installation (i.e. site preparation and planting) and long term management of vegetative buffer systems designed for air quality management (Tyndall and Grala, 2008; Lorimor, 2002). This lack of information has been identified as one of the chief barriers to swine producer adoption of this air quality technology (Tyndall, 2008). Since the long term use of vegetative buffers represents an “out of pocket” expense for most producers, the use of vegetative buffers is ultimately contingent upon the financial feasibility of the technology at the farm level.

V. Objectives:

The objectives of this study are to 1) measure particulate and odor constituents across an existing vegetative buffer at a swine production facility, 2) conduct scale model wind tunnel experiments of vegetative buffer effects on air flow for the field site using a model of the existing buffer and several potential buffer designs, and 3) complete an economic assessment of vegetative buffer establishment and maintenance costs at the farm and county level for Iowa.

VI. Materials and Methods:

Objective 1 (Particulates and Odor)

Particulates

Three optical particle counters (Model 9722, Met One Instruments, Inc., Grants Pass, OR) were used for the particulate measurements. The particle counter has the ability to size and count airborne particles in up to eight size ranges. The counter uses scattered light to measure and count particles. Light from a laser diode is collimated to illuminate a sample. Aerosol containing particles are directed through the sample volume where it scatters the incident laser light. The amount of scattered light is converted to a voltage pulse, and based on the amplitude of the pulse signal it will pass through one or move of the size discriminators and into the associated counter size range. The size ranges (bins) used were (in microns) 0.3-0.49, 0.5-0.69, 0.7-0.99, 1.0-1.99, 2.0-2.49, 2.5-4.99, 5.0-9.99 and greater than 10.0. Fifteen minute averages on a per-liter of air basis were recorded using a Model CR1000 datalogger (Campbell Scientific, Logan, UT). Data was transmitted daily via cell phone modem to the National Soil Tilth Laboratory in Ames, Iowa. Along with the OPC's, wind speed, wind direction and precipitation were monitored at the site and hourly averages were recorded.

The site chosen for the study was a 3 building swine finishing facility housing approximately 2500 head. A single row of Austree willow trees (*Salix matsudana x alba*) and partial rows of jack pine (*Pinus banksiana)* and eastern red cedar (*Juniperus virginiana*) serve as a buffer. The row of willows is located 155 feet north of the buildings and 300 feet to the west. Samplers were placed between the buildings and the buffer to the north at 60 ft and 140 ft. A third sampler was placed just north of the buffer (170 ft from building). Pigs began arriving at the site on May 6 with average weight of 25-35 pounds. Beginning Oct 6 pigs were sent to market at a average weight of 220-250 pounds. An aerial photo of the site is shown in Figure 1.

Figure 1: Photo of site.

Odor - Air Sampling

All samples were collected on glass sorbent tubes (178 x 6 mm diameter) containing a multi-bed sorbent packing of Carbopack C and Carbopack X (1:2 ratio v/v) custom made by Supelco, Inc. (Bellafonte, PA). Prior to use, the sorbent tubes were conditioned on a Tube Conditioner (Gerstel, Inc. Baltimore, MD) at 300°C for a minimum of 2 hours with a nitrogen purge of 50-70 mL min^{-1}. Conditioned tubes were either loaded into field gas samplers (GS 301 gas sampler, Gerstel, Inc.) or placed in-line with personal sampler (222-4 Series, SKC, Inc, Eighty Four, PA). Air samplers taken with GS1 samplers were placed at five different locations around the facility with samples collected at 100 mL min^{-1} for 12 L (sampling time approximately 2 hours). Total volume of air sampled for each sorbent tube was recorded by the GS1 gas samplers. Personal samplers were placed at several different locations at the facility and 1 mile north of the facility with samples collected at approximately 10-15 mL min^{-1}. Total volume of air sampled was internally recorded on sampler counters. All surfaces exposed to the flow path prior to the sorbent tubes were constructed of either Teflon®, glass, or polypropylene material. Sampled sorbent tubes collected in the field were stored at ambient temperatures until transported back to the laboratory and stored at <-20°C until analyzed. All samples were analyzed within 60 days of the time they were sampled in the field. Prior to analysis, all samples were allowed to equilibrate to ambient temperatures. After analysis, the sorption tubes were conditioned as previously specified.

Odor - Plant Material Extraction

Plant material was collected from the tree-lines on the north side of the facility with samples collected on both the north and south sides of individual trees in the willow and pine rows at heights of 2, 4, and 8 ft above the ground. Collected samples were placed in plastic bags and stored in a freezer (<-20°C) until processed. Samples were weighed and placed into an ATIS™ (Supleco, Bellefonte, PA) extraction glassware (13 mm id X 76 mm length) apparatus. The apparatus heated vessels to approximately 110°C, while purging the contents of the extraction cell with humidified nitrogen gas at 75 mL min^{-1} for a 1-2 hrs (total volume 4-9 L). Volatile organic compounds extracted were captured onto sorbent tubes (see description above) placed in the apparatus. All sorbent tubes were stored in freezer (<-20°C) for no longer than 30 days.

Odor - Analytical Analysis

Sorbent tubes were analyzed by thermal desorption (TDS) using an Agilent 6890N GC (Agilent Technologies, Inc.). Two different 6980N GC instruments were used one contained only a 5973N Inert MSD (Agilent Technologies) with an odor port (Gerstel, Inc., Baltimore, MD) for GC-O analysis, while the other was equipped with both a MSD (5975N, Agilent Technologies) and pulsed flame photometric detector (OI Analytical, College Station, TX) connected in parallel. Both GC systems used a Gerstel TDSA (Gerstel, Inc.) as its TDS unit, each were equipped with PTV (programmed temperature vaporizer) inlets (CIS 4, Gerstel, Inc.) and both separated compounds on a 30m x 0.25mm x 0.25μm FFAP column (J&W Scientific, Inc., Wilmington, DE) using a helium gas set at a maximum of 1.4 mL min^{-1} constant flow.

Thermal desorption (TDS) parameters were the following: splitless mode; initial temperature, 60°C; final temperature, 300°C; initial time 0.5 min; final hold time 3 min; ramp, 60°C min^{-1}; with a transfer line temperature of 320°C. The inlet was packed with glass bead/Carbopack C material with the following parameters: solvent vent mode; initial temperature, -30°C(-160°C when performing GC-O analysis), final temperature, 320°C, initial time, 0.2 min, final time, 3 min; ramp, 12°C sec^{-1}, vent flow 40 mL min^{-1}, and purge split flow 20 mL min^{-1} with 1 min delay. The 1.0 min delay essentially creates a splitless injection between the PTV and column.

The two different GC instrument oven temperature program were used. The first program: 1) initial temp, 80°C hold 0.05 min; 2) ramp 10°C min^{-1} to 220°C; and 3) ramp 50° C min^{-1} to 240°C and hold 5 min. The second GC instrument oven temperature program for GC-O analysis was: 1) initial temp, 45°C hold 0.05 min; 2) ramp 10°C min^{-1} to 220°C; and 3) ramp 50° C min^{-1} to 240°C and hold 5 min. The MS transfer line and source temperatures were 240 and 150°C, respectively, and MSD was operated in Scan mode (29-350 amu) at 4.4 scan s^{-1}.

Objective 2 (Wind Tunnel Simulations)

Three vegetative buffer configurations to reduce odor and particulate transport downstream from feeding facilities were evaluated in the low speed wind tunnel (LSWT). Scale models of buildings and trees at wind speeds of 2, 5 and 10 m/s were evaluated for their effects on the vertical wind profiles (2 to 400 mm above the floor of the wind tunnel) using 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). Measurements were completed for the equivalent of west and south winds behind the buildings and behind the buildings and tree models. Three different vegetative buffer configurations evaluated: three rows of trees (outside row of willow trees plus two rows of jack pine/eastern red cedar trees), a single row of willow trees, or a single row of hardwood deciduous trees (both scenarios with equivalent total frontal area). The first scenario represents the actual vegetative buffer at the field site. All tree scale models (1:150) were constructed using 8 x 8 wire mesh. 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.

Objective 3 (Economic Analysis)

A regionally stratified sample of Iowa hog production sites was drawn from a 2006 Iowa Department of Natural Resources (IDNR) database listing confinement feeding operations in Iowa with registered manure management plans (ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/agriculture/confinement_feeding_operations.html; all facilities in Iowa with ≥ 1,000 animal units must submit a manure management plan to the IDNR). Iowa was stratified into four quadrants (northeast, northwest, southeast, southwest) and random sample proportional to total number of facilities in each quadrant was drawn (n=60; NE = 17, NW = 25, SE = 10, SW = 8). A 2007 aerial photo of each sampled facility was located in the Iowa State University Geographic Information System orthophoto database and analyzed. A "to scale" site specific shelterbelt system (e.g. taking into consideration existing animal and out building configurations, roads, visible permanent vegetation, and manure storage facilities) was independently designed for each facility following a general design template featuring common design standards for analytical consistency. A two-dimensional linear representation of that shelterbelt system was then over-laid on each orthophoto.

For each shelterbelt design there were at minimum two tree species used: Austree willow and Eastern Red Cedar. The shrub species Red Osier Dogwood (*Cornus stolonifera*) was also included in several designs. All designed shelterbelts were in two-row arrangements with standard 9 feet between tree and 20 feet between row planting configurations. No shelterbelts were located < 100' to the north of all buildings and/or roads to account for winter snow deposition; no tree rows were located < 100' to the south of all buildings to account for needed summer wind-flow (this is particularly critical for curtain walled or otherwise naturally ventilated facilities). Each scaled shelterbelt design was then carefully measured for total length and area under trees so that total trees to be planted (by species) and total land area to be managed over the long-run (e.g. 20 years) could be calculated and financially analyzed. Additionally, in order to express costs on a per animal produced basis, the pig space capacity of each facility was estimated by measuring the dimensions of the animal buildings and dividing the area by 6 feet/ pig of growing space.

These measurements served as the chief parameters for the farm level economic analysis. See Figure 2 below for a general example of a modeled shelterbelt system. Table 1 displays average designed shelterbelt parameters and average sampled production site parameters across all four regions in Iowa.

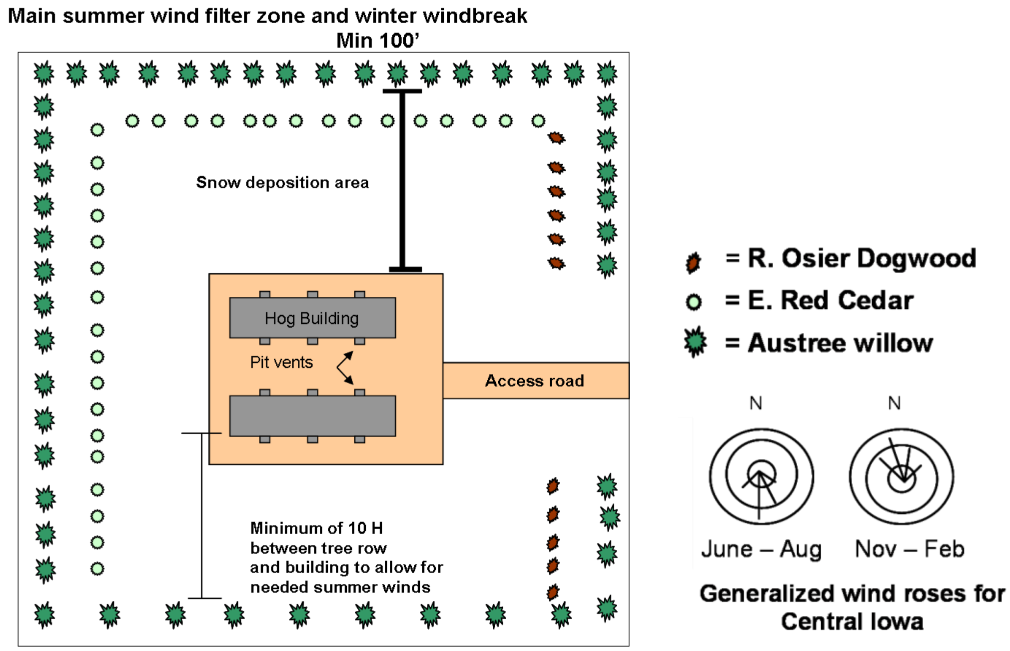


Figure 2. Example general shelterbelt design for a two building swine finishing unit. All model shelterbelts were designed for Central Iowa wind patterns. Ultimately, shelterbelt designs (e.g. planting patterns and on-site location, species used) will be variable and site specific. Figure modified from Tyndall and Colletti (2007).

Table 1. Average designed shelterbelt parameters across all four Iowa regions (n=60)

	NE	NW	SE	SW
Average total length of tree rows (ft)	2,678	2,721	2,631	2,979
Average total length of shrub rows (ft)	227	305	127	236
Average area under trees & shrubs (ac)	1.28	1.32	1.24	1.42
Average # of trees per site	300	302	292	331
Average # of shrubs per site	64	34	42	30

Table ** Average sampled production site parameters (n=60)

	NE	NW	SE	SW
Average number of animal head per site	5,200	6,600	4,800	7,500
Average number of buildings on site	2.4	2	2.6	3.8
Percent of sites with existing shelterbelts	50%	43%	28%	13%

Overall, on average there are numerical similarities across all the facilities sampled and the shelterbelts designed and modeled. The average total length of shelterbelts per farm ranges from a high of 3,215 feet in SW Iowa (taking up a total of 1.42 acres) to a low of 2,758 in SE Iowa (1.24 acres). The production facilities modeled in NE Iowa averaged a high of 364 trees per site and in SE Iowa the facilities averaged a low of 334 plants. Coinciding with the average total length of shelterbelts, the larger facilities are in the SW (averaging a high of 7,500 head) with facilities in the SE averaging a low of 4,800 head. By examining each orthophoto carefully it was possible to determine if facilities currently had tree configurations protecting on-site buildings and/ or planted around the perimeter of the site. Fifty percent of the facilities sampled in the NE currently have trees on-site, 43% in NW Iowa, 28% in the SE and a low of 13% in SW Iowa.

Cost Assessment Details

In general, costs for shelterbelt systems designed for odor mitigation are highly variable and are site/shelterbelt design specific. Still, there are consistently four main categories of expenses associated with shelterbelts: 1) site prep costs, 2) tree establishment costs, 3) long term maintenance costs, and (in some individual cases) 4) land rent (opportunity costs). Table 2 below outlines the typical expenditures that a producer might expect in establishing and maintaining a shelterbelt system. Additionally the financial analysis consisted of two planting stock cost options: 1) planting stock at seedling prices (e.g. 2-3 year old stock); and 2) older planting stock prices (e.g. 6 + year old stock) – planting stock being the main component of the upfront costs. The impact of potential cost share programming (Environmental Quality Incentive Program, EQIP) has also been factored into the analysis.

The farm level analysis considered a time horizon of twenty years. Twenty years is considered reasonable, as the average life span of typical hog facility ownership has been estimated to be between 15 and 20 years (ISU, 1998). The analysis was carried out across a range of discount rates (5%-7%) however the costs presented in Table 2 below reflect a 7% real alternative rate of return (RARR) as 7% represents a 5-year average return on Iowa crop ground and therefore serves adequately as an alternative rate of return for land use in Iowa (Tyndall and Grala, 2008). It is also assumed that each facility accepts the same level of investment risk regarding the use of trees.

Financial Model

Following the model established in Tyndall and Grala (2008) all costs were discounted using standard discounting formulation. The general cost model is:

$$PVC = PVSB^{SP} + PVSB^{E} + PVSB^{M} \quad [1]$$

Where PVC = Present value of total costs; $PVSB^{SP}$ = Present value of shelterbelt site preparation costs (includes tilling or otherwise preparing land for tree planting); $PVSB^{E}$ = Present value of shelterbelt establishment (includes all planting stock, actual planting and other related actions); and $PVSB^{M}$ = Present value of shelterbelt maintenance needs (includes activities such as: weed management and tree/shrub replacement).

For the purpose of presenting the costs in multiple ways, the total discounted costs for each scenario are then converted into equivalent annual value (EAV) of costs using a capital recovery factor following Gumaa et al., (1998):

$$EAV = PVC * CRF \quad [2]$$

$$CRF = [\ i(1+i)^{N}] / [(1+i)^{N} - 1] \quad [3]$$

Table 2. Transaction costs and year(s) in which they occur, for the three modeled shelterbelt scenarios. All costs are in 2008 dollars US.

	Year(s)	Price/ Unit [1] (US 2008 $)	Source of Price Information
Site Prep			
Plowing	0	$13.60/ac	a
Spray purchase	0	$1.25/ac	b
Spraying operation	0	$19.00/ac	c
Disking	0	$20.00/ac	c
Shelterbelt Establishment			
Tree purchase costs	1	Variable [2]	d,e,f
Shrubs purchase cost	1	Variable [2]	d,e,f
Tree planting cost	1	$1.00/tree	c
Shrub planting cost	1	$1.00/tree	c
Spray purchase	1	$1.25/ac	b
Spraying operation	1	$19.00/acre	c
Permeable plastic mulch	1	$633/linear mile	g
Maintenance			
Tree replanting	2-4	Variable [3]	d,e,f
Shrub replanting	2-4	Variable [3]	d,e,f
Weed control (mowing)	2-5	$31.46/linear mile	c
Other relevant costs			
Overhead/management [4]	Annual	$18.02	h
Land rent (tillable pasture)	Annual	$177/acre	i
Cost Share Programming			
EQIP [5]	1	50% cost share on establishment costs including plant stock	

[a] Iowa State University, 2008.; [b] Based on 2008 cost of 2.5 gallon container of generic glyphosate; [c] Iowa State University, 2003; [d] Cascade Forestry Nursery, 2007; [e] Kelly Tree Farm (2008 online catalog), 2008; [f] Iowa Department of Natural Resources, 2007; [g] PFRA, 2008; [h] Robert Grala pers. Comm. 2008; [i] ISU Extension, 2008.

[1] Units are variable depending upon cost item; prices listed as per linear mile assume a treatment strip of 10' by 5280' or a "price/ acre" to “price/ linear mile” conversion factor of 1.21.

[2] Low price scenarios: 15” cuttings of Austree = $1.00/tree; 12”-18” Eastern red cedar = $ 2.50/tree, 12”-18” red osier dogwood = $1.50/shrub; High price scenarios: potted Austree = $ 7.50/tree; 18” – 24” potted Eastern Red cedar = $ 12.50/tree, 4 year old Red Osier dogwood = $3.50/ shrub.

[3] It is assumed that tree mortality will equal 8% during the second through the fourth years after shelterbelt establishment and replacement costs follow the two different pricing scenarios.

[4] Includes taxes, insurance, energy requirements, etc.

[5] The EQIP parameters modeled were from Crawford County, Iowa (NRCS, 2007); NRCS Practice code 380, windbreak establishment for air quality (objectionable odors, particulate matter), payment equals 50% cost share on average cost.

Where CRF is the Capital Recovery Factor, i = annual real discount rate, and N = number of years in the evaluation. The EAV annualizes all costs and allows pork producers to examine costs on a long term planning horizon. By dividing the EAV of each shelterbelt scenario by the number of pigs produced annually presents total costs as per unit of production (per pig) costs and spreads the costs out across all the pigs produced in a twenty-year period. This method is appropriate because the shelterbelt systems are designed to mitigate swine odor over an estimated ownership span (ISU Extension, 1998) and therefore costs are spread over all the pigs produced at that facility over a 20 year period.

Cost Analysis Parameters

The calculated costs of the various shelterbelt models aggregated and averaged across the four Iowa regions are presented in a number of ways. The average present value of costs (at 7% ARR) for each region was calculated to capture the total costs of establishing and maintaining the shelterbelts over a 20 year period. This was calculated with and without land rent factored in. Because across Iowa between 37% and 45% of the total cost to producers comes during the site preparation and establishment phase (primarily from the costs of the planting stock) these “up-front” costs are isolated and presented. Additionally, costs per pig produced over a 20 year period are presented. Furthermore, total costs were calculated to display the effects of existing EQIP funding. It should be noted that currently not all EQIP programming at the county level in Iowa accepts shelterbelts as a Best Management Practice for air quality. Moreover, those counties that do may have different EQIP payment parameters. Because of this the EQIP program used by Crawford County has been used for analytical purposes; Crawford County pays out 50% cost-share for average shelterbelt (practice Code 380) establishment costs (NRCS, 2007).

VII. Results:

Objective 1 (Particulates and Odor)

Particulates

The particulate data set was quite extensive as 1 minute data averaged over 15 minute intervals were collected from June thru October. Monthly averages with no regard to wind direction are presented in Figure 3. OPC 1 is nearest the building and OPC 3 is on the outside of the tree buffer area. Figure 4 is a summary of all particulate counts sorted by wind direction. This data indicates the complexity of particulate measurements with regards to possible interferences and background values. Multiple samplers are needed to accurately measure these factors. Actual differences between OPC 2 and OPC 3 on selected days for each of the months are shown in Figures 5-9. These figures clearly show that season and animal size are important variables. In Table 3, particulate size distribution data is presented averaged over the entire time of data collection.

The wind direction data shown in Figure 4 is a good representation at what is happening on the site. Winds from the south sweep over the buildings and into the path of the samplers. OPC 1 which is closest to the buildings would be expected to have the highest particulate counts, but this was not the case. The sampler may have been positioned too close to the buildings and thus missing the particulate plume. This shows the importance of sampler location. There is no shelter belt on the east side of the facility. The particulate counts for all samplers were elevated when the winds were from the east blowing across large open fields. The low counts when winds blow from the west is not fully understood but could be the result of fewer days with winds from this direction or the higher elevation of land to the west.

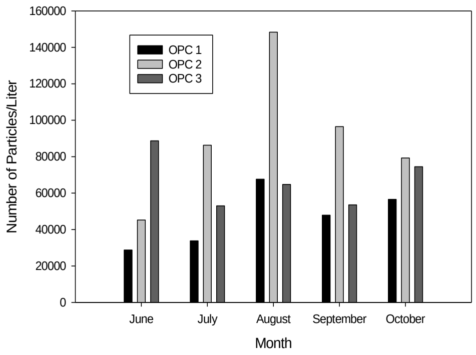


Figure 3: Effects of Month.

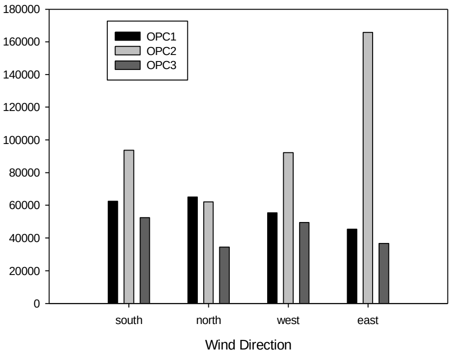


Figure 4: Effects of Wind Direction.

The monthly data shown in Figure 3 shows a predicted trend: OPC 2 higher than OPC 1 and OPC 3. The exception is for June when the pigs were small and cool temperatures were the norm resulting in a ventilation system operating with minimal fan velocity. The June data represents only part of the month which could contribute to the different particulate counts.

Figures 5-9 shown below are a snapshot from one day in each month when winds were from the south. The data presented in these figures follows that shown in Figure 4.

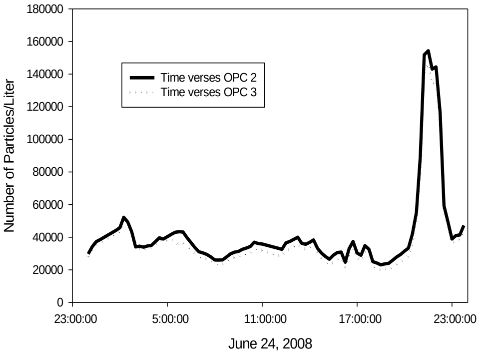


Figure 5: One Day in June.

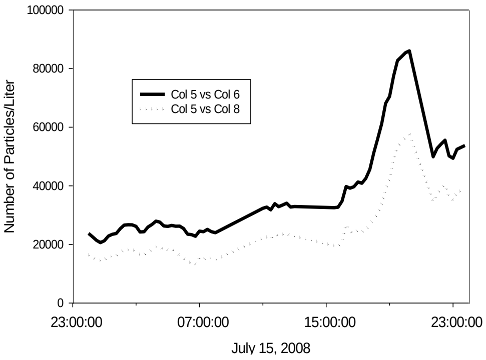


Figure 6: One Day in July.

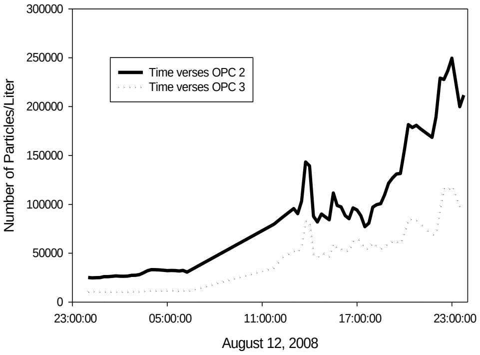


Figure 7: One Day in August.

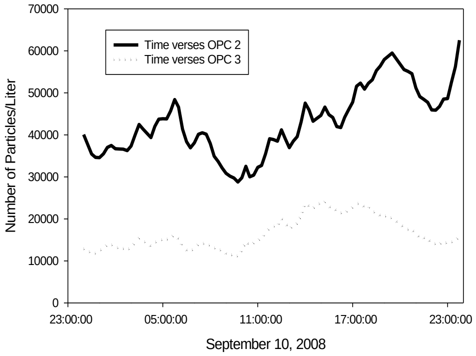


Figure 8: One Day in September.

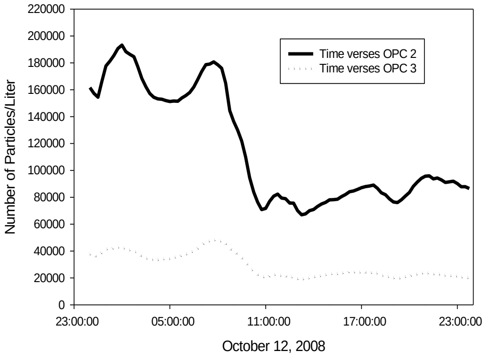


Figure 9: One Day in October.

The data shown in these figures clearly show a trend where the particulate counts for OPC 2 are greater than OPC 3 when the winds are from the south. The lone exception is in June when the pigs were small and the ventilation system is reduced due to cool temperatures. When the winds were from the south there was an overall reduction of 43.9% due to the tree buffer. The data for October 12 don't follow the same pattern as for the other months. Removal of pigs began on October and extended over a 2 week period. Truck traffic and building cleaning might account for the unusual shape of the curves, but nevertheless, there was a reduction.

The last aspect of this element of the study was to look at the size distribution of particulates measured. The data presented in Table 3 is a composite of the entire data set comparing particulate size distributions from OPC 2 and OPC 3. Large particles (> 10 microns) are not shown in the table because their contribution was less than 0.1% of the total. Differences can be seen in 4 of the 6 size fractions. For the 0.3-0.49 micron fraction, the values were 94.3% and 88.9% for OPC 3 and OPC 2, respectively, indicating a larger proportion of small particulates in the north side of the buffer. For size fractions 0.5-0.69 microns, 0.7-0.99 microns, and 1.0-5.0 microns there was an increase in the percentages for OPC2 versus OPC 3. A higher fraction of larger particulates on the building side of the buffer is to be expected.

Table 3. Particulate size fractions.

Size (microns)	OPC 3 (%)	OPC 2 (%)
0.30-0.49	94.31	88.93
0.50-0.69	3.27	8.16
0.70-0.99	0.93	1.38
1.00-1.99	0.61	0.98
2.00-4.99	0.87	0.86
5.00-9.99	0.11	0.13
Total	100.11	100.43

Odor

Key chemical classes associated with odor measured from both the swine housing and pit fans included: volatile fatty acids (VFA), phenolic compounds; and indole compounds. Samples taken from the swine housing area showed high levels of VFAs with some 4-methylphenol; however, samples taken from the pit fan show increased levels of indole and 3-methylindole (data not shown). Of these three chemical classes the indole compounds odor thresholds are typically 1-2 orders magnitude lower than phenolic compounds, which are lower than VFAs. Based on odor activity values (concentration of compound in air/odor threshold value) the indole compounds are typically the most odorous for compounds emitted from the pit fan, while in the swine housing area butanoic acid, 3-methylbutanoic acid, and 4-methylphenol are key odorants.

Figures 10 and 11 shows the results of an average day for a week long sampling event (late August and Mid-September) 2008) for samplers placed between swine buildings (Central), northern edge of facility before the shelterbelt (North) and past the shelterbelt into corn field (Corn Field). Figure 10 clearly shows the effectiveness of the shelterbelt for removing VFAs with peak concentrations occurring at 5:00-7:00 pm (18:00:00) and concentrations reduced by over 50% in both the August and September samplings. While this is a positive result, the odor threshold concentrations for these compounds (VFAs) are significantly higher (less odorous) than for the aromatic compounds (i.e., phenol and indole compounds) so removing these compounds from air stream will not have the same effect as removing the aromatic compounds.. The more odorous compounds represented by 4-methylphenol (p-cresol) show that the shelterbelt had mixed results with the August sampling showing little to no different between the north and corn field samplers, and September sampling showing that levels of this compound are reduced when comparing the different field samplers (Figure

11). There results show that shelterbelt do remove compounds from the air stream they just don't remove the odorous aromatic compounds as effectively as they do the VFAs.

As the pine needles sorbed very low amounts of VFAs and non-detectable amounts of the aromatic odorants, results are reported for the willow leaves only. Odorants sorbed to willow leaves somewhat support the findings of the field air sampling in that VFAs are effectively sorbed, while odorous aromatic compound sorption to plant material is not as clear. In the August sampling, VFA concentrations were significantly higher ($p = 0.03$) for front side of the trees facing the swine facility compared to the back side, but in the September sampling the data would suggest there is a trend in comparing sorption of VFA on the front and backside of the

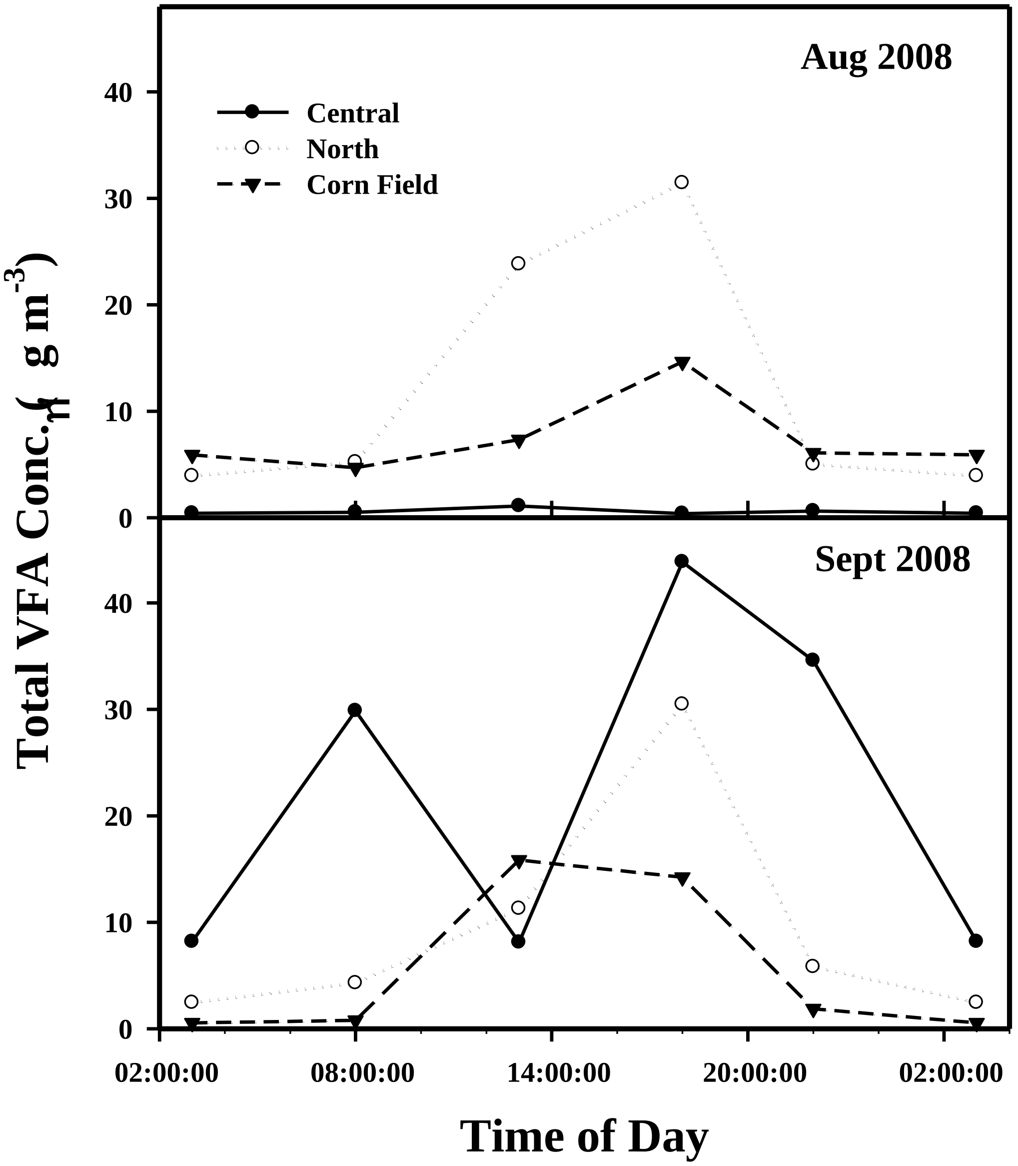


Figure 10. Concentrations of total VFAs in air measured from a swine facility collected in August and September.

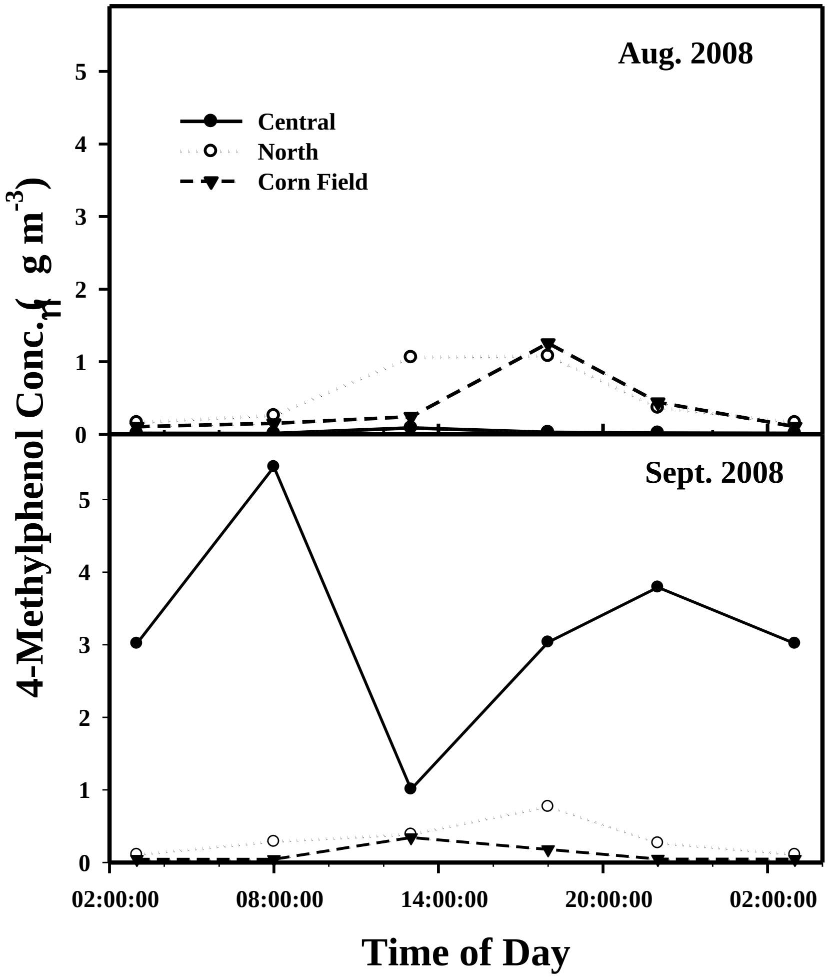


Figure 11. Concentrations of 4-Methylphenol (p-cresol) in air measured from a swine facility collected in August and September.

trees. For the more odorous VFAs (i.e., butanoic acid and 3-methylbutanoic acid), the results are a little weaker with the August sampling showing significantly higher ($p = 0.1$) levels of sorbed on the front side compared to the backside of the tree and the September sampling showing no effect. For phenolic compounds, there was no effect of compounds sorbed on either the front side compared to back side of the trees. For indole compounds there is evidence of trends; however, the trends would indicate more indole compounds sorbed on the front side of the tree line in September and more sorbed to the back side on the August sampling. These results confirm that VFAs are more effectively removed from the air stream compared to odorous aromatic compounds. However, what is interesting is that plant material taken from 8 ft had significantly higher amounts of the odorous VFAs, phenolic, and indole compounds sorbed to compared to samples taken from either 2 or 4 ft. This may indicate that as the shelterbelt matures there effectiveness for lowering odor increases; however, more research is needed to confirm these findings.

Table 4. Concentration of odorants sorbed to willow leaves.

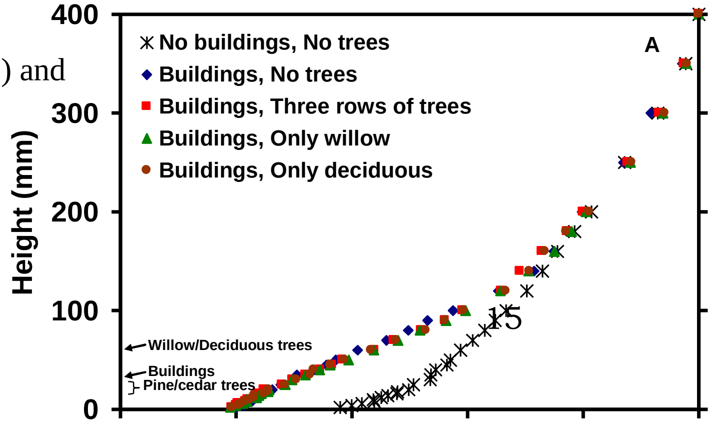
Compounds	2 ft		4 ft		8 ft	
	North	South	North	South	North	South
	μg g^{-1}					
Aug Sampling						
Acetic Acid	8.2	24.4	15.3	20.2	4.5	11.4
Total VFA[a]	10.8	26.9	16.9	23.0	5.4	20.4
Sum Odorous VFA[b]	0.4	0.9	0.5	0.4	0.4	3.9
Phenol	0.72	0.61	0.00	0.53	0.68	0.94
4-Methylphenol	0.06	0.20	0.11	0.00	0.08	0.01
Sum Odorous Phenols[c]	0.07	0.20	0.11	0.01	0.33	0.19
Sum Indoles[d]	0.01	0.03	0.00	0.02	0.68	0.03
Sept Sampling						
Acetic Acid	12.9	24.6	5.6	13.6	11.4	9.5
Total VFA	14.6	26.9	6.3	23.7	23.2	30.3
Sum Odorous VFA	0.7	0.8	0.2	1.1	4.2	5.8
Phenol	0.00	0.43	0.00	0.28	1.58	0.33
4-Methylphenol	0.02	0.00	0.05	0.07	0.14	0.30
Sum Odorous Phenols	0.02	0.01	0.09	0.08	0.18	0.34
Sum Indoles	0.01	0.01	0.00	0.01	0.00	0.19

	2 ft	4 ft	8 ft
Avg. Conc.			
Acetic Acid	17.6	13.7	9.9
Total VFA	19.8	17.5	19.8
Sum Odorous VFA	0.7	0.6	3.5
Phenol	0.44	0.20	0.88
4-Methylphenol	0.07	0.06	0.13
Sum Odorous Phenols	0.07	0.07	0.26
Sum Indoles	0.01	0.01	0.22

[a]Total VFA: Total Volatile Fatty Acids Includes Acetic Acid, Propanoic Acid, 2-Methylpropanoic acid, Butanoic acid, 3-Methylbutanoic acid, Pentanoic acid, Hexanoic acid, Heptanoic acid.; [b]Sum Odorous VFA: Includes Butanoic acid and 3-Methylbutanoic acid; [c]Sum Odorous Phenols;: Includes 4-Methylphenol, 4-Ethylphenol, 4-Propylphenol; [d]Sum Indoles; Includes indole and 3-Methylindole (skatole).

Objective 2 (Wind Tunnel Simulations)

The wind tunnel experiments demonstrated the potential impact of vegetative buffers to substantially affect wind velocity and air mixing near swine confinement buildings. Figure 12 shows wind velocity profiles (A) downwind from the buildings (i.e. south wind at field site) and (B) further downwind behind the vegetative buffer. Buildings alone had a large impact on decreasing wind velocity. The presence of trees further downwind appeared to have little effect on wind velocity between the buildings and trees (Fig. 12A). A ~50% reduction in wind velocity was observed near the ground for all and a reduction was observed upto 5-7 x's the building height (75 to 100' at field scale). Wind speed behind the tree buffer was reduced only slightly further (Fig. 12B) and only to a height of 2-4 x's the building height.



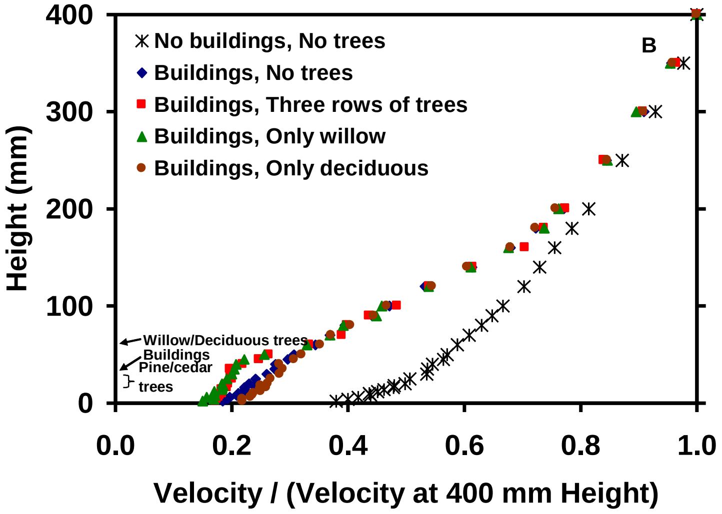


Figure 12. Wind velocity ratio profiles as affected by buildings and vegetative buffer configurations (A) at a distance of 6H (95' at field scale) downstream from the building models and (B) 6H downstream from the willow tree models. All data are for wind tunnel reference velocity of 10 m/s (22.5 mph). These experiments represent south winds at the field site with the trees downwind from the buildings with the wind perpendicular to the buildings and tree rows.

Turbulence intensity is the standard deviation of the wind velocity divided by the mean wind velocity. Higher turbulence intensities indicate disturbed flow with greater mixing and less direct horizontal transport of air and any odor or particulates entrained in the air. As for wind velocity, turbulence intensity between the buildings and the tree rows was not affected by the presence of the trees (Fig. 13A). Increased turbulence intensity was observed behind the willow and multiple row models (Fig. 13B).

In general, the effect of both buildings and trees on wind velocity and turbulence (Figs 12 and 13, respectively) was observed at heights lower than 100 feet (200 mm in our experimental scale). The impact of buildings perpendicular to air flow parameters was greater than for tree models further downwind. The combined effect of buildings plus trees consistently persisted up to a height of ~100 feet (200 mm in our experimental scale).

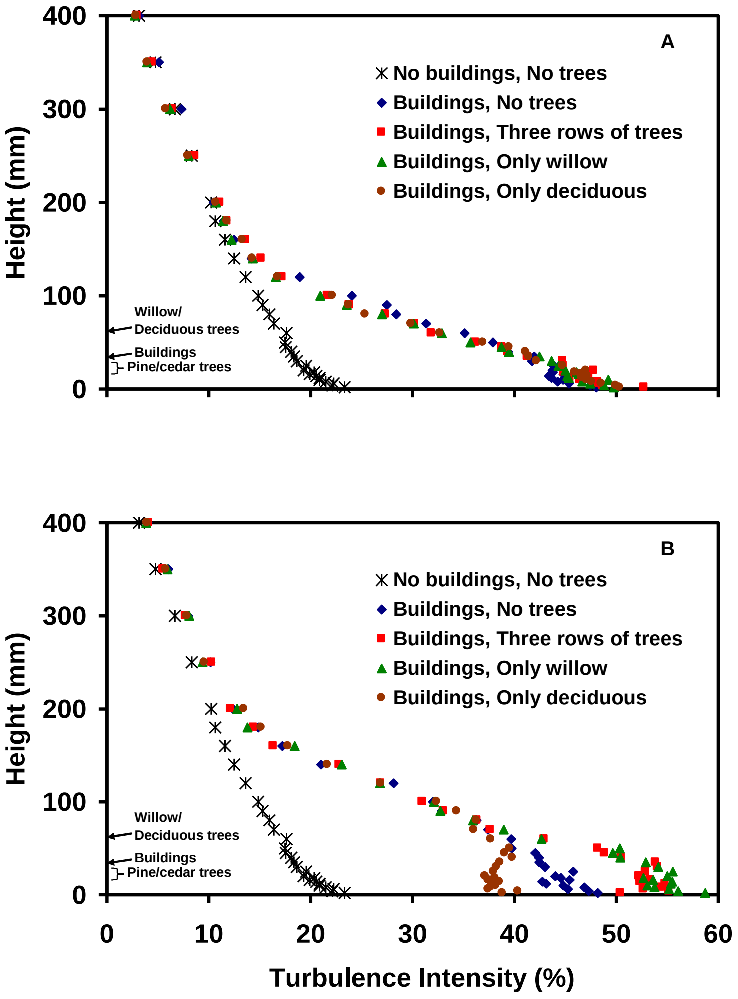


Figure 13. Turbulence intensity profiles as affected by buildings and vegetative buffer configurations (A) at a distance of 6H downstream (95' at field scale) from the building models and (B) 6H downstream from the willow tree models. All data are for wind tunnel reference velocity of 10 m/s (22.5 mph). These experiments represent south winds at the field site with the trees downwind from the buildings with the wind perpendicular to the buildings and tree rows.

Objective 3 (Economic Analysis)

This multi-scale financial analysis begins at the farm level using discounted cash-flow methods to examine the costs of establishing and managing shelterbelt systems for swine facilities in Iowa. By taking a random sample of existing hog confinements throughout Iowa (n=60), site specific shelterbelt systems were designed for each production site. Assuming each shelterbelt was designed as a retrofit system, the full costs of establishing and managing these shelterbelt systems were calculated for each facility. The effects of the cost share program EQIP were then examined. Individual farm level costs were averaged regionally and aggregated by county to estimate the total investment needed by the Iowa hog industry to utilize shelterbelt systems for air quality purposes and to get a baseline understanding of potential cost share program outlays.

Cost Results

Examining first the low cost scenarios (based on seedling prices for planting stock), producers in SE Iowa would experience the lowest average costs of $3,896 total for establishing and managing a shelterbelt system over a 20 year period. Producers in SW Iowa would face the highest costs of $4,500 per site. In terms of upfront cost only there is just a $229 difference between high and low costs ($1,671 versus $1,447). Across all of Iowa the total costs per pig produced (over 20 years) comes to $0.036 per pig. Overall, EQIP reduces total 20 year costs by 18% and upfront costs by just under 50%. Per pig costs are lowered by almost a penny per animal. As yet another way to think about costs, with the low cost situation the total costs come to about $1.40 per linear foot of shelterbelt.

As compared to the lower cost scenario, the high price scenario (based on older, more expensive planting stock) raises total costs by an average of 118% (for an Iowa wide average of $9,080 per site) and upfront costs by over 167% (to an Iowa wide average of $4,122 per site). The overall effects of EQIP are more pronounced when upfront costs are higher with the cost-share benefits reducing total costs by 54% (upfront costs are consistently reduced by just under 50%). In the high cost situation, per pig costs more than double on average to about $0.08 per pig; EQIP cuts the cost per pig roughly in half. With these higher plant costs, the shelterbelt itself comes to about $3.05 per linear foot.

It should be noted that ultimately with shelterbelts the total costs are contingent upon the initial choice of planting stock, the relative long-term health and maintenance of the system, and the choice of long term weed control (i.e. chemical or mechanical weed elimination; use of organic or synthetic mulches, etc.). With drier soils a drip irrigation system may be necessary and would add roughly $0.01/ per pig produced.

For most swine producers in Iowa, the land for the production site is not considered active cropland and land rent is therefore not a constant financial factor, however for space limited facilities (e.g. not enough room on the production site for planting trees) surrounding land area (likely cropped) may need to be rented or if owned by the producer, forgone. For analytical purposes the effects of land rent was factored in; the 2008 state average $177 per acre was used (ISU Extension, 2008). On average, factoring in annual land rent for the area under trees on each site, total 20 year costs increase by 60% for the low cost position and by 23% for the high cost position. Table 5 below displays the full range of costs per scenario for all four regions in Iowa.

Previous research has determined that the mean willingness to pay (WTP) for the use of shelterbelts among Iowa hog producers is $0.14 per pig produced annually (Tyndall, 2008). Therefore based on this cost analysis all of the calculated expenses are considerably under what Iowa producers are WTP. For the low cost scenario the costs are about $0.10/ pig under producer WTP ($0.11/pig with cost share); for the high price scenarios the costs are between $0.05 and $0.06 below producer ($0.10/pig with cost share). This result suggests that shelterbelts would be a financially feasible technology for Iowa producers to utilize to incrementally mitigate odors.

Table 5. Summary of the total shelterbelt costs at 7% (real ARR) for each region in Iowa. All costs are presented in 2008 dollars US.

Low cost scenario [1]				
Costs without cost-share	**NE**	**NW**	**SE**	**SW**
Present Value Costs w/o land rent	$4,064	$4,149	$3,896	$4,519
Present Value Costs with land rent [2]	$6,821	$6,970	$6,514	$7,593
Upfront costs (Site prep & establishment)	$1,507	$1,539	$1,442	$1,671
Total costs per pig [3] produced (20 yr period)	$0.039	$0.036	$0.035	$0.035
Costs with cost-share (EQIP) [4]				
Present Value Costs w/o land rent	$3,329	$3,399	$3,193	$3,704
Present Value Costs with land rent	$6,086	$6,220	$5,811	$6,778
Upfront costs (Site prep and establishment)	$773	$789	$739	$857
Total costs per pig 2 produced (20 yr period)	$0.033	$0.029	$0.028	$0.028
High cost scenario [1]				
Costs without cost-share	**NE**	**NW**	**SE**	**SW**
Present Value Costs w/o land rent	$8,878	$9,063	$8,522	$9,881
Present Value Costs with land rent [2]	$11,635	$11,884	$11,140	$12,955
Upfront costs (Site prep & establishment)	$4,025	$4,103	$3,889	$4,473
Total costs per pig [3] produced (20 yr period)	$0.086	$0.079	$0.076	$0.076
Costs with cost-share (EQIP) [4]				
Present Value Costs w/o land rent	$4,588	$4,681	$4,416	$5,105
Present Value Costs with land rent	$7,345	$7,502	$7,035	$8,179
Upfront costs (Site prep and establishment)	$2,032	$2,071	$1,963	$2,258
Total costs per pig 2 produced (20 yr period)	$0.045	$0.041	$0.039	$0.039

[1] Low price scenarios: 15” cuttings of Austree = $1.00/tree; 12”-18” Eastern red cedar = $ 2.50/tree, 12”-18” red osier dogwood = $1.50/shrub; High price scenarios: potted Austree = $ 7.50/tree; 18” – 24” potted Eastern Red cedar = $ 12.50/tree, 4 year old Red Osier dogwood = $3.50/ shrub.

[2] The 2008 average (Iowa) land rental rate was used at $177 per acre (ISU Extension, 2008).

[3] It was assumed that for each modeled facility there are 2.2 turns of animal stock per year.

[4] The EQIP parameters modeled were from Crawford County, Iowa (NRCS, 2007); NRCS Practice code 380, windbreak establishment for air quality (objectionable odors, particulate matter), payment equals 50% cost share on average cost.

VIII. Discussion:

The vegetative buffer evaluated produced clear results in particulate reduction but mixed results with regard to odor reduction and sorption onto plant tissue. An overall 44% reduction in particulates was measured under the experimental conditions. About 94% of the particles on the north side of the buffer had very small diameter in the range of 0.3-0.5 microns. Under the same set of conditions only 88% of the particulates on the building side of the buffer were 0.3-0.5 microns. Determining the effectiveness of the shelterbelt for removing odorants coming from the swine facility proved difficult and produced mixed results. The shelterbelt removed compounds from the air stream just not the odorous aromatic compounds as effectively as the VFAs (~50% reduction). The wind tunnel component of the study quantified the wind velocity reduction and increase in turbulent mixing downwind from the building. The presence of the trees reduced the wind velocity further and increased the mixing, which should enhance particulate trapping and odor sorption.

In order to assess the total investment required by the Iowa hog industry to utilize shelterbelts for air quality management, total state wide vegetative buffer costs have been estimated by multiplying the number of facilities (with manure management plans) within each average cost zone as defined by the four Iowa regions. These total costs are aggregated and GIS mapped on a county wide basis. Additionally, since most cost share programming is allocated on a county by county basis (e.g. EQIP is administered by Natural Resource Conservation Service county offices) this analysis give an approximation of total outlays needed by county so as to better target government expenditures.

If all producers utilized generic shelterbelt systems as defined for this study the total outlay by region is summarized in Table 6 below. The region with the highest aggregate costs is NW Iowa with a total outlay of just under $7.2 million; the region with the least required expenditures is SW Iowa with a total of about $2.4 million.

Table 6. Total expenditures needed for each region in Iowa to retrofit each swine production cite with shelterbelts.

Region	Number of operations	Total expenditures needed for shelterbelts (rounded nearest 1,000)
NE	4,063	$6,346,000
NW	3,398	$7,187,000
SE	3,896	$3,569,000
SW	3,704	$2,441,000

The top five counties in total expenditures required are:

1. Sioux County = $1,199,000
2. Hamilton County = $784,000
3. Hardin County = $744,000
4. Franklin County = $739,000
5. Lyon County = $690,000

See Figures 14 and 15 below for a map representation of the county assessment of total investment required by Iowa hog producers to utilize shelterbelt systems as defined by this analysis and the county assessment of total upfront investment required by Iowa hog producers to utilize shelterbelt systems. Again, this upfront cost being the amount that most cost-share programs would subsidize.

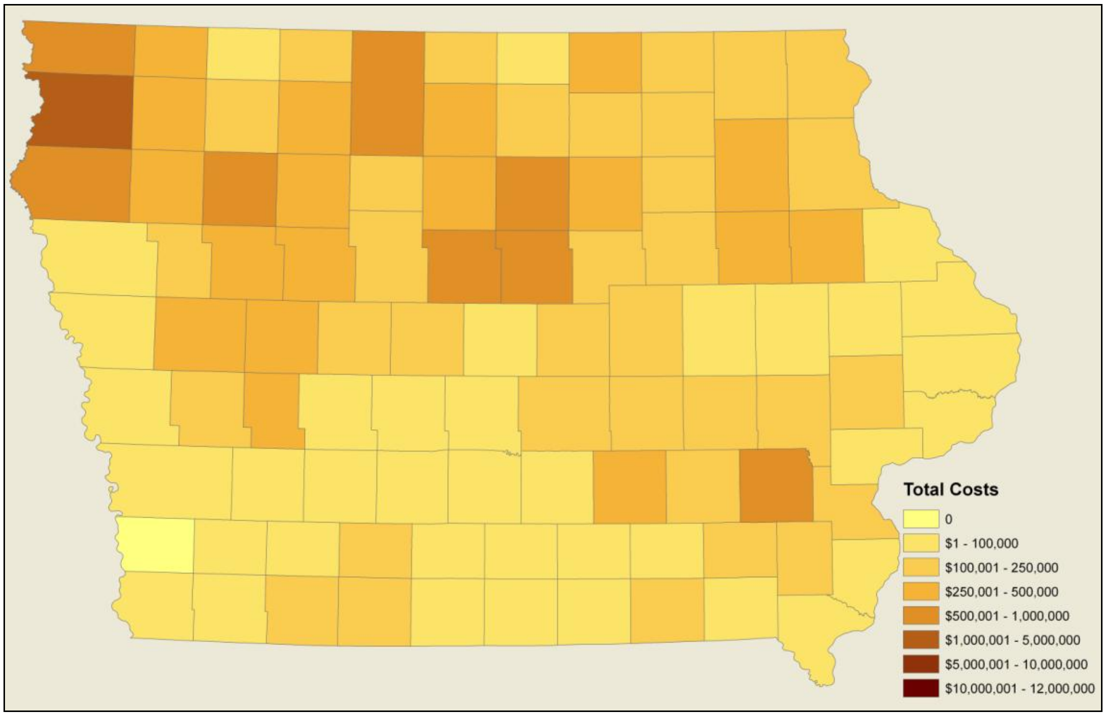


Figure 14. County assessment of total investment required by Iowa hog producers to utilize shelterbelt systems as defined by this analysis.

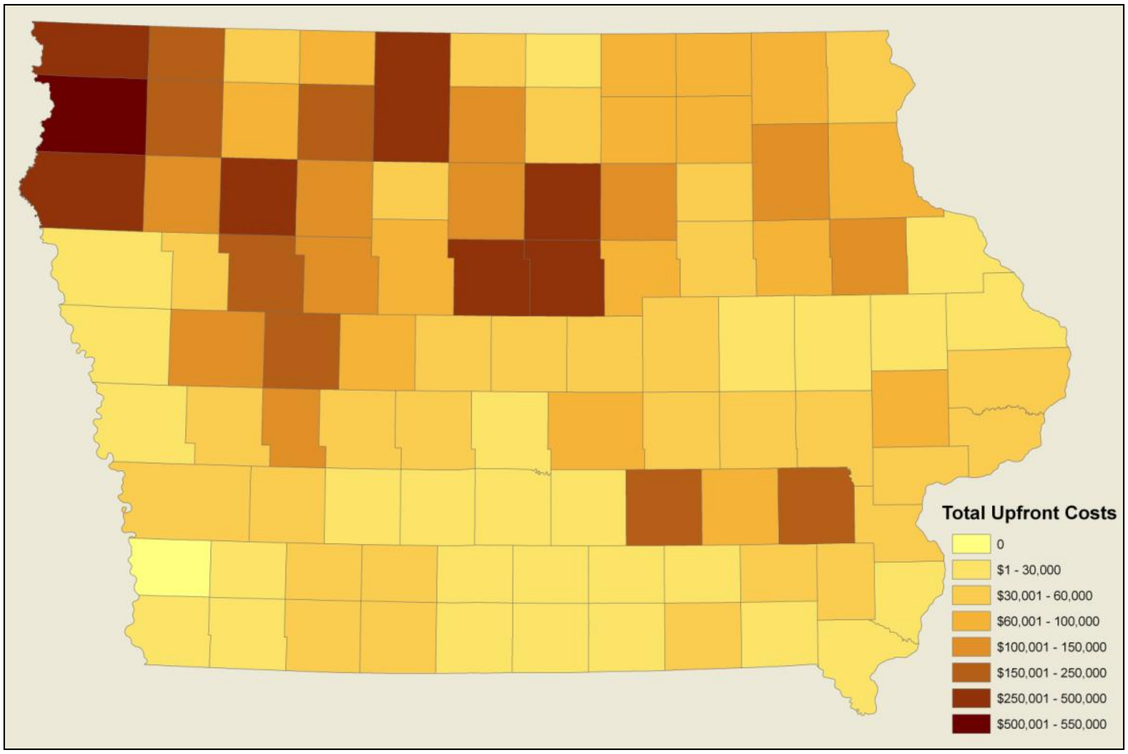


Figure 15. County assessment of total upfront investment required by Iowa hog producers to utilize shelterbelt systems as defined by this analysis. This is the amount that most cost-share programs would subsidize.

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Appendix

A Note on General Shelterbelt Maintenance Requirements

All shelterbelts need to be established in appropriately prepared planting areas (see section below on site preparation) using regionally appropriate nursery stock. All shelterbelts should have a well thought out long-term maintenance plan to ensure the overall health of the system and to keep long term costs/labor down. Another key design factor is mixing the species used. This is recommended for two main reasons: 1) increased species diversity reduces the risk of whole scale pest/pathogen loss, and 2) some species (e.g. hybrid willows and poplars) feature very rapid growth but often have relatively short healthy life spans (e.g. 15-20 years), mixing in slower growing but longer lived species will allow for a robust and mature shelterbelt system to remain after other species are removed.

There are three main hazards that must be avoided when utilizing shelterbelts yet these are all easily avoided with proper shelterbelt design and implementation. Shelterbelt designs need to prevent: 1) winter snow deposition problems by planting trees too close to access roads and buildings. In Central Iowa for example winter winds largely come from the North/Northeast. Therefore trees planted to the north and east of buildings/roads should plan for a planting distance anywhere from 50-200’ away. 2) Trees should not be planted so close to buildings that they prevent appropriate air flow into and out of the buildings. For mechanically ventilated buildings trees can be planted as close as 5-6 times the diameter of the fans and avoid causing back pressure (Ford and Riskowski, 2003), but that distance may not be healthy for the trees. A minimum distance of 40 feet away from fans has been recommended (Malone et al., 2006). For naturally ventilated systems, one does not want to impede necessary summer winds (which in Central Iowa tend to come from the South/South east) blowing into the buildings. 3) Visibility into and out of the facility grounds is important, so keep the mature heights of trees in mind when planting trees near access roads.

Appropriate site preparation is one of the main keys to the long term health of tree plantings and will contribute toward lower tree mortality, faster tree growth and ultimately, lower time, money and effort in managing the system over the life of the operation. In many cases the grounds of a livestock facility - the area where trees are to be planted – features highly compacted soils, subsurface soil piling, poor drainage, etc. Many VEBs fail (e.g. high tree mortality) because of inadequate site preparation. When planting trees directly into tilled crop ground, site preparation requirements will likely be lessened. Table 6 below outlines possible site preparation requirements prior to tree planting. It is always recommended that a producer seek advice from a forestry professional before proceeding with a VEB system.

Table 6. Generalized site prep requirements prior to tree planting for new livestock facilities:

1 year before VEB establishment (Fall: Oct-Nov):	Year 1 (Spring – late April/Early May)
– 4’ Kill strip (e.g. Round Up) – Disk/cultivate (work soil to 8” depth) – Seed cover crop (e.g. clover, rye)	– Disk/ cultivate again & if possible rototill – Soil should have no clumps & minimal residue – Grass seed may be desired (sow outside of mulch and or weed mat zones)