A biophysical and socio-economic examination of the use of shelterbelts for swine odor mitigation

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A biophysical and socio-economic examination of the use of shelterbelts for swine odor mitigation

by

John Charles Tyndall

A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

Major: Forestry (Forest Economics)

Program of Study Committee:
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2003
This is to certify that the doctoral dissertation of

John Charles Tyndall

has met the dissertation requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For Major Program
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## FINANCIAL FEASIBILITY OF USING SHELTERBELTS FOR SWINE ODOR MITIGATION

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GENERAL INTRODUCTION

"In the last two years, odors associated with animal feeding operations have become a major public policy issue in a number of states—North Carolina, Iowa, and Indiana, just to name three", Richard Rominger, Deputy Secretary of Agriculture, March 3, 1999 USDA Air Quality Task Force Minutes (USDA, 1999a).

"The odor issue goes beyond scientific data. It's an emotional issue out in the country, and it's dividing farmers, it's dividing neighbors, it's dividing families", Jim Trotter, Illinois farmer, March 3, 1999 USDA Air Quality Task Force Minutes (USDA, 1999a).

This dissertation has two primary foci: 1) the exploration of the potential for the innovative use of strategically designed configurations of trees and other vegetation to be an effective way to biophysically and socio-economically reduce swine manure odor; and 2) assess market based incentives centered upon the production and sale of pork meat differentiated by having been produced with "extra" care for agro-environmental issues such as air and water quality. The goal is to establish trees and shelterbelts as a legitimate Better Management Practice (BMP) that can help livestock producers meet current and future agricultural air quality standards. The work presented here displays compelling evidence that trees may be able to help control odor through physical and biological means and be a socio-economically preferred and financially feasible technology. Due to the structural changes within the swine industry in the US over the past 20 years, many once common and manageable externalities, such as odor and water pollution are now becoming pervasive to the point of legal nuisance. As traditional pollution control remedies have evidently had limited success in preventing this state of affairs, for the sake of economic sustainability the swine industry must take new, creative steps to avoid litigious social situations by protecting rural air and water sources and subsequently the quality of life of surrounding individuals and communities. As the work in this dissertation attests, shelterbelts can and should be part of a "suite" of odor control strategies, that collectively reduces odor to manageable and hopefully, acceptable levels. As the first manuscript suggests, the use of shelterbelts can lead to positive biophysical impacts with regards to odor mitigation. In the second manuscript, the
technological use of shelterbelts is shown to be among the most economical technologies available to pork producers and in most cases is well below revealed producer willingness to pay levels for odor control. The third manuscript demonstrates that while, from a pork producer's point of view, the use of shelterbelts may not be as straightforward as once believed, there appears to be many recognized advantages. And from the standpoint of pork consumers, the reduction of swine odor may be part of a bundle of "special" attributes that are worth a price premium for pork meat possessing these attributes. To provide some necessary context for the three manuscripts within, this introduction will briefly describe the structural changes that have occurred in the US livestock agriculture, with a special focus on the US pork industry. An introduction to the potential social and economic ramifications of swine odor is also included.

Evolution of Livestock Agriculture in the United States

The current stage in the evolution of livestock agriculture in the United States is toward increased industrialization and involves the infusion of multiple technologies, the concentration of production and processing facilities and the integration of inputs to production, processing, and marketing. This evolution is most easily identified by increases in the overall size of the facilities and in the average number of animals per farm system as well as the advanced use of animal confinement systems. These changes in size are primarily due to perceptions that large operations benefit from economies of scale, particularly in terms of expenditures for labor, feed, and facilities, which have caused producers to try to capture those potential benefits (SOTF, 1995).

The industrialization, consolidation, and concentration of animal production in the U.S. is not unique to any one single livestock group. This is and has been a trend in all the major livestock types: that is the cattle, dairy, swine and poultry industries (for the purpose of this study poultry is considered "livestock" where as much literature will separate poultry into its own category). Examples of this trend in the U.S. are numerous.

In terms of overall animal production in the U.S., the total number of animal units (AU's) increased about 4.5 million (about a 3% increase) between 1987 and 1992. An animal unit is an index that sums the number of animals, across species, based on average
live weights per species. According to U.S. Environmental Protection Agency (EPA) specifications one AU equals one beef head, 0.7 dairy cows, 2.5 hogs, 55 turkeys, and 100 chickens. However, during this same period, the number of livestock farms decreased, indicating a consolidation within the industries overall and greater production from fewer, larger production facilities (EPA, 1999).

![Number of Operations Graph](image)

Table 1. Increase in the Average Number of US Animal Units (AUs) per Operation from 1978 to 1992.

<table>
<thead>
<tr>
<th>Operation Type</th>
<th>Increase in AU's</th>
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<tbody>
<tr>
<td>Cattle</td>
<td>56 %</td>
</tr>
<tr>
<td>Dairy</td>
<td>93 %</td>
</tr>
<tr>
<td>Hog</td>
<td>134 %</td>
</tr>
<tr>
<td>Layer</td>
<td>176 %</td>
</tr>
<tr>
<td>Broiler</td>
<td>148 %</td>
</tr>
<tr>
<td>Turkey</td>
<td>129 %</td>
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*a Source US EPA, 1999
Above in Figure 1, a comparison of 1978 and 1992 shows this consolidation within the industries; likewise, Table 1 displays the increase in the average number of AU's per operation from 1987 – 1992. Through the use of confinement systems, often a large number of animals are concentrated into relatively small geographic areas. To get a brief idea of how many large-scale confinement systems there are, in the cattle industry, only 2 percent of feed operations accounted for 40 percent of all the cattle sold in 1997 (US Senate Committee on Agriculture, Nutrition, & Forestry, 1997). In 1984, 50% of beef cattle that were fattened in lots with greater than 16,000 head capacity (Eghball and Power, 1994a). In 1998, there were about 9,400 U.S. cattle and calve operations with over 1000 head, with 46% of the inventory in Nebraska, 19% in Missouri, and 12% in Iowa (USDA, 1999b). In the U.S. milk cow industry there were 7,455 operations in 1997 that had over 200 head, with 24% of the operations located in California and 9% in Texas (USDA, 1999c). The poultry industry, between 1969 and 1992, saw the number of broiler house chicken farms decrease by 35 percent while production during that same time nearly tripled (US Senate Committee on Agriculture, Nutrition, & Forestry, 1997). The number of U.S. hog operations whose inventory was over 5,000 head was 1,915 operations and accounted for 42% of the total inventory (USDA, 1998). And to look at a livestock industry generally not considered major, such as sheep, consolidation of production also occurs. In terms of breeding sheep in 1999, 39% of the total sheep inventories were on operations of between 500-4,999 head and 15% were on farms of over 5000 head, with most of the production in Texas and California (USDA, 1999d).

The U.S. Swine Industry

In the 1990’s there were such remarkable changes in the pig production process as well as geographic migration of production sites that this subject is worthy of additional examination. From the 1950’s to 1990, the industrialization of the U.S. swine industry lagged behind the industrialization of other U.S. livestock and poultry industries. For example, in the 1950’s the poultry industry made structural changes while becoming fully industrialized. The industrialization of the swine industry was thought to be following right behind, yet it took forty years for the changes to manifest (Hurt, 1994). The industrialization
of the swine industry, like all the other modern animal production industries, is linked to structural change caused in part by specialization and intensification of production. Again the increased size of a swine production facility is an integral part of the substitution of capital for labor that characterize a developing economy and occurs in varying degrees, in all parts of agriculture (Rhodes, 1995).

The evidence of swine production intensification in the U.S. is 1) that the number of hog farms in the US decreased from the high of about 1.1 million in 1965 to about 114,380 in 1998 (USEPA, 1999) and 2) that from 1991-1997 the number of US hog operations declined 8.9% annually, yet the number of hogs marketed during that period increased by 14% (Parcell and Dhuyvetter, 1997). The average hogs per farm in Iowa (the nations number one producer) were 579 in 1995, a 58% increase from the 1989 average. The average for North Carolina (the number two producer) was over 1,200, a 511% change (Benjamin, 1995).

Productivity within the swine industry has increased over the past 15 years with rapid technological advances in disease control, genetics, and management practices (Benjamin, 1995). This has led to increased pigs per litter and market weights and the rapid improvements on meat quality as well as an increase in the ratio of annual pork production per head of breeding stock (Dhuyvetter and Parcell, 1997). As a result of these productivity gains, U.S. swine producers today can produce the same amount of pork as in 1980 which was the peak year for per capita pork production, using less labor, less feed, and an inventory of 20 % fewer hogs (Benjamin, 1985).

Demand for pork products has increased as well. The pork producers and processors have responded to consumer tastes and preferences to improve meat quality, consistency and leanness, causing domestic and international demand to increase dramatically. Between 1987 and 1997, pork exports increased 700% by volume (Reifschneider, 1999). The U.S. average consumption of pork increased by 5 pounds in 1998, the only meat protein source with any significant increase in consumption (Reifschneider, 1999). The relatively high rate of return on capital invested in pork production has been noted as another factor leading to increased industrialization of the pork industry (Hurt, 1994). Indeed, swine farms who are part of the Iowa State University records program achieved > 25 % annual average rate of return on capital from 1980 to 1994 (Hurt, 1994). Interesting to note that from 1994 to 1999
the swine industry as a whole has seen its financial situation change considerably with periods of very depressed market prices, it appears to be the larger farms as a whole have largely been able to remain in business.

Another major factor influencing the changes in the swine industry is the economic importance the industry has on regional economies. In Iowa, pork production generated receipts of $3.0 billion in 1996 (Scanes, 1998). In North Carolina, pork production has overtaken tobacco and poultry to become the primary agriculture product, with gross farm income of about $1.6 billion in 1996 (SOTF, 1995). The regional importance of the swine industry is not unique to just the United States but applies to any agricultural region producing hogs. For example, an economic impact analysis for Alberta, Canada reported that as a result of production expenditures, each hog operation with 1,000 sow equivalents are estimated to contribute between $3.5 and $3.8 million annually to the local economy, and an additional $100,000 to $500,000 regionally (Alberta AFRD, 1998).

Though this evidence about contributions to regional economics is compelling, there is growing dissent regarding the total socio-economic and environmental benefits to local and regional communities stemming from large-scale animal production (Thu, 1998). Recent reports regarding the rural Midwest clearly suggests that odor emitted from concentrated livestock production facilities is a significant social problem that negatively impacts rural and state economies, human health, and the quality of rural life (Thu et al., 1998; Wing and Wolf, 2000). Livestock odors are ubiquitous in rural communities, but four factors are causing an increase in odor nuisance and a need for new marketing and management strategies. First, large-scale livestock confinement production has led to increased concentrations of manure. Second, urban/suburban expansion into the agricultural landscape has put many more people with limited agricultural experience into closer proximity to livestock production. Third, the current livestock odor problem is characterized by high concentrations of odorous emissions that travel across highly modified landscapes relatively devoid of any significant natural barriers that can impede, alter, absorb, or dissipate the odor plumes prior to contact with people (e.g. Iowa has about 93% of its natural landscape converted to fairly homogeneous agricultural uses). And fourth, market economics and regulatory policy of livestock production create limited producer incentives to control externalities (i.e. water and air
pollution) beyond minimum regulatory requirements; to do more may put producers at a financially competitive disadvantage.

Livestock production, communities, and the environment in which people live, work and play are at risk if effective solutions are not forthcoming. There is persuasive evidence that consumers would be willing to pay premiums for meat products produced in “environmentally friendly” ways (Kliebenstein and Hurley, 1999, Hudson, 1998) as well as a public interest in what are perceived to be more “natural” (i.e. biological vs. chemical/mechanical) ways of dealing specifically with air pollution (Kliebenstein and Hurley, 2000). This evidence suggests a public understanding of both consumer responsibility (consumers being integral variables in both the cause and solution to livestock pollution) and the need for socio-environmental changes. Livestock producers, however, have not yet benefited from this potential added income. Also, due to the market structure whereby live animal production is separated from processing to meat and final consumption, many livestock producers cannot benefit from a final product price premium without some kind of prior agreement. Subsequently consumers willing to act responsibility may simply be left with environmentally friendly values and preferences that are empty of effect. While there are engineered odor-control strategies that are physically effective in attenuating odor, they tend to be rarely used because of high cost concerns by livestock producers (and/or society). Still, the current approach to solving livestock odor problems typically involves strictly engineering based strategies, introduced in a “top-down” manner by “experts” to users. These strategies often come with high producer costs and with little regard for societal preferences or any concern in a broad sense between a large “community of producers and consumers” and “quality of life”. Whereas there has been research that considers the costs of livestock odor damages and odor control (i.e. Palmquist et al, 1997 and Lorimor, 1999), to our knowledge, the socio-economic benefits and to whom they accrue because of livestock odor reductions or protection from, have not been fully identified or quantified. Knowledge of such benefits is information that can be the catalyst for social and individual change.
Swine Odor Nuisance

Odor is a serious nuisance problem. It has been noted by odor researchers that perceptions of odor differ from individual to individual and are characterized by personal preferences, opinions, experiences, and variability in our olfactory systems (Williams, 1996). There are also specific conditions that can govern our perceptions of livestock odor (Williams, 1996; SOTF, 1995):

- **Control** – People often are better able to cope with objectionable odor if it is believed that they have some control over the situation.

- **Understanding** – In many cases, people can tolerate a problem better if they understand its source. Being accustomed to the odor-causing situation.

- **Context** – People react as much to the context of an odor as they do the odor itself. Preferences, imagination, cultural associations, and visual images often all play a role in odor perception, i.e. if someone perceives swine to be filthy animals, that person would be more likely to find swine odors quite objectionable.

The trend in U.S. livestock industry has affected all of these conditions as production has expanded from the typical mid-western swine/animal belt states to areas west and the southeast, often where environmental laws are more lax. This brings livestock production into contact with people who are less experienced with and often less understanding of farming. Urban expansion has caused co-mingling of rural and urban communities, putting homes in closer proximity to livestock producers. For example, a 1998 survey of Iowa farmers conducted by Iowa State University found that 46% of the 2,312 survey respondents live \( \frac{1}{2} \) mile or less from a livestock facility (see Figure 2) (Lasley, 1998). This finding is consistent with average separation distances nationwide. Table 4 lists the average separation distances of U.S. pork producers by operation size, showing that the majority of sizable hog odor sources are less than one-half mile from the nearest occupied home (USDA, 1996). As discussed in detail later, under certain weather conditions, odor can travel much further than one half mile (NPPC, 1995).
All of these factors (changes in geographic location, urban expansion, limited separation distances) have caused the issue of odor control to become of paramount concern for the public and for livestock producers.

![Pie chart showing distance from residence to closest neighbor's livestock facility.](image)

**Figure 2.** Distance from annual survey respondent’s residence to closest neighbor’s livestock facility. Source, Lasley, 1998

**Table 2.** Average separation distances of U.S. hog manure storage facilities and manure lagoons from the nearest occupied house. a

<table>
<thead>
<tr>
<th>Capacity of Hog Facilities</th>
<th>500-999 (# Head)</th>
<th>1,000-2,499 (# Head)</th>
<th>+2,500 (# Head)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Facility to Nearest Occupied House (ft)</td>
<td>755</td>
<td>770</td>
<td>1,200</td>
</tr>
<tr>
<td>Manure Lagoon to Nearest Occupied House (ft)</td>
<td>1,386</td>
<td>1,344</td>
<td>3,191</td>
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*a Source USDA, 1996

**Social and Economic Ramifications of Swine Odor**

There are serious social ramifications involved with the issue of livestock odor and odor management. Much research supports the concern that livestock generated dust and
gas concentrations can affect human and animal mental and physical health (Schiffman et al., 1998). Also, there is increased concern that bio-aerosols and airborne endotoxins within the odor plume could cause humans and animals health problems (Homes, 1995). Research points to decreased real estate values (Hudson, 1998; Colindres, 1998; Palmquist, 1997) and negative effects on recreation and tourism (Okun, 1997; Hatfield, 1997). Neighbors and communities are being strained by the livestock odor issue (Chapin, 1998; Thu, 1998; Thu, 1997; Person et al., 1995). Legal and civil rights battles have been cited in the national media including a Pulitzer Prize winning news article from the News & Observer, Raleigh, NC and a “60 Minutes” piece about large-scale hog farms and African-American communities (Thu, 1998; News & Observer, 1995).

Legal Considerations and Livestock Odor

To date, odor and air quality issues involving industrialized animal production in the U.S. have received relatively little regulatory attention. Unlike many European livestock producing countries, there are no U.S. federal laws and that regulate livestock odor directly (Chapin et al., 1998a; Hamilton, 1992), some countries with strict livestock odor control laws include Great Britain, the Netherlands, Germany, Denmark, Sweden, and Greece. There are also very few state laws regulating odor directly, for example, Minnesota has a hydrogen sulfide reduction program which is currently the most extensive livestock air pollution program in the United States (Chapin et al., 1998a). Oklahoma signed Senate Bill 1175 in June of 1998, which includes a provision requiring an Odor Abatement Plan (OAP) for new and expanding swine facilities. The OAP must include preventative, site-specific methods for reducing odor from: 1) animal maintenance sources, 2) waste storage, 3) land application, and 4) carcass disposal (Chapin et al., 1998b). However, there are no provisions regarding success of abatement and/or monitoring. Also, Colorado just recently declared that owners of factory hog farms would have to cover waste lagoons and control odors emanating from their operations under rules adopted by the Colorado Air Quality Control Commission (Eddy, 1999).

Most other state regulation involving odor is ancillary to other concerns such as water quality issues. For example, odor controls typically include enforced separation distances
from occupied dwellings, wells, and surface water, although such regulation occurs mostly to protect surface and belowground water quality (Heber, undated). Federal interpretation of odor issues can be summed up in the EPA administrators’ office stating that odors are a local problem amenable to local controls rather than a national problem requiring national controls (Sweeten and Levi, 1996). In short, the U.S. EPA also offers no odor control assistance. This statement may be the result of the assumption that almost all malodorous substances are thought to be non-toxic, organic or highly reactive inorganic compounds, that do not cause physical damage or pollute anything (at least in a legal sense) (Sweeten and Levi, 1996).

Until recently, there was not much information regarding any chronic or acute medical conditions caused by repeated or prolonged exposure to odor concentrations. This topic is being studied to a higher degree now (Schiffman et al., 1998; Donham, 1998; Cunnick, 1995; Donham, 1990) and it may play a more significant role in future odor control regulation. This lack of regulation in the U.S. has forced neighbors of animal production facilities to resort to traditional common-law nuisance suits instead of depending upon agency intervention (Chapin, 1998; Hamilton, 1992). State “right-to-farm” laws typically have extended animal producers some protection against nuisance suits, however, recent changes in some states have left many producers vulnerable to litigation and indeed some odor related lawsuits have recently gone to trial (Chapin, 1998; Gault, 1998; News and Observer, 1995). A 1999 Animal Confinement Policy Task Force survey, of the 35 participating states, 17 indicated that currently there was active court action involving confined livestock operations, much of it odor related (Edelman, 1999).

The high costs that are often associated with defending nuisance suits, even when successful, make them a very serious issue to all livestock producers in the U.S. and worldwide (Hamilton, 1992). The cost and risk of litigation are, perhaps, the major reasons why all 50 states have created right-to-farm laws protecting, to an extent, the rights of food producers to produce the nation’s most important commodity without fear of litigation over common farm externalities (Hamilton, 1992). These laws are designed to protect existing agricultural operations by giving farms that meet state (and Federal) mandated legal requirements a defense against nuisance suits (Chapin et al., 1998a; Hamilton, 1992). North Carolina's right-to-farm law is typical. It declares that an agricultural operation, which has
existed for a year without being a nuisance, is presumed not to be a nuisance even when new neighbors move adjacent to it. This applies to any rural neighbors as well as urban and suburban expansion (Nolo Press, undated).

Several states list specific annoyances that are not considered a legal nuisance to neighbors. The lists include odor, noise, dust and the use of pesticides, the very conditions that, without the right-to-farm laws, could lead to a lawsuit by a neighbor. Right-to-farm laws do not give farmers complete freedom to manage their operations with disregard. Farmers must operate in a legal and reasonable manner to be eligible for the law's protection. Some states, New York and Florida for example, do not allow a protected farming operation to undergo a large increase in size (Hamilton, 1992). Many right-to-farm laws do not allow farmers to substantially change their operations, if they are to remain protected under the law. Also no right-to-farm laws protect operations that do not follow normal waste management procedures and regulations or who deliberately annoys neighbors (Nolo Press, undated).

Of considerable importance to this issue the Iowa Supreme Court made a decision on September 23, 1998 that effectively struck down the Iowa right-to-farm law, Iowa Code, Chapter 352.11. (Borman v. Board of Supervisors, No. 192/96-2276, Iowa, September 23, 1998). The court unanimously ruled that the nuisance protection such as odor from livestock production, offered to Iowa farms operating in designated agricultural areas, amounted to an easement and was flagrantly unconstitutional (Lucht, 1998). The Justices concluded that “the challenged statutory scheme amounts to a commandeering of valuable property rights without compensating the owners, and sacrificing those rights for the economic advantages of a few...(and) is plainly we think flagrantly unconstitutional.” (NRDC, 1998).

When the United States Supreme Court refused to rehear the Iowa case and let the ruling stand, it opened up the possibility for national ramifications, putting into question all the 50 states right-to-farm laws. In Iowa, opinions relating to the court decision are varied. The Iowa Center for Rural Affairs (1998) hoped the decision will “open up the door for debate on policies relating to pork production in Iowa and other states and allow the state to promote responsible pork production on independent, family farms”. The Iowa Pork Producers Association, however, was very much concerned that the ruling would open the door to removing other nuisance protection clauses and damage the attractiveness of
investing in agriculture (Lucht, 1998). The Iowa Farm Bureau considered the ruling a serious threat to livestock production across the country. However, the words of a Springville, Iowa family farmer may be the most salient: "(Animals) smell. Where are we going to raise them?" (Cedar Rapids Gazette, 1999).

Livestock Odor and Odor Control

Regardless of how odors may cause air and water pollution and perhaps human and animal health problem, odors need to be dealt with by livestock producers. Lasley (1998) in an annual survey of Iowa farmers indicated that 85% of the surveyed farmers (n = 2,312) believed that people who live in the country must accept the presence of livestock. While most (71%) of Iowa farmers also feel that most livestock producers are doing a reasonable job in controlling negative externalities (i.e. odor and noise), 63 percent agreed that the frequency of livestock odor is increasing in Iowa. Lasley also reported that while 83 percent of the farmer respondents indicated that they were not opposed to neighbors raising livestock just as long as it did not affect their quality of life. Nearly one-fourth of the respondents, however, perceive that neighboring livestock production is diminishing their quality of life. Odors from livestock and poultry production and manure storage and land application were listed as the major detractors to their quality of life (Lasley, 1998).

Many odor control management technologies are available. They generally fall into one of three strategic categories: the first deals with the prevention of odor and involves technologies such as manure and feed additives; the second technology attempts to capture and destroy odors before they are released into the atmosphere and involve techniques such as chemical scrubbers and biofilters; and the third technique uses innovations that attempt to disperse and/or dilute odors before they can accumulate and become a nuisance and involve manipulating air movement using barriers made of living trees and shrubs (Schmidt and Jacobson, 1995). It is this last strategy that is the particular focus of research within this dissertation.
Dissertation Organization

This dissertation reports the candidate's original work on the bio-efficacy and socio-economic feasibility of the use of shelterbelts to mitigate swine and other livestock odor. This dissertation follows Iowa State University's alternate format and features three manuscripts. Each manuscript was written by the author in a format suitable for publication in refereed academic journals. The first manuscript is titled "Mitigating Swine Odor with Strategically Designed Shelterbelt Systems: A Review" and will be submitted to Agroforestry Systems. The second manuscript is titled "The Financial Feasibility of Using Shelterbelts for Swine Odor Mitigation" and will be submitted to the Journal of Soil and Water Conservation. The final manuscript is titled "Environmental Responsibility, Consumer Values and the Use of Trees to Mitigation Swine Odor: A Focus Group Exploration" and will be submitted to Agriculture and Human Values. These three manuscripts are preceded by a general introduction and literature review and are followed by a general conclusion section.

Objectives

This study was conducted in order to provide a strong foundational point for continued research into the biological and socio-economic feasibility of using shelterbelts as part of a managed system of odor mitigative strategies, a topic of which until now has never been analyzed and released to the academic community and to the public at large. The specific objectives of this study were:

1) To analyze all the available direct, indirect, and anecdotal evidence supporting the use of shelterbelts as a bio-physically and psycho-socially effective swine odor mitigation technology.

2) To examine farm level financial feasibility of several unique, farm specific odor mitigative shelterbelt systems. Feasibility being determined within the context of revealed pork producer willingness to pay for odor mitigation above and beyond standard manure management expenses.

3) To explore by way of focused discussions the attitudes and opinions of both pork producers and consumers of pork products regarding the potential of market based incentives that might encourage the more widespread use of shelterbelts as an odor
mitigation strategy. The market based incentives largely being based on consumer willingness to pay for pork products that ultimately were produced with special care for the environment (specifically air quality and swine odor).
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MITIGATING SWINE ODOR WITH STRATEGICALLY DESIGNED
SHELTERBELT SYSTEMS: A REVIEW

A paper to be submitted to the Journal of Environmental Quality

John Tyndall and Joe Colletti

Abstract

A potential incremental approach to dealing with livestock odor is the use of shelterbelts (trees and shrubs) arranged in strategic designs near and within swine facilities which can play a significant role in bio-physically mitigating odor in a socio-economically responsible way thereby reducing social conflict from odor nuisance.

There is compelling evidence that shelterbelts can ameliorate livestock odor by directly impacting the main biophysical characteristics and the socio-psychological perceptions of livestock odor. Because the odor source is near the ground and the tendency of the plume is to travel along the ground, shelterbelts of even modest heights (i.e. 20-30 ft) may be ideal for plume interception, disruption, and dilution. Shelterbelts can be adapted to fit the production situation and expected/experienced odor plumes. Depending on the shelterbelt design and tree/shrub species used, it can deal with the temporal changes to provide long term, year round plume interception, with increasing effectiveness over time. More is also becoming known about how landscape aesthetics affect how people might perceive livestock odor, suggesting that landscape elements such as shelterbelts can lead to improvements and perhaps more positive interpretations of livestock odor and the farm systems that create them.

Based on evidence available in research literature, there are five primary ways that shelterbelts can mitigate livestock odors: 1) Physical interception and capture of dust and other aerosols by trees and shrubs; 2) Dilution of gas concentrations of odor into the lower atmosphere; 3) Deposition of dust and other aerosol from reduced wind speeds; 4) Acting as a biological sink for the chemical constituents of odor after interception; and 5) Enhancing the aesthetics of pork production sites and rural landscapes.
It should be emphasized that shelterbelts are amenable to use with the three main sources of livestock odor: animal buildings, manure storage systems, and agricultural land that has manure applied. Most other odor mitigation technology is very often source specific and not adaptable throughout the farm. Shelterbelts can be used throughout the entire farm and agricultural landscapes. It is a technology that is not limited to producer use only. In fact, properly designed shelterbelts, may be the only odor technological approach that can be effectively used by the public, as well as producers. Further, as opposed to other odor mitigating technologies that typically depreciate over time, shelterbelts may be the only odor control technology that theoretically increases in effectiveness over time. As with other “tree” based technologies used in agriculture, their effectiveness comes from providing ecological infrastructure within an otherwise ecologically simplified system. As the trees grow larger, and more morphologically complex their ability to mitigate odors can become increasingly efficient.

Introduction

The Natural Resource Conservation Service (formerly the Soil Conservation Service) defines air quality as a measure of the concentration of particulates and gasses relative to an accepted standard that limits the use of the air for a designated purpose at a specific location (Vining and Allen, 1993). Unfortunately for many people living, working, playing, or passing through parts of rural America, the quality of the air is below accepted standards. Recent reports clearly indicate that odor emitted from concentrated livestock production facilities in the Midwest, particularly pork production, is a significant social problem that negatively impacts rural and state economies, human health, and the quality of rural life (Wing and Wolf, 2000; Thu and Durrenberger, 1998). Whereas livestock derived odors are ubiquitous with animal agriculture, five factors are thought to cause an increase in odor nuisance and a need for additional technological and management strategies. First, large-scale livestock confinement production has led to increased concentrations of manure. Second, urban/suburban expansion into the agricultural landscape has put many more people with limited agricultural experience into closer proximity to livestock production. Third, the current livestock odor problem is characterized by high concentrations of odorous emissions.
that travel across highly modified landscapes relatively devoid of any significant natural barriers that can impede, alter, absorb, or dissipate the odor plumes prior to contact with people (e.g. Iowa has about 93% of its natural landscape converted to fairly homogeneous agricultural uses). Fourth, market economics and regulatory policy of livestock production create limited producer incentives to control water and air pollution beyond minimum regulatory requirements; to do more may put producers at a financial disadvantage. And fifth, the traditional technology diffusion process used in livestock production may not be suited because of the varied stakeholders in livestock odor nuisance issues. Livestock production, communities, and the environment in which people live, work and play are at risk, if creative and effective solutions are not forthcoming.

A potential incremental approach to dealing with livestock odor is the use of shelterbelts (trees and shrubs) arranged in strategic designs near and within swine facilities can play a significant role in bio-physically mitigating odor in a socio-economically responsible way thereby reducing social conflict from odor nuisance (MWPS, 2002; Tyndall and Colletti, 2000; Tyndall and Colletti, 2001). This review will focus only on swine odor mitigation, as swine production has historically been associated with the most frequent odor nuisance complaints (Hardwick, 1985).

**Shelterbelts and Swine Odor**

**Shelterbelts Defined**

Shelterbelts are vegetation systems that typically use trees and shrubs to redirect wind and reduce wind speeds, thereby modifying environmental conditions within the upwind and downwind sheltered zones. The effects from a shelterbelt depend on several physical and management characteristics. The internal and external structures of a shelterbelt are very important.

In terms of the internal structure, porosity (also often referred to as density) is the most commonly used descriptor. It is a simple ratio of perforated area to total area (Heisler and DeWalle, 1988). Shelterbelts with a porosity/density of 40 to 60% provide the greatest reduction in wind speed over the greatest distance (Brandle and Finch, 1991). External
structure can be described as the height, width, and number of rows, species composition, length, orientation, continuity, and overall design of plantings or natural configurations. Management characteristics can include: the goals of the shelterbelt; species selection, planting technique and planting design; manipulation of porosity; and maintenance (Brandie, 1999).

The wind dynamics involved with a shelterbelt are that when wind approaches a row of trees, some of it will pass through, some will pass around it, with the remaining wind being lifted up and over the vegetation. The lifting aspect will begin at some distance on the windward side, typically a distance equal to 2 to 5 times the height (referred to as 2 -5 H) of the shelterbelt. Measured reductions in wind speed to the lee (downwind) of a shelterbelt have been varied, with some being recorded as far as 50H of the shelterbelt (Heisler and DeWalle, 1988). Wind speed reductions to about 30H are more typical. Reductions in wind speed and changes in the turbulent transfer between stratified air layers, can produce beneficial microclimate changes. These beneficial changes include (Cleugh, 1998): solar radiation transfers (the amount of energy per unit surface area per unit time), improved temperature conditions, more efficient moisture relations, and increased CO₂ fluxes. The magnitude of wind dynamic and microclimate changes will vary within and between shelterbelt systems depending upon the internal, external, and managerial characteristics of the system (Brandie, 1999).

**Constituents of Swine Odor**

To have a better understanding of the shelterbelt – livestock odor dynamic, an examination of the physico-chemical characteristics of livestock odor is a good place to start. When discussing odor, the distinction should be made between odors and gases. The term "odor" actually refers to the complex combination of gases, vapors, and dust that result from both the feed method, animal living arrangements and the anaerobic decomposition of manure (Chapin et al, 1998, NPPC, 1995). Anaerobic decomposition of animal manure involves a complex series of digestive reactions by diverse populations of bacteria that metabolize the nutrients contained within the manure and subsequently converts these chemicals to various odorous compounds (Williams, 1996). Researchers have identified
upwards of 330 specific odorous components in animal manure odor that are end products and intermediates of the anaerobic decomposition process (Schiffman et al. 2001; Zahn et al. 1997). In the United States, more than 75 percent of the swine production systems process waste anaerobically (Zahn et al., 1997). The familiar manure odor is a product of a complex interaction and intermingling of individual odorous and non-odorous components (Bottcher, 2001b, Melvin, 1996). Gases refer solely to the specific gaseous compounds that are produced and emitted from a source, primarily ammonia (NH₃), hydrogen sulfide (H₂S), methane (CH₄), and carbon dioxide (CO₂). Some gasses particularly highly volatile compounds like ammonia and methane have potentially chronic effects as gas effects and seem involved with long-term environmental degradation rather than short-term odor nuisance (Jacobson, 1997). Collectively, the chemicals that make up swine odor are referred to as volatile organic compounds (VOC's). It is clear that aerosols generated in animal facilities (such as animal houses and manure storage) and from land application of manure are intense and detectable at appreciable distances (Hammond et al., 1981). An aerosol is a suspension of solid or liquid particles in a gas with particle size ranging from 0.002µm to more than 100µm, this includes such things as dust, clouds, fumes, mist, fog, smog, smoke and sprays (Hinds, 1999). The majority of odorous chemicals and compounds are easily absorbed onto and carried by particulates (Hammond and Smith, 1981). Themilius (1997), Laird (1997), and Hammond and Smith (1981) all conclude that by removing and/or controlling these particulates, animal houses, lagoons, and feedlots may become relatively odorless.

Researchers have identified the important dust-borne odorants in swine confinement facilities as being various long chain fatty acids, phenols, and carbonyl compounds (Hammond and Smith, 1981; Hammond et al., 1979). Hartung (1986) discovered that 1.0 m³ of the exhaust air from a 500 head pig fattening unit can contain dust borne 6.27 µg volatile fatty acids and 2.76 µg phenolic/indolic compounds. Eby and Willson (1969) report that most of the odor from poultry houses can be eliminated by removal of air borne dust. Hartung (1986) concluded that filtering the dust from exhaust air could reduce odor emission from animal houses up to 65%.
Shelterbelt and Swine Odor Interactions: Odor Mitigation

Many odor control management technologies are available. They generally fall into one of three strategic categories: the first deals with the prevention of odor and involves technologies such as manure and feed additives; the second technology attempts to capture and destroy odors before they are released into the atmosphere and involve techniques such as chemical scrubbers and biofilters; and the third technique uses innovations that attempt to disperse and/or dilute odors before they can accumulate and become a nuisance and involve manipulating air movement using obstructions made of both constructed materials and living barriers of trees and shrubs (Schmidt and Jacobson, 1995).

The potential of shelterbelts to mitigate livestock odor arises from the tree/shrub impacts on the central characteristics and physical behavior of livestock odor. These characteristics (Jacobson et al., 2001; Guo et al., 2001; Smith, 1993; Hammond et al., 1981; Takle, 1983) are:

- The livestock odor source is at or very near ground level;
- There is limited odor plume rise, due to common weather conditions (i.e. temperature inversions) and limited mechanical turbulence;
- An odor plume has spatial and temporal variability;
- A plume may be very extensive covering a large land area;
- There is often a close proximity of people to odor sources;
- The majority of odors generated in animal facilities that are intense and detectable at appreciable distances travel as aerosols (particulates);
- There appears to be a major socio-psychological component to the perception of odor being a nuisance.

There is compelling evidence that shelterbelts can ameliorate livestock odor by affecting these characteristics and softening the overall impact that livestock odor has on people and the environment. Because the odor source is near the ground and the tendency of the plume is to travel along the ground (Takle, 1983), shelterbelts of even modest heights (i.e. 20-30 ft) may be ideal for plume interception, disruption, and dilution (Bottcher, 2001,
Heisler and DeWalle, 1988; Laird, 1997; Themelius, 1997). Shelterbelts can be adapted to fit the production situation and expected/experienced odor plumes. Depending on the shelterbelt design and tree/shrub species used, it can deal with the temporal changes to provide long term, year round plume interception, with increasing effectiveness over time. More is also becoming known about how landscape aesthetics affect how people might perceive livestock odor, suggesting that landscape elements such as shelterbelts can lead to improvements and perhaps more positive interpretations of livestock odor and the farm systems that create them (Mikesell et al., undated; Kreis, 1978).

Based on evidence available in research literature, there are five primary ways that shelterbelts can mitigate livestock odors by:

- Physical interception and capture of dust and other aerosols by trees and shrubs
- Dilution of gas concentrations of odor into the lower atmosphere
- Deposition of dust and other aerosol from reduced wind speeds
- Acting as a biological sink for the chemical constituents of odor after interception
- Enhancing the aesthetics of pork production sites and rural landscapes.

It should be emphasized that shelterbelts are amenable to use with the three main sources of livestock odor: animal buildings, manure storage systems, and agricultural land that has manure applied. Most other odor mitigation technology is very often source specific and not adaptable throughout the farm. Shelterbelts can be used throughout the entire farm and agricultural landscapes. It is a technology that is not limited to producer use only. In fact, properly designed shelterbelts, may be the only odor technological approach that can be effectively used by the public, as well as producers.

Several sources (Koelsch, 1999; WED, 1999; NPPC, 1999; Lorimer, 1998; OCTF, 1998; Jacobson et al., 1998) list shelterbelts as odor control devices, but provide little physical, biological, or economic quantification as to effectiveness. Gassman (1995) concluded in a review of available literature regarding odor modeling that shelterbelt and other vegetation impacts on odor movement and abatement should be a research priority.
Physical interception of dust and other aerosols

Swine confinement buildings are generally ventilated in one of two primary ways: ventilation by way of natural, open-air methods and by way of mechanical ventilation, or a combination of the two. Regardless of the ventilation process utilized, it is this ventilated air that contains significant quantities of dust particles and odorous gases. This air is in most cases exhausted without prior treatment. Once outside the confinement, depending on the current climatic conditions, the can travel significant distances.

Vegetation can and does filter airstreams of particulates. As air moves across vegetative surfaces, leaves and other aerial plant surfaces remove some of the dust, gas, and microbial burden normally carried by the wind. It is also generally accepted that trees and other woody vegetation (i.e. shrubs) are among the most efficient natural filtering structures in a landscape in part due to the very large total surface area of leafy plants, often exceeding the surface area of the soil containing those plants by as much as 200-fold (Schultze, 1982).

Direct filtering occurs when particles are removed from air streams due to interception by and deposition onto plant surfaces. Much of the particulate load can be directly impacted onto plant surfaces as eddy currents that form in turbulent airflows reduce the resistance of the boundary layer of these surfaces. Eddy currents occur when laminar airflow is disrupted by aerodynamically rough surfaces such as leaves and branches (Beckett et al., 2000a; Beckett et al., 2000b; Beckett et al., 1998). And once impacted, it takes very high winds for particles to become re-suspended (Ould-Dada and Baghini, 2001; Beckett et al., 1998). Interception and impaction by tree laminar surfaces typically involves particulates with diameters between 0.1 and 10 μm (the so called PM10 range) (Beckett et al., 2000b). For particles of dimensions 1- 5 μm, interception by fine hairs on leaf surfaces and non-laminar surfaces (stems, petioles, bark) may be the most important retentive mechanism (Smith, 1984). This is important as Stroik and Heber (1986) revealed in a study of aerial dust in commercial swine finishing houses, that 93.3 % of the particles sampled were 5.2 microns and smaller. Also, particles from swine facilities are often irregular in shape generally classified as flakes, fibers, spheres or cubes (Dawson, 1990), and as noted by Freer-Smith et al. (1997) such shapes are advantageous for retention onto leaf surfaces. Quantification of this process, however, has been limited.
Recent wind tunnel experiments and field studies have quantified the capture efficiency (ratio of particulates hitting and being retained by tree surfaces to the amount of particulates in the air stream) of several differing tree species as well as total particulate loads (Beckett et al., 2000a). Beckett et al. (2000b) exposed five different tree species - Pine (*Pinus nigra* var. *maritime*), Cypress (*X Cupressocyparis leyandii*), Maple (*Acer campestre*), Whitebeem (*Sorbus intermedia*), and Poplar (*Populus deltoids X tricocarpa*) - to 1 μm diameter droplets of NaCl over a range of air speeds within a wind tunnel. They found that particle trapping efficiency of *Pinus* was about 93%, 96%, and 98% greater than that of *Sorbus*, *Populus*, and *Acer*, respectively. *Cypress* had particle trapping efficiencies of about 83%, 90%, and 95% greater than that of *Sorbus*, *Populus*, and *Acer* respectively. *Sorbus* had particle trapping efficiencies 71% and 43% greater than *Populus* and *Acer* respectively. Such results seem to confirm greater capture efficiency for species with more complex shoot structures, with smaller (conifer needles) or hairier leaves (e.g. *Sorbus*). Efficiencies also increased with wind speed (maximum efficiency was recorded at wind speeds of 10 m s⁻¹) though it is not known at which wind speeds capture efficiency eventually drops off (Beckett et al. 2000b). In a parallel study, Beckett et al. (2000c) examined the actual accumulations (weight) of particles (PM10, PM2.5, and soluble ions – coarse, fine, and ultra fine grain particles) within the same tree species as above in urban settings in the UK. They found that all five tree species captured the three size ranges of particulates with similar efficiency at both urban sites studied (one a small urban park, the other a agricultural research site on the campus of the University of Sussex). That is the same pattern of particulate capture can be seen for each size range at each site. And just as with the wind tunnel simulations, Corsican pine (*Pinus nigra* var. *maritime*) was by far the most efficient particulate filter with Cypress (*X Cupressocyparis leyandii*) ranked second. Among the broadleaf species observed, the Whitebeem (*Sorbus intermedia*) accumulated a significant amount of the coarse fraction particulates, which may be explained by this species rough and hairy abaxial (lower) leaf surfaces (Beckett et al., 2000c). In contrast, poplar (*Populous deltoids X tricocarpa*), with comparatively smooth and leathery leaves, was the least effective particle collector.

Ucar and Hall (2001) reviewed research with regards to shelterbelts mitigating pesticide drift and concluded that spray droplet capture efficiency of tree species is among
the most important variables (along with toxicity tolerance and micro-climate suitability) when developing the drift mitigating strategy. They too noted the general superiority of conifers for particulate capture and suggest that because conifers are “in leaf” year round they may also be more effective temporally. This an important factor with regards to odor because even though odor nuisance increases in warmer weather, odor events do happen year-round. Yet studies have shown that non-laminar (stems, petioles, bark) particulate capture can still be significant. For example, Ucar and Hall (1998) cite a study by Porskamp et al. (1994) that observed alder (Alnus spp.) windbreaks reducing pesticide drift up to 90% when in leaf, yet still up to 70% when they were absent of leaves. Wind tunnel tests have shown non-laminar particulate capture contributing upwards of 37% of the total particulate load (particle size = 2.75 μm) to European beech trees, and upwards of 47% of the total load (particle size = 5.0 μm) to White poplar (Little, 1977).

Another factor influencing particle capture is the trees roughness on a larger scale as defined by the overall canopy structure of individual trees or grouping of trees. A highly complex canopy (i.e. the pinnate structure of ash Fraxinus spp.) creates more opportunity for wind obstruction in the through flow and therefore more internal turbulence (Beckett et al., 2000a). Also noted, was that younger, smaller trees of species that are efficient particle filters also are highly effective at removing particulates due to their greater foliage densities compared to much larger, mature specimens (Beckett et al., 2000a).

It is difficult to get an understanding of just how much particulate matter is accumulated. Some studies indicate actual amounts such as Steubing and Klee (1970), who measured the considerable filtering capacity of Pinus mugo along the roadsides in Frankfurt, Germany and found that P. mugo has a filtering effect with up to 0.18 mg cm\(^{-2}\) (1,800 mg m\(^{-2}\)) of dust on the leaf surface (Farmer, 1992), or Beckett et al., (2000b) who noted particulate weights of 488 mg m\(^{-2}\) and a total foliar surface area (ab- and ad-axial surfaces) of 341 m\(^2\) on a single juvenile linden tree (Tilia x europea) within a shelterbelt in Fulmer, East Sussex, UK. To suggest the importance of such information, an example from Takai et al. (1998) assumes that the inhalable dust emission rate is 88 g/h for a medium-sized mechanically ventilated hog farm with 500 pig fatteners, or an emission rate of roughly 2100 g of particulates per day. A single, 20 ft linden tree (Tilia x europea) may at least have the
capacity of holding about 166 g of particulates at any time in dry weather (this includes only insoluble particles – the weight of the soluble load can easily equal that of the insoluble). This also does not include particulates captured by any of the woody parts of the tree (stems and bole). Linden shelterbelts placed within and around this hypothetical farm, depending on overall length and number of rows could have anywhere from 100 to 400 trees (or even more) with a potential total particulate load of around 16,000 – 66,400 grams of particulates. Yet the calculation of actual capacity, or total particulate loads within individual trees or grouping of trees is confounded by the ambient conditions of each site. Precipitation - which can effectively wash both soluble and insoluble particulates from tree surfaces (Beckett et al., 2000c), ambient humidity, diurnal weather patterns, topography, the complex daily variability in emissions of the various particulate sources, and even the positioning of the plant material (natural planting vs. designed planting) collectively create an ecosystem context that make published total particulate loads site specific and of limited generalizability, except to the extent that they can show that the particulate capture capacity exists and may be substantial.

Perhaps additional filtration evidence can be found in overall patterns of particulate deposition. The total particulate capture of trees is dependent not only on the species-specific morphological capacity for particulate capture, but also upon the particle loads in the airstreams. That is, the higher the particulate load in the wind stream, the more particulates are found to be captured and held by these plants. Freer-Smith et al., (1997), shows a filtering effect within a small urban woodlot near a major highway in Surrey, UK, as the number of particles counted on leaf surfaces decreased significantly as distance from the highway (the particulate source) increased. This capture pattern was also evident with the filtering of coalmine dust within a 15m wide mixed age (24 – 50 year old trees) greenbelt consisting mostly of birch (Betula pendula) in Kansk, Siberia (Spitsyna and Skripal’schikova, 1992). Both suggest that the airstream is becoming “cleaner” as it travels through the trees. For information regarding total particulate capture, Beckett et al., (1998) provides a more extensive review, particularly with reference to urban trees.
Based on the literature there are some general conclusions that can be made regarding the particulate filtering capacity of trees (Beckett et al., 2000a, 2000b, 2000c; Spitsyna and Skripal'schikova, 1992; Smith, 1984):

- There is a high correlation (i.e. r values from 0.7 ± 0.19 to 0.98 ± 0.02) between leaf surface area and the quantity of dust accumulation.
- The greater the surface roughness of the leaf, the greater the particulate capture efficiency for particles 5 μm and less. Surface roughness increases with the presence of leaf hairs and pronounced veination.
- Smaller leaves are generally more efficient than larger leaves in collecting particulates.
- Leaves with complex shapes and large circumference-to-area ratios appear to capture particulates most efficiently.
- Conifers are up to 46 times more efficient in capturing particulates than broadleaf species.
- Non-laminar surfaces (petioles, stems, bark) also accumulate significant amounts of particulates in the PM_{10} range.
- The more irregular in shape the particulates are, the greater the capture and retention on tree surfaces.

**Dilution of gas concentrations of odor into the lower atmosphere**

The conditions leading to pollutant trapping by the atmosphere are well known (Takle, 1983; Takle et al, 1976). Low wind velocity, radiational inversions and lack of physical landscape features that create turbulence all contribute to pollutants being trapped at ground (Jacobson et al., 2001; Guo et al., 2001; Takle et al, 1976). Odor has a tendency to be most severe during stable, night-time conditions with low to moderate wind speeds, at which times odors emitted near the surface will not diffuse upward but remain near the surface and travel by way of near laminar flow that will meander over the terrain (OCTF, 1998; SOTF, 1995; Takle, undated). Most odor events are recorded between 5 and 7 AM and between 7 and 10 PM, both high residential activity hours (Jacobson et al., 2001).

Air temperature is also a major factor. At higher temperatures, the conditions for anaerobic decomposition can improve, and greater volatility of odorous compounds may
occur (NPPC, 1995; SOTF, 1995). When these weather conditions occur singly or simultaneously, it has been noted that odor can be transported over distances greater than two miles (NPPC, 1995). Shelterbelt systems may be of value in dealing with these situations.

Shelterbelts have the ability to lift the odor plume into the lower atmosphere aiding in the dilution and dispersion process. As studies in the distribution of windblown pollution indicate, the properties of the underlying surface (terrain) is important in deflecting the airstream or in modifying the rate of mixing and consequent dilution of the material carried with it (Pasquill, 1974). As discussed in McNaughton (1988) within the near vicinity of shelterbelts, heat, vapors, CO$_2$ and other scalar quantities (including odor plumes) are transported along streamlines by the prevailing winds and only across streamlines by turbulence. Shelterbelts present an obstacle to the wind creating turbulence, deflecting air streams upward. McNaughton (1988) further notes that as the air streams top the obstacle, the stream is redirected, becomes compressed and increases in speed. This effected zone above the shelterbelts has been noted at heights of 1.5 H (that is 1.5 times the height of the barrier) to 1.7 H. Therefore, for a shelterbelt that is about 20 feet tall, this effected zone will extend roughly 30 - 34 ft above ground level. This zone then widens and follows the air stream downwind and acts as a source of turbulent kinetic energy. Thus shelterbelt height is a significant variable, the taller the barrier the higher air will be pushed into the lower atmosphere.

Both field and wind tunnel studies that have examined the dynamics of shelterbelts cite a somewhat triangular “quiet” zone that extends from the top of the shelterbelt down to a distance of about 8 H. Immediately above this quiet zone the longitudinal turbulent fluctuations are more energetic and larger in scale (Cleugh, 1998). It is within this zone that much of the dilution of the odor plume into other air layers may take place, see Figure 1 for a schematic of these processes. This dilution effect is not only that part of the odor plume is mixing with other, “higher-off-the-ground” air layers; there is also a slower release of odorous particulates and gases into the airstreams that continue downwind. Therefore the odorous concentration of the plume that does continue downwind is reduced. The plume is also more uniform in terms of concentration, which is beneficial with regards to how the human olfactory system processes exposure to odors (Lammers, 2002).
Overall turbulence on the scale of the entire shelterbelt is also very important. Porosity is of particular importance, in terms of turbulence, as shelterbelt porosities of < 40% are associated with the greatest amount of turbulent energy transfer. Recent wind tunnel and field studies performed by North Carolina State University have shown that artificial wind break walls deflect ventilated building air so that air flows higher above the ground or the surface of downwind lagoons improving potential dilution of odors to the point of recorded noticeable positive odor reduction downwind (OCTF, 1998; Bottcher et al., 1999). By examining the behavior of smoke emissions, researchers have observed enhanced vertical mixing of swine building exhaust plumes due to the presence of artificial, non-porous windbreak walls (Bottcher et al., 2000; Bottcher et al., 2001).

Figure 1. Schematic representation of turbulence and zone of potential odor dilution. Adapted from Raine (1974) as used in McNaughton (1988).

Odor plume modeling has also indicated this vertical mixing in simulations. Using three-dimensional fluid dynamic algorithms with simultaneous diffusion calculations Lammers et al. (2001) observed that an odor emission from a livestock building would experience an elevated mainstream that is distributed by turbulent eddies in the lee of a solid
flow barrier such as an adjacent building. The impact of a diffuser type barrier such as a shelterbelt with an unspecified level of porosity shows a slightly different plume pattern in that there is still an elevated mainstream but the dispersion is more uniform, and therefore, diluted in the downwind stream (Lammers et al., 2001; Lammers, 2002). However, it should be noted that actual dilution effects are currently not well understood. Lammers et al. (2001) notes that shelterbelts could be a location of odor concentration and it is not yet known if there are any on-farm implications because of this. Bottcher et al. (2001) warns that smoke simulations indicate that dilution benefits are reduced during periods of stable wind flows.

Buildings are not the only odor source that can benefit from air stream manipulation by shelterbelts. Anaerobic manure lagoons and other uncovered manure storage facilities are also major sources of swine odor. Liu et al. (1996) numerically simulated the effects of tall barriers around manure lagoons and predicted reductions in downwind malodorous lagoon emissions of 26% to 92% for a range barrier distance to height ratio from 8 to 0.6. This reduction is largely due to the prevention of particulates from passing over the lagoon surface, thereby limiting the concentration and movement of VOC’s convecting off of that surface.

**Encouraging dust and other aerosol deposition to the windward and lee sides of a shelterbelt by reducing wind speeds**

A partial understanding of the aerodynamics of shelterbelt systems exists. Much progress has been made in understanding turbulent transport of air over, around, and through windbreak structures as well as quantifying wind speed alterations (Wang and Takle, 1995; Zhang et al, 1993; McNauton, 1988; Heisler and DeWalle, 1988; Kort, 1988). The air turbulence and wind speed reduction creates situations where wind borne particles can be deposited at much shorter downwind distances than would occur without the shelterbelt. A barrier effect has been noted in the hedgerow systems in Britain as downwind spatial deposition patterns of various propagules have been identified (Burel, 1996). Ucar and Hall (1998), investigating windbreaks and agrochemical drift mitigation, discussed the exponential trends of drifted spray deposits. They suggest that even a simple vegetative barrier such as a single row of trees would reduce potential chemical drift significantly due to
reduced wind speed, though they pointed out that that does not mean reduction to significant levels in all cases. Ucar and Hall (2001) also conclude that pesticide drift reduction offered by shelterbelts evidently arises from two main causes. The first cause is the reduction of within-crop wind speed, which is responsible for the aerial movement of pesticide aerosols; the second cause is due to interception of fugitive pesticide aerosols within the shelterbelt itself.

Laird (1997) and Themelius (1997) both modeled the potential of windbreaks to deal with odor carrying dust using an open circuit wind tunnel and a small-scale model of an open air ventilated hog confinement building and a simulated shelterbelt. The hog house dust was simulated with highly ground walnut shells positioned within the model hog house. Digital imaging was used to examine the brightness of the wind tunnel floor as a measure of dust deposition behavior. Multiple scenarios were tested examining differences in particle deposition by the number of parallel shelterbelts of various heights and thickness as well as different wind speeds and angles. The objective was to minimize the particle/dust mass that leaves the farm boundaries. Table 1 below displays some results of modeled dust reduction due to shelterbelts.

Table 1. Downwind dust reduction associated with different wind parameters as modeled by way of wind tunnel examination using 3 rows of simulated shelterbelts. Shelterbelt heights and distance from building translated from 1:50 scale. a

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>Angle of Wind (°)</th>
<th>Height of shelterbelt</th>
<th>Distance from building</th>
<th>Percent Lost Without Shelterbelt</th>
<th>Percent Lost with Shelterbelt</th>
<th>Percent change with shelterbelt</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0</td>
<td>16.4 feet</td>
<td>62.7 feet</td>
<td>57.4</td>
<td>29.1</td>
<td>49.3</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>16.4 feet</td>
<td>62.7 feet</td>
<td>75.3</td>
<td>32.8</td>
<td>56.4</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>12.3 feet</td>
<td>62.7 feet</td>
<td>80.0</td>
<td>51.7</td>
<td>35.4</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>16.4 feet</td>
<td>62.7 feet</td>
<td>81.9</td>
<td>49.3</td>
<td>39.8</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>16.4 feet</td>
<td>62.7 feet</td>
<td>96.4</td>
<td>63.0</td>
<td>34.6</td>
</tr>
</tbody>
</table>


Based on the results, wind velocity, angle of wind, number of shelterbelts, and the height of the shelterbelts are the most important variables with wind velocity being the most
important. Successful reduction in mass transport far down stream, ranged from 35% to 56%, with the conclusion that this reduction would provide a substantial reduction in the effects of offensive odors in surrounding areas (Laird, 1997). Both researchers, however, noted the need for full-scale field-testing.

Both researchers, however, noted that in order for the information they gathered to be useful in full-scale applications, it remains necessary to perform field-testing. Vegetation type was not a variable nor was windbreak porosity, which has been noted as possibly the most influential factor in reducing wind speed (Ucar and Hall, 1998; Brandle and Finch, 1991; Heisler and Dewalle, 1988). Dust interception by the vegetative barriers was loosely considered as it was noted that 'part' of the total dust mass that was prevented from leaving the test farm model was retained at the shelterbelts.

**Acting as a sink for the chemical constituents of the odorous pollution**

Not much is known about the ability of trees and other plants to ameliorate odor by way of intake or absorption of odorous chemicals or the managerial use of vegetation for this purpose. There is, however, indirect evidence that this is possible. In the last few decades there has been tremendous interest in the ability of plants to remove pollutants from the air, and several reviews have addressed the capability of plants to act as a sink for air contaminants (Kwiecien, 1997; Smith, 1994; Bennett and Hill, 1993; Hill, 1971).

Aerosol chemicals can enter the plant in three ways: 1) gaseous diffusion through open stomata, 2) if chemicals are soluble, they can enter through the stomata in dissolved form, and 3) chemicals can be adsorbed and absorbed into plant tissues (Landolt and Keller, 1985; Smith, 1984). The rate of pollutant transfer is regulated by a series of resistances (Saxe, 1990; Smith, 1984). It has been emphasized that other than pollutant concentration and exposure time, stomatal resistance is the most important factor determining the uptake of pollutants by the plants (Landolt and Keller, 1985). Diffusion through open stomata is considered the route of least resistance. This is regulated first by the plant surface boundary layer (the perfectly still layer of air surrounding all surfaces) and then by the concentration gradient between the ambient air and the sorptive surfaces of a plants interior (Kimmins, 1997; Treshow and Anderson, 1989). Diffusability and solubility of pollutants are the main
factors that affect the rate of boundary layer penetration. Once the boundary layer is penetrated and contact is made with the leaf surface, a pollutant may enter by two routes: absorbed by way of passive diffusion through the stomata (if soluble, pollutants will often enter in solution) or adsorbed through the tissues (Saxe, 1990). One study of interest examined different sorption rates of sulfur dioxide and ozone between conifers and deciduous trees during a fumigation study and determined that sorption rates were higher in conifers (Elkley et al., 1982).

A waxy, lipophilic cuticle resists adsorption of pollutants into plant tissues. The cuticle does offer significant resistance to the movement of water and solutes but it is not impermeable, as evidenced by the fact that most agricultural chemicals are applied as foliar sprays and many of those chemicals, such as herbicides and systemic insecticides, must penetrate the cuticle to be effective (Schonherr and Riederer, 1989). Interestingly, lipophilic substances (i.e. organic fatty compounds) actively accumulate in lipids on plant surfaces (the cuticle is composed of cutin, which is a lipid-based polymer (Taiz and Zeiger, 1991). The leaves of tree species are highly lipophilic and due to lipophilic affinity, they are excellent accumulators of lipophilic foreign substances (Reischl et al., 1989; Reischl et al., 1987). For example, as measured in field experiments, nitrogen-based chemicals and compounds have shown high affinities for leaf cuticles and other plant surfaces (Asman et al., 1997). This affinity of nitrogen-based chemicals to leaf cuticles is enhanced with increased relative humidity and decreased vapor pressures (Asman et al., 1997). Both typically occur within the leeward quiet zone of shelterbelts. Depending on the porosity of the shelterbelt, relative humidity is typically 2 to 4 percent higher in sheltered areas than in open areas (Brandie and Finch, 1991). Asman et al. (1997) suggested that reductions in NH₃ might be achieved indirectly by modifying local scale atmospheric transport and because a relatively large percentage of the emission is dry deposited close to the source, benefits might be achieved by planting a managed farm woodland system around known sources to increase dry deposition and reduce deposition to more critical areas.

Some research suggests that trees can be used as bio-indicators for pollution emission location and prediction (Reischl et al., 1989; Reischl et al., 1987; Gaggi et al., 1985). Reischl et al. (1989), using gas chromatography tests recorded accumulations of chlorinated
hydrocarbons (anthropocentric VOC's) in the foliage of 15-year-old spruce trees (*Picea abies*). Foliage samples were taken at different locations in the proximity of different pollution emitters such as an industrial area, an urban area, and a hazardous waste landfill and where then compared to samples from a "clean air" site (an area of considerable distance from a pollution source). The study found much higher concentrations of pollutants from the samples located in the polluted areas as compared to the low levels recorded for the clean area. In similar studies, Gaggi et al (1985) and Gaggi and Bacci, (1985) also found measurable levels (1 to 50 ng/g) of chlorinated hydrocarbons in the leaf litter of various conifer and deciduous species as well as different lichen species (Beattie, 1999).

Other indirect evidence supporting the intake of aerial pollutants into plants are from studies that have examined pathways of intake by comparing chemical translocation through soil and intake of volatilized chemicals from the soil. Nash and Beall (1970) found that sorption of DDT residues vaporized from surface treated soil was 6.8 times greater than that obtained through root uptake and translocation. In tests examining levels of polychlorinated biphenyls (PCB's) in plant tissues, Bacci and Gaggi, (1985) suggested that the lack of correlation of PCB levels in soil compared to PCB levels in the foliage indicated that during the study, PCB intake was through vapors rather than soil translocation (Beattie, 1999).

Complete understanding of the sorption and uptake process does not yet exist, however there are numerous studies that attempt to identify and quantify different pathways and to model the process (Welke et al., 1998; Schonherr and Baur, 1994; Schreiber and Schonherr, 1993; Screiber and Schonherr, 1992; Sabljic et al., 1990; Trapp et al., 1990; Riederer, 1990; Lendzian, 1984).

Another potential air pollution sink exists on and within the microorganisms that coexist on plant surfaces. The surfaces of plants, depending on such factors as plant species, humidity, season, leaf age and health are usually covered with micro-organisms of all kinds, various forms of fungi, bacteria, and yeasts dominate (Schreiber and Schonherr, 1993; Dickson and Preece, 1976; Preece and Dickson, 1971). In an early review, Smith (1976) hypothesized that since epiphytic organisms have been exposed to many compounds now considered as pollutants for millennia and that this exposure occurs at the atmospheric: plant
interface, that these microbes may behave as sinks for certain particulates and gaseous pollutants. Schreiber and Schonherr (1992, 1993) determined that microorganisms often influence and effect the quantification of foliage uptake of chemicals to the point where care must be made to separate the mechanism during related research.

It is known that many different microorganisms are capable of metabolizing and/or breaking down chemical pollutants such as anthropocentric VOC's (Baker and Herson, 1994; Muller, 1992; Fry et al, 1992) and this process is used in many different types of bioremediation techniques (Baker and Herson, 1994). It is also known that microorganisms are capable of metabolizing odorous VOC's as this is the process by which biofilters are effective at mitigating odors from livestock buildings (Nicolai and Janni, 1997; Li et al., 1996). It is not, however, currently known how effective epiphytic microorganisms are at metabolizing and/or degrading odorous VOC's or if such a process could be effective in mitigating ambient and downwind odorous conditions.

Smith (1984) listed some generalizations regarding gaseous/aerosol pollutant interception and/or uptake into plants that can be made based on controlled experiments and with seedlings. Among the more important were:

- **Plant uptake rates increase as solubility of the pollutant in water increases.**
- When the plant surfaces are wet, the pollutant removal rate may increase up to 10-fold. When conditions are damp, the entire aerial plant surface is available for uptake. Horn and Vedt (1980) while using wind tunnels, determined that trees with wet leaves accumulated 100 times more aerosol sulfur than dry trees and also determined that conifers were better aerosol collectors than deciduous trees).
- **Moisture stress and limitations on solar radiation act to limit stomatal openings and can hinder pollutant uptake significantly.**
- **Pollutants are absorbed most efficiently by plant foliage near the canopy surface, where light mediated metabolic and pollutant diffusivity rates are greatest.**
- **Because numerous forces and conditions regulate the rate of pollutant uptake, the rate of removal under field conditions will be highly variable.**
• However, the rate of pollutant removal can increase linearly as the concentration of the pollutant increases.

Aesthetics

That socio-psychological factors play a role in livestock odor being perceived as a nuisance has been known for some time. Researchers have documented that perceptions of odor differ from individual to individual and are characterized by personal preferences, experiences, opinions, imagination, cultural associations, visual images, and variability in our olfactory systems (Distel and Hudson, 2001; Williams, 1996). In an early review regarding the minimization of livestock odor impacts, Kreis (1978) made several observations in this regard. It is explained that avoiding nuisance complaints is difficult, in part, because of interactions of the social and psychological background and the individual preferences of those who are directly affected by livestock odor. He cites Little (1971) who points out that psychologists have stressed that a priori bias either positive or negative towards an odor source often influences emotional responses to that odor source. It is further suggested that additional ‘aesthetic insult’ from that odor source, be it other pollutants (such as water pollution), or other more cosmetic factors such as disorderliness or distasteful architecture may negate many odor amelioration attempts (Kreis, 1978). Additionally, visual cues have been noted to be associated with higher incidences of odor nuisance complaints (Kreis, 1978 citing Waller, 1971).

Mikesell et al. (2001) interviewed all the neighbors within a variable radius (≤1 mile) of seven large swine farms in Pennsylvania and discovered an inverse relationship between the “attractiveness” of a farm and reported negative odor intensity ratings. That is, those farms that appeared to be more subjectively attractive were perceived to be less odorous. However, quantification of actual odor emission rates at each farm was not attempted, and the characteristics of what constitutes “attractiveness” were not defined.

The specific aesthetic appeal of shelterbelts within agricultural landscapes has been examined. Cook and Cable (1995) find by way of a photo (slide show) elicitation survey of Kansas State University undergraduates that photos of Great Plains shelterbelts (both single belts and systems) rate very high on scenic quality indices whereas open and barren
agricultural landscapes rate very low on scenic quality indices. They conclude that 1) shelterbelts add quite positively to the scenic beauty of Great Plains landscapes and 2) that observer background characteristics appear to have little to do with scenic quality evaluations of shelterbelt landscapes, therefore suggesting a loosely generalizable appreciation of the landscape aesthetics of shelterbelts. Also, Ronneberg (1992) listed improved aesthetics as a major benefit of general shelterbelt use, stating that studies have shown "Visual diversity...is preferred to open landscape". Relatedly, Kliebenstein and Hurley (1999) conducted a "general public" survey regarding environmental impacts and other farm issues, 68% (n = 329) agree that filtration of swine building air for odor reduction is somewhat to very acceptable, with a general high approval of technology that is considered "natural" (which it could be argued, includes shelterbelts), as opposed to technology which is mechanical or chemical in nature.

Professionals involved with livestock agriculture generally accept that a well-landscaped operation, which is visually pleasing or screened from view by landscaping is much more accepting to the public than one which is not (Lorimor, 1998; NPPC, 1995; Melvin, 1996). It is this notion of visual screening that has made landscaping and shelterbelts a common suggestion from agricultural engineers with regards to minimizing odor problems. If it is made known to neighbors and local communities that a shelterbelt is being used as a pollution (air or water) control tool, it may serve as very visible proof that a livestock producer is making an extra effort to control odor.

**General Shelterbelt Design Considerations**

Shelterbelts designed for the purpose of particulate capture can be located on the production site anywhere particulate emissions occur. Main on-site locations of particulate emissions are swine buildings, agricultural fields that receive land applications of manure, heavily used roads, and any outdoor animal systems (i.e. feedlots or hauling lots). For plantings near buildings it was noted that they should extend high enough to fully intercept the plumes of airflow issuing from the fans (e.g. 4 m high for typical buildings) (Bottcher et al., 2000). Care must also be taken so as not to compromise building ventilation. If naturally ventilated, trees and/or shrubs must not impede necessary wind patterns. For mechanically
ventilated buildings, vegetation must not be close enough to impede ventilation intakes and outlets or maintenance. Based on examinations of artificial windbreak walls (Bottcher et al., 2000), a distance of two to four fan diameters downwind from the fans are sufficient to prevent back pressures, however the eventual crown width of the tree species must be factored in. Thus some suggest that shelterbelts should be located at a distance at least five times the diameter of the fans (Malone and Abbot-Donnelly, 2001).

Care always needs to be taken when vegetation is planted to avoid any negative on-farm situations. The mature size of vegetation must be known so that trees and/or shrubs will not grow into hazards. If used near roads or feedlots, trees should not be planted in ways that impede sight lines and create snow deposition hazards in the wintertime. Likewise, if planted as a perimeter around agricultural fields, snow deposition patterns are critical so as to prevent excessive moisture problems in the spring and/or to possibly enhance moisture in dryer areas.

As the research indicates, conifers and/or broadleaved trees with complex, irregular, hairy, and compound leaf surfaces and structure are apparently the best species for particulate capture. Typical crowning behavior should be examined as some species have a tendency to maintain crowns to the ground, a feature beneficial in preventing gaps for particulate laden air to push through. If shelterbelts are to be planted near or around manure lagoons, the rooting habits of the tree species used should be known to prevent tree roots from compromising the protective lining of the lagoon that prevents leaching of pollutants into the soil and ground water sources.

Windbreak structure is of prime concern when it comes to particulate interception. Aspects such as height, length, width, and porosity (density) all have important implications. For interception, shelterbelt height is important to the degree that the odor plume is intercepted as much as possible, a shelterbelt that is shorter than the plume will only intercept that portion that comes into contact with the trees. Because the odor source is near the ground and due to typical weather patterns in agricultural areas, the tendency of the plume is to travel along the ground with limited rising and mixing (Takle, 1983), therefore shelterbelts of even modest heights (i.e. 20-30 ft) may provide adequate plume interception. Shelterbelt length needs to be considered with regards to the width of the plume, again for proper plume interception. An initial rule of thumb may be to size the shelterbelt length at least as wide as
the width of a building ventilation system, the width of a manure lagoon, or the width of an agriculture field that has received a manure application) and typically expands with distance from that source.

Porosity is of significant concern for particulate capture as there needs to be adequate air flow through a shelterbelt so that particulates have an opportunity to make contact with tree surfaces and create instances of internal turbulence. A shelterbelt that is too dense simply pushes most of the wind up and over and particulate capture efficiency diminishes significantly (Ucar and Hall, 2001). Capture efficiencies also increase with wind speed (maximum efficiency was recorded at wind speeds of 10 m s\(^{-1}\)) though it is not known at which wind speeds capture efficiency eventually drops off (Beckett et al. 2000b). Therefore, total deposition of particulates to a shelterbelt is determined by a trade-off between enough porosity promoting throughflow of particulate laden airstreams and enough density to promote particulate contact with tree surfaces, implying an optimum value for porosity (Raupach et al., 2001). Dorr et al. (1998) (as cited in Ucar and Hall, 2001) suggested a theoretical optimum porosity of 40% to 50% for capturing windborne pesticide droplets. It was also suggested by Dorr et al. (1998) that a system of shelterbelts that is multiple rows of belts with this level of porosity, provide increased surface area for particulate capture. Thus the widths of the shelterbelt and the number of rows involved are important factors for particulate interception and capture.

With regards to promoting odor plume dilution, species considerations for this particular dynamic can be different than those of particulate capture. Here height and overall shelterbelt porosity is of critical concern. Some species, which may not be the best for particulate capture, may be more appropriate here. Species such as poplar (\textit{Populus} spp.) grow quite quickly (1-4 ft per year has been observed in the Midwest US), and may be desired as at least a nurse tree, one that can provide early height while other slower growing species (i.e. some conifers) take more time. As shelterbelt porosities of < 40 % may be desired to achieve desired turbulence, the overall crowning habit of species should be understood, as some species maintain a fuller crown even as they grow taller. There is also empirical evidence that suggests that a wedge-shaped belt, facing wedge first into prevailing wind can push airstreams higher into the atmosphere (Brandle, 1999).
**Generic Shelterbelt System Demonstration**

Below is basic diagram of a shelterbelt design associated with a hypothetical swine production facility. The shelterbelt design shown is very generic. This generic design provides "buffering" around the major sources of livestock odor.

![Diagram of shelterbelt system](image)

Figure 2. A hypothetical extensive shelterbelt system design for a larger scale, tunnel ventilated swine finishing facility. The design shown requires 1000 + trees and shrubs. Drawing does not show specific species or between tree spacing and row locations to scale; only general row locations.

The design can easily be adapted to fit other livestock confinement and/or feedlot systems. The wind in Iowa primarily comes from the south, southwest, and southeast during...
the summer months and the north and west during the winter. The orientation of shelterbelts above reflects this.

Below is a picture of an odor mitigation designed two row, mixed species shelterbelt planted on the perimeter of an anaerobic manure lagoon in Central Iowa.

Figure 4. Newly planted (April 1999) two row, mixed conifer/hardwood species shelterbelt located along the east side of a manure lagoon in the northeast corner of a swine production facility in central Iowa. Photograph by A. Hawkins, Iowa State University

Shelterbelt Impact on Odor Perception

Penkala (1977) suggests the primary goal of odor mitigation is to minimize or eliminate perceived odors. Achievement of this goal can be measured by reductions in: 1) odor concentrations reaching populated areas, 2) number of people affected by objectionable odors, 3) time duration of exposure to odors, and 4) number of occurrences of odor events. Legally defined separation distances aid in the dispersion of odors. In Iowa, for example this distance is between 1250 and 3000 feet depending on the size of the facility and number of head of animals (Lorimor, 1999). Because most of these distances are determined based on protection of water sources, the distance is often not enough to reduce odor concentrations to levels that eliminate odor nuisance. As the evidence above suggests, shelterbelts have the
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ability to reduce odor concentrations significantly at or very near the source, which greatly enhances the effectiveness of that separation distance. Appropriate shelterbelt designs, through the combined effects of each dynamic – particulate capture, plume dilution, particulate drop out, and biological attraction of odorous chemicals to vegetation - should be able to decrease the concentration levels of odor plumes leaving production sites and, therefore, contribute to the physical decrease of odorous chemicals moving in the airshed. This, in combination with legal separation distances should significantly limit odor plumes reaching populated areas, reduce the total number of people affected downwind, reduce the time duration of exposure to odors, and allow for reductions in the number of occurrences of odor events. And any aesthetic landscape improvements may contribute to a more positive response to odor that does reach critical receptors - people.

However, key to that assessment is the notion of ‘appropriate’. If a shelterbelt is planted without the consideration of ecological, biochemical, and engineering principles and knowledge, shelterbelts can be inefficiently utilized or worse they could be ineffective (Khan and Abbasi, 2001). Ucar and Hall (2001) also stress that existing shelterbelts and other vegetation may work quite well for their original purpose (i.e. erosion control, crop/animal protection, riparian buffer zones), but in establishing shelterbelts for other goals (such as odor mitigation) careful design is imperative. Moreover, shelterbelts should not be considered as substitutes for a separation distance or used in decisions regarding the setting of legal distances. They also should not be considered as an alternative for standard best management practices (Ucar and Hall, 2001). Ideally shelterbelts are to be used with other proven odor mitigating technologies and/or suitable manure management practices for the additive benefits of incremental odor amelioration.

Conclusions

There are some very real concerns about and barriers to appropriately using shelterbelts within and near livestock production sites. Though shelterbelts are comparatively inexpensive to establish and maintain as an odor control technology, they do represent a cost both initial and over time. Recent research, however, has shown that total costs are significantly below what swine producers have been reported to be willing to pay for odor
control, for example an economic analysis of the shelterbelt design shown in figure 2 revealed total costs between $0.18 and $0.35/per pig marketed below USDA determined willingness to pay for odor control by a producer of that size (Tyndall, 2003; USDA, 1996).

There is the time needed for the vegetation to grow. A difficult problem when the odor problems are right now and retrofitting plant material is the management option. It is likely that trees need to be at least 3-5 years old before any noticeable benefits occur (though aesthetically, benefits may occur sooner). Shelterbelts also have space needs. Some livestock systems are more space limited than others. And several rows of trees throughout a production site can add up to hundreds of trees. Furthermore, facility land space may be limited because of maintenance and access roads and trees need to be located so as to not hinder the use of those roads. Of particular concern, is that for optimal use some shelterbelts may best be planted on land that is not part of the production site, particularly around fields where manure is spread. This may require coordination across property ownerships and the planting of trees on edges of active agricultural land. Government assistance programs such as the Conservation Reserve Program (CRP) and Environmental Quality Incentives Program (EQIP) may provide some financial support but coordination of this kind is often difficult to manage.

Knowledge of tree growth and maintenance to maximize tree health and prevent unnecessary tree mortality (e.g. avoiding certain herbicides, proper mowing procedures, and providing suitable moisture levels) is required. Many information entities typically have expertise in trees/forestry or in farm systems and rarely expertise in both (Schafer, 1989). Such situations have led to on-farm failures of tree systems and ineffective use tree based technologies.

There are also time requirements for maintenance that may or may not include: mowing, spraying, irrigation, and occasional tree replacement; 5-10% plus tree mortality is common over the first 10 years for many otherwise healthy shelterbelts (Horvath, 2002). Some concern has been expressed regarding the notion that shelterbelts can provide habitat for on-farm pests such as rats and other mammals as well as undesirable insects. Research on this topic is limited. But there has been very little evidence that this has been a serious
problem with crop field shelterbelts. Undoubtedly research is needed to fully answer this question.

Because empirical evidence is lacking it is difficult to assess the bio-effectiveness of this technology at this point. But it can be reasoned that there are several likely means of effectiveness. The lower the overall level of odorous emissions emanating from a production site, the more effectual shelterbelts can be. It is likely that there is a threshold at which shelterbelts (and other technologies) are simply overwhelmed and a nuisance situation may continue to exist. Field and laboratory tests are needed for a better understanding of this threshold.

It is known that livestock odor has site-specific idiosyncrasies in its biophysical behavior and also idiosyncrasies in the social reaction to it, yet many current advances in odor mitigation seem to ignore this fact. Odor nuisance complaints are on the rise in the Midwest so it seems clear that there is something missing with this current technological approach. Indeed, Person et al. (1995) call attention to this by suggesting the status quo in managing odor nuisance is not at all adequate in the face of the changes in livestock agriculture. Furthermore they state that the “appropriateness of recommendations for new technology and management practices, will depend upon their being simultaneously compatible in an extensive interactive system that functions in a community, natural (resource), economic, (and environmental) context all of which are tightly coupled” (Person et al., 1995).

It is for these reasons that the use of shelterbelts is advantaged, in that there is evidence that they are quite adaptable to the ecosystem and production variability of livestock production sites and production regions. There is also information that the presence of trees in agricultural landscapes has socio-aesthetic advantages that most other odor mitigation technology lack completely. Shelterbelts are also a technology that can be considered “production technology neutral” in that swine producers of all kinds – confinement, modified confinement, hoop house, pasture - as well as size neutral in that producers of all sizes can plant designed shelterbelt systems. Shelterbelts, very uniquely, offer a technology that both producers and rural residents and communities can appropriately use, suggesting “user neutrality”. Further, as opposed to other odor mitigating technologies
that typically depreciate over time, shelterbelts may be the only odor control technology that theoretically increases in effectiveness over time. As with other “tree” based technologies used in agriculture, their effectiveness comes from providing ecological infrastructure within an otherwise ecologically simplified system (Schultze et al, 2000). As the trees grow larger, and more morphologically complex their ability to mitigate odors will become increasingly efficient. Though this improvement overtime is contingent upon the health and maintenance of the shelterbelt systems and the continuance of hog production best management practices.

Clearly, the published information on the ability of and use of shelterbelts for on-and off-farm odor reducing benefits is limited and further bio-physical, economic, and social qualification and quantification of this technology is needed. Yet the existing evidence seems to indicate that shelterbelts can help incrementally to reduce odor pollution and sustain both the swine industry and the quality of rural life.
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FINANCIAL FEASIBILITY OF USING SHELTERBELTS FOR SWINE ODOR MITIGATION

A paper to be submitted to Agroforestry Systems

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Abstract

This study is a farm-level financial examination of shelterbelts as a biologically based technology for swine odor management. Shelterbelts are purposefully designed and planted rows of trees and shrubs around the main sources of odor – the swine buildings, the manure storage systems, and crop fields that receive land applied manure. As recent research suggests if shelterbelts are utilized appropriately (proper species, scale, location, etc.), they should play a significant role within a “suite” of odor mitigation strategies, which collectively will reduce odor nuisance risk for all the stakeholders in rural air quality. The specific objectives of this financial analysis of the use of shelterbelts for odor mitigation are: 1) To assess the farm level financial nature of planting and maintaining four model shelterbelt systems for incremental swine odor mitigation; 2) To compare shelterbelt costs with known pork producer willingness to pay (WTP) for odor control figures; and 3) To assess the effect of federal programs on reducing the financial burdens of shelterbelts. To perform the analysis, four model pork-finishing farms were developed by examining real pork finishing farms in Iowa. A sensitivity analysis examined the effects of differing discount rates and the effects of two federally funded cost share programs, Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Program (CRP).

The calculated costs for shelterbelt establishment and maintenance over a twenty-year period for all four model pork finishing farms, when considering a “seedling price scenarios” ($0.50 per tree/shrub), on an amortized per pig produced basis were all well below the reported producer willingness to pay (WTP) for odor mitigating technology as detailed by the USDA. Some of the “high priced scenarios” (average of $9.59 per tree/shrub) did exceed the
WTP threshold for producers of certain sizes. Yet, when cost share and incentive programs (e.g. EQIP and CRP) are factored in, the total amortized costs are lowered below all WTP thresholds. The seedling price scenarios are slightly more sensitive to the interest rates used, with a 5% to 7% reduction in the present value costs with an increase in the real interest rate from 5% to 7%. Whereas, with the higher priced scenario, the decrease in present value costs over that same interest rate change is about 2%.

Based on the above cost information, it is clear that the use of shelterbelts, in many cases only add only a few pennies to overall production costs. Some of the results even show ample positive cost margins (possibly as much as $0.33 - $0.59 per pig produced of extra costs to spare) to suggest room for shelterbelts to be part of a “suite of technology”. It is recognized that with regards to odor control, no single technology is 100% effective, yet if a comprehensive management program is developed and followed, nuisance odor can approach elimination.

**Introduction**

Concern for the “quality of life” of rural people and communities has been a frequent topic in recent examinations of sustainability issues regarding rural communities, farming landscapes, and the livestock industry (Wing and Wolf, 2000; Ikerd, 1999; Thu and Durrenberger, 1998). The process of defining “quality of life” with regards to rural people and communities is subjective and dynamic. But one aspect of the concept is reasonable personal freedom from livestock odor. Recent reports regarding the rural Midwest clearly indicate that odor emitted from concentrated livestock production facilities, particularly pork production, is a significant social problem that is negatively impacting rural and state economies, human health, and the quality of rural life (Wing and Wolf, 2000; Thu and Durrenberger., 1998). Iowa’s press cautioned that for the consideration of economic sustainability, a state like Iowa cannot afford to depress it’s livestock industry by way of legal actions, yet states that “It’s important to the state’s economy that (swine) production flourish here, but in a manner that respects the outdoors, health concerns and the quality of life” (Des Moines Register, 2002). While odors from swine production are and have been ubiquitous with animal agriculture and tolerated by rural communities, structural changes in
the US swine industry (i.e. increased farm size, increased concentration of animal manure) have caused odor to become much more pervasive and offensive. With less delineation between rural and urban areas and new development pushing further into areas that were once strictly rural, many more people are being affected by livestock odor. Combined with recent legal precedence that now limits agricultural nuisance protection (e.g., Borman v. Board of Supervisors, 1998) the potential for litigious social outcomes is increasing. Unlike many European livestock producing countries, there are no U.S. federal laws that regulate livestock odor directly (some countries with strict livestock odor control laws include Great Britain, the Netherlands, Germany, Denmark, Sweden, and Greece, Chapin et al., 1998a; Hamilton, 1992). Likewise, only 10 states regulate livestock odor directly. Iowa and North Carolina, the top two U.S. pork-producing states respectively, only deal with swine odor indirectly, largely by way of separation distances (depending on the size of the production: 750 – 3000 ft for Iowa and 750 – 5000 ft for North Carolina). Though recently, Iowa has started applying a matrix process for new construction and/or expansion that largely involves odor precautions (Lawrence, 2003).

The costs involved with a successful defense against an odor nuisance suite can be enough to put the operation in financial danger (Hamilton, 1992). And, the social and economic benefits involved with winning a nuisance case also often do not exceed the costs in terms of money, time, and social relationships (DeLind, 1998). If litigation can be avoided by having producers take steps to protect the surrounding countryside from odor pollution, particularly if such measures are financially feasible, it makes social and economic sense to do so (Hamilton, 1992).

Current research regarding livestock odor problems and perception, strongly suggests that limits in odor free air are becoming more pervasive throughout a year, being perceived at higher levels of offensiveness, and effecting more and more people (Thu and Durrenberger, 1998; Lasley, 1998). Lasley (1998) in an annual survey of Iowa farmers indicated that 85% of the surveyed farmers (n= 2,312) believed that people who live in the country must accept the presence of livestock. Yet, 63 percent agreed that the frequency of livestock odor is increasing in Iowa. Lasley (1998) also reported that while 83 percent of the farmer respondents indicated that they were not opposed to neighbors raising livestock just as long
as it did not affect their quality of life, nearly one-fourth of the respondents perceive that neighboring livestock production is diminishing their quality of life. Odors from livestock and poultry production and manure storage and land application were listed as the major detractors (Lasley, 1998). However, in a different survey, 71% of the respondents (n=1000) indicated that it is better to have pork production in Iowa and some odor problems in their community rather than to have clean air while forgoing pork production (Hayes et al., 1998).

This study is a farm-level financial examination of shelterbelts as a biologically based technology for swine odor management. Shelterbelts are purposefully designed and planted rows of trees and shrubs around the main sources of odor – the swine buildings, the manure storage systems, and crop fields that receive land applied manure. The USDA’s National Animal Health Monitoring System Swine 2000 report noted that 33% of respondents across 17 states use shelterbelts/windbreaks specifically for air quality management (Vansickle, 2002).

As recent research suggests (Khan and Abbassi, 2001; MWPS, 2002), if shelterbelts are utilized appropriately (proper species, scale, location, etc.), they should play a significant role within a “suite” of odor mitigation strategies, which collectively will reduce odor nuisance risk for all the stakeholders in rural air quality.

The specific objectives of this financial analysis of the use of shelterbelts for odor mitigation are:

- To assess the farm level financial nature of planting and maintaining four model shelterbelt systems for incremental swine odor mitigation.

- To compare shelterbelt costs with known pork producer willingness to pay (WTP) for odor control figures.

- To assess the effect of federal programs on reducing the financial burdens of shelterbelts.
Shelterbelts and Odor Mitigation

A critical assumption to this financial analysis is that shelterbelts can be bio-physically effective in attenuating swine odor. Based on research literature, there are five primary ways that shelterbelts can mitigate livestock odors by:

- Physical interception and capture of odor-laden dust and other aerosols by trees and shrubs (i.e. Beckett et al., 2000a, 2000b, 2000c).

- Dilution of gas concentrations of odor into the lower atmosphere (i.e. Lammers et al., 2001; Gassman, 1995).

- Deposition of odor-laden dust and other aerosols from reduced wind speeds (i.e. Laird, 1997; Themelius, 1997).

- Acting as a biological sink for the chemical constituents of odor after interception (i.e. Beattie, 1999).

- Enhancing the aesthetics of pork production sites and rural landscapes (i.e. MWPS, 2000; Mikesell, undated).

It should be emphasized that shelterbelts are amenable to use at the three main (on-site and in some cases off-site) sources of livestock odor: animal buildings, manure storage systems, and agricultural land that has manure applied. Most odor mitigation technology is odor source specific and not adaptable throughout the farm. Shelterbelts can be designed so as to agree with the site and ecological specificity of individual farms. Shelterbelts can also be used throughout agricultural landscapes, in that the use of this technology is not limited to producer use only. If it is made known to neighbors and local communities that a shelterbelt is being used as a pollution (air or water) control tool, it can serve as very visible proof that a livestock producer is making an effort to control odor.

While engineered technology exists to ameliorate livestock odor (MWPS, 2002; Heber et al., 1999), costs, complexity, preference and education seem to limit their use. Kliebenstein and Hurley (2000) found in a study of pork meat consumers that 82% of the respondents were somewhat to very concerned about environmental impacts, particularly air
quality, associated with pork production. Further the consumers expressed a preference for odor management strategies that could be considered more “natural” as opposed to mechanical or chemical. Additionally, 68 % of respondents were somewhat to very accepting of air filtration from buildings as a means to capture and dilute odor.

Possible Shelterbelt Designs for Four Hypothetical Pork Feeder Finisher Farms

Four model pork-finishing farms were developed by examining real pork finishing farms in Iowa. Each model farm reflects different pork production, building ventilation and manure storage technologies and will serve as the frame for financial comparisons involving farm-specific shelterbelt designs to mitigate odor. A sensitivity analysis will examine the effects of differing discount rates and the effects of two federally funded cost share programs, Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Program (CRP), (see Table 1 below for details of each program). Under current EQIP rules, shelterbelts are approved BMP’s for erosion control, snow fencing, and boundary markers. State Natural Resource Conservation Service EQIP agents have the discretion to accept environmental quality technologies for federal funding within their standards of Best Management Practices (BMP’s). It is assumed that shelterbelts would be accepted as a BMP for NRCS air quality standards.

Model Farms

Farm A, Large sized confinement - Farm A is a 3,764 head, tunnel ventilated, confinement-finishing farm, which turns out 10,500 pigs annually. The manure storage is in two, above ground, concrete storage tanks with the capacity to hold the estimated 1.65 million gallons of manure produced annually. This farm requires about 660 acres of cropland on which to apply manure.
Figure 1. The shelterbelt design for Farm A, Large sized confinement requires 950 trees and 214 shrubs. The spacing between trees and rows are not drawn to scale. The wider spacing recommended for the southwest corner of the farm allows for proper airflow to the intake end of the tunnel-ventilated buildings. An additional 2,145 trees are needed for this farms application fields.

**Farm B**, medium sized confinement - Farm B is a 900 head, mechanically ventilated, confinement-finishing farm, which turns out 2,520 pigs annually. The manure storage is a square earthen pit with the capacity to hold the estimated 394,200 gallons of manure
produced annually. This farm needs about 160 acres of cropland on which to apply the manure.

Figure 2. The shelterbelt design for Farm B, medium sized confinement requires 325 trees and 141 shrubs. The spacing between trees and rows are not drawn to scale. An additional 1,045 trees are needed for this farms application fields.

Farm C, Small sized confinement - Farm C is a 570 head, naturally ventilated confinement-finishing farm, which turns out about 1,596 pigs annually. A single concrete,
above ground slurry store holds the estimated 245,660 gallons of manure produced annually. This farm requires about 100 acres of cropland on which to apply manure.

Figure 3. The shelterbelt design for Farm C, Small sized confinement requires 178 trees and 51 shrubs. The spacing between trees and rows are not drawn to scale. The wider spacing recommended for the southwest corner of the farm allows for proper airflow to the naturally ventilated buildings. An additional 835 trees are needed for this farm's application fields.
**Farm D, Small non-conventional** - Farm D is a 360 head, naturally ventilated, hoop structure-finishing farm, which turns out about 1,008 pigs per year. The manure and bedding material used is handled as solid manure and is removed after each turn. Roughly 25 acres is required to apply the estimated 520 tons of solid manure produced and bedding used annually.

![Diagram of Farm C's shelterbelt design](image)

Figure 4. The shelterbelt design for Farm C, Small sized Hoop Structure finishing farm requires 122 trees and 145 shrubs. The spacing between trees and rows are not drawn to scale. An additional 394 trees are needed for this farm's application fields.

The assumptions underlying each model farm shelterbelt design and the farm level financial comparisons are as follows:
- There are two main odor sources receiving odor mitigative attention with shelterbelts. The first shelterbelt component is for the farm itself, which includes the swine buildings and the manure storage facilities. The second shelterbelt component is for a contiguous crop field that receives manure from the production facility for nutrient capture purposes. These odor sources are examined separately and in combination.

- The swine farms are assumed to be located in central Iowa. Summer winds primarily come from the south and the southwest; winter winds come primarily from the north and the northwest.

- Each shelterbelt design assumes the use of both deciduous and coniferous trees and/or shrubs, which are appropriate for the geographic location of each swine farm. It is understood that shelterbelt designs may include differing species compositions, however all costs for planting material are averaged across several likely species, and separated by being deciduous or coniferous and being trees or shrubs.

- Each finishing farm has 2.8 turns of animal stock each year and animal mortality is not considered.

- All manure storage, with the exception of the hoop house farm, has a one-year slurry storage capacity. The manure produced on the hoop house farm is handled as a solid. Manure application is based on both the variable nutrient content of the manure and the variable nutrient credit of individual application fields, so it is assumed that for the crop fields receiving slurry manure, each field requires 2,500 gallons per acre of manure (Sutton et al., 1996); for the field receiving solid manure, 46 tons per acre of manure is needed.

- All costs are in 2002 US dollars.

**Financial Appraisal**

This study used standard cash-flow analysis to examine the costs of establishing a designed shelterbelt within and around the four model pork finishing facilities. Costs examined include costs for: site preparation, shelterbelt establishment, shelterbelt repair and
maintenance, and land rent for shelterbelts planted around crop fields. The benefits examined consist only of government transfer payments specifically from the Environmental Quality Incentive Program (EQIP) for any shelterbelts planted in and around the finishing facility proper and from the Conservation Reserve Program (CRP) for shelterbelts planted around the manure application fields. Measures of odor mitigation effectiveness from shelterbelts will not be considered. Table 1 below lists out the transaction costs and year(s) they occurred in which the cash flow analysis is based.

Table 1. Transaction costs and year(s) in which they occur, for the four model farms.

<table>
<thead>
<tr>
<th></th>
<th>Year(s)</th>
<th>Price/ linear mile</th>
<th>Source of Price Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site Prep</strong></td>
<td></td>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Plowing</td>
<td>0</td>
<td>$13.70</td>
<td>a</td>
</tr>
<tr>
<td>Spray purchase</td>
<td>0</td>
<td>$5.69</td>
<td>b</td>
</tr>
<tr>
<td>Spraying operation</td>
<td>0</td>
<td>$13.30</td>
<td>a</td>
</tr>
<tr>
<td>Disking</td>
<td>0</td>
<td>$13.31</td>
<td>a</td>
</tr>
<tr>
<td>Tilling</td>
<td>0</td>
<td>$13.70</td>
<td>a</td>
</tr>
<tr>
<td>Overhead/management</td>
<td>Annual</td>
<td>$17.00</td>
<td>b</td>
</tr>
<tr>
<td>Land rent</td>
<td>Annual</td>
<td>$145.20</td>
<td>c</td>
</tr>
<tr>
<td><strong>Shelterbelt Establishment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree purchase costs</td>
<td>1</td>
<td>Variable</td>
<td>d,e,f</td>
</tr>
<tr>
<td>Shrub purchase cost</td>
<td>1</td>
<td>Variable</td>
<td>d,e,f</td>
</tr>
<tr>
<td>Tree planting cost</td>
<td>1</td>
<td>$0.15</td>
<td>b</td>
</tr>
<tr>
<td>Shrub planting cost</td>
<td>1</td>
<td>$0.15</td>
<td>b</td>
</tr>
<tr>
<td>Spray purchase</td>
<td>1</td>
<td>$5.69</td>
<td>b</td>
</tr>
<tr>
<td>Spraying operation</td>
<td>1</td>
<td>$13.30</td>
<td>a</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tree replanting</td>
<td>2-4</td>
<td>Variable</td>
<td>b</td>
</tr>
<tr>
<td>Shrub replanting</td>
<td>2-4</td>
<td>Variable</td>
<td>b</td>
</tr>
<tr>
<td>Weed control</td>
<td>2-5</td>
<td>$19.00</td>
<td>b</td>
</tr>
<tr>
<td>Shelterbelt removal</td>
<td>20</td>
<td>$294.03</td>
<td>b</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQIP</td>
<td>1</td>
<td>75% of establishment costs</td>
<td>g</td>
</tr>
<tr>
<td>CRP</td>
<td>1,15</td>
<td>Establishment cost share, land rent, incentive payment</td>
<td>b</td>
</tr>
</tbody>
</table>

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Footnotes:

1. Since most listed costs are published on a per acre basis, prices per linear mile assume a treatment strip of 10' by 5280' or a "price/ acre" to "price/ linear mile" conversion factor of 1.21.

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Iowa State University, 2002a.; Grala, 2002; Iowa State University, 2002b; Cascade Forestry Nursery, 2002; Country Landscapes, 2002; Iowa Department of Natural Resources, 2002; NRCS, 2002.
For the "Seedling Price" scenario, plant material costs for each model farm are $0.50/tree and shrub. For the "High Price" scenario the costs are as follows: Farm A = $12.11/tree and shrub; Farm B = $10.26/tree and shrub; Farm C = $6.88/tree and shrub; Farm D = $9.12/tree and shrub.

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

Includes taxes, insurance, energy requirements, etc.

CRP program for Iowa was used: total of 90% establishment cost share + 100% land rent/acre + additional 20% land rent/acre for shelterbelts + $150/acre upfront payment.

Two planting stock cost scenarios are used following two suppositions; a seedling price for 1 to 2 year old deciduous and conifer trees (IDNR, 2002) and a high price for older (4-6 years old), larger, ball and burlapped tree and shrub stock. The analysis considered a time horizon of twenty years. Twenty years is reasonable, as the life span of the average hog unit has been estimated to be between 10 and 15 years and well-managed hog production facilities have high resale value (ISU, 1998). A 7% real alternative rate of return (RARR) is used assuming each model farm accepts the same level of investment risk.

All costs were discounted using standard discounting formulation (Klemperer, 1996). The two general cost models without any governmental support are:

\[
PVC = PVSB_{sp} + PVSB_{e} + PVSB_{m}
\]

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, irrigation, tree/shrub replacement, root or branch pruning).

Cost equation [1] is modified to include governmental support from the cost share programs EQIP and/or CRP:
\[ \text{PVC}^{\text{GOV}} = \text{PVSB}^{\text{SP}} + \text{PVSB}^{\text{E}} + \text{PVSB}^{\text{M}} - \text{PV}^{\text{CShare}} \]  \[ \text{[2]} \]

The total discounted cost for each scenario are then converted into equivalent annual value (EAV) of costs using a capital recovery factor following Gumaa et al., (1998):

\[ \text{EAV}_K = \text{PVC} \times \text{CRF} \]  \[ \text{[3]} \]

\( K = 1 \) Without government assistance

\( K = 2 \) With government assistance

\[ \text{CRF} = \frac{[i(1+i)^N]}{[(1+i)^N - 1]} \]  \[ \text{[4]} \]

Where \( i = \) annual real discount rate, \( N = \) number of years in the evaluation. The \( \text{EAV}_K \) annualizes all costs and allows pork producers to compare the shelterbelt cost with other odor technology. Costs of the model shelterbelts, equations 1-3 are reported in two ways, first PVC and \( \text{PVC}^{\text{GOV}} \) are established for each shelterbelt design. The second way is to divide the \( \text{EAV}_K \) of each model shelterbelt by the number of pigs produced annually; this presents total costs as per unit (per pig) of production costs and spreads the costs out across all the pigs produced in a twenty-year period.

The calculated costs for shelterbelt establishment and maintenance over a twenty-year period for all four model pork finishing farms, when considering the seedling price scenarios, on an amortized per pig produced basis were all well below the reported producer willingness to pay (WTP) for odor mitigating technology as detailed by the USDA (USDA, 1996). Some of the high priced scenarios did exceed the WTP threshold for producers of certain sizes. Yet, when cost share and incentive programs (e.g. EQIP and CRP) are factored in, the total amortized costs are lowered below all WTP thresholds.

**Farm A, Large Sized Confinement**

Farm A with regards to annual pig production is the largest finisher farm examined (producing 10,500 pigs annually) and has the most area developed as production grounds
(5.91 acres). The design for this farm as shown in Figure 1 requires 1,163 trees/shrubs for the facility grounds and 2,145 trees around the application field.

Looking first at the present value costs (PVC) for this farm at 7% RARR the total costs (farm and field components combined) are $11,788 and $49,559 for the seedling price and high price scenarios respectively. With cost share (PVC\textsuperscript{Gov}), the total present value costs decrease considerably to $2,983 and $16,850 for the seedling price and high price scenarios respectively.

However it is by examining the equal annual value costs per pig produced (EAV 1 and EAV 2), that the costs are put into a production unit perspective. Considering the seedling cost scenario without the use of cost share programs, the shelterbelt system in and around the facility grounds would cost the producer about $0.01 per pig produced over twenty years with a real alternative rate of return (RARR) of 7%. To plant shelterbelts around the application field costs increase $0.09 per pig produced over twenty years. For the high price scenario, the total (farm and field) cost increases to $0.40 per pig produced over twenty years. When cost share programs are used (EQIP for the farm and CRP for the application field), the costs decrease to $0.03 and $0.14 per pig produced over twenty years (for the seedling and high price scenarios, respectively).

The pork producer willingness to pay for odor mitigation technology estimated for producers of this size (2,500 + head) was $0.38 per pig produced (USDA, 1996). Thus by utilizing shelterbelts as an odor mitigation technology and without using cost share programs Farm A under the seedling price scenario has a $0.18 per pig cost margin that would be available for another non-shelterbelt odor control technology. However, under the high price scenario there is a negative margin of $0.07 per pig. This means that total costs per pig are $0.07 more than the willingness to pay on a per pig basis. Yet with the use of EQIP and CRP, Farm A would have positive margins of between $0.35 and $0.23 per pig produced (seedling and high price scenarios, respectively). To examine further the total cost per pig produced breakdowns for Farm A, by shelterbelt component and by price scenario see table 2.
Table 2. Cost breakdown per pig produced at 7% Real Alternative Rate Return for each model farm, by shelterbelt component and by price scenario. The weighted average high prices are listed for each model farm. Costs in 2002 US dollars.

<table>
<thead>
<tr>
<th>Model Farm</th>
<th>Seedling price ($0.50/tree)</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Farm Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td>$1,413</td>
<td>$604</td>
</tr>
<tr>
<td>EAV 1</td>
<td>$0.01</td>
<td>$0.02</td>
</tr>
<tr>
<td>EQIP ¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC&lt;sup&gt;Gov&lt;/sup&gt;</td>
<td>$992</td>
<td>$352</td>
</tr>
<tr>
<td>EAV 2</td>
<td>$0.01</td>
<td>$0.01</td>
</tr>
<tr>
<td>Field Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td>$10,375</td>
<td>$5,055</td>
</tr>
<tr>
<td>EAV 1</td>
<td>$0.09</td>
<td>$0.19</td>
</tr>
<tr>
<td>CRP ¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC&lt;sup&gt;Gov&lt;/sup&gt;</td>
<td>$1,991</td>
<td>$970</td>
</tr>
<tr>
<td>EAV 2</td>
<td>$0.02</td>
<td>$0.04</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td>$11,788</td>
<td>$5,659</td>
</tr>
<tr>
<td>EAV 1</td>
<td>$0.11</td>
<td>$0.21</td>
</tr>
<tr>
<td>EQIP/CRP¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC&lt;sup&gt;Gov&lt;/sup&gt;</td>
<td>$2,983</td>
<td>$1,322</td>
</tr>
<tr>
<td>EAV 2</td>
<td>$0.03</td>
<td>$0.05</td>
</tr>
</tbody>
</table>

¹For EQIP and CRP information see table 1.

Farm B, Medium Sized Confinement

Farm B with regards to annual pig production is the second largest finisher examined (2,025 pigs annually). As seen in Figure 2, this model farm required 466 trees/shrubs for the facility grounds, 1,045 trees around the application field. Looking first at the present value
costs (PVC) for this farm, without governmental assistance, at 7% RARR the total costs (farm and field components combined) are $5,659 and $26,641 for the seedling price and high price scenarios respectively. With cost share (PVC\textsuperscript{GOV}), the total present value costs decrease considerably to $1,321 and $7,597 for the seedling price and high price scenarios respectively.

Considering the EAV's, starting with the seedling cost scenario, to plant this shelterbelt system in and around the production facility (farm) at 7% RARR costs the producer about $0.02 per pig produced over twenty years. Adding a shelterbelt to an application field increases costs by $0.19 per pig produced. For the high price scenario, the total (farm and field) cost $1.00 per pig produced over twenty years at 7% RARR. However, if cost share programs (EQIP for the farm and CRP for the application field) are used, those totals decrease to $0.05 and $0.28 per pig produced over twenty years (for the seedling and high price scenarios, respectively).

The pork producer willingness to pay for odor mitigation technology estimated for producers of this size (1,000 to 2,499 head) was $0.43 per pig produced (USDA, 1996). Thus by utilizing shelterbelts as an odor mitigation technology and without using cost share programs Farm B under the seedling price scenario has a $0.22 per pig cost margin that would be available for another non-shelterbelt odor control technology. However, under the high price scenario there is a negative margin of $0.57 per pig. This means that total costs per pig are $0.57 more than the willingness to pay on a per pig basis. Yet with the use of EQIP and CRP, Farm B would have a positive margin of between $0.38 and $0.15 per pig produced (seedling and high price scenarios, respectively). To examine further the total cost per pig produced breakdowns for Farm B, by shelterbelt component and by price scenario see table 2.

**Farm C, Small Sized Confinement**

Farm C with regards to annual pig production is the second smallest pork finisher examined (producing 1,600 pigs annually). As seen in Figure 3, this model farm requires approximately 225 trees/shrubs for the facility grounds and 854 trees around the application field. Looking first at the present value costs (PVC) for this farm, without governmental
assistance, at 7% RARR the total costs (farm and field components combined) are $4,462 and $13,306 for the seedling price and high price scenarios respectively. Cost share (PVC\textsuperscript{GOV}) considerably decreases the total present value costs to $1,073 and $3,255 for the seedling price and high price scenarios respectively.

For the EAV’s considering the seedling cost scenario to plant and maintain a shelterbelt in and around the production facility (farm) at 7% RARR would cost the producer about $0.02 per pig produced over twenty years. Adding a shelterbelt to an application field increases costs to $0.24 per pig produced. For the high price scenario, the total (farm and field) cost increases to $0.84 per pig produced over twenty years at 7% RARR. When cost share programs are used (EQIP for the farm and CRP for the application field), those totals are reduced to $0.06 and $0.21 per pig produced over twenty years (for the seedling and high price scenarios, respectively).

The pork producer willingness to pay for odor mitigation technology estimated for producers of this size (1,000 to 2,499 head) was $0.43 per pig produced (USDA, 1996). Thus by utilizing shelterbelts as an odor mitigation technology, without using cost share programs Farm C under the seedling price scenario would have a positive margin of $0.17. Under the high price scenario there is a negative margin of $0.41 per pig. With the use of EQIP and CRP, Farm C would have positive margins of between $0.37 and $0.22 per pig produced. To examine further the total cost per pig produced breakdowns for Farm C, by shelterbelt component and by price scenario see table 2 above.

**Farm D, Small Sized Hoop Structure**

Farm D with regards to annual pig production is the smallest finisher examined (producing just over 1,000 pigs annually). As seen in Figure 3, this model farm requires approximately 267 trees/shrubs for the facility grounds and an additional 394 trees for the application field. Examining first the present value costs (PVC) for this farm, without governmental assistance, at 7% RARR the total costs (farm and field components combined) are $2,189 and $8,632 for the seedling price and high price scenarios respectively. Cost share (PVC\textsuperscript{GOV}) considerably decreases the total present value costs to $615 and $3,717 for the seedling price and high price scenarios respectively.
For the EAV's, considering first at the seedling cost scenario, the shelterbelt system in and around the production facility (farm) grounds at a RARR of 7% would cost the producer about $0.02 per pig produced over twenty years. Shelterbelts around an application field increases costs by $0.18 per pig produced over twenty years. For the high price scenario, the total (farm and field) cost increases to $0.81 per pig produced over twenty years at 7% RARR. When cost share programs are used, these totals are reduced to $0.06 and $0.35 per pig produced (for the seedling and high price scenarios, respectively).

The pork producer willingness to pay for odor mitigation technology estimated for producers of this size (between 900 - 1000) was $0.65 per pig produced (USDA, 1996). Thus by utilizing shelterbelts as an odor mitigation technology, without using cost share programs Farm D under the seedling price scenario would have a total cost positive margin of $0.45. Under the high price scenario there is a total cost negative margin of $0.16 per pig. With the use of EQIP and CRP, Farm D would have total cost positive margins of between $0.59 and $0.30 per pig produced.

The application fields are the most expensive shelterbelt feature, representing between 50% and 89% of the PVC and PVC$^\text{GOV}$ costs. The greater the establishment costs from the use of older, more expensive planting stock, the less prominent the application field cost becomes. With the seedling price scenarios ($0.50/ tree and shrub) for all the model farms and without using cost share programs, the application field component represented about 89% of the total cost (averaged across the three interest rates) and about 70% of the total cost when EQIP and CRP are utilized. With the higher priced scenarios (average price of $9.59/ tree and shrub), without cost share the application field components represented 71% of the total cost and about 51% when EQIP and CRP are utilized. The seedling price scenarios are also slightly more sensitive to the interest rates used, with a 5% to 7% reduction in the present value costs with an increase in the real interest rate from 7% to 5%. Whereas, with the higher priced scenario, the decrease in present value costs over that same interest rate change is about 2%.

Considering the seedling price scenarios, the mean amortized costs for all four model farms for the farm only shelterbelt component is just $0.02 per pig produced and with EQIP cost share the per pig cost decreases to $0.01. The application field shelterbelt
component adds $0.17 without cost share and $0.03 with CRP cost share and planting incentives. For the high price scenarios, the farm shelterbelts on average cost $0.23 per pig produced without cost share and $0.12 with. The application field shelterbelts cost $0.51 per pig produced without cost share and $0.12 with.

Conclusions

Farm A consistently has the lowest costs across all scenarios, despite having the most extensive shelterbelt system. The apparent "economies of scale" advantage for the largest producer is somewhat reduced when cost share programs are considered. For example Farm A experiences only the third largest cost reduction percent in cost per pig.

Under the seedling price scenario and without cost share Farm B, the second largest farm studied with the second most extensive odor mitigating shelterbelt system has the second highest per pig produced costs. When cost share is considered Farm B’s per pig costs are ranked third; this is due to Farm B receiving the highest percentage cost reduction. Under the high price scenario and without cost share Farm B’s shelterbelts are the most expensive; this is due largely to Farm B having the greatest per tree costs. With cost share under this scenario, Farm B has the second highest costs with the second highest percent cost reduction.

Under the seedling price scenario, Farm C’s shelterbelt systems are the most expensive, both without and with cost share (despite receiving the second highest cost share related cost reduction). This is largely due to it being the second smallest farm, producing only 1,600 head annually. Under the high price scenario Farm C is the second most expensive without cost share and the third most expensive with. The change in ranking between the price scenarios is due to Farm C: 1) having the lowest "high price" and 2) receiving the highest percentage cost share related cost reduction.

Farm D, being the smallest farm studied producing just over 1,000 head per year, without cost share benefits has the third most expensive shelterbelt system in both price scenarios. When cost share is considered, under the seedling price scenario it has the second most expensive shelterbelt and under the high price scenario Farm D has the most expensive shelterbelt systems. Both of these changes are largely due to Farm D receiving the lowest percentage cost reductions under both price scenarios.
Based on the above cost information, it is clear that the use of shelterbelts, in many cases only add a few pennies to overall production costs. The results of this study also emphasize the importance of cost share programs. As with the use of cost share programs all the costs examined are below the USDA (1996) swine producer willingness to pay for odor control. Some of the results even show ample feasibility excess (possibly as much as $0.33 - $0.59 per pig produced extra costs to spare) to suggest room for shelterbelts to be part of a "suite of technology". It is recognized that with regards to odor control, no single technology is 100% effective, yet if a comprehensive management program is developed and followed, nuisance odor can approach elimination (SOTF, 1995).

It should be noted that with regards to how shelterbelts mitigate swine odor, in that effectiveness of trees and shrubs is based on the way shelterbelts manipulate wind patterns and airflows, there are some limited technological substitutes. Artificial windbreak walls (sometimes known as Air Dams), made of wooden braces and poly-blend tarp materials and biofilter walls made of hay bails and or some other organic matter held in a chicken wire matrix can provide many of the shelterbelt benefits thinking specifically of dilution and particulate control (Bottcher et al., 2000; Hoff, undated research brief). These technologies do have the distinct advantage of likely being effective immediately after construction. It is believed that depending on the size of the growing stock at planting, species used, and geographic locations, shelterbelts will take at least 3-5 years before reaching an appropriate size and shape for efficient wind manipulation and adequate provision of filtering surface area. Yet the use of this artificial technology is really limited to the filter zones of the farm. Filter zones being the main ventilation areas of the facility. These alternatives also do not create any of the aesthetic benefits of using shelterbelts that in many cases may be one the main perceived benefits (DeYoung, 2002; National Hog Farmer, 2002).

Shelterbelts also have further distinct technological benefits over these other approaches. The use of shelterbelts is a legitimately size neutral technological method for dealing with odor. As this study shows, shelterbelts can be designed for relatively large farms (Farm A) and for comparatively small farms (Farm D). This example also emphasizes that shelterbelts are also technology neutral in that regardless the pork production method and manure storage method (e.g. Full confinement vs. hoop house; mechanical vs. natural
ventilation; earthen pit/lagoon vs. above ground concrete manure storage) shelterbelts can be
planted in reasonably unobtrusive ways, not in any way impacting the efficiency of the
production of pork. Perhaps, the most interesting technological advantage that shelterbelts
possess is that it may be the only approach to dealing with swine odor that isn’t limited to
swine producers alone. Rural individuals and communities alike can plant shelterbelts.

To conclude, two critical points need to be made. One, because of the time it takes
shelterbelts to reach effective size proportions; it is critical that shelterbelts are planted as
soon as possible. While shelterbelts are easily retrofitted, ideally they should be co-planned
with all new facilities. Second, it is perhaps most critical that the use of shelterbelts gain
more credibility as an odor mitigating technology among agricultural engineers and
agricultural extension personnel. It is the advice of these experts in the field that often
decides that fate of a technological approach. And as mentioned near the beginning with
regards to how EQIP is managed, it is very often up to them (i.e. state Department of Natural
Resources, NRCS) to have a technology listed as a Best Management Practice and therefore
part of much needed cost share possibilities. Pork producers are in a legitimate quandary in
that they face distinct risk of nuisance litigation at the same time that their profit margins are
thin at best and very often negative on average. The costs of even pennies per pig can seem
too much to bear under such economic conditions. As other studies have shown in the past
that when the government offers to help pay for agricultural externalities such as air and
water pollution, farmers are much more likely to participate in promoted technological
approaches (Purvis et al., 1989). It is our contention that shelterbelts can and should be a part
of overall plans to improve the sustainability of both rural communities and of the livestock
industry. In states such as Iowa and North Carolina time is of the essence.
References


ENVIRONMENTAL RESPONSIBILITY, CONSUMER VALUES AND THE USE OF TREES TO MITIGATE SWINE ODOR

John Tyndall and Joe Colletti

Abstract

This paper is an interpretive analysis of a series of focus groups that examined the notion that environmental quality (with special reference to air quality and swine odor) may be marketed by way of producing and labeling as such, "environmentally friendly" pork products. Part of the analysis examines pork producer and consumer interest in the use of shelterbelts as an environmental quality enhancing technology. Four focus groups (two each of pork producers and pork consumers) occurred during the summer of 2002. The results of the focus groups benefit our research approach in two main ways. One, revision of survey tools to be used in the near future, based on feedback provided by the focus group participants allowing calibration for higher levels of precision and validity. And two, enhancement of our theoretical approach to examining attitudes and behavioral intentions in ways that will help bolster expressions of: 1) producer interest in use of shelterbelts for odor mitigation; 2) pork producer interest in producing and marketing pork with enhanced environmental (i.e. reduced odor) attributes; and 3) consumer willingness to pay for pork products that are labeled as 'environmentally friendly'. The two pork producer groups consisted of a total of 16 Iowa hog producers all of whom have raised hogs for over twenty years. The pork consumers were selected based on their majority role in the food shopping for their family. The two pork consumer groups consisted of a total of 21 pork consumers.

Pork producers identified likely common barriers to the on-farm use of shelterbelts. They acknowledged that introducing trees or simply having them as part a livestock system does require knowledge of tree growth and maintenance to maximize tree health and prevent unnecessary tree mortality (e.g. avoiding certain herbicides, proper mowing procedures, and providing suitable moisture levels). Essentially producers will need to take on a new
relationship with the ecosystem within and around their facilities to create and maintain the most effective shelterbelt designs.

Producers indicated the potential role of government cost share and/or incentive programs to pay for incremental odor mitigation measures. The use of BMP's will likely guide approval of odor mitigation progress (van Ravenswaay and Blend, 1997). Therefore it is imperative that beneficial technologies gain recognition.

If consumer's pay for environmental protection by way of a premium for pork products produced with more pollution control then the "traceability" to the producer must be transparent. Pork products must be able to be traced back to the environmentally sound production source. Also consumer preferences regarding "natural" technology such as shelterbelts as a recognized BMP should be incorporated by producers whenever possible.

Continued research is needed into the quantification of the ability of specific shelterbelt designs to mitigate hog odor. Also producer-oriented extension must occur to provide appropriate informational materials and outlets explaining the benefits and costs of using shelterbelts. Additional consumer education must be developed that leads to consumer awareness of agro-environmental quality issues. Some consumers must express their environmental concerns by purchase of differentiated pork meat products.

Background

It's been said that the sustainability of industries within agriculture will be shaped by its collective ability to improve environmental impact technologies (Kliebenstein, 1998). Perhaps it is the US swine industry that illustrates this idea best. While water quality issues have long been the main environmental concern regarding the hog industry (Jackson, 1997), it is swine odor nuisance that may prove to be the most damaging to both rural communities, the swine industry, and to state economies. As suggested by R. Douglas Hurt, director of the Center for Agricultural History and Rural Studies at Iowa State University:

"Hog odor is the most divisive issue ever in agriculture, damaging the fabric of rural society, and disenfranchising pork producers from their communities, even on the roads in front of their farms." - (ATTRA, 1999, pp.8-9).
Odor emitted from concentrated livestock production facilities, particularly pork production, is a significant social problem that is negatively impacting rural and state economies, human health, and the quality of rural life (Wing and Wolf, 2000; Thu and Durrenberger, 1998). Compounding the situation, hog odor is largely unregulated. There currently are no federal laws that regulate livestock odor and few state laws (Chapin et al., 1998). Yet legal protections once extended to many pork producers against nuisance litigation have been considerably relaxed. And, the risk of litigation is on the rise. Pork producers are often singled out as the entity that should bear the full responsibility for ameliorating pollution that comes off their farm. The commodity pork market is characterized by narrow profit margins, so pork producers perceive limited incentive (or ability) to take on extra costs beyond standard manure management practices to deal with odors originating at their facilities.

**Market Potential for “Environmentally Friendly” Pork**

There may be however, a market-based approach that provides sufficient incentive for producers to incrementally reduce personal nuisance litigation risk and social dissonance that arises due to swine odor through enhanced odor mitigation technology. Economists have suggested that consumers may be willing to pay extra for expected public benefits such as reductions in odor pollution. The Swine Odor Task Force assembled by the North Carolina General Legislative Assembly has recommended that market-based incentive approaches be used to deal with livestock odor. A certification process might offer marketing advantage if products were packaged with labeling “produced with conservation benefits” (SOTF, 1995). A recent national survey by the Federal Reserve Bank of Chicago “indicates that over half of America’s consumers are willing to pay some premium for food produced in a socially and environmentally responsible manner” (Hudson, 1998). Another survey by Better Homes and Gardens® magazine found that 80% of the respondents would be willing to pay more for pork

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1 Only 10 states regulate livestock odor directly. Iowa and North Carolina only deal with swine odor indirectly largely by way of separation distances (depending on the size of the production: 750 – 3000 ft for Iowa and 750 – 5000 ft for North Carolina).

2 Very recently a $33 million dollar nuisance remedy ($32 million of it punitive) against a hog confinement operation was granted to four families in northwest Iowa, with the main offender in the compliant being unpleasant odors and noxious gasses (Des Moines Register, 2002).
products produced in ways that protect the environment. Moreover, 56% would be willing to pay between 10 and 25 cents more per pound for “environmentally friendly” pork meat, and nearly 30% stated price was no issue (McGlone, 2000).

Expressing a willingness to pay is different than actual observed purchasing behavior. Kliebenstein and Hurley (1999) used an experimental economic method (a Vickery auction) to determined consumer willingness to pay specifically for environmental sustainability and improvements in air, surface, and ground water quality as affected by pork production (Kliebenstein and Hurley, 1999). Sixty-two percent of the participants (n = 329, distributed across four different states) actually paid up to a 22% price premium (their revealed preferences) for pork meat produced at a production site that made significant provisions for air and water quality protection. The provisions were not described.

Consumer theory suggests that consumer utility and choice is based on the attributes of the product, so the more desired attributes are bundled, the more attractive the product. Consumers also seem to prefer certain management strategies and technologies that livestock producers use to enhance or protect environmental quality\(^3\). Hurley and Kliebenstein (2000) found in a study of pork meat consumers that 82% of the respondents were somewhat to very concerned about environmental impacts, particularly air quality, associated with pork production. Consumers expressed a preference for management strategies that were perceived as being more “natural” as opposed to being chemical or mechanistic in nature. Additionally, 68% of respondents were somewhat to very accepting of air filtration from buildings as a means to capture and dilute odor (Hurley and Kliebenstein 2000). These results suggest consumer preferences for agro-environmental quality could be bundled with preferences for “natural” management/technology methods.

### Odor Mitigation with Shelterbelts and the Marketing of Clean Air: An Exploration

To resolve the hog odor problem two needs arise. First, to mitigate swine odor in the most biophysically effective and financially efficient ways possible. Second, to allow the

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\(^3\) It should be noted that consumer preferences for agricultural air and water quality could be directed toward local or regional agricultural concerns or toward global concerns (or both). Examples of global concerns may include: reducing fossil fuel consumption, NOx air pollution, global warming, and hypoxia in the Gulf of Mexico.
consumer and producer preferences and values to guide appropriate odor mitigation technology.

Research evidence suggests that shelterbelt arrangements near and within livestock facilities can play a significant role in bio-physically, socio-psychologically and economically mitigating odor (Khan and Abbasi, 2001; Bottcher et al., 2000; Laird, 1997; Themelius, 1997). Overall, there is a need to assess producer and consumer attitudes, values, and behavioral intentions regarding modified livestock odor management strategies that include the use of "natural", live plant-based bio-filters (e.g. shelterbelts). This paper presents results from part of a study of pork producers, odor mitigation, living biofilters (shelterbelts), and pork consumers. We examined three main topics:

1) The opinions of pork producers pertaining to the use of shelterbelts for odor mitigation;

2) The interest of pork producers in producing and marketing environmentally differentiated pigs; and

3) Consumer interest in environmentally friendly pork products and the farm technology used to produce it.

To evaluate these three facets of our research, several questions need to be answered directly. Technology diffusion research suggests that producer use of management strategies is often a functional relationship between various incentives and the socio-economic variables of individual producers (Clifford and Hoben, 1995). In terms of managing odor with shelterbelts, what are these incentives and socio-economic variables? How might government incentive programs be involved? How can producers modify their technology and management to include shelterbelts? Pertaining to pork consumers, what is consumer understanding of odor management using shelterbelts? Are consumers willing to pay a premium for pork produced with preferred odor control technology? How can improved consumer education be facilitated? Thinking of the marketing aspects of our inquiry, if consumers are willing to pay premiums, how might producers gain access to these premiums? Can the incremental cost of enhanced odor management strategies involving
shelterbelt buffers be more than offset by price premiums received by producers operating in this new market?

Methodology: Pork Producer and Consumer Focus Groups

Surveys of pork producers in Iowa, North Carolina, and Washington State as well as a concomitant survey of pork consumers from those same states will be administered during the spring and summer of 2003. To refine and enhance these surveys four focus groups (two each of pork producers and pork consumers) occurred during the summer of 2002. The results of the focus groups benefit our research approach in two main ways:

- Revision of survey tools based on feedback provided by the focus group participants allowing calibration for higher levels of precision and validity.
- Enhancement of our theoretical approach to examining attitudes and behavioral intentions in ways that will help bolster expressions of: 1) producer interest in use of shelterbelts for odor mitigation; 2) pork producer interest in producing and marketing pork with enhanced environmental (i.e. reduced odor) attributes; and 3) consumer willingness to pay for pork products that are labeled as ‘environmentally friendly’.

Focus groups are an excellent tool to help researchers bridge gaps between themselves and their target audiences in vocabulary, language, culture, regions, and ways of thinking (Sterns and Ricks, 1999). Theoretically, the survey tool is capable of recording consumer behavioral intentions to act in a certain way (spend money on certain foods), yet there is often a discontinuity between behavioral intentions and actual behaviors, particularly when it comes to environmental (“green”) decisions. There is a call for behavioral research to limit the distance between what is known as the Attitude – Behavior split (A-B split) (Bell, 1998).

The focus group discussions helped tremendously in designing research tools designed to find high A-B correlations as suggested by Unger (1994): 1) Use of multi-indexed questions that allow for checks on internal consistency and cross correlations; 2) A-
B measures that are high on specificity and conceptual congruency. Specificity is enhanced when both variables (A and B) are measured at the same level of specificity. Congruency is enhanced when it can be *a priori* surmised that a particular attitude can/will improve likelihood of actualized behavior. And, 3) a close examination of the contextual variables that play significant roles in how consumers behave. Two levels of context will be examined. Personal level context involves behavioral intentions and attitudes towards the act and situational level context involves reference groups, immediate social influences, visibility and awareness of products, and consequences of the behavior.

**The Focus Groups**

The focus group discussions were between 1.5 and 2 hours long and participants were initially contacted by phone. The focus groups were administered and performed by personnel from the Statistical Lab at Iowa State University. Participant lists and list sources are being kept strictly confidential.

The producers selected for participation consisted of a mix of production sizes and production techniques to ensure a blend of needs, experiences, and ideas to add robustness to the discussions. The two pork producer groups consisted of a total of 16 Iowa hog producers all of whom have raised hogs for over twenty years. In total, five producers raise over 5,000 head annually, six raise between 2,000 and 5,000 head, four produce between 1,999 and 500 head, and one producer raised less than 500 pigs annually. Three of the producers used hoop structures while the rest had confinement operations. Ten producers operate farrow to finish operations the others were primarily finishing farms. Several producers did custom feeding for particular marketing reasons. All but two producers were male, the average age at their last birthday was 46 years, and the majority had at least some college education. Ten of the producers have operations located less than one half mile from their nearest (non-relative) neighbor, the others had facilities between one half and one mile from their nearest (non-relative) neighbor.

The pork consumers were selected based on their majority role in the food shopping for their family. The two pork consumer groups consisted of a total of 21 pork consumers. All but four of the consumers were female. The average age of the participants at their last
birthdays was 55 years. Ten of the consumers have children under the age of 18 living at home. Nine consumers lived in cities with populations over 50,000 and eight consumers lived on farms, the rest lived in towns of less than 2,500 people.

**Findings and Observations**

The following is an interpretive analysis of the four focus group discussions. Whenever possible key participant quotes are used. The pork producer participants are identified by size and type of operation listed in parentheses after each comment. When needed, missing contextual information is included in parentheses within the quoted comments. And on occasion the level of consensus by the group over particular comments or ideas is also displayed.

Again, the focused discussions with the pork producers centered on two main topics:

1) Pork producer interest in use of shelterbelts for odor mitigation;
2) Pork producer interest in producing and marketing pork with enhanced environmental (i.e. reduced odor) attributes;

The discussions with the pork consumers centered on one main topic:

1) Consumer willingness to pay for pork products that are labeled as ‘environmentally friendly’.

**Pork Producer Opinions Regarding the use of Shelterbelts and Odor Mitigation**

*What do pork producers think about shelterbelts and landscaping in general?*

*With regards to odor mitigation what did they think might be the advantages of this technology?*

There was a distinct understanding of the socio-psychological benefits of using shelterbelts specifically for odor mitigation among the producers. The notion of “out of sight-out of mind” was prominent in the discussion of advantages as was a high level of agreement about the general aesthetic improvements that trees in and around pork production facilities can make. Comments such as “I would rather have a nice set of buildings with trees than a neighbor with a run down farm, and junk all in their yards.” (Feeder hogs – 2 hoop buildings) and “I don’t know for sure if they do anything about odors, but they sure do camouflage
some of these facilities" (Mid sized - custom feeder) received majority agreement among the participants. But there was a perceptible level of uncertainty about the bio-physical ability of shelterbelts to ameliorate odors, "Where I live, over by a huge (pork complex), they put a ring of trees around the place and it sure looks a lot better. But I don’t know if it helps much with the odor because when the wind is right I still smell it. (Mid sized crop farm/ custom finishing)" or "In Arkansas, with chickens, they are all hidden behind trees, but now that odor just sort of oozes through all those trees. (Small farrow to finish 3)". This is a critical issue in the adoption and appropriate use of this shelterbelt based technology (Khan and Abbasi, 2001; Ucar and Hall, 2001). The use of shelterbelts needs to be based on an engineering approach applying sound logic to design details and a comprehensive ecological plan for the trees for pork producers to manage odors with shelterbelts. But because field based quantification of the biophysical advantages is currently lacking and published examination of the concepts are limited (Inside Agroforestry, 2002), anecdotal evidence is largely driving any interest in the technology. And as noted above, along with positive anecdotal evidence, there exists negative anecdotal evidence. It was clear, that among the producers present, a technical understanding of the shelterbelt/swine odor dynamics was lacking. The idea that trees “might keep the odors from blowing around (small scale- hobby pork producer)” was as technical as the understanding got. Because of this, any understanding of the beneficial use of trees seems to be largely limited to only the aesthetic advantages. Though there was a distinct interest in learning more about the concept. Nevertheless, it is critical that it is understood by all interested that the use of shelterbelts for odor mitigation involves an engineered or “designed” approach. There is a significant difference between a farm/facility that has trees on it and even a farm/facility located in “the woods” and a specifically designed shelterbelt within a system of inter-linking shelterbelts. This point is a call to us as researchers to expand our quantified knowledge of this technology and for the creation and dissemination of proper extension materials that serve to guide producers with the appropriate use of shelterbelts for maximum odor mitigation results.\footnote{Both laboratory and field work on the quantification of the effectiveness of shelterbelts to mitigate odor is currently underway (Bottcher et al. 1999). There are also currently 10 Iowa livestock producers who are}
There was, however, a general understanding that the mitigation of hog odor is not as simple as “putting in something (technology)”. Indeed there are limitations to all technological approaches to livestock odor mitigation (MWPS, 2001). The observation that, “It’s all about concentration. I mean too big is too big no matter what you do. Plant whatever you want and it’s not going to do anything. ” (Small family farmer, 248 crop acres/100 sows) recognizes the bio-physical limitations of shelterbelt use. It is likely that there is a threshold at which shelterbelts (and other technologies) are simply overwhelmed and a nuisance situation could exist. Though exact scientific and engineering guidelines for pork facilities do not exist it can be surmised that there exists a continuum of effectiveness, largely based on the type of production technology and the number of animals being managed. Based on the evidence available (Kahn and Abassi, 2001; Bottcher et al., 2000) the lower the overall level of odorous emissions emanating from a production site, the more effective shelterbelts can be. Researchers are confident that shelterbelts (particularly in combined use with other odor reducing strategies) can make significant positive changes in the so called FIDO factors of odor nuisance perception, that is the frequency, intensity, duration, and overall offensiveness of the odor event being experienced (MWPS, 2002; Gassman, 1995).

A very interesting point well received was made by one producer, “I would be very interested in knowing what the public thinks of these things, because it doesn’t matter if shelterbelts really work or not (as long as) the public thinks they do, it might be worth it ” (Small scale farrow to finish). So this means the public relations benefits alone might be worth the extra cost (money and time) involved in establishing and maintaining shelterbelts. In fact the statement ‘Shelterbelts are a public relations tool to help display stewardship efforts’ was greeted with complete group acceptance further establishing this potential benefit.

**Barriers to Using Shelterbelts for Odor Mitigation**

There was a high level of agreement that the presence of trees often presents unwanted hassle and increased work. Prevalent commentary included: “Too much effort for participating in Iowa State University’s Odor Control Demonstration Project using landscaping that was planted in 1997.
upkeep – you've got to deal with them for a long time.” (Large scale farrow to finish), “Added frustration” (High level of agreement), and “You need expensive mowing equipment.” (Small scale feeder production – 2 hoop buildings). Concerns about on-farm health hazards were also prevailing. Unwanted wildlife was of greatest concern, some producer comments included, “I also go with the idea that it’s (having shelterbelts) just going to harbor more rodents.” (1800 ac crops/ 6500 feeder pigs), “Animal and disease control (will be a problem)... If you bring more animals (wildlife) to the buildings (by giving them habitat), you might increase the spread of diseases.” (300 sow hoop producer) and “Mice, rodents” (high level of agreement).

These concerns are valid. There will be time requirements for maintenance that may or may not include: mowing, spraying, irrigation, and occasional tree replacement as 5 -10% (or more) tree mortality is common over the first 10 years even for many otherwise healthy shelterbelts (Horvath, 2002). Likewise, care may be needed to watch for hazard tree situations and storm damage clean up is possible from time-to-time. Yet typically, maintenance requirements do have a tendency to lesson as the shelterbelt matures. Requirements are highest during the establishment period (years 1-5) and become less throughout the juvenile stage (6-10) and beyond. Still, it is possible for management needs to be fairly continuous over time, “(We) put them (shelterbelts) up and then 20 years later they start dying and now we are spraying them twice a year.” (Contract feeder – 8,000 head). There has been very little evidence that this has been a serious problem with crop field shelterbelts. Undoubtedly further scientific investigation is needed to fully answer this question. Some producers expressed a concern about required space to accommodate trees and the production buildings and manure storage areas. Another producer concern was the negative impact trees have on crops. The producers agree that shelterbelts “(Take) cropland out of production.” (High level of agreement).

There were also producers who felt that the presence of trees would create unpleasant or even highly detrimental situations on their farms. Concerns such as “I don’t want to restrict airflow in the summer.” (Feeder hogs – 2 hoop buildings) or “I hoop finish so I don’t want a bunch of trees around anyway because I want those summer winds and in the winter we just stack hay bales, which do the same thing, and we don’t have to mow around
those (300 sow hoop producer)” were two expressions of this apprehension. These concerns are extremely valid from a shelterbelt design standpoint particularly for pork production systems that rely on natural ventilation for both air quality (dissipation of dust and gasses) and animal health reasons (temperature control). Shelterbelt designs can accommodate these concerns.

Financial Feasibility and the Use of Shelterbelts
The most decisive issue involved in the creation, adoption, and diffusion of appropriate environmental quality technology that came out in the focus group discussions is the financial feasibility of individual producers to use technology such as shelterbelts. Because much of the technology used for environmental (i.e. water and air) improvements and/or protection entails extra cost that typically have no offsetting returns, shelterbelts may add a financial burden to producers.

We asked pork producer to indicate how much it costs for their current odor management practices. When asked what they are currently paying on a per animal basis for odor mitigation the discussion centered on comments such as:

“I'd have no idea how to figure this” (high agreement)

“I could guess but…”

“Does this include fixed costs?” (Farm manager for absentee landowners, Farrow to finish – large scale)

“I might be doing something for other reasons, but it might deal with odor too so does that count as an odor control cost?” (Mid sized - crop farmer and finisher)

“I don’t think anyone could answer this over the phone, none of us would have a per head cost on that” (high agreement).

Confusions in answering these questions indicate a further need to investigate how symmetrical financial feasibility information is between the creators and promoters of odor mitigation technology and the users and managers of this technology. Asymmetries (if they exist) such as this can lead to a market failure of sorts in the use of beneficial and appropriate
environmental quality technology. Perhaps this is a partial answer to why a lot of biophysi-
ically effective odor mitigating technologies often get underused (SOTF, 1995).

A follow up question asked what producers might be willing to pay to deal with odor (ultimately seeking a maximum willingness to pay for odor mitigation). During the focus group however, it became evident this concept of willingness to pay for odor mitigation is certainly not very straightforward. When the producers were asked about possible willingness to pay for odor mitigation, two points of contention stood out. One point was the idea that willingness to pay for non production related technology and management has distinct temporal qualities, “I see a problem with willingness to pay depending on what stage of the (economic) cycle your in, whether its (market price received by producers) at 50 cents/ lb or at 20 cents/lb” (Large-scale farrow to finish 1) and “If you asked today (a day of low market prices) we would most likely say ‘nothing’” (Large-scale farrow to finish 2). The other point is the idea of whose responsibility is it to provide (pay for) environmental quality above and beyond what producers already feel they are providing. Producers were concerned about their costs. The observation that “I’m all for these buffers … But unless the government is going to come and pay for them (buffers) then I’m not going to (plant them)” (large farrow to finish 1), represented a general sentiment of the producers present. There was a understanding of the potential for governmental subsidies by way of cost share or other incentive programs, “As far as putting up shelterbelts there is government money through the NRCS, you know so costs might not be that great” (small family farmer 248 crop acres/ 100 sows), was a comment that received a high level of understanding. Other reactions included: “If you get really good feedback on something like this (the survey), who’s to say they (the government) won’t pay for it (environmental quality technology)” (Small scale farrow – finish 1) and “If the American consumer cares about these things, they might be willing to pick up the tab (by way of tax dollars)” (Small scale farrow – finish 2). Still, there is clear frustration on the part of producers, as they desire to be good stewards and good neighbors but feel constrained financially to go “above and beyond” what they are already doing, “…we all understand the importance (of dealing with odor) and (the issue is) becoming more important, but we can only do so much with things as they are (referring to the weak agriculture economy)” (large scale farrow to finish 1) (high level of agreement).
The Pork Producer Marketing Segment

Potential of Environmentally Friendly Niche Marketing

Another goal of our study is to evaluate producer interest in marketing environmental quality through the production of environmentally friendly pork products with particular attention to the use of shelterbelts as a preferred Better Management Practice. The central concept is that producers will receive a price premium for live animals that eventually become these products. We began this topic with a discussion of niche marketing in general. While all the producers were familiar with the idea of niche marketing differentiated pork products most felt that such marketing wasn't realistic for their type of operations. Though three producers participating in these focus groups used niche markets (one whose animals end up primarily as entrees in high end restaurants in Iowa, another markets mostly in the US west, and a producer who raises only Berkshire hogs and sells them for their unique marbling qualities). Ultimately, with the subsequent survey we are attempting to quantify current and potential niche marketing. We are interested in the type of arrangements (i.e. contracts or other measures) that are available to producers. One Iowa producer pointed out, “Contract feeding is getting to be a lot of the production around here, so not many producers are actually marketing anything anymore.” (Contract feeder – 8,000 head). Examinations then will need to be made into the myriad of different contracts (or other arrangements) possible, for example arrangements between hog growers/producers and the integrators (owners of the pigs), between integrators and the packers, between packers and food distributors/food brokers, and variations in between.

Despite marketing complications, a fair number of US pork producers currently participate in a niche market of some kind. For example a recent Iowa producer survey showed that about 25% of Iowa Pork Producer Association members sell hogs by “specialty or niche” marketing (Iowa Pork Producer, 2002), and even more producers are interested in entering a niche market. That same survey estimated an additional 47% of member producers were “Interested, but not participating” in value added/niche marketing.

Many niches, involve meeting consumer preferences for meat quality attributes such as extra-lean meat, certain breed related marbling qualities or even extra fat - “I get paid
more for the west coast market for pigs with more fat” (Small scale farrow – finish 2). Marketing non-meat quality attributes, specifically environmental attributes, however, is different. This difference was noted during the discussions as one of the small scale producers questions, “And then you ask what a consumer would be willing to pay? … for odor I don’t think anyone would care. These urbanite sorts might pay more for no antibiotics or animal byproducts (for health reasons), but odor?” (Small scale farrow - finish 1). Interestingly, there are meat products that receive a substantial amount of consumer interest that may fall into both categories at the same time, and that is the marketing of organic or ‘natural’ meats⁵. There are consumers who purchase organic/natural meats for health and/or food safety reasons, but there are also those who purchase these same products for additional (and in some cases singular) reasons that involve issues such as animal welfare and environmental preservation (Wheatley, 2001). But despite this notion and studies that show a considerable degree of consumer interest in environmentally friendly meat (Kliebenstein and Hurley, 2000; SARE, 1999) there was a high level of skepticism noted by pork producers regarding the marketing of ‘environmentally friendly’ pork⁶, for example, “Does anyone (here) know of any markets for environmental quality? Is this (examining the market potential) even a good question?” (small family farmer 248 crop acres/ 100 sows). In the context of getting paid through the market for using specific environmental quality technology such as shelterbelts, the following remark from a small scale farrow to finish producer had most producers agreeing, “You might have to do it (plant shelterbelts) on a grant sort of way (i.e. cost share programs) rather than paying a little bit at the supermarket. It’s a little unrealistic to think that they (consumers) would do that (pay more money at the grocery store)” (Small scale farrow – finish 2) and “If you polled, say, New York City, where

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⁵ The USDA endorses three different Organic pork labels - "100 percent organic" – Pork products produced exclusively using organic method as defined by the USDA organic regulation; "Organic" - 95 percent or greater of the ingredients (by weight, excluding water and salt) are organically produced. The remaining five percent must be on the National List of Allowed Synthetic and Prohibited Non-Synthetic Substances; and "Made with organic" - 70-95 percent of the inputs (i.e. feed) are organically produced. The organic ingredients need to be listed on the principle display panel. Whereas Natural pork includes products that have been processed and handled in compliance with USDA natural standards (USDA FSIS Policy Memo #055). These standards prohibit the use of artificial ingredients, coloring ingredients or chemicals and require minimal meat processing. www.iowapork.com/production_orgnat.html.

⁶ A key assumption is that the meat quality and meat safety attributes are unchanged, the product is differentiated only because extra odor management was under taken.
probably not many people have ever smelled (hog) odor, I think the average consumer won’t even know what you mean (about environmentally friendly or “clean-air” pork). Or care.” (small scale farrow – finish 2). Still it was mentioned that natural food and specialty meat stores are “popping up all over the place” and wouldn’t be doing so if there weren’t people willing to buy these types of products.

Kirschenmann (2001) noted that specific examinations of the marketing of differentiated pork products need to identify what advantages can these kinds of markets provide to producers. Probing the advantages of producing differentiated pork with attributes linked to greater odor control, the producers identified the need for a reliable market arrangement or mechanism that allow premiums to flow back to the producers. As the higher prices are very often paid closer to the consumer end of the value chain it was recognized that, “…higher prices get lost in the middle somewhere. We (pork producers) never see any of the money.” (300 sow - high-end restaurant market). And while higher prices can be received by the producers (such as by the focus group participants who essentially direct market their hogs), there may or may not be any advantages such as a steadier or more consistent price or demand for the differentiated hogs in that, “Higher prices for these (differentiated) products also depend on the market cycle. When everyone else was getting $10 and I was getting $30, well it made a difference but when everyone was at $60 and I was at $55, well then…” (Small scale farrow – finish niche marketer 1).

Though the producers participating in the focus groups did not show much interest themselves in this concept, it was suggested that some kind of assurance would definitely be needed to limit any risk the producer might feel from attempting a new product, “I think some (producers) would do this depending on how stringent you (labeling entity) are on the rules. If you were willing to spend so much on extra odor control then how much would you need in return to do this?” (small farrow to finish 1) and “Any interest would probably depend on the return and the assurances. And how much cost and hassle.” (small farrow to finish 2).

There seems to be debate among producers as to what constitutes environmental improvements or protections, “I don’t like this question at all because every one (all pork producers) will say they have clean water and air.” (crop farm/custom finisher) and “How
can one product be ‘clean air, clean water’ when we are all doing these things (to keep pollution down)?” (1800 ac crops/ 6500 feeder pigs). If one production site is declared to be an example of good stewardship because of “extra” odor mitigation management, what might that suggest about those producers who do not appear to have extra odor mitigation management. From an industry point of view there may be risk in such potential dichotomies. Many of the producers think there is a need to educate consumers about what pork producers are doing to deal with environmental issues such as odor control. When asked ‘which of the following do you think are the most effective ways to educate consumers about these ideas? Would you suggest using ... printed materials available at the meat counter, public service announcements on TV or radio, newspaper articles, or even Web sites’, a common theme appeared yet again, “All these might work but who pays for them?” (high agreement).

**Pork Consumer Focus Groups**

The producer focus groups indicated a well-developed consumer interest is needed to give pork producers reason to start marketing “clean-air” pork. Research has shown that very often, social context (i.e. convenience, expense, social norms) was the major determinant of many environmental behaviors. “Social context alone was sufficient to produce the desired behavior, while pro-environmental attitudes simply enhance the effect of context...” (Derksen and Gatrell, 1993)

To gauge environmental awareness (however individually defined) of consumers, we asked consumers to rate themselves with a ‘green scale’ – ‘How often do you consider environmental issues when purchasing food products? On a scale of 1 to 5...’. During the focus groups only one consumer stated that environmental issues played a major role in her food shopping. We examined revealed preferences for food products that possess non-food attributes and the shopping context that enables consumers to reveal preferences. Shopping context means what is needed to enable a consumer to easily meet their demands for environmentally friendly foodstuffs. Examples of ‘context’ include where pork consumers primarily shop for meat, what kind of consumer education they are familiar with (i.e. labels),

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7 This study was primarily examining attitudes toward recycling and subsequent recycling behavior.
and beliefs about the consequences of their shopping behavior (i.e. an improved production environment).

Considered as a socio-contextual issue ‘environmental labeling’ is key to the sale and purchase of differentiated meat as environmental labels may allow consumers to express their preferences for an embodied environmental characteristic of that (otherwise undifferentiated) good (Erickson and Kramer-LeBlanc, 1997). Further, it is presumed that interested consumers will be willing to pay higher prices for these differentiated foods, thereby stimulating a supply response (Erickson and Kramer-LeBlanc, 1997). Product labeling has been defined as “any policy instrument of a government or third party policy that somehow regulates the presentation of product-specific information to consumers” (Teisl and Roe, 1998). A distinction is also made between labels that describe, “use” characteristics such as price, taste, and nutrition and labels that describe “non-use” characteristics which include environmental impacts and/or animal welfare issues regarding the products production process (Teisl and Roe, 1998)\textsuperscript{8}.

The presumption is that the use of shelterbelts to enhance odor control is a ‘non-use’ environmental attribute and should have no impact on the meat itself. Several consumer participants brought up the important issues about whom the labeling entity should be, “I am way at the extreme when it comes to shopping because I specifically look for labels. As an organic food buyer, I don’t go by governmental approval; I go by independent third party organic certifying agencies. Then there are consumer advocacy groups that give their approval (as well). The Food Alliance out in Washington (state) does this.” Also a distinction was made between trusting a label (i.e. trusting the labeling entity) and finding that a label has “swayed (their) purchase” showing the importance of separating these concepts in future survey questions. It was suggested during these focus groups that programs such as the National Pork Boards’ “Pork, the Other White Meat” promotional slogan may have more impact on purchases of particular pork than the label alone as one consumer noted how such slogans have become “part of our culture”\textsuperscript{9}.

\textsuperscript{8} Though there are products that to many consumers’ ‘use and non-use’ are intertwined, such as with organic foods that are purchased for a combination of use and non-use reasons (Wheatley, 2001).

\textsuperscript{9} This has added implications as the “Pork, the Other White Meat” promotion was funded with the now contested pork checkoff dollars, yet may have a very beneficial pork industry impact.
Where consumers shop for meat may have major implications for optimal product location of environmentally friendly pork. For example, Grannis et al. (2000) found that people who do most of their shopping at what are recognized as “natural food stores” exhibit higher than average environmental awareness and display more revealed preferences for environmentally differentiated beef and pork (e.g. “natural” pork). Both the consumers and the pork producers who participated in this focus group series recognized the potential of natural food stores (or “health food” stores) as potential outlets for a differentiated pork product, “To a lot of people a natural food store is their supermarket”. However it should be noted that research on other differentiated pork (natural pork) showed that there are substantial segments of the population willing to pay premiums, indicating that there may be demand suitable for traditional grocery stores (Grannis and Thilmany, 2001).

Discussion of willingness to pay for environmentally friendly pork products brought out a number of important insights. One, it was believed by most of the consumers that there would be distinct proximity effects regarding the appreciation and therefore demand for a product that is labeled for reduced odor benefits, “People who have never been bothered by odor will probably be unwilling to pay extra.”. In agreement with the sentiments of the pork producers, demand for environmentally friendly pork (emphasizing reduced outdoor/local odor) may likely decline the more urban the consumer is – “If someone in Des Moines (Iowa) gets asked this question (WTP for environmentally friendly pork) they are going to say $0” and may also depend on the experience that consumers have with agricultural pollution in general, “Whether or not if someone’s been touched by odor or not might be what makes them care. Or water problems might make them care about odor too.” Still, another consumer comment received a high level of acceptance, “In response to the idea that ‘city folk’ probably won’t care much about these ideas - Very recently there was a hog manure holding tank that burst and ended up in the Des Moines River. People read the paper and have information.”, implying that increased media exposure about environmental issues can be a factor in consumer education and influencing demand. Also related is the suggested support of a needed market mechanism identified in the producer focus group discussions which would guarantee that at least some of any premium being paid flows back to the producer. A consumer stated that “(I) would be more likely to pay extra if I knew that that
extra money was going to the producer” (high level of agreement). This also suggests that along with the environmental quality the consumer values, this mechanism in of itself may hold value for the consumer.

There is some confusion between a pork product that features a single “non-use” attribute (i.e. odor-free, antibiotic free or animal welfare friendly) versus a pork product featuring multiple attributes or at least implying multiple attributes (such as a label stating that a product is ‘sustainable’). When going over a list of actual differentiated pork label titles (i.e. organic, anti-biotic free, animal-friendly, sustainable) the term ‘sustainable’ required clarification yet after elucidation there was a general appreciation for the notion that multiple attributes leads to lower cost additive effects. With one product, multiple consumer objectives can be reached at an acceptable cost. If one can pay for animal welfare and a cleaner environment in a single $0.10 per pound premium (for example) over undifferentiated meat then that makes sense to the consumer. There was a general approval of the ‘sustainable’ concept. Yet it was clear there is a high degree of consumer confusion.

Discussion

Key Focus Group Results

Pork Producers

Though not statistically valid, the information gathered during these focus groups, did shed light on how pork producers think about environmental management in general and odor mitigation with shelterbelts specifically. Pork producers identified likely common barriers to the on-farm use of shelterbelts. They acknowledged that introducing trees or simply having them as part a livestock system does require knowledge of tree growth and maintenance to maximize tree health and prevent unnecessary tree mortality (e.g. avoiding certain herbicides, proper mowing procedures, and providing suitable moisture levels). Essentially producers will need to take on a new relationship with the ecosystem within and around their facilities to create and maintain the most effective shelterbelt designs.

Producers indicated the potential role of government cost share and/or incentive programs to pay for incremental odor mitigation measures. The use of BMP’s will guide
approval of odor mitigation progress (van Ravenswaay and Blend, 1997). Therefore it is imperative that beneficial technologies gain recognition. For example the government cost share program that most applies to on-farm odor management is the USDA’s Environmental Quality Incentive Program (EQIP). Under current EQIP rules, state Natural Resource Conservation Service (NRCS) EQIP agents have the discretion to accept environmental quality technologies for federal funding within their standards of Best Management Practices (BMP’s). At this time it is unknown if shelterbelts for odor mitigation would be accepted as a BMP for NRCS air quality standards. Shelterbelts are approved BMP’s under EQIP for erosion control, snow fencing, and boundary markers. With more research and increased voluntary use, shelterbelts may become listed within BMP standards for odor mitigation opening the way for cost share incentives.

Pork Consumers

Several outcomes should result from consumer participation with respect to livestock odor reduction (Halkier, 1995). Environmental responsibility should be experienced as co-responsibility between consumers and producers in practice. For example, the swine industry should make sacrifices such as odor mitigation beyond the minimum regulations. These sacrifices should be “visible”. This factor distinctly favors technology such as shelterbelts and other types of buffer strips. Fortunately as the producers pointed out, promoting environmental stewardship efforts for public relation benefits is a recognized benefit. And consumers need to recognize that higher consumer prices may result because of higher costs to producers to deal with odor at a higher level of effectiveness. Consumer education regarding food production is paramount. As one consumer stated, “Most consumers are really far removed from where their food comes from.” Environmental responsibility needs to influence positive outcomes. If the responsibility is manifested through higher final demand prices, than that premium must either flow backwards through the chain of production or bypass it altogether (e.g. contracting or direct marketing) all the way back to the individual livestock producer. Ideally, the premium received by the producer should just offset the added production costs of implementing odor control technology. If consumer’s pay for environmental protection by way of a premium for pork products produced with more
pollution control then the "traceability" to the producer must be transparent. Pork products must be able to be traced back to the environmentally sound production source. Also consumer preferences regarding "natural" technology such as shelterbelts as a recognized BMP should be incorporated by producers whenever possible. These focus groups have given us valuable insights into shelterbelt-pork odor mitigation research questions. Our surveys will be much better tools because of the feedback.

Continued research is needed into the quantification of the ability of specific shelterbelt designs to mitigate hog odor. Also producer-oriented extension must occur to provide appropriate informational materials and outlets explaining the benefits and costs of using shelterbelts. Additional consumer education must be developed that leads to consumer awareness of agro-environmental quality issues. Some consumers must express their environmental concerns by purchase of differentiated pork meat products. From a technology adoption and diffusion standpoint, the use of shelterbelts may face an uphill battle. As one pork producer puts it, "It would help if you could plant them (shelterbelts) five years before you build the place (hog facility)." (Feeder hogs – 2 hoop buildings) perhaps signifying the challenge ahead.
References


Laird, D.J. 1997. Wind tunnel testing of shelterbelt effects on dust emissions from swine production facilities. Thesis (M.S.)--Iowa State University.


This dissertation serves as a "jumping-off" platform for ongoing research. As discussed in the third manuscript, the summer of 2003 will see to the finish a large-scale survey aimed at probing the opinions and behavioral intentions of both swine producers and consumers of pork meat. Swine producers from Iowa, North Carolina (the top two states in hog production) and Washington State (ranked 34th but earmarked for possible expanded hog populations) will be asked for opinions regarding the establishment and maintenance of shelterbelts for odor mitigation. The producers will also be queried for interest in the production of differentiated pork products that have been produced with special care for agro-environmental quality. Consumers of pork from the same states listed above will be asked for their attitudes and willingness to pay for these differentiated pork products.

The first manuscript, "Mitigating Swine Odor with Strategically Designed Shelterbelt Systems: A Review" provided compelling evidence which establishes the use of shelterbelts for odor mitigation as an odor mitigation technology that further deserves considerable research attention. Here is what we know about shelterbelts and livestock odor. The potential of shelterbelts to mitigate livestock odor arises from the tree/shrub impacts on the central characteristics of livestock odors. These characteristics (Smith, 1993; Hammond et al., 1981; Takle, 1983) are:

- The livestock odor source is at or very near ground level;
- There is limited odor plume rise, due to certain weather conditions (i.e. temperature inversions) and limited mechanical turbulence;
- An odor plume has spatial and temporal variability;
- A plume may be very extensive covering a large land area;
- There is often a close proximity of odor sources to people;
- A majority of odors generated in animal facilities that are intense and detectable at appreciable distances travel as aerosols (particulates).
There is compelling evidence that shelterbelts can ameliorate livestock odor by affecting these characteristics and softening the overall impact that livestock odor has on people and the environment. Because the odor source is near the ground and the tendency of the plume is to travel along the ground (Takle, 1983), shelterbelts of even modest heights (i.e. 20-30 ft) may be ideal for plume interception, disruption, and dilution (there is also considerable particulate capture) (Bottcher, 2001, Heisler and DeWalle, 1988; Laird, 1997; Themelius, 1997). Shelterbelts can be adapted to fit the production situation and expected/experienced odor plumes. Also, depending on the shelterbelt design and tree/shrub species used, it can deal with the temporal changes to provide year round plume interception.

Based on research results, there are four primary ways that shelterbelts can mitigate livestock odors by:

- Dilution of gas concentrations of odor into the lower atmosphere
- Deposition of dust and other aerosol from reduced wind speeds
- Physical interception of dust and other aerosols by trees and shrubs
- Acting as a sink for the chemical constituents of odor after interception

To a considerable degree the ability of shelterbelts to reduce odor is directly related to their ability to reduce particulate matter. The majority of the odorous compounds (collectively known as volatile organic compounds or VOC’s) easily absorbs onto and are carried by particulates (Hammond and Smith, 1981). Themelius, 1997; Laird, 1997, Hammond and Smith, 1981 conclude that removing and/or controlling these particulates will cause animal houses, lagoons, and feedlots may become almost odorless. Meister et al. (1984) suggests that trees in a forest can clean the air of microparticles of all sizes by way of interception at least twenty times better than barren land. Leaves with complex shapes and large circumference to area ratios collect particles most efficiently. Thus, conifers may be more effective particle traps than deciduous species (Smith, 1994) and have a temporal advantage because of the leaves being on the trees year round.

Shelterbelts create turbulence at the surface that intercept and disrupt odor plumes traveling in a laminar flow and helping to push the plume into the lower atmosphere.
facilitating dilution (OCTF, 1998; SOTF, 1995; Takle, undated). Also, they lower wind speeds over storage lagoons, which reduces convection of odorous compounds from the surface and allow for slower release of the odor plume, which also facilitates dilution (Bottcher et al., 1999). Pesticide drift mitigation research suggests that due to reduced wind speeds drift pesticide will drop from the air stream. Even with broadleaf species, which generally have less surface area than coniferous species, downwind pesticide aerosol drift reductions of 70% (no leaves) to 90% (in leaf) have been recorded (Porskamp et al., 1994).

Two wind tunnel modeling by Laird (1997) and Themelius (1997) have shown that scale model shelterbelts reduce up to 56% in downwind transport of odorous particulates due to both the physical interception of particulates and by way of causing particulates to drop out of the air-stream due to reduced wind speeds. Liu et al. (1996) used numerical simulation to evaluate the effectiveness of planting trees along the perimeter of a liquid manure storage facility (lagoon) to reduce odor emission rates. Results showed that odor emissions were reduced from 26% to 92% for barrier distance from lagoon to barrier height ratio from 8 to 0.6. Also, Beattie et al. (1999 - present) are currently working to quantify the ability of plant material, including trees, to adsorb and absorb livestock manure generated VOC's onto and into plant tissues thus providing a biological sink for these pollutants. VOC's have a distinct affinity to the lipophilic membrane (cuticle) that covers plant leaves and needles. Researchers have quantified measurable quantities of anthropocentric VOC's that have accumulated at the surface of plants (adsorption) and within the plants tissues (absorption) (Reischl et al., 1989; Reischl et al., 1987; Gaggi et al., 1985). Also, microorganisms that dominate the surface of plants (Preece and Dickenson, 1971) adsorb and absorb VOC's and provide additional surface area for collection. These microorganisms have the ability to metabolize and breakdown VOC's (Screiber and Schonherr, 1992; Muller, 1992; Beattie et al, 1999-present).

The second manuscript, “The Financial Feasibility of Using Shelterbelts for Swine Odor Mitigation”, helps to establish that the use of shelterbelts specifically for odor mitigation can be a financially feasible management strategy for many producers of varying size and production technology (i.e. producers with < 500 head to producers with >5000head; hoop house to full confinement). As can be seen in the summary table 1 below, only the
analysis scenarios that featured very high establishment costs experienced total per pig costs that were above producer willingness to pay (WTP) for "non-manure storage" odor control. Non-manure storage costs meaning costs above and beyond standard manure management practices. In the table, ‘feasibility excess’ means that the costs were that much below known WTP figures for producers of that size. ‘Feasibility deficits’ means that the scenario costs exceed producer WTP.

Based on the analysis explained in the second paper, it is clear that the use of shelterbelts, in many cases only add a few pennies to overall production costs. The results of this study also emphasize the importance of cost share programs. As with the use of cost share programs all the costs examined are below reported swine producer willingness to pay for odor control. Some of the results even show ample feasibility excess (possibly as much as $0.33 - $0.59 per pig produced extra costs to spare) to suggest room for shelterbelts to be part of a “suite of technology”. It is recognized that with regards to odor control, no single technology is 100% effective, yet if a comprehensive management program is developed and followed, nuisance odor can approach elimination (SOTF, 1995).

Table 1. Summary table from the second paper, “The Financial Feasibility of Using Shelterbelts for Swine Odor Mitigation”. Feasibility Excess (↑) or Deficits (↓) per pig produced based on reported USDA pork producer Willingness to Pay for odor mitigation (USDA, 1996) technology for each test pork finishing farm by price scenario.

<table>
<thead>
<tr>
<th>Farm</th>
<th>No Cost Share</th>
<th>With EQIP/CRP</th>
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<tr>
<td>A</td>
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</tr>
<tr>
<td>Without</td>
<td>↑ $0.22</td>
<td>↓ $0.57</td>
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<tr>
<td>With</td>
<td>↑ $0.38</td>
<td>↑ $0.15</td>
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<tr>
<td>B</td>
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<tr>
<td>Without</td>
<td>↑ $0.18</td>
<td>↓ $0.07</td>
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<tr>
<td>With</td>
<td>↑ $0.35</td>
<td>↑ $0.23</td>
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<tr>
<td>Without</td>
<td>↑ $0.17</td>
<td>↓ $0.41</td>
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<td>With</td>
<td>↑ $0.37</td>
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<td>Without</td>
<td>↑ $0.45</td>
<td>↓ $0.16</td>
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<tr>
<td>With</td>
<td>↑ $0.59</td>
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The third paper, "Environmental Responsibility, Consumer Values and the Use of Trees to Mitigation Swine Odor: A Focus Group Exploration" provided insights into what swine producers think about the use of shelterbelts for odor mitigation. Among the producers who participated in the focus groups there was limited technical understanding of the shelterbelt – swine odor dynamic as discussed in the first manuscript of this dissertation, yet an appreciation of the potential psycho-social benefits such as visual screening and improved aesthetics. Producers also respected the notion that shelterbelts can be a very visible technology on the landscape, and therefore can have public relations benefits. There were, however, many reservations about the management of shelterbelts with regards to the time and effort commitment required. There was also considerable concern about the potential pest hazards that shelterbelts may bring to a production site (i.e. habitat and cover for rodents). Some producers were concerned about possible negative airflow impacts making the production site unpleasant from a worker standpoint and dangerous from an animal standpoint (for naturally ventilated buildings – be it hoop house of confinement – proper airflow is needed for both ventilation and temperature regulation). Still, the producers recognized the importance of dealing with odor and understand that at some point in their business, tradeoffs will occur involving increased work and cost to manage odor vs. damaging public relations and having potentially litigious odor problems. All of this points to the need for producer education regarding shelterbelts as a technology that emphasizes the engineered, highly designed aspects of their use. Assuaging concerns about damaging needed air patterns and showing the potential of all the facets of the tree/odor dynamic. It is also a call to us as researchers to continue with both field and laboratory quantification of the mitigation process.

With regards to the marketing of agro-environmental quality through the production and sale of pork meat that was produced with special care for air quality both the swine producers and the pork consumers who participated helped outline the probable market structure and gives us an idea about current and future demand for such products. From a consumer point of view, it is likely that any environmentally friendly pork product would need to be a "bundling" of many like attributes, such as air quality and water quality, or even environmental attributes and animal welfare issues. From a producer standpoint niche
marketing differentiated products may only work for those who are not contract producers and for those who comfortable taking on the risks of non-mainstream pork marketing.

These focus groups have given us otherwise inaccessible insights into our research questions. We believe the survey tools to be used in our continuing research will be much more robust, helping us to limit various survey biases, due to their exposure to the experiences of two of the major stakeholders in swine odor impacted agro-environmental quality. Further, concomitant tasks for our research team have been outlined by this exploratory research with particular reference to the acceptance of shelterbelts as an air quality BMP, which is a critical need with regards to being recognized by cost share programs such as the Environmental Quality Incentives Program. Continued research is needed into the quantification of the ability of trees to mitigate odor. A program of producer-oriented extension must be developed with regards to the most appropriate informational materials and outlets explaining the benefits and potential drawbacks of using shelterbelts. And a program of consumer education must be developed that leads to consumer awareness of agro-environmental quality issues and for markets for particular differentiated meat products.

Final Thoughts

Ultimately this research is about the coexisting sustainability of both rural communities and the livestock industry, to protect producers from a potentially litigious externality and to protect or improve the quality of life of private citizens. This investigation addresses and reinforces the idea that there is a shared responsibility between livestock producers and the public as consumers of livestock goods and services in maintaining or enhancing a healthy and productive agroecosystem in which cost-effective and socially acceptable levels of environmental amenities (e.g., odor-free air) occur. The answers we seek are part of a larger effort to deal in a holistic manner with complex agricultural (crop and livestock) production and socio-environmental issues facing the US. The Association For Temperate Agroforestry recently listed shelterbelts as air pollution buffers as "high priority" in their Research and Technology Transfer Needs for the Next Millennium statement (AFTA, 2000). The traditional engineering and financial aspects of livestock production combined
with limited opportunity for public input has often been counterproductive toward effective animal odor control. Yet as articulated by the NRCS Agricultural Air Quality Task Force, it is believed "that (livestock) producers can and will provide many of the control measures required to comply with air quality standards as our society requires, but it is imperative that they be provided the knowledge and flexibility to design and voluntarily apply these controls locally as the technology would suggest for best strategies and economic feasibility" (AAQTF, 1997). This needed knowledge can and should be provided to all stakeholders affected by livestock odor. Allowed flexibility of programs or policy towards control strategy design also requires stakeholder input. Management strategies to reduce unwanted odor and to improve the sustainability of livestock production and rural communities must be biophysically effective, economically feasible, and socially acceptable.

While the scope of this work is narrowed to workable parameters, this exploration requires a brief consideration of larger socio-agricultural issues. Allen et al. (1991) expressed concern that many approaches to agricultural sustainability seem to accept the current evolutionary path of agriculture (i.e., size increases, industrial technology, capital intensive) as given or unchangeable and seek "sustainable" approaches to these now conventional or industrial production practices. Or to provide technology that act as "band-aids" to common problems associated with industrial agriculture such as water quality or air pollution. These studies enter into this critique at the onset. From a sustainability standpoint, there was early concern that the use of shelterbelts may be overly geared towards larger, industrial oriented livestock producers who, it has been extensively argued (Ikerd, 2000; Thu and Durrenburger, 1998; Jackson, 1998), are causing inordinate amounts of ecological and social problems. If shelterbelts are effective at mitigating odor from industrialized producers than perhaps a case could be made that this work is helping to prolong practices that are, from a broad social point of view, inherently unsustainable or that shelterbelts are a mere ecological "band-aid" and many of the larger problems may subsequently go unexamined.

Though at this point unstudied, arguments to the contrary exist. At the very least individuals as well as entire communities should be protected from externalities that affect quality of life. Also, many legal experts point out that the social, economic, and psychological costs of nuisance or negligence litigation are extremely high for all involved
(Delind, 1998; Hamilton, 1992), thus reducing the potential for the need of legal remedies may have social value in its own right. Importantly, shelterbelts are size and production type neutral, that is, producers of all sizes can both retrofit or (ideally) plan them into new production sites and shelterbelts can fit into any type of production process (e.g. full confinement or Swedish style hoop-house systems). What's more it is quite important to keep in mind that the use of shelterbelts to help ameliorate the effects of odor is not limited to livestock producers. Rural residents, people living in expanding urban areas close to agriculture fields, and recreational sites can also plant shelterbelts in and around their homes, neighborhoods, and communities. The public can take a proactive role in current and future protection against odor problems emanating from existing, new, or expanding livestock operations.

Another concern within agriculture is that as production systems become larger, specialized, and standardized, the infrastructure that supports the industry also becomes more specialized in order to increase the efficiency of the total industry (economies of standardization) (Jackson, 1998). Examining and creating various new market options can possibly help maintain infrastructure for producers of various size style not just the larger, industrialized ones. By investigating which producers (by size and production technology) can benefit the most, directly and indirectly, by using shelterbelts to mitigate odor emitted from their system, can enhance the likelihood of these benefits becoming reality. By having a diverse industry, consumer options expand competitiveness spreads out further throughout a region, increasing beneficial multiplier effects (Ikerd, 2000; ATTRA, 1996).

These three research papers are part of a long-term “systems approach” effort focused on a shared decision-making process between all the relevant stakeholders in the creation of “odorfree” air. Ultimately, to assess the value of such a dialogic process of agricultural infrastructure design. Included in this systems approach is the research and outreach entity(ies) involved in agro-ecological issues, indicating the responsibility on our part to be: creative in cooperatively attempting to help solve problematic issues thus preventing a “top down” approach in disseminating advice and interacting with producers and the general public (i.e. promoting horizontal methods of technology transfer and reverse learning – such as learning from farmers and rural residents); to provide technology that is easily
understandable, assessable, affordable, size-neutral (technology amenable to livestock producers of all sizes); to provide multiple benefits to all stakeholders; and if possible to innovate with a technology that is not so user specific (i.e. any stakeholder can use and promote).

Unfortunately, while several sources (Koelsch, 1999; WED, 1999; NPPC, 1999; Lorimer, 1998; OCTF, 1998; Jacobson et al., 1998) list shelterbelts as odor control devices, they provide little physical, biological, or economic quantification as to effectiveness. Gassman (1992) concluded in a review of available literature that shelterbelt and other vegetation impacts on odor movement and abatement have yet to be studied in detail. However, both laboratory and field work on the quantification of the effectiveness of shelterbelts to mitigate odor is currently underway (Iverson, J., James, W., and B. Munson, 1999-present; Beattie et al., 1999-present; Bottcher et al, 1999). There are also currently 10 Iowa livestock producers who are participating in Iowa State University's Odor Control Demonstration Project using landscaping that was planted in 1997. At least two other Iowa livestock producers (both swine) have independently installed shelterbelt systems for odor control within the last few years and one large-scale beef lot has made serious inquiries. With this above research, combined with previous work (Tyndall and Colletti, 2000) and this current and future work, it is hoped that shelterbelts will soon become standard features in rural landscapes, increasing ecological diversity, combining with and encouraging other diversifying practices such as riparian buffer systems enhancing the flow of energy through ecosystems and human societies alike. It is believed that these small landscape elements can be a starting point and continuing point for an agriculture that is appreciably different from the current path of industrial methods. Clearly much needs to be done.
Conclusion References


Laird, D.J. 1997. Wind tunnel testing of shelterbelt effects on dust emissions from swine production facilities. Thesis (M.S.)--Iowa State University.


