PRACTICES & TECHNOLOGIES AIMED AT REDUCING ENVIRONMENTAL IMPACTS FROM HOG PRODUCTION

Canadian Pork Council

Conseil canadien du porc

SCIENTIFIC & ECONOMIC EVALUATION

Dear fellow producer,

As many of you are aware, the Canadian Pork Council has, and is currently, taking part in numerous environmentally based national programs aimed at increasing our understanding of how Canadian pork production can play a role in both food production and continued environmental stewardship. We have had valuable research completed through the Hog Environmental Management Strategy, which later folded into the Livestock Environmental Initiative. We have been involved in developing a National Environmental Management Standard for our industry, and most recently, we have partnered with other Canadian industry groups in the Greenhouse Gas Mitigation Program for Canadian Agriculture.

Numerous insights concerning how best to integrate pork production and environmental sustainability have been gained through participation in these programs. A variety of provincial, regional and national programs have been developed through partnerships with provincial pork associations and governments. The pro-active approach to maintaining environmental integrity embraced by these organizations is to be commended.

The Canadian pork sector is, however, characterized by its diversity. With this in mind, the Canadian Pork Council set out to develop a technology and management guidebook that would highlight the majority of environmental technologies and management practices currently available to Canadian producers, complete with economic and scientific evaluation.

Some of the technologies analyzed in this resource manual may not be applicable to your region, and some you may have tried already on your operation with varying degrees of success. This guidebook outlining "Practices and Technologies Aimed at Reducing Environmental Impacts from Hog Production: Scientific and Economic Evaluation" has been designed as a reference for your operation, and a starting point for management practice evaluation. It will be important to consider your own farm as you search this guidebook for technology information and consider how your operation might be different from the case studies evaluated. This will certainly effect how the economic evaluation will transfer to your personal situation. Also consider that as this is a national initiative, your local regulations may not allow for specific management practices to be implemented on your operation. We encourage you to contact your provincial pork association or government before making major changes to your environmental stewardship program and maintain a close relationship with these groups to avoid becoming non-compliant with local regulations.

We hope that you enjoy this environmental management guidebook that has been provided to you free of charge by the Canadian Pork Council. We look forward to a continued partnership in maintaining a viable pork sector operating with the highest level of on-farm environmental stewardship possible.

Kind regards,

Clare Schlegel
President
Canadian Pork Council

Acknowledgements

Agriculture and Agri-Food Canada   Agriculture et Agroalimentaire Canada

PAMI

Canada's ratification of the Kyoto Protocol in December 2002 launched Canada into a new era of environmental awareness and activity. The Greenhouse Gas Mitigation Program for Canadian Agriculture, established in April 2002, is a program designed to give the Canadian agricultural community the information it requires to take part in the Kyoto based activities and discussions that followed Canada's becoming a Kyoto signatory country.

This 'Guidebook for Environmental Management in the Canadian Pork Sector' is brought to you free of charge through the Canadian Pork Council's Greenhouse Gas Mitigation Program with funding support from Agriculture and Agri-Food Canada.

Although greenhouse gas management continues to be an ever increasing area of environmental importance in the Canadian agricultural sector, this guidebook does not focus solely on greenhouse gas management. Rather, this guidebook seeks to highlight a wide variety of technologies and management practices that deliver practical and economical benefits to the Canadian pork sector.

Not all technologies or practices suggested will deliver the same level of increased efficiency or profitability. The economic analysis that accompanies each technology or practice description should be considered a starting point only, a rough estimate. Barn operators will need to consider how a specific technology will apply to their specific situation and incorporate these considerations into the economic analysis.

The Canadian Pork Council is pleased to offer you this environmental management resource manual. We hope you find the information useful, and that combination of scientific and economic information will allow you to make more informed decisions about environmental management on your operation.

Remember, that a hog operations environmental performance is generally linked to the level of management efficiency that exists on the farm. Efficient farms are profitable farms. The technologies and management practices described in this guidebook will hopefully help in making the link between environmental management and farm profitability on your operation.

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Sincerely,

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Q. What is the Greenhouse Gas Mitigation Program?

A. In April 2002, Agriculture and Agri-Food Canada announced funding for the Greenhouse Gas Mitigation Program for Canadian Agriculture under the Climate Change Action Fund 2000. The program aims to increase awareness within the agricultural sector about the science of greenhouse gases (GHG), where they are produced on the farm, and how their production can be minimized. A network of demonstration farms has been established, allowing producers to witness, first-hand, the GHG reduction options available to them. As well, information about the program, and the Beneficial Management Practices (BMP) being promoted, is being highlighted in numerous agricultural-industry publications across Canada.

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fact sheet

Q. What are Greenhouse Gases?

A. There are three greenhouse gases (GHG) that are of particular importance to the agricultural sector, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is produced when fossil fuels are used to produce power or heat, or when intensive tillage is practiced, breaking down soil organic matter. Methane is produced from liquid manure storages when bacteria, working in an environment free of oxygen, decompose manure carbon into methane gas. Nitrous oxide is the most powerful agricultural GHG and is produced when soil containing nitrate nitrogen, becomes saturated with water. Certain anaerobic bacteria will use nitrate instead of oxygen for respiration under these conditions and produce nitrous oxide in the process.

Q. Are the three agricultural GHG gases different?

A. Certainly, the strength of each GHG is measured in carbon dioxide equivalents (CO_2e).

One molecule of methane will trap as much heat energy in the atmosphere as 21 carbon dioxide molecules, thus producing 21 CO_2 equivalents. Nitrous oxide will trap 310 times as much heat as CO_2, making N_2O the most potent of the three agricultural greenhouse gases.

Greenhouse Gas	GWP* Relative to Carbon Dioxide (CO_2e)
Carbon Dioxide	1
Methane	21
Nitrous Oxide	310

*Global Warming Potential

Q. Why is greenhouse gas production a problem?

A. The earth's atmosphere regulates the temperature of the earth by trapping a portion of the sun's heat energy as it is reflected off the earth's surface. Greenhouse gases, after being released into the atmosphere, cause more of the sun's heat energy to become trapped in the atmosphere and can result in an increase in the earth's atmospheric temperature. This is known as the "Greenhouse Effect".

The Greenhouse Effect
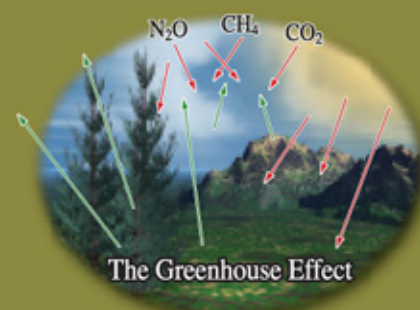
Q. Won't greater atmospheric temperatures help me achieve higher crop yields?

A. Not necessarily. Along with higher overall atmospheric temperatures, climate scientists predict that weather patterns may change and that the frequency of "abnormal" weather events may increase. This may mean more extreme wet or dry years, with fewer "normal" years, which allow for consistent crop production.

Q. As a hog producer, why should I make efforts to reduce GHG production on the farm?

A. Greenhouse gases are produced when carbon and nitrogen become "misplaced" on the farm. Hog farmers use carbon (C) as energy, and nitrogen (N) as protein to produce high quality meat products. However, not all feed protein and energy can be used by growing animals, and some of the feed carbon and nitrogen will pass through the hog digestive system and become part of the manure stream. Minimizing the bypass of feed nutrients into the manure pit will decrease the costs associated with growing hogs and reduce the potential for producing GHG on your operation.

CONSIDER THIS...

If reducing GHG can increase efficiency and gains in efficiency increase profitability, then a reduction in GHG emissions will increase profitability...

Q. How can I reduce greenhouse gas production on my hog operation?

A. FEEDING STRATEGIES

Start by looking at your feeding system. Has your rate of average daily gain been increasing? How efficiently are you feeding your animals? Simple changes such as a switch from dry feed to wet/dry feeders can increase feed efficiency. Amino acid supplements are being used by many producers to reduce the level of feed crude protein in the diet, lowering the amount of manure nitrogen produced. Adding the phytase enzyme to rations has also been shown to increase feeding efficiency, as well as reduce manure phosphorus output.

A. MANURE STORAGE MANAGEMENT

Frequent removal of manure from hog facilities can help keep manure methane production to a minimum. Manure stored in the barn will tend to be warmer than manure stored outdoors, and will produce more methane. Manure storage covers have the potential to offer a host of on-farm benefits, in addition to GHG management. Covers can trap manure gases such as methane, hydrogen sulphide and ammonia and keep them within the manure liquid, instead of escaping to the atmosphere. Covers are also highly effective in reducing manure odour production.

A. MANURE NITROGEN MANAGEMENT

Production of nitrous oxide accounts for a significant part of Canada's agricultural emissions, being the most powerful of the three greenhouse gases pertinent to the hog industry. The key to avoiding N_2O production is not to leave soil nitrate-nitrogen stranded in saturated soils. Applying manure before seeding or after crop emergence will avoid the presence of soil nitrate during wet spring thaw conditions. Applying manure nutrients to match crop requirements and avoiding excess soil nitrate after harvest will also help to minimize N_2O emissions. The added benefit of increasing nutrient use efficiency with in-crop manure applications will also help to reduce your commercial fertilizer bill.

A. MANURE TREATMENT TECHNOLOGIES

Anaerobic digestion is a process where manure is mixed and heated in a vessel free of oxygen, the process encourages the production of methane which is then used to produce heat and electricity. Diesel engines are capable of running on methane gas, with a few minor modifications. Linking a modified engine with a generator can turn your manure storage into your own on-farm power plant. Significant engine heat is produced during power generation and can be used to heat hog barns, dry grain, heat houses or other farm buildings. GHG production on the farm is lessened and manure odours are reduced significantly during anaerobic manure treatment.

Q. What is in store for Canadian pork producers and greenhouse gases?

A. Producing high quality crops and livestock is something Canadian farmers have done for decades. Along the way they have consistently learned how to use carbon and nitrogen more efficiently. Greenhouse gas production is linked to this efficiency, as is farm profitability. If a farmer can reduce GHG production by being more efficient in how carbon and nitrogen are used on the farm, the farm's bottom line will increase as well.

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For more information on the Canadian Pork Council Greenhouse Gas Mitigation Program visit us online at www.cpc-ccp.com/envir/GHGMP.htm

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Forward

This guidebook contains 33 chapters on environmental technologies related to the Canadian Pork sector. These many technologies are verification of the efforts being made by the producers, researchers, and industry to ensure that hog production occurs in an environmentally friendly manner. It is difficult to give complete information on each technology without publishing a major book. Instead, the goal was to keep this guidebook relatively short by limiting the length of each section to about four pages. This was intended to provide enough information to give the producers a taste of these technologies so they can decide which ones may warrant more investigation. For those technologies that are of further interest, the producer can get more detailed information from the *Literature Cited* subsection at the end of each chapter and by contacting professionals in those areas.

To be consistent, each section has been broken into the same subsections. Following is list of the subsections and a brief description of its intent.

Description: This subsection provides an introduction and general overview description of the technology.

Environmental Advantages and Disadvantages: These two subsections briefly identify the pros and cons of each technology from an environmental perspective. In some cases the relationship to the environment may not be immediately obvious, but the connection is there. For example, a technology that requires less manufacturing can have hidden environmental benefits and the reverse is true.

Costs: This subsection provides an indication of costs in Canadian dollars. It would have been ideal if a standardized system of reporting costs could have been used such as $/marketed pig; but depending on the technology or information available this was not always possible. Thus best effort was used to provide the most meaningful numbers. However, considerable caution should be used with these costs as the technologies are ever changing and today's costs may be significantly more or less than those obtained from the past literature. ALWAYS, have a professional provide current, accurate cost information before adopting any new technology.

General Assessment: This is a brief summary that ties all information together.

Complementary Technologies: Many new technologies link with other new technologies. This sub-section lists other environmental technologies that complement the technology described in the chapter.

Literature Cited: Further information can be obtained from this list at the end of each chapter of all cited and relevant literature. This allows the reader to obtain more detailed information from the original research papers. Some papers may be available online. In order to efficiently search for these papers, type only the title of the paper in quotations in the search line of a search engine (i.e. www.google.ca). If too many hits are received, also type the last name of the author outside the quotations with or without a "+" depending on the search engine.

DISCLAIMER: Finally, and as mentioned above, each technology is constantly changing, new one's are developed while others move to obsolescence so this guidebook should be treated as preliminary information and not the final word on the technology or its impact, cost or liabilities. All information is provided "as is" and the authors make no representations, warranties, or conditions, either expressed or implied, in connection with the use of or reliance upon this information. This information is provided to the recipient entirely at the risk of the recipient, and because the recipient assumes full responsibility, the authors shall not be liable for any claims, damages, or losses of any kind arising out of the use or reliance upon the information (including omissions, inaccuracies, typographical errors, and infringement of third party rights).

Table of Contents

Section 1 - Managing the Barn Environment

Chapter 1   Barn Design

1.1   Confinement Building Design

Description

The design of the hog barn can affect the environment in many positive ways. Proper integration of the barn with other farm activities ensures that the hog operation is a net benefit to that environment. This is particularly true of the manure, but also applies to the entire hog barn operation. Hog manure must be removed from the animal space and eventually transported and stored where it can become a crop nutrient. The air inside the building needs to be conditioned and exchanged with fresh outside air to a lesser or greater extent depending upon stocking density, choice of manure handling system, and the quality of the building envelope. Similarly, dust and odours should not be introduced to the surrounding environment. Modern technology can effectively manage every environmental impact of the barn design. Owners and builders have a responsibility to understand how choices made in planning the barn affect the environment throughout the life of the barn.

Decisions based upon energy are a good measure of how the project will manage greenhouse gas emissions (GHG). Almost every aspect of project planning has some energy impact, from siting to design to choice of materials and the construction schedule. Lower GHG impact will usually benefit the budget as well.

Building materials require energy to produce (Table 1-1). Energy is also consumed to deliver the materials to the construction site. Developers can control the total energy impact of the construction phase by using the least amount of building material, manufacturing materials like concrete as close as possible to the work site, and even by compressing the construction schedule to reduce the number of trips made to and from the construction site.

The typical swine building design relies on concrete for the foundation and wood for the walls and roof. Concrete walls may be used as an alternative to wood frame construction. Commercial choices include pre-cast panels, cast-in-place, tilt-up, or plastic forming systems (PFS). Any of these provide a durable, pre-finished building shell for a cost premium that may be justified over the life of a 25 year business plan. The biggest advantages are durability and ease of cleaning.

Minimizing the cost of the building shell must not be done at the expense of its thermal efficiency. In conventional slatted floor buildings, high quality insulation and vapour barriers control heat loss, prevent drafts, and even minimize the rate of deterioration. Proper insulation not only helps control heating costs but also provides improved comfort year round. An often overlooked problem is heat loss at the foundation. Insulating the exterior of the foundation reduces heat loss and improves comfort. All wall sections must be constructed to prevent rodent infiltration.

Table 1-1. Energy to Produce Common Building Materials.

Material	Energy to Produce (BTU/lb)
Plastic – HDPE	44,000
Paint oil-based	42,000
Paint, latex	38,000
Plastic – PVC	30,000
Steel - galvanized	15,000
Steel - mild	14,000
Insulation, fibreglass	13,000
Insulation, cellulose recycled	6,300
Wood – plywood	4,500
Steel - rebar or recycled	3,800
Cement	3,400
Gypsum wall board	2,600
Wood – kiln dried softwood	1,100
Concrete, f.o.b. plant	500
Straw, baled	100
Source: Baird, 1997.	

The "conventional" approach to swine barn design hinges on liquefying the manure. Pigs lie on concrete, wire, or plastic floors that are either fully slatted or partially slatted to allow manure to fall through into holding pits. In some jurisdictions, public opposition to open manure storage has resulted in manure being held for months directly under the animals, a design known as in-barn storage or "full basement" barns. Such systems do not reduce the odours and gases from anaerobic decomposition, but they do allow for some control on their discharge to the atmosphere. The building acts as a tank cover, and chimney exhaust fans can be used to discharge the manure odour higher for better dispersion.

Typical construction involves concrete foundation elements with wood wall and roof.
Photo Courtesy: Miles Jorgenson

Penning is an important decision. In parts of Canada, hog producers have tapped into the oil industry as an economical source of penning steel by using oil field leftovers for all types of stalls, gates, panels, and hardware. Several types of excellent quality plastic panels are now available for group pens. The major advantage of this type of penning is its comparative ease of cleaning. Far less water and detergent will be used in the life of the building when smooth plastic surfaces are used. Galvanized, painted or coated, and stainless materials cost much more than bare steel, but again there can be savings in cleaning cost. There has been a trend toward larger and larger group sizes, and this has greatly reduced the amount of penning, especially in finisher barns (Table 1-2). Less penning not only reduces cost but also leads to improved management through automated sorting.

Water use can be significantly affected by choices made in the design of the barn. Washing accounts for a relatively small percentage of water use, but if the water is heated, the energy impact of choosing easy to wash building elements can be very significant. Wet-dry feeders and liquid feeding systems may reduce consumptive waste. A well designed barn should all but eliminate the need to flush manure pits with fresh water.

Designers are constantly challenged to protect a barn owner from functional obsolescence. Functional obsolescence occurs when the existing barn no longer fits with the herd dynamics or management practices of the industry. Sow productivity is constantly evolving as new genetics are introduced and new production strategies are implemented. A classic example is the relative need for hog finishing spaces. Two decades ago, each sow would produce perhaps 18 piglets per year, pigs grew more slowly, and pigs were shipped at a weight below 220 lb (100 kg). Today, sows are reaching 28 piglets per year, pigs grow fast, and finishing pigs are marketed at weights of 250 lb (115 kg) plus. This has had a huge effect on the space requirement for finishing pigs and change is continuing. Producers should expect further change (Table 1-3).

Environmental Advantages

A well-planned barn design can save costs and reduce the impact on the environment. Construction savings are possible by choosing the most environmentally appropriate materials and by planning animal space efficiently. Once operational, the design of the building continues to influence environmental factors like odour, water use, and manure by-products. By considering the changing need over the life of the facility, early obsolescence can be averted.

Table 1-2. Pig Space by Floor Type (ft^2).

Hog Class	Full Slat	Part Slat	Bedded
Weanling	2.8	3.1	3.5
Grower	6.7	7.5	8.6
Finisher	8.7	9.7	11.1
Gilts & Sows	-	22.5	24.7
Boars	-	60.2	79.6
Source: AAFC Code of Practice			

Environmental Disadvantages

Livestock cannot be raised without some impact on the environment. The design of the buildings in which they are raised can only be expected to contain and manage, not to eliminate, the by-products that result from production of the primary product (i.e. meat). It is important to understand how planning decisions will affect the gross output of the facility. There is significant room to influence the impact of barn odours, water use, manure, and operational energy through careful planning.

Cost

Construction costs become less significant when

PVC penning and wall liners reduce cleaning time and water use.
Photo Courtesy: Miles Jorgenson

taken over the life of the project. As a line item in the operating budget, most buildings equate to about 10% of the overall cost of production. However, it is almost universally challenging to justify high construction costs at the time of building because of the difficulty of raising capital.

Table 1-3. It is Difficult to Predict a Building's Fit 15 Years into the Future.

Change Indicator	1990	2005	2020
"Large" Herd Size, typ.	500 sow	5,000 sow	?
Sow Productivity, typ.	16 pigs/sow/yr	24 pigs/sow/yr	?
Sow & Boar Body Length	6 ft	7 ft +	?
Weaning Age	28 days	18 days	?
Finishing Group Size/Pen	20	250 and up	?
Preferred Market Weight	100 kg	115 kg +	?
Source: Jorgenson, Direct Experience			

Costs of several conventional hog buildings are shown in Table 1-4.

There are often extenuating circumstances that dictate whether the use of least cost facilities warrants consideration. Modern farms are challenged to manage with hired labour, and there is constant pressure to become more efficient. This usually means that the builder must at least consider using labour saving technology as much as possible. Labour management is what has driven the move away from bedded housing. As more positive experiences with such options as bioshelters are demonstrated, the tide may turn. Developers must consider the evolving nature of the business and strive to protect their investment from premature obsolescence by watching the horizon and ensuring the barn that is built today has a good chance of still working with tomorrow's industry.

Table 1-4. Cost Ranges of Confinement Hog Buildings.

	Finisher Building		Nursery Building**		Farrowing Building**	
	1,000 head		600 sows		600 sows	
Capital Cost Range	$144,730	$300,000	$78,960	$94,740	$710,400	$789,600
Cost/Marketed Hog*	$6.40	$13.27	$0.76	$0.91	$6.82	$7.58

* Cost/marketed hog is based upon the assumption that the operation has 2.26 cycles/year.

** Assumes 10 piglets/sow/cycle; 10,413 marketed hogs produced (mortalities taken into account); includes cost of equipment (feeders, waterers, manure handling).

Sources: Landblom et al, 2001; University of Michigan, 2001; EPA, 2001

General Assessment

Very few barns built before 1990 are still in use today. This is partly a result of the destructive nature of hogs. It is also a result of significant change in the hog industry and in hog production in general. Farms have become fewer and larger causing rapid growth in herd size. Modern engineering has allowed for more space efficient building designs, especially wider roof spans. Sows continue to be raised in stalls, but there is a movement to larger group sizes at the stages of hog production that has reduced penning.

Most barns use slatted floors to handle the manure as a liquid slurry. Automation has improved the dependability and efficiency of heating, ventilation, feeding, and watering equipment. Manure regulations have forced changes in barn design in some jurisdictions, driving the adoption of full basement storage vaults. These trends can be expected to continue as new technology arrives and new ways of raising hogs are proven beneficial. Producers are wise to continue evaluating barn designs that offer new technology, and they must continually test the barn plan against the current needs of a developing animal species.

Complementary Technologies

Barn designers have access to the same evolving building technologies of materials and construction techniques as other builders. Experience has prevented mistakes in adopting inappropriate industrial and commercial building types to housing for swine. Some new types of buildings have revolutionized hog housing. The fabric covered hoop shelter or biohousing has proven to be well suited to raising some classes of hogs on straw bedding with minimal capital and equipment cost. On the other end of the spectrum, concrete wall forming systems have provided an attractive and durable alternative to wood frame construction.

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1.2   Lighting

Description

Lighting plays a significant role in reproductive and overall swine production performance. The cost of electricity for lighting is a small percentage of the cost of production for swine; however, it is possible to reduce energy costs, increase lighting levels, and actually improve performance (Table 1-5) with well designed, energy efficient lighting systems. A good lighting system should provide proper light levels economically with low maintenance costs.

Light output from a lamp is measured in the term "lumens" (lm). Typical lumen outputs are shown in Table 1-6 along with other light system information. The light level at the working surface is measured in foot-candle (fc) or lux, where 1 fc equals 10.76 lux. A bright sunny day in mid-summer will be around 8,000 fc. Whereas, typical light levels occuring in some pens and corner areas of barns can be less than 0.5 fc.

Vapour proof 4 ft fluorescent fixture.
Photo Courtesy: Agviro Inc.

With today's relatively high light levels and much higher photoperiods, incandescent lamps are extremely inefficient. They are only about 5% efficient at converting energy to light, wasting the remainder as heat energy. In addition, they attract flies and other insects. They are also quickly coated with dirt, which is very difficult to clean and further reduces the amount of light output. Incandescent lamps also have a relatively short life. Regular lamps last 1,000 hours while "long life" lamps last 5,000 hours.

Table 1-5. Recommended Light Levels and Photoperiods for Swine Housing.

Type of Housing	Light Levels (foot candles)	Photoperiod (hours/day)	Comments
Breeding/Gilts	>10	14 to 16	- necessary for estrus cycling
Gestation	>5	14 to 16	- to assist missed cycles, bring estrus on again
Farrowing	5 to 10	8	- if no heat lamps, some light in room 24 hr/day
Nursery	5	8	- some light in room 24 hr/day
Grower-Finisher	5	8	- minimum 6 hr/day unbroken light recommended

The main light source in swine production should typically be fluorescent. Fluorescent lamps are very energy efficient (compared to incandescent), have long life cycles, and have been shown to provide adequate light quality for swine. Retrofitting to fluorescent from incandescent typically has a payback of one to two years. Conversion from incandescent to fluorescent will reduce energy usage by up to 75%. Fluorescent lamps last 24,000 hours and only cost about $2.00 each.

The new standard for barns where ceiling height is less than 12 ft (3.7 m) is the T-8 fluorescent fixture with electromagnetic ballast, mounted in a weatherproof fibreglass or plastic housing with a continuous gasket between the lens and fixture. These units are typically more than four times as efficient as regular incandescent fixtures and the lamps last at least 24 times longer than regular life incandescent lamps.

Compact fluorescent (CF) lamps provide good energy efficiency and are easily retrofitted into incandescent fixtures. They have a rated life of 10,000 hours. Generally, compacts are a good, low cost retrofit. However, CF lamps have a shorter equipment life and higher cost of replacement compared to standard 4 ft (1.2 m) T-8 fluorescent tube systems.

Where barn ceiling height exceeds 12 ft (3.7 m), the more efficient high intensity discharge (HID) fixtures, including metal halide and high pressure sodium, should be considered. They are easier to install and maintain and require fewer fixtures to provide the same level of light.

Environmental Advantages

Converting from incandescent to fluorescent will reduce energy usage by up to 75%. High pressure sodium is even more efficient but normally requires ceilings over 12 ft (3.7 m) high.

Environmental Disadvantages

Despite low capital costs, operating costs of incandescent lighting is high because of shorter lives and less efficiency. Incandescent will also dim over its life, and its efficiency will decrease.

Costs

The economics of converting to fluorescent are very straightforward.

Placing one, 150 watt, regular life incandescent lamp per pen in the center would provide just over 3 fc (32 lux). This system would cost about $100 to install and $284 annually to operate. Installing four, 4 ft (1.2 m) double tube, waterproof T-8 fluorescent fixtures, with one fixture per pair of pens, would provide an increased light level of 5 fc (54 lux) (a 66% increase). This T-8 system would cost $400 to install and only $41/year to operate. For a retrofit, the payback is 1.6 years; for a new facility, the payback is an even faster 1.1 years.

A lighting retrofit from incandescent to vapour proof fluorescent (and some compact fluorescent) fixtures on a 240 sow farrow-to-finish facility realized annual savings of over $5,000. The cost of electricity was about $0.07/kWh and the payback was less than two years.

Table 1-6 gives the efficiency and life of most common lighting types.

Table 1-6. General Characteristics of Light Sources Used for Indoor Lighting of Swine Facilities.

Lamp Type	Lamp Size (W)	Efficiency (lumens/W)	Typical Lamp Life (hr)
Incandescent	34 to 200	11 to 20	750 to 2,000
Halogen	50 to 150	18 to 25	2,000 to 3000
Fluorescent	32 to 110	75 to 98	15,000 to 20,000
Compact Fluorescent	5 to 50	50 to 80	10,000
Metal Halide	70 to 400	60 to 94	7500 to 10,000
High Pressure Sodium	35 to 400	63 to 125	15,000 to 24,000

General Assessment

With the relatively high light levels and much higher photoperiod being used in today's swine facilities, the old Edison style incandescent lamps are becoming obsolete. There are a number of alternatives that provide better light efficiency, higher output, reduced operating costs, and lower levels of maintenance.

Complementary Technologies

Programmable on/off timers to meet daily swine lighting needs and motion sensor switches in personnel areas are complementary technologies.

T-5 tubes (5/8 in (16 mm) diameter) are just starting to surface in the lighting industry. These are supposed to have better light conversion and lower energy requirements than the current standard T-8 tubes (1 in (25 mm) diameter).

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1.3   Deep Litter Systems

Description

There has been some interest in using litter, usually straw, sawdust, cornstalks, or similar material, as bedding. Bedding materials utilized for deep litter systems must provide a multitude of factors. These include a clean, comfortable physical environment for the animal, the required insulation properties, immediate absorbency, and proper retention balance of produced liquids. It should also provide adequate porosity, structure, and texture to facilitate composting, an appropriate pH level, proper carbon nitrogen retention, and be cost effective. The litter is mixed with the excrement and handled as a manure system.

Large amounts of straw bedding keep animals comfortable and reduce stress.
Photo Courtesy: MAFRI

Anecdotal evidence suggests that pigs prefer a litter system. The animals are observed to be more active and spend a significant amount of time rooting through the litter. Overall herd health is improved with litter systems if managed correctly. The bedding must be kept dry, especially in the dunging area. Overall use of medication is less. Incidences of sore feet and legs were reduced and tail biting was eliminated in a litter system (SARE, 2001).

The use of a deep litter system as a low capital, low energy input is also common. An uninsulated shelter can be erected economically. Bedding is managed as needed to provide pigs with dry material. In the summer, ventilation is important to cool the pigs. In the winter, the pigs burrow into the straw to stay warm. Inputs into a system could be limited to feed, water, and straw. Typically, an electric waterer is used for the winter months.

Solid manure systems require some specialized equipment and common equipment. A front-end loader is a necessity but fairly common on a livestock operation. Specialized equipment may include spreaders for application and scrapers for the barn. A skidsteer loader may be an option depending on operating room inside the barn.

The most common form of deep litter system is biohousing. Litter is added on an as-needed basis to meet the thermal and social needs of the pigs. Producers may spread the material themselves or add in bulk, allowing for the activity of the pigs to distribute it throughout the pen. The manure and litter is removed, typically with a front-end loader, at the end of each pig cycle, roughly every three to four months. Barns can be constructed or renovated to use litter for manure handling or just bedding. An automated system might have a central alley where the litter is distributed to the pens. Pig activity distributes the litter through the bedding area to the dunging area and eventually into a gutter along the outside wall, which can be scraped either automatically or by a front-end loader. Similarly, a partially slatted floor could be used where the bedding area contains litter and the slatted portion serves as the dunging area. This arrangement gives the benefits of litter for bedding with the convenience of passive manure collection and an automated liquid manure handling system.

Environmental Advantages

Solid manure handling has a better concentration of nutrients and a better C:N ratio for field application. It does not pose the risk of runoff as does a liquid application system. If the manure pack is properly managed and not allowed to get too wet or uneven, ammonia and hydrogen sulfide emissions are minimized.

Environmental Disadvantages

Using litter requires more labour and management. The pens require periodic cleaning and frequent addition of litter, especially if the desired dunging area is litter based. Ventilation is important. Barns

will require an increased minimum ventilation rate to accommodate the increased moisture levels. This is also true of the shelters, as many producers try to close the building too tightly to keep the pigs warmer.

Costs

The cost of bedding material itself will depend upon the type of material used and whether the bedding is produced on the farm or is purchased and hauled to the farm. Bedding cost will be determined by cost per bale and the amount of bedding used. It is suggested that 1 to 1.5 large bales are required per week per 100 hogs (Canada Plan Service). Bedding material costs are about $3.00/head marketed (White, 2001) amounting to $1,356/year for a 200 head finisher facility. The cost of bedding will be reduced if the material is produced on the farm.

General Assessment

Solid manure handling reduces or eliminates many of the odour complaints associated with liquid manure handling. It also reduces the risk of runoff during application by concentrating the nutrients in the manure. The environmental and animal welfare benefits are an offset to the added labour and management time required.

Complementary Technologies

Composting is a natural fit for a deep litter system. Manure is in solid form and ready for composting without the requirement of solid-liquid separation. The nature of the bedding material can reduce the required amount of carbon source material to be added to the compost.

Biohousing systems depend on deep litter as an integral part of the system.

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1.4   Biohousing

Description

Biohousing refers to low energy input housing for livestock. Typically, it is an uninsulated building designed for deep litter use and natural ventilation. The most common form presently in use is the hoop structure. These are generally built using a 4 ft (1.2 m) high wall with a series of arched steel ribs covered with a UV resistant tarp. The inputs consist of water, feed, and bedding.

Ventilation is accomplished by orientating the structures to take advantage of prevailing wind conditions. Ventilation can be supplemented mechanically if desired or required. Side vents are being investigated and are common in warmer climates.

Bedding is brought in as required to maintain a dry layer for the pigs. Straw, sawdust, cornstalks, or any

The most common biohousing is the hoop or quonset style buildings.
Photo Courtesy: MAFRI

similar material may be used. After each production cycle, roughly three to four months, the manure pack and bedding are removed by front-end loader or skidsteer and fresh bedding is applied for the next group.

Environmental Advantages

Advantages associated with solid manure handling over liquid manure handling are odour reduction and less risk of runoff. An electric waterer used to prevent freezing in the winter may be the only electrical input required, although some lighting for night inspections may be desired.

Environmental Disadvantages

There is significant loss of N from the bedding in swine hoop structures. The majority of the losses appear to be in gaseous forms such as N_2, N_2O, and NH_3, but there is potential of leaching into groundwater. Only 10% or less of the N losses accumulated in the top 4 ft (1.2 m) of the soil (Garrison et al, 2001). The $N-NO_3$ concentrations under a hoop structure were shown to increase approximately three times the control value in less than a year (Richard et al, 1998). There is more labour involved in operating a bioshelter, especially considering the time and energy to process and transport the bedding material and extra feed consumed in the winter. Stockpiling of manure prior to spreading is not visually appealing and may cause loss of nutrients through runoff. Flies can be an annoyance during the warm months and there are potential health problems because parasites and roundworms can be locked into the manure pack or soil. It is extremely difficult to disinfect this type of building.

Costs

The low construction cost of hoop structures is the most attractive feature. Material costs are significantly less than a conventional barn. Input costs related to heating and ventilation are eliminated in this system through the use of bedding and natural ventilation. However, there is a definite increase in feed consumption, especially during the winter months.

The cost for a hoop structure is from \$55 to \$72/pig space (Canada Plan Service; Gegner, 2001) with wooden-framed structures significantly less than steel-framed structures. Assuming 12 to 14 ft^2/pig (1.1 to 1.3 m^2/pig) (Canada Plan Service), the cost is \$4.58 to \$5.14/ft^2 (\$49 to \$55/m^2). The cost of feed and manure handling systems is about \$47.38/pig space (Larson et al, 2000).

Based upon a structural life of ten years, equipment life of five years, 5% salvage value, 8% interest rate, 2% insurance rate, and 2.26 cycles/year, the fixed cost for a hoop structure to house 200 finisher

hogs is $3,891 to $4,344 or $8.61 to $9.61/marketed hog. The labour required for a hoop structure finishing operation is between 0.25 and 0.58 hours/head marketed (Larson et al, 2000; Duffy and Honeyman, 1998). Based upon a labour rate of $12/hour, the annual labour cost is from $1,356 to $3,146 for a 200 head hoop structure, which would include the application of bedding material. The cost of the bedding material will depend upon the type of material used and whether the bedding is produced on the farm or is purchased and hauled to the farm. Bedding material costs run from $3.00 to $6.90/head marketed (Larson et al, 2000; White, 2001), amounting to $1,356 to $2,378/year for a 200 head finisher facility. Bedding cost will be determined by cost per bale and the amount of bedding used. It is suggested that 1 to 1.5 large bales are required per week per 100 hogs (Canada Plan Service). Electrical cost will be small unless internal air circulating fans are used. Assuming maintenance costs are 2% of initial costs, the cost per marketed hog for a hoop structure is $15.01 to $19.92.

Increased costs associated with hoop structures are found in the form of feed, veterinary costs, and labour. During winter months, feed efficiency is decreased in hoop structures, requiring as much as 10% more feed. Swine also take longer to reach market weight; two to three days extra during the summer and up to ten extra days in winter months (White, 2001). The additional days needed for growth translate into additional feed costs and can result in fewer turns per year. While hoop raised swine are generally healthier than those raised in confinement systems, medical costs may also increase due to the need of treatment for parasites obtained from the soil. Labour required per head is also greater in a hoop facility as compared to a confinement operation.

Compared to a High Rise™ or confinement building with mechanical ventilation, the costs for electricity and fuel are significantly reduced. The cost of bedding may also be reduced if the material is produced on the farm. Additionally, during years of low market price the swine operation can be abandoned and the building can be used for other functions such as machinery storage, and then returned to swine production when the market turns around.

General Assessment

The low capital costs and benefits of solid manure handling are some major advantages of biohousing. The similar performances and improved animal welfare make biohousing an attractive alternative. Improved management and construction practices, such as installing a liner underneath and careful site selection, could reduce the risk of nitrogen leaching.

There is more labour involved in operating a bioshelter, especially considering the time and energy to process and transport the bedding material and extra feed consumed.

Complementary Technologies

Composting is a natural fit. The deep bedding material acts as a high-carbon bulking agent.

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Chapter 2   Herd Health and Comfort

2.1   Ventilation

Description

The primary reason to ventilate swine facilities is to provide optimum air quality for both the pigs and the producer. Optimum air quality is important to ensure the pigs remain healthy and gain weight. The ventilation system also provides cooling benefits during warm weather.

Energy costs are directly affected by the amount of ventilation required by the barn. Too much ventilation during cold weather removes heat from the building, increasing costs. At the same time, if the ventilation rate is inadequate, indoor air quality will deteriorate and pig health will suffer. By carefully managing the minimum winter ventilation rate, operating costs can be controlled and pig health maximized.

Mechanical fans exhausting from building.
Photo Courtesy: Agviro Inc.

Although energy efficient fans are an important part of the ventilation system, heating costs typically exceed fan operating costs. Interlocking the heating system with the ventilation system, to prevent them from working against one another, will save energy dollars.

Swine production facilities will be either mechanically or naturally ventilated. Some swine facilities have what is known as a "hybrid" system, which is a combination of both mechanical and natural ventilation systems.

Mechanical ventilation uses electrically driven fans to provide the necessary airflow in a swine facility. Most mechanically ventilated swine facilities use a negative pressure system to draw fresh air into the building. A smaller number of operations use either positive or neutral pressure ventilation systems.

The ventilation fans are sized to control interior moisture levels and air quality during cold weather and to prevent the building from becoming too hot during warmer weather. This usually involves a number of stages of different sized fans to provide the required airflow, depending on the outside temperature.

In negative pressure ventilation systems, the ventilation fans exhaust (blow) air out of the facility. Atmospheric pressure then pushes air into the facility because of the lower interior pressure (or suction) created by the fans. This is the most common type of mechanical ventilation system found in swine facilities in Canada.

In positive pressure systems, the ventilation fans blow air into the facility rather than out of it. This displaces the air inside and forces it out of the building through air vents. Positive pressure systems are more difficult to control than negative pressure systems, and they may force moisture-laden exhaust air into the exterior walls and ceiling, where it will condense and accelerate building deterioration. This system normally requires more fans and may also force barn air into rooms used by the operators.

Neutral pressure systems have two sets of fans. One set of fans blows fresh air into the facility, while the second set blows stale air out. This type of ventilation system has merit for certain applications, such as retrofitting existing facilities where it may be difficult getting fresh air into the facility. Neutral pressure systems use two sets of fans to do what one set will do in a negative pressure system, so electrical operating costs will be much higher.

Natural ventilation involves the use of chimneys and sidewall openings to provide the required amount of ventilation. Fans are not used. Wind and the tendency for warm air to rise are the underlying principles behind natural ventilation. A 10 mph (16 km/h) wind can achieve about four times the air

flow rate typically provided by a mechanical ventilation system. As a result, the system operating costs are virtually zero. However, achieving the desired amount of ventilation consistently and uniformly is often difficult in a naturally ventilated facility. The stack effect will only take place when the barn air is warmer than the outside air. During warm weather, there may be no difference between the inside and the outside, so the only air exchange that takes place will be due to the wind. If there is little or no wind in the summer, indoor air quality will be affected. Winter problems include frost build-up on and freezing of the sidewall panels, dripping chimneys, down-drafting, temperature variation from one end to the other, and fluctuating interior temperatures.

Insulated sidewall panels and roof chimney vents.
Photo Courtesy: Agviro Inc.

To increase the effectiveness of natural ventilation systems, the barns must be located an adequate distance from wind barriers and orientated at right angles to prevailing winds. Well insulated and close fitting panels are especially important in colder climates such as the prairies. Inner walls that create the rooms should be parallel to wind direction.

A dual ventilation system makes use of both mechanical and natural ventilation in the same facility and takes advantage of the best parts from both. The fans operate mostly in cold weather with summer ventilation being provided by adjustable sidewall panels. By installing fans and a small number of inlets, air will be exhausted at the required rate, and fresh air will be uniformly distributed throughout the barn in cold weather. Excessive drafting through sidewall openings is virtually eliminated. The winter fans can be operated in periods of warm weather when the wind is not blowing to supplement the summer ventilation rate. The exhaust fans, sidewall panels, heaters, and controls must function as a system to avoid poor air flow/distribution and subsequent health challenges. An alarm system can be installed to partially lower the sidewall panels in the event of a power failure.

Dual ventilation is a good compromise system for ventilating feeder barns and dry sow facilities. This is not a new idea; dual ventilation systems are common in the Midwest US. They are becoming more common in the more temperate parts of Canada.

Selecting the correct size of fan for any of the above systems is important. Over-sized fans will cycle on and off too frequently, causing wide room temperature fluctuations. They will also over-cool the room, wasting energy. Under-sized fans are not able to maintain the desired inside temperature, resulting in poor indoor air quality.

The fans should be sized to provide a wide range of airflows from the minimum winter continuous rate to the summer temperature control rate. To avoid rapid room temperature changes, the fans should be staged. Staging can be achieved with a combination of single- and variable-speed fans. It is fairly common to see the first two stages of ventilation provided by variable speed fans. The increased ventilation rates required in warmer weather would then be provided by several larger single-speed fans.

Fans may be wall, pit, or ceiling mounted (chimney). Location within the room is a critical part of a good ventilation design, particularly as room sizes have increased.

Comparison of fan performance needs to be done properly. For example, motor amperage and horsepower do not provide meaningful comparisons. The preferred method to compare the energy efficiency of ventilation fans is to take the airflow (ft^3/min) and divide it by the power (watts) to give a CFM/W rating.

The CFM/W ratings should be determined by an independent test laboratory certified by the Air Movement and Conditioning Association (AMCA). For example, the University of Illinois' Bioenvironmental and Structural Systems (BESS) Laboratory tests a large number of commercially available ventilation fans annually. Results of their annual fan performance testing are given on their

website (www.bess.uiuc.edu), as well as being published in a book. CFM/W ratings should be provided for a range of static pressures. Compare fans at the same static pressure, typically 0.10 in (2.5 mm). The greater the CFM/W rating, the better the efficiency. Check to see if the airflow (CFM) drops off as the static pressure increases. This means that the fan will perform poorly against wind pressure effects. The ventilation fans should be sized to match the design ventilation stages.

Environmental Advantages

Good air quality will be achieved with proper ventilation system design, equipment installation, and management. A properly designed fan-based negative pressure ventilation system will optimize ventilation rates and energy costs. Natural ventilation requires little energy as fans are not required. Electrical operating costs are reduced, noise levels in and around the building are low, and backup power generation is not required. Dual ventilation takes advantage of the best parts from both methods of ventilation. By installing fans and some ceiling air inlets, air is exhausted at the required levels and uniformly distributed throughout the barn.

Environmental Disadvantages

If airflow is too low, air quality deteriorates and challenges pig health. If airflow is too high, heaters will run too long and waste energy dollars and possibly not even keep the barn warm enough. All fan systems have a dependence on electricity, and fans can be noisy. In systems without natural ventilation, backup power is required. Positive pressure systems are much more complex to control and can accelerate deterioration of the building from forcing building air into the walls. It may also force poor quality air into hallways and offices. Natural ventilation systems lose effectiveness when there is no wind. They also require barn siting to optimize wind effectiveness and barn room design that allows airflow. Natural ventilation systems are most suited for livestock that do not require very warm temperatures such as finishers and dry sows.

Costs

There are a large number of different types and sizes of swine facilities throughout Canada, so a standard price that compares the different ventilation systems has not been established within the industry. System costs can vary a great deal between facility types, sizes, and system designs. When building a new facility or renovating an existing one, the swine operator should get several equipment companies or contractors to quote on their design. Selection of the winning bid can be done based on factors such as prices, quality or equipment, service, and reputation.

Fan operating costs for swine finishing facilities have been measured over a range from $0.25 to $1.75/hog marketed with the dual system being the lowest and positive pressure being the highest. Operating costs for natural ventilated facilities are minimal and the lowest of all mentioned systems.

General Assessment

Negative pressure systems have become the standard for mechanical ventilation of swine facilities in Canada for a number of reasons. They are easy to control, require few fans yet offer uniform distribution, do not force building air into the walls, and are very reliable at reasonable cost.

Natural ventilation facilities can provide several important advantages to mechanical facilities including lower electrical costs, reduced noise levels, and natural lighting. The reduced ability to control the air quality for both the livestock and workers is a very tough trade-off. The extra costs in heating the building resulting from this reduced control can easily outweigh the lower electrical operating costs.

Dual ventilation is a good compromise method between mechanical or natural ventilation for the ventilation of finisher and dry sow barns. Dual ventilation systems are becoming more common throughout Canada.

Complementary Technologies

Complementary technologies of mechanical ventilation systems include controls that can interlock to heating and cooling systems, lighting, feed systems, and provide historical recording. Other technologies include monitors for static pressure, H_2S, NH_3, and alarm systems.

Water sprinkling is also a complementary technology to ventilation when cooling is desired.

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2.2 Heating

Introduction

To provide optimum air quality and environmental conditions for the pigs, swine facilities in Canada usually have to be heated for some part of the year. Energy usage of heating systems can be quite variable, which in turn can have a positive or negative impact on economics and the environment. A properly designed and sized heating system is essential. Over-sized heaters tend to cycle on and off frequently, creating uncomfortable conditions and wasting energy. Under-sized systems will not be able to maintain the desired room temperature, adversely affecting the health and performance of the pigs. The proper design, installation, and management of the heating system can reduce producers' production costs and greatly improve animal comfort.

The various stages of hog production (gestation, farrowing, nursery, and grower/finisher) have specific requirements that must be considered when designing the heating system. The two main options for heating swine facilities are area heating (heats the entire barn or room) and zone heating (heats only part of an area).

A number of area heating systems are available. They include hot water, forced air, and infrared heaters.

A hot water heating system has one or more boilers and a distribution system consisting of pumps, piping, controls, and possibly radiators. Hot water heating systems may have lower operating costs when compared to other heating systems. However, this is not always the case, especially if poorly sized or designed. Also comparison of "combustion efficiency" alone does not provide a complete picture. The total system efficiency must be considered, and this will usually require trained professionals to compare all of the factors.

Heat mats providing zone warmth to piglets.
Photo Courtesy: Agviro Inc.

Controls are an important part of any hot water heating system. Boiler controls, like ventilation controls, have become quite sophisticated, often including complicated electronics. A good boiler control system will maintain the desired supply water temperature and improve efficiency. Some boiler controllers have a feature called "Outdoor Reset". This feature allows the controller to adjust the supply water temperature according to the outside temperature, which improves efficiency. Variable injection is a relatively recent boiler system development. It uses either variable speed pumps or three or four way mixing valves to inject the necessary amount of hot water from one line into another.

There are a number of different methods of delivering the hot water from the boiler to the various parts of a swine production facility. They are finned pipe, forced air radiator, and floor heating piping. Finned pipe is straight pipe with metal fins along the length. The additional surface area provided by the fins increases the heat output per length of pipe, but they are susceptible to clogging, so avoid using finned pipe in dusty locations. A forced air radiator works on the same principles as the radiator on a car engine. A thermostatically controlled electric fan blows room air through the radiator. Floor heating involves the installation of plastic or metal tubing in the floor of the pen or room. The tubing may be located in or beneath the concrete floor and as such, requires a solid floor.

Forced air gas heaters, also called "unit or box heaters", have been used extensively in swine barns throughout Canada. The products of combustion, namely carbon dioxide and water vapour, are normally vented directly into the room.

An infrared tube or "radiant tube" heater is a long black tube with an air intake, burner, and blower at one end and the exhaust at the other end. Infrared heating directs heat where it is needed - on the pigs and the floor. The floor is warmer directly under the heater and cooler further away. Infrared heaters have quickly gained popularity in the swine industry for use in nursery and grower/finisher facilities. Many producers like the improved air quality, better heat distribution, and lower energy costs as compared to other heating systems.

The room layout is very important when considering a radiant heater. Since radiant heaters heat objects, they have mostly been used for pigs housed in pens. Heating nursery or feeder pigs in group pens is an excellent application, as the pigs can find their desired "thermal comfort zone".

Creep heating provides zone or spot heating to piglets in farrowing or nursery rooms. A mature sow prefers a room temperature of about 68°F (20°C), while the piglets require much warmer temperatures of up to 100°F (38°C) when first born. Heat lamps, heat mats, or a combination of the two may be used to provide warmer temperatures for the piglets in the creep area. Heat lamps provide infrared (radiant) heat source for the pigs in the creep area. Energy efficient heat lamps, such as the PAR 38 design, are available in either 100 or 175 watts. Heat lamps typically use more energy than heat pads.

Environmental Advantages

Boiler and infrared tube heating offers better air quality than forced air gas heaters. Infrared heaters only heat objects and not the entire air space. Creep heating in the farrowing rooms allows the piglet and sows to be comfortable in spite of their different temperature preferences. Heating pads use less energy than heat lamps for that application.

Environmental Disadvantages

Solid fuelled boilers typically have greater emissions than oil or gas fired boilers. Forced air gas heaters normally exhaust the products of combustion, such as carbon dioxide, water vapour, and possibly carbon monoxide, into the room, thus requiring extra ventilation.

Costs

Conventional boiler (either gas or coal fired) capital costs are $0.02 to $0.047/Btu/hr ($78 to $160/kW) (SGA, 2004). Fuel costs of conventional boilers will depend upon the heating rate and the fuel type. For 50 to 500 kW units, the fuel cost is $1.65 to $16.50/hour of operation, based on a natural gas price of $0.0097/ft^3 ($0.3423/m^3). Biofuel combustion systems (BCS) have higher capital costs as compared to conventional boilers, ranging from $0.036 to $0.147/Btu/hr ($123 to $500/kW) (NRC, 2000; SGA, 2004) and require more space. Fuel costs for heating water with a BCS will depend upon the source and quality of the biomaterial. Table 2-1 shows a few fuel types, the amount of energy delivered, and the hourly fuel cost for a 170,000 Btu/hr (50 kW) BCS.

Table 2-1. Fuel Sources for Biofuel Combustion Systems.

Fuel Type	Cost	Delivered Energy (BTU/lb)	Hourly Fuel Cost BCS (170,000 BTU/hr)
Whole Tree Chips (green, softwood)	$36/ton	5.8	$1.12
Saw Dust (kiln dry, hardwood)	Low cost, $9/ton	12.4	$0.13
Straw (air dry)	Low cost $7/bale (farm produced)	10.4	$0.07 to $0.20
	$20/bale (purchased)		$0.24 to $0.70
Modified from: NRC, 2000.			

Infrared tube heaters run on either propane or natural gas, have lengths of 20 to 60 ft (6 to 18 m), and are rated from 50,000 to 150,000 Btu/hr (15 to 44 kW) (DRPC, 2005; Feldmann and MacDonald, 2000). The cost for tube heaters ranges from $1,475 to $1,624. Based on a natural gas cost of $0.0097 ft^3 ($0.3423/m^3), the cost per hour of operation per unit at full capacity is $0.49 to $1.47. For a 1,200 head wean to finish barn, four tube heaters are suggested (Feldmann and MacDonald, 2000), resulting in fuel costs between $1.96 and $5.81/hour of heating.

Forced air heaters (propeller type, blower type, or gas-fired indoor duct) cost from $1,917 to $2,784 (Mid-Valley Radiants) for units that are rated at 100,000 to 200,000 Btu/hr. Compared to tube heaters, the cost for heating a 1,200 head barn is higher with the annual cost per hour of heating at $8.72/hour. It is suggested that ventilation capacities need to be increased by 2.5 ft^3/min (0.07 m^3/min) for every 1,000 Btu/hr of heater capacity (Harp and Huhnke, 1992).

Heat pads are more cost efficient than heat lamps. For example, in a room with 10 farrowing crates, although the lamp's capital costs would only be $530 compared to $1,400 for pads, annual operating costs are $804 for lamps but only $332 for pads.

Management of the heating system is critical if energy efficiency is desired. A good quality controller that interlocks the heating system with the ventilation system is essential. It will not take long for a poorly set controller to waste thousands of dollars in a heating season.

Hallways or air plenums are commonly used to warm the incoming fresh air before it enters the rooms. This reduces cold air drafts and, in periods of extreme cold (below -4°F (-20°C)), prevents the air inlets from frosting up and the rooms from becoming foggy. It is critical to ensure that the preheat plenums are properly designed and managed. If the incoming fresh air is warmed up too much in the preheat area, the winter temperature exhaust fans in the rooms could begin to operate, wasting energy. One 2,200 sow farrow to finish facility reduced the preheat temperature by 36°F (20°C) and saved over $43,000 in one year.

Some infrared heaters now have a two-stage burner that allows a high and a low heat output. This can provide up to a 12% energy savings and 35% less on/off cycling as compared to a single-stage burner (MacDonald, 1996). Many users report improved feed intake and feed conversion, faster days to market, and reduced mortalities with infrared heaters. Converting from heat lamps to heat pads has a very good payback period. Many producers install both heat lamps and heat pads.

General Assessment

Hot water systems have several advantages over forced air gas fired "unit" heaters. Also, the infrared tube radiant heaters have gained considerable popularity over unit heaters with producers due to improved air quality, better heat distribution, and lower energy costs. For zone heating of piglets, pad heaters have several advantages over heat lamps. The selection of a heating system is complex and the use of qualified professionals is recommended to obtain a system that best matches the specific requirements.

Complementary Technologies

New technologies for heating systems are continually evolving. Sources such as solar or some of the evolving bioenergy sources can harness energy that might be readily available at the site. For example, anaerobic digesters can convert energy from manure into heat. Technologies such as heat exchangers and windbreaks will also reduce energy consumption for heating.

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2.3   Cooling

Description

There are a number of reasons to include summer cooling systems in swine production facilities. Just as humans lose their appetite in hot weather, pigs will decrease their feed intake. Feeder pigs reduce feed intake by 0.92% for every 1°F (0.5°C) increase in the effective environmental temperature (EET) above 70°F (21°C).

Air speeds greater than 50 ft/min (0.25 m/s) combined with sprinklers can provide as much as a 25°F (14°C) reduction in the pigs' EET. Sprinklers reduce the EET about 9°F (5°C), while high air speeds reduce the EET by15 to 18°F (8 to 10°C). If cooling is not used on a day with an average inside temperature of 90°F (32°C), feeder pigs will reduce their feed intake by 18%. For breeding stock, room temperatures greater than 86°F (30°C) will adversely affect boar semen production, resulting in reduced breeding performance in the future. Providing the best comfort level possible also makes sense from an animal husbandry point of view.

Fan-based systems that can be used include air inlets that drop down and direct air straight into the pen, or thermostatically controlled circulating fans. Air speeds at pen level can reach 200 ft/min (1.0 m/s).

Air inlet directing air to pens.
Photo Courtesy: Agviro Inc.

Tunnel ventilation is a system where a large number of exhaust fans are located in one end of the barn with the opposite end of the barn being mostly air inlet. The fans and inlet opening are designed to provide an air velocity of about 250 ft/min (1.3 m/s). Capital and operating costs for a tunnel ventilation system can be fairly significant.

It may be more economical to cool by using a water-based cooling system in combination with higher air speeds. It is very important to manage the water-based cooling system properly. Incorrect operation will result in excessive water usage causing increased indoor relative humidity and overflowing into the manure storage pits. The main techniques of providing supplemental cooling using water include evaporative cooling systems, dripper systems, sprinkler systems, and misting systems.

Evaporative cooling systems are large water soaked pads located on the sidewalls of a building. All the summer intake air must pass through them. Air drawn into the barn picks up moisture by evaporation as it passes through the pads. This reduces the air temperature by up to 10°F (5.5°C). The big advantage of evaporative systems is that the cooling occurs without any water coming in contact with interior surfaces. This minimizes slippery floors and reduces the likelihood of building deterioration. Although evaporative cooling systems are extremely efficient, they do have drawbacks. Additional fan capacity may have to be provided to compensate for the increased static pressure caused by drawing the inlet air through the pads. Prevention of algal growth on the pads requires routine maintenance. Evaporative cooling systems tend to be fairly complicated and relatively expensive.

A dripper system is best used where the pigs are closely confined, such as in farrowing crates or gestation stalls. A reasonable amount of cooling can be provided by slowly dripping water onto a sow's head. Proper location of the dripper will allow the sow to move away from the dripping water. Dripper systems are usually made entirely of plastic and are easy to install, maintain, and operate. Although drippers use relatively low volumes of water, they can result in unwanted water on solid floors.

With a sprinkler system, water droplets are sprinkled liberally in a pattern determined by the nozzle and the water pressure. Sprinkler systems are made of plastic and are easy to install. The goal of a sprinkler system is to wet but not soak the pig's skin. When the water evaporates, it causes a cooling effect. Even very hard water causes little problem for low pressure sprinkler systems that operate at about 40 psi (276 kPa). Maintenance consists of soaking components in vinegar and scrubbing when required.

Due to large sprinkler areas and limited control over whether the pigs are in the areas when the sprinklers are on, water wastage will occur. Although some producers have used garden sprinklers, these sprinklers have very large and widely varying droplet sizes resulting in even greater water wastage.

Evaporative cooling pad.
Photo Courtesy: Agviro Inc.

Sprinklers have been developed that maximize coverage area and minimize water usage. Dripless nozzles are available that prevent the water line from draining when the water pressure drops below about 30 psi (207 kPa). Dripless nozzles prevent excessive water waste and allow all of the sprinklers on a common water line to start operating at the same time.

In addition to cooling, a sprinkler system can be used to establish proper dunging habits in partially slatted swine feeder barns. A controller that allows a timed event (on/off), and which may be over-ridden due to increased indoor temperatures, will allow a smoother conversion to cooling when it is necessary.

Drying (evaporative cooling) is the key to the effective use of a sprinkler system, so allow ample time for the pigs to dry off. Air movement, either from the fresh air inlets or from circulation fans, will quicken this process.

Misting systems operate at higher pressures (200 to 1,200 psi (1.4 to 8.3 MPa)) and use metal (brass, etc.) nozzles. The higher pressures combined with very small holes in the nozzles produce tiny droplets which easily evaporate and lower the inside temperature. These are precision systems so the supply water must be filtered.

Environmental Advantages

Use of increased air speed and water-based systems are very efficient methods to achieve cooling in a hog barn. Supplemental cooling during periods of hot weather will prevent a decrease in feed intake by feeder pigs, prevent a reduction in boar semen production, and improve animal comfort. Large fans used in tunnel ventilation are usually more efficient than smaller fans. Sprinklers can also reduce dust.

Environmental Disadvantages

Tunnel ventilation providing air speeds of about 250 ft/min (1.3 m/s) has significant capital and operating costs. These systems will not lend well to barns with different sized pigs that prefer different temperatures or if the barn is not designed properly for through flow. Poorly maintained water cooling systems can create excessive room humidity and dump water onto the floor and into the pit.

Costs

Cooling costs when using existing ventilation fans and inlets only consist of fan energy costs. Similarly, ceiling mounted circulating fans do not have significant capital or operating costs. However, capital and operating costs for tunnel ventilation systems can be fairly significant.

Costs associated with water based cooling systems are provided in Table 2-2.

Table 2-2. Comparative Costs of Water Based Cooling Systems.

	Evaporative Pad	Dripper	Sprinkler	1,000 psi Mister
Installed Cost	$4,800	$1,500	$1,500	$3,000
Operating and Maintenance Costs	$500/yr	Minimal	Minimal	$258/yr

General Assessment

Supplemental cooling on hot days will prevent a decrease in feed intake by feeder pigs, prevent a reduction in boar semen production, and improve animal comfort. Cooling can be achieved with increased air movement using the existing ventilation system or with additional fans. Additional cooling can be achieved using a combination of increased air speeds and water based cooling to reduce EET by as much as 25°F (14°C).

Complementary Technologies

Ventilation systems are a complementary technology to supplemental cooling. Building design including insulation and reflective surfaces are also complementary technologies to assist with cooling. Air conditioning is also an option but is very costly so it is only practical in specific applications where heat stress causes significant loss, such as boar stud facilities.

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2.4 Barn Hygiene

Description

The primary objective of hygiene is to lower the dose of infectious pathogens that may be transmitted from the environment to pigs. It has been well documented that animal performance is better in clean environments than dirty environments, and cleanliness is probably responsible for a large percentage of the growth performance benefits from all-in/all-out production. Because young pigs are more susceptible to infections from enteric organisms, sanitation is especially important for nursery facilities.

(1) Pathogen Vectors: Most swine diseases are transferred from one animal to another by direct contact. The easiest and most frequent avenue for introducing disease into a herd is via the replacement boar or gilt. Purchasing boars and gilts from as few sources as possible reduces this risk. Disease does not always enter a farm with purchased stock.

Animal performance is increased in clean environments.
Photo Courtesy: MAFRI

Disease also enters indirectly when it is carried on contaminated boots, clothing, supplies, and equipment or indirectly by airborne particles blown from adjacent barns. Disease prevention methods include: (1) having a set of boots and clothing to wear exclusively in the barn; (2) transport and service vehicles should be thoroughly washed before returning to the farm; (3) farm visitors should be discouraged; (4) equipment that has been in contact with other pigs should be thoroughly cleaned and disinfected before returning to the farm; and (5) feed and watering equipment should be arranged so that it cannot be infected from feces or urine.

(2) Thorough Cleaning and Removal of Organic Matter: Use building materials that are easy to clean. A survey of 127 French farms indicated that the practice of damping rooms immediately after removing pigs increases the ease and thoroughness of cleaning. It is hypothesized that damping prevented drying of fecal matter. Additionally, greater distances between the surface of the slurry and the floor prevented "splash back" and recontamination during the cleaning process. A major mode of transmission of worm parasites is via contamination of the environment with infected feces. For example, eggs of ascarid worms stick to concrete surfaces and the usual disinfectants used on farms do not kill these eggs. The best method of decontamination is a thorough cleaning with detergent and steam (McCallister, 1998).

(3) Proper Use of Disinfectants: Studies evaluated several disinfectants commonly used in swine farms and research laboratories. The disinfectant classes (products tested) are shown in Table 2-3.

Most hog pathogens only survive for a brief amount of time outside the host in the absence of organic materials or moisture. The relative importance of the stages of sanitation are: (1) 90% removal by removing all visible organic matter; (2) 6 to 7% killed by disinfectants; and (3) 1 to 2% killed by fumigation (Dritz, 2002).

Environmental Advantages

Several practices that improve hygiene are neutral or environmentally friendly. Many management techniques that prevent contamination or simple cleaning have no environmental impact but rather promote a healthier barn environment for the pigs and workers.

Table 2-3. Disinfectants.

Active Compound	Uses	Range of Effectiveness	Disadvantages	Common Brand Names
Chlorhexidine	Equipment cleaning, premises, foot baths	Some bacteria and viruses. Ineffective against parvovirus, pseudomonas	Reduces activity against certain organisms	Nolvasan®
Chlorine, Hypochlorites, Chloramines	Equipment cleaning	Bacteria and fungi, limited effect on bacterial spores and viruses	Inactivated by organic material, may be irritating	Chloramine-T® Chlorox® Halazone®
Cresols, Phenols	Equipment, premises, foot baths	Variety of bacteria, limited effect on fungi and viruses, poor against bacterial spores	Strong odour with coal or wood tar distillates	Cresl-400® Environ® Laro® Lysol®
Formaldehyde, Other Aldehydes	Equipment, premises, foot baths	Variety of bacteria, bacterial spores, fungi and viruses	Irritating fumes	Cidex® DC&R® Formaldegen® Formalin®
Idophors	Cleaned equipment	Bacteria and fungi, limited effect on bacterial spores and viruses	Inactivated by organic material	Betadine® Iofec® Isodyn® Losan®
Quaternary Ammonium Compounds	Equipment cleaning	Variety of bacteria and fungi, limited effect on bacterial spores and viruses	Inactivated by organic material, neutralized by soaps	Germex® Zphiran® Hi-Lethol®
Source: Meyerholz and Gaskin, 1981				

Environmental Disadvantages

Improper use of drugs and some bacteria control methods, such as the use of antibiotics in swine feed, can promote the growth of antibiotic resistant bacteria or pass resistance genes to humans through their zoonotic potential. The presence of drug residues in slaughtered swine represents a food quality and consumer confidence issue.

Costs

Barn cleaning can be performed using a pressure washer. Pressure washer systems will cost between $130 and $200. Hot water systems, which will cut through grime faster than colder water washers, cost two to four times more. Operation costs for hot water systems are also greater due to the heating cost for the water. Chemical disinfectants can improve cleaning efficiency and reduce odours; however, such chemicals may increase operating costs. The costs of a few of the disinfectants in Table 2-3 are listed in Table 2-4.

Table 2-4. Cost of Disinfectants.

Brand Name	Common Container Quantity	Cost*
Nolvasan®	US gallon	$57
2% Chlorohexidine Scrub	US gallon	$47
Chloramin-T®	1.1 lb	$81
Halozone®	2.2 lb	$979
Lysol®	19 oz	$9
Cidex®	US quart	$20
Betadine®	18 oz	$33
* 2004 prices		

General Assessment

Hygiene in the barn can be a very cost effective and environmentally friendly method of reducing exposure to infectious pathogens. Management to reduce contamination, cleaning of organic matter, and use of disinfectants are all optional methods to improve hygiene. They help to reduce the need for drugs and biologies to prevent and treat disease.

Complementary Technologies

Considering the growing concerns surrounding antibiotic use in food animals, many researchers have been studying alternative methods of disease prophylaxis and growth promotion. Among these are probiotics, prebiotics, enzymes, diet acidification, fermented liquid feeding, neutraceuticals, minerals, novel antibodies, vaccination, and improved management and husbandry practices.

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2.5   Pest Reduction

Description

Some of the common pests include houseflies, stable flies, lice, mange, cockroaches, and beetles.

The housefly and the stable fly are the two most common nuisance flies in swine production. Normal infestations of houseflies have not been shown to adversely affect the productivity of swine. However, stable flies may cause direct reduction in feeding efficiency and rate of gain (Mock, 1997). The wounds and skin irritation produced by these parasites result in discomfort and irritation for the animal, and animals may expend considerable energy trying to escape. Both house and stable flies have been shown to transmit disease and be a cause of neighbor complaints.

Flies should not be allowed to enter a swine building.
Photo Courtesy: Prairie Swine Centre

Flies, as pests, should be managed at a swine farm. It is easier and more cost effective to prevent fly populations than it is to reduce an established population. The key to control is the use of an integrated pest management approach that starts with sanitation and uses cultural, physical, biological, and chemical options to control flies at their different stages of life. Flies typically have four stages of development: egg, larva, pupa, and adult. Flies breed in fresh manure, spilled feed, silage, and moist animal bedding. Flies should not be allowed to enter a swine building. Installing and maintaining screens over all air access points will limit the number of flies that can enter and subsequently breed. Eliminating breeding environments for the flies that do enter buildings is 75% of a fly control program.

Fly control can be looked at from two perspectives, larval (first three developmental stages) and adult control. The flies in the larval stages require a moist environment for 10 to 21 days to survive. Organic material at 50 to 85% moisture content is ideal. To minimize fly development, remove any spilled feed, manure, and soiled bedding material weekly. Liquid manure usually has too high of a moisture content for satisfactory egg laying and larval survival. Mechanical agitation can kill many flies in the larval stage. Applied larvicides should be used as a last resort measure but not as a continuous method in a fly control program. Ration fed larvacides are an exception (Mock, 1997).

Fly control at the adult stage has a number of different components, all of which should be used. The most aggressive is chemical control. Insecticide resistance builds quickly in fly populations so plans should include rotating the insecticide active ingredient. Baits should only be used to supplement a spray method.

Surface or residual spraying should be targeted at fly resting areas and anywhere fly specks are observed. For houseflies, spraying should be done on ceilings, upper walls, and rafters; for stable flies, resting areas are about 3 to 4 ft (1 to 1.2 m) above the floor level (Mock, 1997). Table 2-5 shows the expected coverage for surfaces of different porosity.

Larvacide techniques generally only last one to three weeks due to the acidic nature of the manure breaking down the chemical (Campbell, 1996). Lime can also be used as a larvacide, using enough to cover the entire pit, with weekly reapplication required.

Hogs infested with hog lice or sarcoptic mange show similar symptoms. The skin becomes inflamed, and the hogs spend a considerable portion of their time scratching. Lice can also cause anaemia in young pigs (McKean et al, 1992). Hogs often have lice and mange simultaneously. They are both spread through physical contact between hogs.

Hog lice and eggs are visible to the naked eye as they grow up to a 0.25 in (0.64 cm) in length. They are bluish-black to brown in colour. They feed in both the adult and nymph stages by piercing the skin to suck blood. Lice crawling around on the swine's body and feeding cause skin irritation. Hog lice may transmit diseases.

Sarcoptic mange is a skin disease caused by mites burrowing under the upper layer of skin. Detection requires scraping of the skin and examining it under magnification for mites and their eggs.

Many insecticides control lice without controlling mange, but the proper application of sarcoptic mange insecticides will control lice. Eliminate lice and mange before farrowing as most pesticides cannot be used on pigs under weaning age. Treat all swine on the farm at the same time. If this is not possible, do not allow any contact between infected and non-infected pigs, not even a common fence line. Most louse and mange pesticides will also control ticks on pastured swine.

Table 2-5. Residual Surface Coverage Based on Porosity.

Surface Type	Coverage (gal/1,000 ft^2)
Unpainted Plywood	2.3
Painted Plywood	0.8
Unpainted Concrete	30
Painted Concrete	3.0
Modified from Stringham, 1997.	

Cockroaches and beetles are often abundant in feed mixing areas. Some beetle larvae can consume and contaminate feed. General cleanup can control most infestations before they start. Immediate sanitation of a vacated building allows the natural antiseptic action of oxygen and sunlight to occur. Pesticides are available to control cockroaches and beetles.

It is important to follow label instructions when dealing with insecticides to protect human and animal health and prevent environmental damage. When using insecticides, proper safety equipment will be required for the workers. Impermeable gloves, goggles, breathing apparatus, and protective clothing all add to the total capital costs of these technologies.

Table 2-6 shows various insecticides for residual sprays, area sprays, and other methods for controlling pest populations.

Environmental Advantages

Reduction of pests reduces animal stress and also reduces the possibility of annoyances created for neighbours.

Environmental Disadvantages

Larvicides are susceptible to groundwater leaching and range from moderately to highly toxic to birds and aquatic life. Larvicides are also a skin, eye, and respiratory irritant. Some sarcoptic mange and louse controls are moderately to highly toxic to birds and/or aquatic life. Most of the chemicals are less susceptible to groundwater leaching than larvicides but are of a greater risk to runoff contamination of waterways. Most chemical pest control programs control positive insects, such as bees, as well as negative insects.

Pesticide tolerance levels for residues found in meat animals must be taken into consideration to ensure food safety.

Costs

The capital cost associated with the elimination of breeding areas can include the cost of washing equipment, a manure agitation system, composting, and black plastic for covering manure. Pressure washers can cost $130 to $200/unit. The cost of a 6 mil (0.15 mm) black plastic tarp is about $0.10/ft² ($1.07/m^2). Heavier tarps (12 mil (0.3 mm)), which will have longer life spans and be more durable, cost about $0.44/ft^2 ($4.74/m^2).

Area spraying requires a fogger ($85 to $315), a hydraulic sprayer (up to $235), or a mist blower ($720 to $800 gas powered, $160 ¼ hp electric).

Electronic fly catchers cost between $90 and $180. A single unit can service between 1,000 and 4,000 ft^2 (93 to 372 m^2).

Dusting systems for lice and mange control can cost as much as $290.

Table 2-6. Insecticides for Pests.

Insect to Control	Application Method	Chemical	Tradename(s)
Fly	Bait	Malathion	Malathion
		Methomyl	Improved Golden Malrin®
		Trichlorfon	Depterex®
	Residual Sprays	Cyfluthrin	Countdown®, Tempo WP®
		Diazinon	Dryson WP®
		Dichlorvos	Vapona®, DDVP
		Dimethoate	Cygon®
		Fenvalerate	Ectrin®
		Lambda-cyhalothrin	Grenade WP®
		Malathion	Malathion
		Methoxychlor	Marlate 50 WP®, Methoxychlor II EC®, Sur-Noxem®
		Permethrin	Atroban®, Permethrin®, Permectrin II EC®, GardStar 40 EC®, Pounce®
		Tetrachlorvinphos	Rabon 50WP®
		Tetrachlorvinphos + dichlorvos	ReVap®
		Trichlorfon	Dipterex®, Dylox®
	Space Sprays	Dichlorvos	Vapona®
		Fenvalerate	Ectrin®
		Malathion	Malathion
		Methoxychlor	Methoxychlor II EC®
		Naled	Dibrom®
		Permethrin	Permectrin II EC®
		Pyrethrins	Exciter
	Direct Animal Spraying	Pyrethrins	Exciter
	Feed Additives	Tetrachlorvinphos	Rabon 50WP®
Mange and Lice	Pour On	Amitraz	Taktic®, Swine Guard®
	Spray On	Amitraz	Taktic®
		Fenvalerate	Ectrin®
		Malathion	Malathion
		Permethrin	Atroban®, GardStar 40 EC®, Permectrin II EC®
		Phosmet	Prolate
Lice	Pour On	Fenthion	Tiguvon®
		Fenvalerate	Ectrin®
	Spray On	Methoxychlor	Marlate 50 WP®, Methoxychlor II EC®, Sur-Noxem®
		Coumaphos	Co-Ral WP®
		Tetrachlorvinphos	Rabon 50WP®
	Dusting	Coumaphos	Co-Ral WP®
		Methoxychlor	Marlate 50 WP®
		Permethrin	Permectin II EC®
		Phosmet	Prolate
		Tetrachlorvinphos	Rabon 50WP®
Modified from: Stringham, 1997; Campbell, 1992; Hall, 1993			

Much of the operation costs for eliminating fly breeding areas will be labour. Pressure washing should be done once every two weeks. Cleaning stalls of waste, bedding, and spilled food should be performed weekly, and bedding should be replaced every seven to ten days.

Controlling fly population with baits can add to the labour costs in production, as well as chemical costs and electricity costs. Baiting is generally only effective with houseflies, as stable flies feed off the pigs. Electronic fly catchers electricity costs are $0.30/bulb/1,000 hours of operation. The operating costs of mange and lice control are mostly limited to labour and chemical costs.

General Assessment

Pest control is very important as stable flies, lice, and mange can reduce weight gain and feed efficiency. The key to pest management is to eliminate a breeding environment, as it is easier to prevent pests than it is to control them. Chemical solutions, although sometimes necessary, have a greater risk of environmental contamination. Most modern swine operations have few problems with lice or mange as skilled management preclude these problems.

Complementary Technologies

Good sanitation and manure management practices help reduce insect problems before they start. Other methods of reducing breeding areas for flies include the use of a manure storage system, proper and timely dead stock disposal, drying solid manure, and soil application.

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Chapter 3   Air Quality and Odour Control

3.1   Ammonia Reduction Systems

Description

The major source of ammonia in swine barns is urea excreted with urine. This urea is converted into ammonia and carbon dioxide by the urease enzyme present in feces. Additionally, ammonia is also produced by bacterial breakdown of protein components in feces. While it is unlikely that a single solution can reduce ammonia emissions from swine barns satisfactorily, ammonia levels can be reduced significantly by implementing a combination of practices involving ventilation, manure management, building hygiene, and

> *Ammonia reduction systems include manure additives, design of manure handling systems, and diet manipulation.*

feed management. Generally, the most important factors that influence ammonia emissions are: (1) pig inventory; (2) pig mass and phase of production; (3) housing type and management; (4) manure storage and treatment; (5) feed nitrogen content; (6) nitrogen excretion rates per pig; and (7) environmental conditions.

Although there are some provincial guidelines available, there is no Canada-wide regulation that provides a limit to ammonia gas concentrations in buildings. In the USA, the recommended maximum gas concentrations suggested by the Occupational Safety and Health Administration (OSHA) is 25 ppm. This is much higher than the maximum of 10 ppm suggested by agricultural scientists in Europe.

Following are three systems of ammonia reduction.

(1) Manure Handling Systems - European researchers are developing gutter scrapers that automatically separate the liquid from the solids. Researchers in the Netherlands compared the relative ammonia emissions for five different manure collection systems. Fully slotted floors with deep pit and long-term storage generated the most ammonia gas. The building with a partially slatted floor and manure pit produced 20% lower ammonia emissions. The ammonia level from a partly slatted floor combined with a sloping floor under the slats from which manure was flushed several times a day was 30% below that for a deep pit. Greater emission reductions were achieved when manure was collected under the slatted floor of flushing water so that the manure falls into the liquid and the solids are submerged. If the mixture was regularly pumped out and replaced by new flushing liquid (as in a pit recharge), the reduction was 60% (Hendriks, 1999).

Cooling manure also reduces ammonia emissions. Using circulating water in a closed loop geothermal system to cool the top 4 in (100 mm) of swine slurry can reduce ammonia emissions by as much as 75% in nursery buildings (Heber et al, 1999).

(2) Manure Additives - Additives for manure have the capability to reduce ammonia as well as other factors such as odour, other gases, and even solid content (Table 3-1).

Pit additives can be applied in a variety of ways depending upon the type of additive and the manufacturer. Additive application can be done in three ways depending upon the manufacturer recommendations and the effect to be produced: a single annual application, an initial application, followed by monthly, weekly, or daily maintenance doses, or monthly, weekly, or daily maintenance doses, with no initial application.

(3) Diet Manipulation - Feeding nitrogen-rich diets favour higher ammonia emissions. Therefore, minimizing the excretion of N by using a reduced protein diet may reduce ammonia volatilization from swine feeding operations.

Manipulation of acidogenic agents uses feed containing monocalcium phosphate or phosphoric acid, which can reduce ammonia by 16 and 30%, respectively. A major challenge with this approach is to

Table 3-1. Ammonia Reduction from Pit Additives.

Product Brand Name	Manufacturer/Supplier	Decrease (%)
95% Certainty of Reduction in NH$_3$		
EM Waste Treatment	EM Technologies, Inc.	15
AWL-80	NatRx, Inc.	10
Biocharge Dry	Biotal, Inc.	7
Krystal Air	Fischer Enterprises, Inc.	7
AgriKlenz Plus	Aqualogy BioRemedics	6
Manure Management Plus^{TM}	Cytozyme Laboratories, Inc.	6
Biological Manure Treatment	K-Zyme Laboratories	5
Peroxy Odor Control	Kennedy Enterprises	3
75% Certainty of Reduction in NH$_3$		
MBA-S	Desert Microbial Products	3
N-P 50	NEO Products	3
Agricycle^{TM} & Microcycle^{TM}	American Bio Catalysts	3
Digest 54 Plus	Alltech, Inc.	2
Modified from: Zang, 2002		

determine what calcium source to use. Limestone increases urine pH in contrast to gypsum or calcium chloride. However, the latter two may negatively affect the dietary electrolyte balance of the animal and affect the animal's gut and health.

Environmental Advantages

Reducing the ammonia emissions from swine operations will: prevent nutrient deposition in the ecosystem; reduce the formation of light scattering aerosols that cause haze and visibility impairment; and reduce the formation of respirable aerosol particles which are a health concern to people working with hogs or living in the vicinity of hog facilities.

Environmental Disadvantages

Some of the ammonia reduction systems have an increased requirement that relates to the environment. Manure additives need to be manufactured. Manure systems to reduce ammonia may require more water and possibly more energy. Diet manipulation may have other effects on hog growth factors if not properly managed and rations are not properly formulated to the nutritional needs of the animals.

Costs

The cost of manure additive technology depends upon many factors. The type and size of the operation, hog density, and frequency of pit clearing-out greatly affect the cost in terms of the quantity of additive required and the number of applications. The condition of the manure pit can also affect the cost. Temperature, pH, state and quantity of solids, and whether chemicals associated with cleaning have entered the storage can all influence the cost effectiveness of this technology. The desired level of reduction will also affect the cost.

The cost of pit additives ranges from \$0.02 to \$1.30/marketed hog (Stinson et al, 1999; Zhang et al, 2000). The range of cost can be reflected in the desired effect in the pit and the function of the additive. In addition to reducing ammonia, some additives are used to reduce odour, others to reduce solid content, others only reduce H$_2$S emissions, and others reduce nitrogen losses. These costs are for the additives alone; labour and equipment to apply the additives have not been included in the evaluation due to the wide range within each category. Application of an additive to the surface of the manure pit may be manual in some cases while in others it may require an investment in automatic pit sprayers and timers to achieve these results. Some additives need to be premixed with water and

others need to be spray-applied over the surface as opposed to being poured into the lagoon/pit, thus increasing labour and equipment costs. It is expected that the costs for labour where maintenance doses are applied will be much greater than for just a single annual application. If the quantity of additive is large due to the size of operation or the frequency of application, a separate room/small building may be required for the storage of the additive, thus increasing the costs.

Costs associated with manure handling systems are largely capital costs and in most cases are related to the barn, manure storage, and manure handling equipment. An example is the system, previously described, to cool the top 4 in (100 mm) of manure that has a capital cost of $38.80/pig in a nursery building (Heber et al, 1999).

General Assessment

There is no single method that satisfactorily reduces ammonia. For new facilities, selecting building and pen designs that reduce the physical wet ammonia emitting surfaces combined with good barn hygiene can result in the highest reduction of ammonia levels in barns. For existing facilities, improved barn hygiene combined with proper ventilation could offer acceptable ammonia reduction at minimal cost. Diet manipulation appears to require more study before it can become a generally accepted practice.

Complementary Technologies

Ventilation of manure can affect ammonia gas emission rates. Air speeds across manure-covered surfaces should not be excessive since the amount of ammonia gas given off by manure increases with air speed. Hence, control systems that prevent excess ventilation rates are a complementary technology.

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3.2   Dust Control with Oil Sprinkling

Description

Swine producers are exposed to high dust levels in pig barns. The Health and Safety Act of Ontario (1996) sets the threshold values for dust in barns as: (1) Total Dust - 10 mg/m³; (2) Respirable Dust - 5 mg/m³. Sprinkling vegetable oil in these buildings has been shown to be an effective method for reducing indoor airborne dust. Suspended dust particles absorb toxic and odorous gases. The reduction of airborne dust concentrations inside buildings may also decrease odour and gas emissions from pig facilities. An oil sprinkling system has been designed at the Prairie Swine Centre to control dust levels in pig buildings using undiluted crude canola oil. Combining the results of different experiments, this system reduced the dust mass concentration by up to 87% compared to rooms where no oil was applied (Godbout et al, 2000; Senthilselvan et al, 1997). The system was

Oil sprinkling with a backpack sprayer.
Photo Courtesy: Ian Seddon, MAFRI

effective in replicating previous dust reduction data collected with automated and manual systems, and this concept can be used to control dust levels in growing-finishing barns. Sprinkling of canola oil can also reduce the indoor odour concentration and emissions of NH_3 and H_2S.

Airborne dust particles in swine buildings carry a wide variety of gases involved in creating the typical pig smell. Theoretically, reducing the dust concentration with oil sprinkling should consequently reduce building odour emissions. However, the results from different experiments indicate a limited effect of oil sprinkling on odour emissions from pig facilities. Although it may mitigate odours in very specific conditions, the main justification for implementing oil sprinkling should be to control indoor airborne dust particles.

Environmental Advantages

Several airborne contaminants in livestock buildings have been identified as being harmful to the welfare of workers, damaging to animal health, and detrimental to animal productivity. One of these contaminants is respirable dust. In addition to health related concerns, dust creates a nuisance in and near pig buildings, increases labour requirements for building and equipment maintenance, and interferes with the performance of heating and ventilating equipment. The use of vegetable oil is an environmentally friendly method to reduce dust.

Environmental Disadvantages

Due to the nature of the oil, fans and louvers can become very dirty rapidly and will need to be cleaned often to maintain optimal ventilation efficiency. Nozzles in the dispensing system can become clogged and will require maintenance. Since oil is sprinkled on the floor, slats can become slippery, creating a hazard to animals and workers. While cleaning up this oil would be counterproductive, precautions should be taken to reduce the risk of injury.

Costs

Oil sprinkling can be done either by hand or with an automated system. Sprinkling by hand requires a backpack sprayer, which costs about $158 (Zhang, 1997). Automated systems are much less labour intensive and cost $3.29/pig space to install (Marsh and Karapetyan, 1999). If the barn is already fitted with a soaker system, the system can be retrofitted for oil sprinkling, costing about $420 for a 1,000 head barn (Marsh and Karapetyan, 1999). If an oil/water mix is to be used, a mixing tank will be required to put the oil into suspension. In a cold climate region, it is more desirable to use systems applying pure vegetable oil rather than a mixture of water and oil. In some conditions, this additional

water sprinkled by the system would increase building heating requirements due to the need for an increased ventilation rate for moisture control.

The largest portion of operating costs for sprinkling systems is the oil. Application rates are typically around 45 gal/1,000 ft^2/year (220 L/100 m^2/year) (Lemay et al, 2001), though applications as low as 9 gal/1,000 ft^2/year (44 L/100 m^2/year) (Neutkens, 2003) and as high as 260 gal/1,000 ft^2/year (1,270 L/100 m^2/year) (Godbout et al, 2000) have been used. In general, the higher the application rate, the greater the dust control. Using a rate of 45 gal/1,000 ft^2/year (220 L/100 m^2/year), dust reductions of as much as 80% may be achieved (Lemay et al, 1999). Assuming 10 ft^2 (0.93 m^2) per animal space and 2.26 cycles/year, the amount of oil required is 0.45 gal (1.7 L) per animal space or 0.2 gal (0.76 L) per marketed hog. Table 3-2 shows prices for different oils and annual costs for oil sprinkling for three different application rates.

Table 3-2. Costs for Oils Used in Oil Sprinkling Technologies.

Oil	Retail Cost $/gal	Wholesale Cost (>264 gal) $/gal	Annual Cost*/1,000 ft^2		
			10 gal/ 1,000 ft^2/yr	45 gal/ 1,000 ft^2/yr	250 gal/ 1,000 ft^2/yr
Crude Canola	3.14	3.14	$31	$141	$785
Purified Canola	6.28	4.73	$47	$213	$1,183
Corn	11.36	8.86	$89	$399	$2,214
Soybean	20.78	15.60	$156	$702	$3,899
Flax	35.39	26.54	$265	$1,194	$6,634
Sunflower	11.36	9.09	$91	$409	$2,271
Johnson's Baby Oil	38.61	33.69	$337	$1,516	$8,422

* Based on wholesale costs.
Modified from: Zhang et al, 1996.

The operating costs of hand held technologies will include labour and oil costs. For a barn marketing 4,000 head annually, 360 hours of labour is required annually for sprinkling and another 30 hours/year for pressure washing (Zhang, 1997). This amounts to about one-tenth of an hour or $1.20/marketed hog (labour rate of $12/hour). Thus, if crude canola oil were used at a rate of 45 gal/1,000 ft^2/year (220 L/100 m^2/year), the annual cost of labour and oil would amount to $1.82/marketed hog.

An automated system can greatly reduce the labour costs associated with oil sprinkling. Labour in such systems is basically associated with cleaning and filling the reservoir with oil. Automated systems have useful lives of about five years, and annual maintenance can be costly at $132/year (Goodrich, 2001) including labour. However, this information regarding system life cycle and maintenance cost should be used only as a guideline, considering that very few systems have yet been operated under commercial conditions for an extended period.

In addition to oil, a surfactant may be used at a rate of 3 gal/55 gal (11 L/208 L) of oil (Goodrich, 2001). However, at a cost of $23/gal ($5/L), this almost doubles the cost for sprinkling crude canola oil. Natural oils have been tried; however, these only mask odours and do not help in the control of dust.

General Assessment

Sprinkling of vegetable oils has been shown to reduce airborne dust by up to 80%. The methods of application range from manual with a backpack sprayer to automated sprinkler systems.

Complementary Technologies

(1) Wet Scrubbers in Ventilation: A wet scrubber is a particle and gas collector that traps fine particles using liquid droplets such as water. Wet scrubbing has the advantage of removing particles without regular maintenance and can also remove water-soluble gases such as ammonia. Disadvantages of wet scrubber designs include the need for using a large quantity of water and the disposal of dirty water (Carpenter and Fryer, 1990).

(2) Dry Filtration: The use of purpose built dry filters in livestock buildings is a method of reducing about half of the dust mass and some bacterial colony-forming particles. Examples of designs for livestock buildings include: (a) ceiling mounted; (b) low profile ceiling mounted; and (c) floor-standing with low-speed air discharge. Manual vacuum cleaning can be required every five days. Dry filtration in large facilities would only be effective if efforts were made to relegate all dust generating sources (Carpenter and Fryer, 1990).

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3.3   Biofilters

Description

The purpose of a biofilter is to reduce, remove, or change the character of the odour of exhaust air from a manure source including deep pit barns, exhaust fans, manure storages, etc. Odours are eliminated through a natural biological oxidation process. A biofilter is simply a layer of organic material, typically a mixture of compost and wood chips, that supports microbial population. Odourous air is forced through organic media and is converted by the microbes to carbon dioxide and water.

Biofilter schematic.
Source: Schmidt et al, 2000

Gases are treated by biodegradation, sorption, and filtration. The lifespan of the filter media varies. The lifespan of peat moss and bark varies from six months to two years depending on the process and properties of the gases being treated. When compost and wood chips are used, the filter may last three to five years. The process may require a prior humidification stage to saturate the air with water.

Biofilter designs are based on volumetric flow rate of the pit ventilation system, specific contaminants and concentrations, media constraints, size constraints, maintenance, and cost. Proven organic media for animal agriculture biofilters range from 30:70 to 50:50 ratio by weight of compost and wood chips or wood shreds. For livestock applications, biofilter media is typically 10 to 18 in (25 to 46 cm) in depth.

Moisture is needed in the biofilter. A sprinkler system may need to be incorporated into the biofilter design if the level of precipitation cannot provide the required moisture in an open-bed biofilter. Depending on climate, a sub-surface soaker system may be incorporated into the biofilter to prevent freezing. Biofilters that are loaded with ammonia concentrations require a leachate system. NH_3 is converted to NO_2 and NO_3. They can only be removed in aqueous form. Otherwise, the NO_3 concentration will rise to toxic levels, thus inhibiting the microbial activity.

The excess hydrogen sulphide and ammonia associated with hog manure has the potential of acidifying the bed. In order to maintain an optimal pH for the microbial community, buffer compounds or leachate may need to be included in the design.

Some production facilities may already have a ventilation system capable of forcing air through the filter. Adjusting the operation for the use of a biofilter will increase the energy consumption of the fans. In some confinement buildings, the fans may have to be changed to more powerful fans capable of forcing the air through the biofilter.

Biofiltration can take up a large amount of room, requiring 50 to 85 ft^2 (4.7 to 7.9 m^2) per 1,000 cfm (472 L/s), though this area can be reduced if the thickness of the media is increased (Schmidt et al, 2000; Nicolai et al, 2002). However, this will result in a greater amount of power needed for the fans. It is reported that a biofilter 1 ft (0.3 m) deep will treat 10 cfm/ft^2 (50 L/s/m^2) (Nicolai et al, 2002).

Environmental Advantages

Odours from livestock facilities are an issue for many communities and livestock producers. Odour sources for livestock production systems include buildings, manure storage, and land application of manure. Most complaints have focused on emissions from outside manure storages. One resulting approach in swine production is to use deep pit manure storage beneath the slatted floor in the livestock building. However, this storage then becomes the major source of odour. Biofiltration can reduce odour and hydrogen sulfide emissions by as much as 95% and ammonia by 65%.
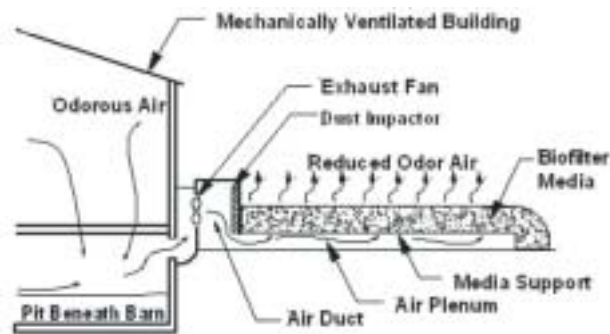
Environmental Disadvantages

While not major, some of the environmental disadvantages include: (1) the need for moisture control; (2) large space requirements; (3) rodent control to stop rodents from burrowing through the media and destroying water application equipment; (4) vegetation control to keep root mass from clogging the filter creating preferential air channels; and (5) extra power to push air through the filter.

Costs

The capital costs associated with biofiltration vary significantly depending upon the materials and equipment already available in the operation. Based upon the ventilation requirements as shown in Table 3-3, the costs range from $30 to $49/sow for a gestation building and from $99 to $165/sow for a farrowing building (Nicolai et al, 2002). Lower costs occur on farms that have a sufficiently powerful ventilation system or that have access to materials for the biofilter that will not need to be purchased. Costs will also depend on the type of material used in the biofilter bed. For example, based upon the numbers above, a biofilter designed for a gestation building for a 700 sow operation (farrow to finish) would have a capital cost of $21,000 to $34,300.

Table 3-3. Ventilation Rates for Hog Production.

Building	Ventilation Requirements/Animal Space (cfm)		
	Cold Weather	Mild Weather	Warm Weather
Nursery	3	15	35
Finishing	10	35	120
Gestation	12	40	150
Farrowing	20	80	500
Source: MidWest Plan Service			

Reapplication of biofilter media will play a considerable role in the annual costs of using this technology for reducing odourous emissions from hog production facilities. Materials used as a biofilter have a wide array of life spans and properties, as shown in Table 3-4.

Table 3-4. Biofilter Bed Lifetimes and Properties for Different Media Types.

	Peat	Soil (Heavy Loam)	Wood Chips	Straw	Compost	Activated Carbon
Bed Lifetime (yr)	N/A	10 to 30	2 to 5	N/A	2 to 5	5
Porosity	Average	Poor	Good	Good	Average	N/A
Moisture Capacity	Good	Good	Average	Average	Good	N/A
Nutrient Capacity	Good	Good	Average	Poor	Good	N/A
Source of Micro Organisms	Good	Good	N/A	N/A	Good	N/A
Adds Porosity	N/A	N/A	Yes	Yes	N/A	N/A
N/A – not available or applicable						
Source: Zhang et al, 2002						

Based on assumptions of 2.26 cycles/year and 10 piglets/cycle/sow, the annual costs range from $9 to $56/sow for an open-bed biofilter for a farrowing building and $3 to $17/sow for an open-bed biofilter for a gestation building (Burrowes et al, 2001; Easter and Okonak, 2000). The costs of owning and operating a closed-bed biofilter range from $12 to $74/sow for a farrowing building and $4 to $22/sow for a gestation building (Burrowes et al, 2001; Easter and Okonak, 2000). These costs include construction, labour, energy cost, maintenance (weed and rodent control), and the replacement of the biofilter medium every three to five years.

General Assessment

Biofilters can eliminate up to 95% of the odours coming from manure pits. The key advantage is that they are inexpensive to install. They require extra management and costs to setup and operate. However, as an environmentally friendly method to reduce odour from manure pit ventilation systems, biofilters are a reasonable option to consider.

Complementary Technologies

Odourous air can also be blown through activated carbon canisters. The odour causing compounds are removed from the air as they are absorbed onto the carbon. The absorptive carbon media must be periodically replaced as it becomes saturated with gases, volatile organic compounds, and odorous gas.

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3.4   Windbreaks

Description

A windbreak is an obstacle that is placed in the flow of wind to reduce its velocity. Two main types of windbreaks are used: artificial windbreaks and natural windbreaks. Artificial windbreaks are made of wood, plastic, or other synthetic materials. Their high cost and lifespan limit their use to the protection of high-revenue crops or small areas such as exercise yards for beef cattle. Natural windbreaks are much more common than artificial windbreaks as they are more durable, aesthetically appealing, and economical. Moreover, the superior height of natural windbreaks provides protection over a greater distance.

A properly positioned windbreak will reduce odour.
Photo Courtesy: PAMI

However, it will take a certain amount of time before the plants that constitute the windbreak can offer protection and can compete with other plants for light, water, and nutrients (Vézina, 1999). The use of effluent for fertilizing and providing moisture to the developing shelterbelt can accelerate maturity. The planting of fast growing, hardy, long lasting trees is also a consideration to improve windbreaks.

The reduction of wind speed behind a windbreak modifies the environmental conditions or microclimate in the sheltered zone. Windbreak porosity, height, width, length, and orientation affect the efficiency of the windbreak.

The porosity, which corresponds to the percentage of apparent voids, is generally used to characterize the structure of thin artificial windbreaks or narrow natural windbreaks (1 or 2 rows of trees). For wider natural windbreaks, the apparent porosity does not correspond to the actual porosity because it only represents the voids in the plane that are exposed to the wind and does not account for the three-dimensional voids through which air can flow (Heisler and DeWalle, 1988). To protect farm buildings and reduce odours, the porosity of the windbreak should be in the 30 to 50% range. This porosity can be obtained by an adequate design of the tree and shrub layout. A properly designed windbreak should allow about 35 to 50% of the wind to pass through it, but at a much slower and more even speed. The other 50 to 65% of the wind will be deflected up and over the windbreak and will not pick up odours to transport to neighbouring areas.

The extent of the zone of influence of a windbreak, all other conditions remaining the same, is proportional to its height (van Eimern et al, 1964). The limit of the zone protected by a windbreak is generally defined as the distance at which the reduction in wind speed is reduced to 20% at a height of 0.5 H (where H is the height of the windbreak). For a medium-density windbreak, that distance is equivalent to 20 H, and the maximum wind reduction is obtained at a distance of approximately 4 H.

Several American authors (Hintz et al, 1986; Smith and Scholten, 1980) recommend very wide hedges made of nearly 10 rows of trees and shrubs. However, the work of Read (1964) showed that narrow and dense hedges could be as efficient as very wide hedges. Experiments conducted in a wind tunnel (Harrje et al, 1982) demonstrated that additional hedgerows do not significantly reduce the heating costs of a house. Moreover, hedges with more rows and thus more plants cost more, demand more maintenance, and take up more space.

Two to three rows of trees and shrubs with a 10 to 13 ft (3 to 4 m) spacing are sufficient to adequately protect buildings, working areas, and pastures. With three rows, it is possible to introduce a broader variety of species. This allows for an easier renewal of the hedge and ensures its protection in case of diseases or infestations of insects.

The windbreak must be positioned perpendicularly to the dominant winds. When the wind hits a tree curtain at an angle other than 90°, the distance to go through is increased, which decreases the permeability of the windbreak (Wilson, 2004).

Environmental Advantages

Windbreaks are thought to reduce odour emissions in two ways; deflecting the wind currents up and over the odour source so less odour is collected and carried away, and by promoting the diluting and rising of air currents as they are carried past the odour source. A properly positioned windbreak will reduce the amount of air that moves past a manure storage facility and therefore reduce the movement of unpleasant odours. Environmental advantages from windbreaks also include decreased energy costs and fuel use, as well as fewer problems with snowdrift on manure storages, which may lead to overflow or structural damage of covers and/or leakage. It has been shown that a strong shelterbelt can result in buildings within the shelterbelt being as much as 30% more energy efficient as compared to buildings completely exposed to the elements (PFRA, 2003; Pollack, 2003). Windbreaks can also reduce soil erosion and air pollutant transfer (substantial amounts of odorous compounds and ammonia emitted from swine buildings are absorbed and transported by dust particles). A tree line shelterbelt can produce some energy in the form of inexpensive fuel for wood burning stoves. Shelterbelts also provide protection and habitat for wildlife and birds. Planting fruit and nut trees in the windbreak can also provide some food for both humans and animals. Properly spaced and managed shelterbelts can provide as much benefit as perennial cover, and the roots and shoots, which remain in place year-round, help to hold steep slopes in place, capture snow for additional soil moisture, and help reduce water erosion by slowing water movement during flooding. Plant-based windbreaks act as sinks for the chemical constituents of odourous pollution. Volatile organic compounds (VOC's), which account for the offensive odour in livestock manure, have a distinct affinity for the lipophilic (fats and oils) membranes that cover plant leaves. Researchers have also determined that quantities of VOC's are absorbed by plant tissues and that the microorganisms that populate the surface of plants also absorb VOC's and provide pollution collection.

Environmental Disadvantages

A poorly designed windbreak may create problems in wind turbulence, which may actually increase odour problems. An improperly designed windbreak may cause problems with snow deposition and create hazards with visibility and drifting snow. Windbreaks may fail due to high wind speeds that cause catastrophic failure of the entire system. Trees and/or structures may be lost and may further damage buildings and manure storage units with debris. Gaps in windbreaks may actually accelerate wind flows and lead to erosion and damage to buildings. Windbreaks take long term planning to establish. Trees and shrubs may require considerable effort to establish in poorer soil conditions. The loss of cultivable land generally constitutes the principle indirect cost related to the establishment of a natural windbreak. Odours are more concentrated in the area between the source of the odours and the windbreak than downwind from the windbreak (Bottcher et al, 1999), which can inconvenience the employees that are working in the immediate surrounding of the barn. On a sunny day, the air temperature in the zone protected by the windbreak can be as much as 5°F (3ºC) higher than the ambient temperature in an unprotected area. During the summer, this temperature rise can increase human and animal discomfort.

Costs

Prairie Farm Rehabilitation Administration's (PFRA, Agriculture and Agri-Food Canada) Shelterbelt Centre provides seedlings and plastic mulch free of charge to agricultural producers with more than 39 ac (16 ha). Owners of rural land holdings of 1 to 39 ac (0.4 to 16 ha) are eligible for a restricted list of tree and shrub species. Currently this service is available only in Manitoba, Saskatchewan, Alberta, and the B.C. Peace Region.

At a cost of $3 to $5/seedling for regions not within the boundaries of PFRA, the cost of planting a shelterbelt is $1,533 to $3,405/¼ mi ($1,200/¼ mi (402 m) for labour and machinery costs for planting and maintenance for three years plus $333 to $2,205 for seedlings), depending upon tree/shrub selection and spacing. Thus for a 10 ac (4 ha) property with two shelterbelt rows 16 ft (5 m) apart, the total capital requirement is $6,132 to $13,620. Due to the length of time needed for shelterbelts to develop, temporary structural windbreaks may need to be considered.

In some communities, conservation organizations may provide a planting service at a reduced rate, thus cutting the cost required for this technology. PFRA's Shelterbelt Centre also provides the use of

a plastic mulch applicator, free of charge, for applying the plastic mulch that improves tree growth and survival by preventing weeds from emerging and competing for moisture, nutrients, and light. On average, it will enhance overall growth by 25 to 30%. To qualify for the plastic mulch, producers must plant a minimum of 0.5 mi (800 m). The annual maintenance of a shelterbelt would consist of minor weeding, mowing of grass or cultivation for weed control between tree lines, and looking for evidence of pests and/or disease. The cost of mowing and weeding would already be incorporated into general property maintenance and checking the health of the shelterbelt can be done while performing these tasks.

The cost associated with artificial windbreak fencing is shown in Table 3-5. Labour was calculated as 50 to 75% of material cost (Darby, 2002).

Table 3-5. Capital Cost for Artificial Windbreaks.

Windbreak Description	Porosity (%)	Material Cost/Foot	Material Cost/¼ Mile	Labour Cost/ ¼ Mile	Capital Cost/ ¼ Mile
8 ft Vertical Board	25	$6.88	$9,081	$4,540 to $6,811	$13,622 to $15,892
8 ft Solid Board	0	$8.09	$10,678	$5,339 to $8,009	$16,018 to $18,687
10 ft Vertical Board	25	$9.19	$12,130	$6,065 to $9,098	$18,196 to $21,228
Source: Darby, 2002.					

Based upon these costs, to entirely surround an 11,000 ft² (1,021 m²) finisher barn housing 1,000 pigs (based upon 10 ft² (1 m²) per pig plus 5%), a windbreak located 20 ft (6 m) from the barn would be 580 ft (177 m) in length. The capital required for such a structure would range from $4,500 to $8,500 or $4.50 to $8.50/pig space. A tarp or other porous material that can be used as a temporary windbreak placed 10 to 20 ft (3 to 6 m) from exhaust fans costs $2.00/pig space (Marsh and Karapetyan, 1999). If a 10 ft (3 m) tall windbreak was constructed to enclose a lagoon 100 ft by 150 ft (30 by 45 m), the capital cost would be $9,100 to $10,600.

Windbreak walls/fences and tarps require additional annual maintenance over natural windbreaks. Cleaning may be required and repairs due to weather related damage will need to be performed. The life expectancy of these structures is significantly less than a shelterbelt.

General Assessment

Windbreaks can benefit livestock operations by reducing wind speeds in winter, which reduces odours, lowers animal stress, improves animal health, increases feeding efficiencies, and decreases barn heating costs.

Besides providing odour control, windbreaks may be adapted to any production method: confinement, hoops, or large barns. These windbreaks are size neutral, low in cost, increase in value over time, enhance the effectiveness of separation distances, and improve the aesthetics of hog farms, which can increase public acceptance. A properly designed and managed windbreak can screen unsightly areas around the farm, filter dust, and buffer traffic or machinery noise. The trees and shrubs used in windbreaks can provide food, nesting habitat, and protection from predators for wildlife and can also provide recreation areas for people.

Complementary Technologies

Increased separation distances and hills can decrease wind speed around buildings and may be considered complementary technologies to windbreaks. The use of biofiltration as an odour reduction technique for livestock operations is also complementary.

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Section 2 - Managing the External Environment

Chapter 4   Manure Storage

4.1   Manure Storage

Description

Manure storage comes in three main forms: earthen, concrete, and steel. Each type has different advantages and disadvantages based on local constraints and other manure management systems employed by the producer. Each region has different bylaws, laws, and Best Management Practices (BMP), so consulting local authorities is a necessity. Most storage systems require engineered design and construction. The storage must be easily accessible and convenient to both the fields and the barns. It should be located to comply with local regulations such as minimum distance separation or to limit the effect of odour on neighbours and communities. Access for agitation and unloading equipment must be considered. All storages should have a fence and/or wall height that limits inadvertent access by humans, livestock, wild animals, or machinery such

Concrete manure storage.
Photo Courtesy: MAFRI

as snowmobiles and tractors. The recommended minimum height is 5 ft (1.5 m). Manure storages should not be located adjacent to watercourses or in areas where runoff and seepage into surface water or groundwater is a high risk. Where there is a risk of subsurface drainage, a trench should be dug around the site approximately 50 ft (15 m) away from the site of the storage down below the level of the drains, typically 4 ft (1.2 m). Any drains that are located under the storage site should be cut off and plugged, and the flow directed around the site in the investigation trench. The floor of the storage should generally not be lower than the highest water table level. Where site conditions do not permit this, a foundation drainage system can be installed that meets local regulations or the discharge designed in such a way as to allow easy monitoring before entering a watercourse. The recommended storage capacity is for up to 400 days of production to allow manure spreading in optimum conditions. Open storages should also be designed to accommodate precipitation. A safety factor called "freeboard" is also incorporated into the design for extreme rainfall events and protection from wave action.

Earthen manure storage systems (EMS) are the most common manure storage method in western Canada. Earthen manure storages are constructed below grade or partially below grade. Earthen manure storages are typically smaller and deeper than lagoons and have very limited capacity for manure treatment. Earthen manure storages can be a single cell or multiple cells. In a multiple cell system, the primary cell is used to settle solids and to provide a more confined area for agitation of the solids. Liquid from the other cells is returned to the settling cell to aid in agitation for land application.

Manure treatment lagoons are significantly larger and handle more diluted manure. This allows for anaerobic degradation. Aerobic treatment is also possible with the addition of aeration. Basic design is for 10 to 12 ft (3.0 to 3.6 m) deep and side slopes of 1:2. Lagoons can be single cell or multiple cells. In a single cell lagoon, the manure is pumped or gravity drained in, stored and treated, and dispersed. In a multiple cell system, the primary cell is smaller and acts as a sediment basin for large particle removal. The second and subsequent cells are larger and treat

Earthen manure storages are the most common type of liquid manure storage on the prairies.
Photo Courtesy: MAFRI

the liquid effluent from the preceding cell. The effluent at the outlet can be reused as flush water in the barn or for irrigation purposes. The total capacity of a multiple cell lagoon treatment system is 40% larger than an earthen manure storage system.

A liner of compacted clay, bentonite, or synthetic materials is required in most regions and recommended in most liquid manure storages. Maintaining the outside berm is crucial in an EMS or lagoon. Trees should not be allowed to take root and animals should not be allowed to burrow in the banks. Access ramps for agitation and unloading equipment should be constructed to withstand their load. Care should be taken not to cause undue erosion or liner disturbance during agitation. The storage should not

Steel storage structures for some locations where the subsoil is very coarse.
Photo Courtesy: MAFRI

be drained completely. A minimum level of manure should be maintained to avoid drying out the liner and the sludge layer on top. Hydraulic conductivity tests have shown the sludge layer is an integral component in reducing seepage. The inlet to the EMS should be below this minimum level to limit erosion from discharge, limit unnecessary agitation and odour production, and to leave ice and natural crust formations undisturbed (Jofriet et al, 1996).

Concrete storage systems can be circular or rectangular, covered or uncovered. Concrete storages can be above grade, partially below grade, or below grade. Rectangular storages are most common for below barn storage. Large, long-term storage under a barn is not recommended, unless the ventilation system has been designed to accommodate the manure gases generated in the pit. Agitation of manure in long-term storages can result in the release of high levels of H_2S and other gases contained in the manure. Under barn storage that is open to the barn atmosphere is typically shallow and emptied frequently, either to an outside storage or to a larger sealed storage underneath.

Rectangular storages must be designed to handle the large stresses in the straight wall. The most common methods are using a roof or slat support or designing the wall as a retaining wall (either cantilever or buttress design).

If the storage is covered, the cover must be able to withstand the load of equipment that has access to the site. If unloading equipment access is not required on the cover, it is recommended that the area be fenced off. It is also important to choose a roof structure that is resistant to corrosion, as it will be subjected to corrosive gases. The cost of the cover will be partially offset by the reduction in size of the storage as it will not be exposed to precipitation.

Circular concrete storage must be designed to withstand the pressure of the manure and ice loads, especially above ground storage. Below grade and partially below grade storages must also withstand soil and equipment loading. Typical size ranges for circular concrete storage structures are 8 to 16 ft (2.4 to 4.9 m) deep and up to 140 ft (42.5 m) in diameter.

Steel storages are generally constructed above grade. Circular steel storages are used where secure containment is a high priority.

There are several treatment options for manure storages to reduce odour, GHG emissions, and nutrient losses. Some of these options have been discussed in other sections, such as pit/lagoon additives and anaerobic digestion. Aeration is another option. Aeration can be either natural or mechanical. Natural aeration only treats surface area rather than volume and therefore requires that the lagoon be only 3 to 5 ft (0.9 to 1.5 m) deep, thus requiring much larger amounts of land (Barker, 1996). For that reason, natural aeration is impractical as the primary treatment for livestock waste. Additionally, in the colder climates of Canada, the surface of the storage may be frozen for as much as five months of the year (Zhang et al, 2002), during which time aeration cannot be used. The organic matter build up within the storage may compromise the effectiveness of the odour control treatment once the ice begins to melt (Jacobson and Schmidt,1994).

Environmental Advantages

Storage systems allow the producer to spread manure during optimum conditions to avoid runoff from fields. Lagoons have the added advantage of anaerobic degradation. Manure can be a tremendous benefit as a source of plant nutrients and as a soil amendment. Proper manure management is essential for gaining maximum benefit from manure and reducing the liability or pollution potential.

Environmental Disadvantages

Manure can be a liability if improperly managed. Proper management practices will eliminate or significantly reduce the liability to producers. Most pork producers "do the right thing" and manage manure properly so it does not adversely affect their family, community, or the general public. Open storage systems release gases such as NH_3 and H_2S and other odourous compounds. The added volume of precipitation must be handled. Covered storages can lead to the trapping of gases, which, if not handled properly, can be dangerous. H_2S concentrations over 500 ppm can cause respiratory failure and high concentrations of CH_4 in a confined space can be flammable and explosive (Clanton and Schmidt, 2000).

Aerating liquid manure storages with forced air or by mechanical means, while reducing overall odour, uses a significant amount of electrical energy and can result in significant manure nitrogen losses as both ammonia and nitrous oxide gas, which is a potent greenhouse gas.

Costs

The initial costs of manure storage will depend greatly upon the volume required for waste storage based on the size and type of operation. Tables 4-1 and 4-2 show the volume of manure produced and the required storage space per pig and examples of storage requirements for a farrow to finish operation, respectively. Another factor influencing the cost of storage will be storage type.

The cost for deep pit storage below the hog barn can cost from $0.14 to $0.18/gal ($0.03 to $0.04/L) (Zhang and Mukhtar, 1995).

The cost for earthen manure storages, either lagoon or earthen basins, range from $0.0039 to $0.0953/gal ($0.001 to $0.025/L) (Harmon, 1996; Fulhage et al, 2002). With earthen storages, additional capital costs occur from adding a liner of clay, plastic, or concrete to the storage. The added cost of clay liners ranges from $0.045 to $0.065/gal ($0.012 to $0.017/L) (Fulhage et al, 2002) of storage depending upon the distance the clay has to be hauled. Lining the storage with concrete can increase the cost from $0.05 to $0.12/gal ($0.01 to 0.03/L) for a 500,000 gal (2.3 million L) storage (Fulhage et al, 2002). Plastic liners can add $0.33 to $5.26/ft^2 ($3.55 to $56.62/m^2) to the total cost (EPA, 2001).

Manure storages constructed from concrete can cost from $0.05 to $0.26/gal ($0.014 to $0.069/L) (Fulhage et al, 2002).

Table 4-1. Daily Manure Production and Storage Volumes.

Class (lb)	Age (weeks)	Manure Production (ft^3/pig)	Required Storage for Liquid Manure* (ft3/pig)
44 to 200	8 to 22	0.18	0.25
11 to 22	3 to 6	0.04	0.06
22 to 55	6 to 9	0.08	0.11
55 to 77	9 to 12	0.12	0.17
77 to 132	12 to 16	0.18	0.25
132 to 176	16 to 20	0.26	0.36
176 to 200	20 to 22	0.32	0.45
Dry Sow		0.40	0.56
Nursing Sow and Litter			
Wean at 3 wk		0.55	0.77
Wean at 6 wk		0.69	0.97

* Calculated from "manure production" by a multiplying factor of 1.4 to account for spillage from waterers, floor washing, and dilution water where required. These figures total 13 to 15 gal/sow.day for the entire farrow-to-finish herd. Depending on location, additional volume may be needed to allow for rain and snow collected in open storages.

Source: West and Turnbull, 1989.

Constructed steel tanks can cost from $0.13 to $0.26/gal ($0.035 to $0.07/L) (Fulhage et al, 2002). Table 4-3 shows the possible price range for a few different sizes and types of operations based upon the information in Tables 4-1 and 4-2.

Table 4-2. Liquid Manure Storage Requirements (Farrow to Finish).

Herd Size (sows)	6 Month Storage		12 Month Storage	
	gal	Land Space (ft^2)**	gal	Land Space (ft^2)**
50	145,300	3,900	290,600	6,600
100	290,600	6,600	581,200	11,500
150	433,200	9,100	866,500	16,100
200	578,500	11,500	1,157,100	20,700
300	871,800	16,200	1,743,500	29,700
500	1,452,900	25,200	2,905,900	47,000

Based on 13 gal/day/sow waste production.
** Calculated assuming storage depth of 10 ft, side slopes of 1:2.
Modified from: West and Turnball, 1989.

Table 4-3. Possible Price Range for Different Sizes and Types of Operations.

Operation	Volume (gal)*	EMS**		Concrete		Steel	
		Min	Max	Min	Max	Min	Max
Farrow to Finish							
100 sow	694,200	$2,707	$80,388	$37,834	$180,909	$91,357	$183,477
600 sow	4,165,500	$16,245	$482,365	$227,020	$1,085,529	$548,180	$1,100,942
Feeder to Finish							
1,000 head	821,500	$3,204	$95,130	$44,772	$214,083	$108,109	$217,122
5,000 head	4,107,600	$16,020	$475,660	$223,864	$1,070,441	$540,560	$1,085,639
10,000 head	8,215,200	$32,039	$951,320	$447,728	$2,140,881	$1,081,120	$2,171,277

* Calculated based on 12 month storage at 13 gal/sow/day (1.6 gal/finisher/day), 20% added to allow for precipitation (assuming no cover).
** EMS (earthen manure storage) cost for with and without liner.

The economies of scale indicate that the cost per gallon for larger operations will be less than those for smaller operations, and the total cost on a per pig basis should also be less for a larger operation. Grading and levelling of the storage site may be required to situate the building above the storage, adding to the size of the initial investment for a gravity driven system. If the storage cannot be filled by gravitational means, a pumping system may be required. Manure pumping systems cost from $33,000 to $46,000 (Zulovich et al, 2001) and will have annual labour, repair and maintenance, and electricity costs associated with them. Pump sizes of 1 to 5 hp (0.7 to 3.5 kW) are suggested (West and Turnball, 1989), and assuming that the pump is running 8 hours/day with a rate of $0.066/kWh, the annual electricity cost will be from $150 to $750.

Most of the labour will be seasonal for agitating the waste, removal of sludge, and performing pump outs. Additional labour may be required to maintain the area around the storage. Steel and concrete slurry tanks have higher labour costs associated with them as compared to deep pit storage (Unterschultz and Jeffery, 2001). The transfer of manure from the hog barn to the storage occurs frequently and thus requires more management and labour as compared to a deep pit storage. Automation of the scrapers and pumps can reduce the labour required but adds to the capital cost of the system. Mechanical scrapers also require more repair and maintenance compared to gravity

draining gutters or slotted floors. Maintenance costs for storage liners are estimated at 5% (EPA, 2001) due to potential damage that can be incurred during sludge removal.

The capital cost associated with mechanical aeration is the purchase of aerators ($2,600 to $9,000 each) (Wefering and Zering; Lorimor et al, 1998) More than one aerator may be required to treat a manure storage (Zhang et al, 2002). It is suggested that the horsepower requirement of the aeration system is 1 hp/1,000 ft^2 (0.8 kW/100 m^2) of surface area (Van Kleck, 1982). Aerators have an expected life of 10 years (Zhang et al, 2002), and the annual repair and maintenance cost is expected to be about 2% of the initial investment. The main disadvantage of aeration treatment is the energy requirement. Based upon the requirement of 1 hp/1,000 ft^2 (0.8 kW/100 m^2), the required lagoon area and the assumptions of 24 hours/day operation and an electricity cost of $0.066/kWh, the annual electricity cost for a 500 sow farrow to finish operation with 12 month storage is about $20,000. There are some other costs associated with aeration treatment. A practice to reduce organic loading of the storage is mechanical separation (Zhang et al, 2002). This would require the use of a solid-liquid separation technique that will add to the capital and operation costs of the treatment.

General Assessment

Storage is a necessary component in the manure handling system. Selection of a system must consider how the various factors relate to the specific producer's requirements. Covered earthen manure storages with an engineered liner are cost effective systems for large volume manure handling provided the producer can afford the space requirement of the storage and has an adequate land base on which to apply the manure. Concrete storage is an option in regions where EMS or lagoon systems are not permitted. Circular steel storage is considered to be the most groundwater friendly storage system, but its limited capacity and comparative high costs are drawbacks.

Complementary Technologies

Lagoon covers are a complementary technology. A permanent cover can reduce the cost of the storage by eliminating the need for the extra required volume allowance for precipitation in high rainfall areas.

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4.2   Covers for Manure Storages

Description

There are several different types of manure storage covers available. The most prominent are straw, geotextile, and synthetics.

The straw used for covering manure storage is mainly barley and wheat straw. Bales are processed and blown onto the lagoon with special equipment in the spring and removed with the manure pump out in the fall. Typical thicknesses applied are from 8 to 12 in (20 to 30 cm), and the treatment lasts anywhere from four weeks to six months. As the straw gets wet from the manure and starts to sink, a second application in mid-summer is commonly required. Peat moss has also been tested as a biocover and was very effective at reducing odour, and it returns to the surface after agitation, but the costs of this technology are significantly greater than those for straw. The use of cornstalks as opposed to straw can reduce the cost

Synthetic manure storage covers shed rainwater and reduce nutrient losses.
Photo Courtesy: PAMI

of a biocover since the cost of the material is less than that of straw; however, odour control will be reduced as cornstalks are much less effective than straw is for controlling odour.

Geotextile covers are tough, porous fabrics that feel like felt. The toughness of the geotextile makes it easy to install. They are generally self-floating and last one to three years. Since the material is porous, it allows the emitted gases to permeate the material and not accumulate underneath the fabric. The cover acts as a biofilter (Lorimor, 1999), but the geotextile fabric is effective for the first year only. The present theory is the spaces become saturated with the emitted gases and therefore reduce its odour absorption capability. For continued use over a three year period, spreading straw on top of the fabric has been shown to be effective. The fabric helps the straw float longer and the straw replenishes the odour absorbing capacity of the cover (Clanton et al, 2001).

Synthetic covers generally consist of nonporous materials such as polyvinylchloride (PVC), polyethylene (PE), and polypropylene. Since the cover material is impermeable, the storage basin does not have to be sized for rain and snow accumulation. The covers trap any produced gas in a bubble that rises. The covers can then become susceptible to wind damage.

Newer technologies that have been developed to address issues related to wind include negative pressure, positive pressure, and structural supports (Lorimor, 1998). The negative pressure system is a patented process where the gas is exhausted from the air space under the cover thus keeping the cover "sucked" down to the surface. (Small and Danesh, 1999) The positive pressure method is the exact opposite. Air is blown into the structure to maintain a taut cover that is not affected by the wind. Structural supports can take the form of a metal or wooden hoop structure and are held in place with a series of cables and ties. The structures can be supplemented by a positive pressure system. In all three systems, the collected gases can be harvested and treated.

All of the covers mentioned can be used on any form of open storage (earthen, concrete, or metal) (Jacobson et al, 1999). However, synthetic covers that require structural supports are generally limited to relatively small spans (less than 100 ft (30 m)). To use a straw cover, some specialized equipment is required. A modified bale chopper with a cannon or gun to shoot the straw onto the lagoon and a supply of good quality barley or wheat straw is also needed. Agitation equipment and a pump that can handle the straw are also required for clean out. No equipment is required to assemble a disposable one-year geotextile cover. A front-end loader is required for removal. Most synthetic covers require custom installation. They are generally custom installed by the individual manufacturers or retailers. Properly maintained synthetic covers have a usable life of 10 to 20 years depending on the individual fabric and support method.

Three other technologies are used to cover manure storage. Leca™ or Microlite™ air-filled clay balls have been found to significantly reduce odour from manure storage (Jacobson et al). A Leca™ thickness of 1.5 in (3.8 cm) can reduce odours by 90% and NH_3 by 65 to 95%, while an 8 in (20 cm) layer of Microlite™ is reported to reduce odour by 56 to 62% and H_2S by 64 to 84%. Air-filled clay balls are expected to have several years of life, but careful attention has to be paid during pump out of the storage. A liquid lid consists of pouring oil down the side of the manure storage unit, creating a cover over the manure that is self-sealing when disturbed. This type of cover is better suited for manure pits under confinement structures and lasts up to two years, as long as the manure pit is not completely drained (Miller, 2003). A permanent cover of wood, steel, or concrete can last up to 20 years with little to no maintenance required and is capable of reducing odour by as much as 99%.

The Top Gun blowing straw onto a manure lagoon.
Photo Courtesy: PAMI

Environmental Advantages

All three systems (straw, geotextile, and synthetic covers) have been proven to reduce odours substantially, 38 to 59%, 70%, and 90 to 99%, respectively. The impact on H_2S and CH_4 emissions have been found to vary from a reduction of up to 90% to an increase with straw covers (Cicek et al, 2004).

The synthetic covers reduce odour and H_2S and CH_4 emissions to minimal levels with proper maintenance and operation. The negative pressure systems can be vented into a treatment system such as a bioreactor or biofilter, or harvested for energy (Small and Danesh, 1999).

Environmental Disadvantages

Proper disposal methods of the geotextile material can vary from area to area. The fabrics can be nutrient laden. Local authorities need to be consulted. Inefficiencies in gas collection are inherent in the positive air pressure system. The leakage of 125 cfm (60 L/s) of air is termed acceptable but still contains odour-causing gases such as H_2S and CH_4 (Zhang and Gakeer, 1996). Straw covers can increase greenhouse gas emissions (Cicek et al, 2004).

Costs

A comparison of costs between differing covers for a 600 sow farrow to finish operation is in Table 4-4. The assumptions made in the calculations are: energy rate of $0.066/kWh; labour rate of $10/hr; repair and maintenance on synthetic covers of 2% capital; interest rate of 8%; fixed costs include depreciation and interest; operating costs include labour, fuel and energy, and repair and maintenance; 2.26 cycles/year with 10 piglets produced/sow/cycle; 10,000 marketed hogs/year.

Factors that add to the cost of straw covers include life extenders such as crude canola oil, polystyrene floats, and plastic bottles. For pump out, a straw-chopping pump is required and more effluent needs to be pumped as straw decreases evaporation but allows in precipitation. The cost of the peat moss is $0.36/ ft^2 ($3.88 m^2) (Heber et al, 1996), as much as ten times that of straw.

Another cost that could occur with permeable geotextile covers is the cost of adding a straw cover if that option is used.

With impermeable cover systems, there may also be costs for a means to eliminate the gaseous build up. This could include methods such as flaring the gas or a procedure for capturing the fuel value of these gases. In addition, because evaporation is reduced, there may be increased hauling costs in arid regions and additional maintenance requirements to remove snow and rain water. With both geotextile and synthetic, there will be the cost of disposal of the cover at the end of its useful life. With

Table 4-4. Summary of the Cost of Covers.

Cover	Straw	Supported Straw	Permeable	Steel	Clay Balls	Synthetic		Liquid Lid***
Comment	12 in thickness	Oil added	Geotextile		3 in thickness	Negative Pressure	Positive Pressure	0.25 in thickness
Cost/ft^2	$0.037	$0.045	$0.35	$6.71	$1.60	$0.65	$1.60	$1.11
Size (ft^2)	43,750	43,750	43,750	14,583	21,875	21,875	14,583	43,750
Capital Costs	$1,618.75	$1,946.88	$10,937.50	$97,854.17	$35,000.00	$14,218.75	$23,333.33	$48,562.50
Fixed Costs	$1,683.50	$2,024.75	$11,375.00	$8,757.95	$10,150.00	$1,965.03	$3,790.50	$26,223.75
Salvage Percent	0.00%	0.00%	0.00%	5.00%	0.00%	3.00%	3.00%	0.00%
Lifetime (yr)	<0.5	1	1	20	4	10	8	2
Operating Cost	$809.38*	$973.44*	$218.75	$0.00	$700.00	$428.92	$2,605.86**	$971.25
Total Annual Cost	$2,492.88	$2,998.19	$11,593.75	$8,757.95	$10,850.00	$2,393.95	$6,396.36	$27,195.00
Annual Marketed Pigs****	10,000	10,000	10,000	3,333	5,000	5,000	3,333	10,000
Cost/Marketed Pig	$0.25	$0.30	$1.16	$2.64	$2.18	$0.60	$1.92	$2.72

* Operating cost is related to reapplication at 50% capital, additional 6 in of straw added after 3 months.
** Electricity for 10, 0.37 kW blowers for the positive pressure system.
*** More appropriate for manure pits under slatted floors.
**** Based on one pump out annually.

positive pressure systems, an under cover structure, such as a web of ropes, may be needed to keep the cover from falling into the effluent while the cover is deflated.

The synthetic covers keep gases from escaping, thereby significantly increasing the nitrogen content of the effluent as compared to the use of a straw cover or a biocover (Jackson and McCartney, 2002). The use of such a cover can therefore decrease the quantity of commercial nitrogen fertilizer purchased. It also results in a manure fertilizer with a N:P ratio more closely matched to crop requirements, reducing the tendency for P buildup in soils where manure is applied annually.

By reducing the amount of precipitation entering the manure storage, costs associated with hauling the effluent should be greatly decreased in regions of Canada with high levels of precipitation. Manure storage capacity is also increased.

The reported cost of air-filled clay balls is $2.64 to $6.60/ft^2 ($28.35 to $70.88/m^2) (Jacobson et al). The variance in cost can partially be attributed to the varying thickness of covering.

Based on a cost of $300/barrel ($575.11/m^3) of crude canola oil, the cost of the liquid lid cover is $1.11/ft^2 ($11.95/m^2) for a quarter inch thick layer.

The cost of a concrete cover can be up to $150,000 for a 600 sow farrow to finish operation (Filson et al, 2000). Assuming 2.26 cycles/year, 10 piglets/litter, 8% interest, 5% salvage value, and 20 year life, the annual cost of such a cover is $14,194 or $1.42/marketed hog. A wood or steel lid for a manure storage with 75 ft (23 m) diameter would cost from $25,000 to $30,000. This translates to a cost of $5.59 to $6.71/ft^2 ($60.17 to $231.11/m^2) (Prairie Swine Centre, 1998).

General Assessment

All three systems, straw, geotextile, and synthetic covers, have been proven to reduce odours substantially, 38 to 59%, 70%, and 90 to 99%, respectively. The impact of covers on H_2S and greenhouse gases has been variable. Reductions of 71 to 90% have been reported in H_2S and CH_4 for all systems; however, recent research has found straw covers increase CH_4 emissions by an average of 247%. Synthetic covers have the added advantages of capturing biogas, improving the fertilizer value of the manure, and excluding precipitation, which can increase storage capacity and reduce manure transportation costs.

Complementary Technologies

The supplier of the negative air pressure cover offers a compressed air agitation system to provide mixing of manure solids under the cover. This technology provides superior agitation to conventional equipment and eliminates the need to draw back the cover for agitation. This agitation system also eliminates the risk of damage to clay liners in the storage, which frequently occurs with conventional agitation equipment. Biogas energy conversion equipment is also a complementary technology.
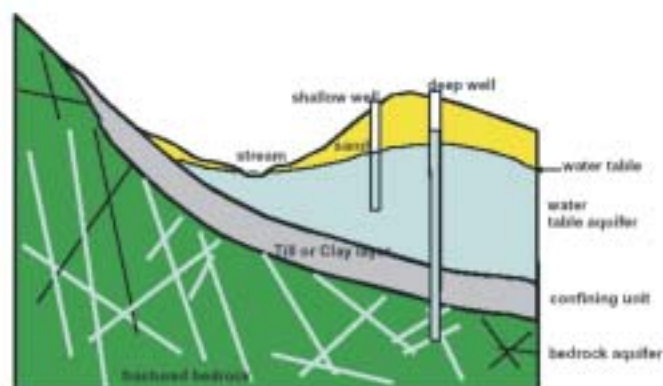
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4.3 Aquifer and Water Source Mapping

Description

An aquifer is defined as a geological unit capable of providing a usable amount of groundwater (MDC, 1996). There are three main types of aquifers: unconfined, confined, and perched. An unconfined aquifer does not have an impervious layer containing it from above. Therefore, the upper layer is at atmospheric pressure and rises and falls with pumping. Unconfined aquifers typically have a local recharge area or source of water. Confined aquifers have an impervious layer constraining it from above. Pressures in the aquifer are typically greater than atmospheric and the aquifers usually have a remote recharge area. Perched aquifers are a local zone of unconfined groundwater occurring at some level above the regional water table. An unsaturated zone

Aquifer diagram.
Source: Vermont Agency of Natural Resources, 2004

separates them from the water table. They can be permanent or temporary, depending on the frequency and amount of recharge (NRCS, 1999). The recharge area of an aquifer or well is defined as the area over which infiltrating waters are expected to reach the aquifer or well. Recharge areas for wells, especially domestic use wells, should be rigorously protected.

Aquifer mapping is of value on a regional, provincial, or even national level, as groundwater does not adhere to manmade boundaries. The aquifer's susceptibility to contamination or its vulnerability should also be assessed. The parameters affecting aquifer vulnerability are given in Table 4-7.

Several methods to determine aquifer vulnerability have been devised. The United States Department of Agriculture (USDA) developed DRASTIC (Depth to the water table, Recharge of the aquifer, Aquifer media, Soil media, Topography, Impact of the vadose zone, Conductivity), an aquifer rating system to try to standardize information from individual states. It is the most common aquifer vulnerability index used in Canada and the US. The Aquifer Vulnerability Index (AVI) used in Saskatchewan determines an average hydraulic conductivity or permeability of the layers above the aquifer. Topography was not included because of the relative consistency of the topography in Saskatchewan. The vulnerability assessment model used in British Columbia ranks the development of the aquifer to establish priority. The demand versus productivity ratio was calibrated and the well developed aquifers, or heavier used, were given a higher priority (Kreye et al, 1998).

Table 4-7. Parameters Affecting Aquifer Vulnerability.

Factor	Characteristic
Soil	Texture, structure, thickness, organic matter, clay content, permeability
Unsaturated Zone	Thickness, lithology, travel time of water
Aquifer	Lithology, thickness, effective porosity, hydraulic conductivity, groundwater flow direction, age, residence time of water
Recharge	Net annual recharge, annual precipitation
Topography	Slope variability of the land
Unit Underlying Aquifer	Permeability, structure, potential recharge and discharge
Surface Water Contact	Gaining or losing stream, evaluation of bank filtration, salt water interface in coastal areas
Land Use	Natural, man-made, population density
Source: Harman et al, 2000	

On-site hydrogeological investigations are the responsibility of the producer. A trained professional, such as a hydrogeologist, should conduct the investigations. The barn sites, storage sites, and all application areas should be investigated to minimize the possibility of groundwater contamination. Contacting all levels of authority to obtain existing information, documentation, and legal obligations is always recommended. Digging or boring a test hole and logging the types of materials and layers encountered can determine the geological characteristics of the site. Samples of each soil layer or strata should be collected and analyzed in a lab. Geophysical methods, such as electromagnetic induction, resistivity, refraction seisomography, and ground penetrating radar can be used to determine geological characteristics but should be correlated with a test hole and samples for best results (NRCS, 1999). Proposed United States Environmental Protection Agency (EPA) regulations would require concentrated animal feeding operations (CAFO) to provide an assessment of groundwater vulnerability on permit applications. The permit application would require a detailed evaluation of the proposed barn and manure storage site or sites and identify all lands receiving manure. All surface waterbodies and groundwater sources in or near the proposed areas would have to be identified and provide a hydrogeological report detailing the surface and groundwater contamination potential for each area. The producer would have to prove there are no hydrogeological links between the proposed areas and the surface or groundwater and that the appropriate preventative measures have been taken to ensure contamination does not occur. Monitoring of the groundwater would also be the responsibility of the producer (EPA, 2001). The monitoring system should be developed by a hydrogeologist who should also supervise installation of the wells.

Environmental Advantages

By assessing the risks of groundwater contamination on all proposed areas of operation, a producer can make appropriate decisions on the implementation and application of their hog operations to reduce or eliminate the risk. Site selection and facility construction plans could be altered to accommodate concerns specific to each individual case. Moving the whole operation to a more suitable site may be an option. Investigation results may dictate what types of storage and application methods are options. For example, on certain sites, earthen manure storage or lagoons may not be viable but engineered metal storage tanks may be. Manure application to specific areas may be reduced or eliminated.

Environmental Disadvantages

There are minimal environmental disadvantages associated with hydrogeological investigations. The time and cost associated with contracting professionals to perform the survey are the only drawbacks.

Costs

On-site hydrogeological investigations will require a hydrogeologist to analyze the site and prepare a report. At an example rate of $110/hour (Fedeniuk, 2004), the hydrogeologist will require about 48 working hours to produce the final report. Four hours of on-farm labour is required to collect and present relevant information to the hydrogeologist. Costs for travel, maps, photocopying, report generation, and miscellaneous expenses can be estimated at 15% of labour costs, resulting in a total cost for the investigation of about $6,000. The added costs can vary greatly depending on the location of the site (EPA, 2001; Fedeniuk, 2004).

Monitoring groundwater requires the installation of monitoring wells. As many as four or more wells may be required depending on site conditions. One well located up-gradient of the manure storage/barn and the other three located down-gradient. The total cost for a 50 ft (15 m) deep well is at least $2,000, which would include drilling, well casing for the first 30 ft (9 m), well screening for the final 20 ft (6 m), gravel for the entire length, and a well cap. A single bailer for sampling costs about $46, so the total capital required is $8,000 for a four-well monitoring system. Drilling costs are representative of Manitoba and costs will be more in regions of high bedrock. The time of year will also influence drilling costs as drilling through frozen soil will add to the cost. Required drilling depths will depend on aquifer depth in the region, ranging from as shallow as 12 ft (4 m) to deeper than 50 ft (15 m) (Fedeniuk, 2004).

To establish a baseline for annual testing, initial sampling and analysis should be included in the capital cost. Sampling and analysis requires one hour of on-farm labour per well and approximately $100/sample for laboratory analysis (EPA, 2001; Fedeniuk, 2004) plus shipping and handling, adding at least $448 to the capital cost.

Annual costs will include operation, maintenance, and sampling. Operation and maintenance is estimated at 2% of initial construction costs (EPA, 2001). Sampling should occur twice per year per well with each sample requiring one hour of farm labour and $100 for laboratory analysis. Laboratory analysis could test for levels of coliform (total and fecal), nitrate-nitrogen, ammonia-nitrogen, chloride, and total dissolved solids. The initial sample should be analyzed for a more complete suite of parameters.

General Assessment

Until this time, each specific site will have to be evaluated individually, drawing on all available data on the groundwater for that region. Completion of a geological investigation and implementation of acceptable technologies and management practices to reduce and eliminate risks demonstrates due diligence.

Complementary Technologies

The establishment of a national aquifer database would benefit the long-term development of the livestock industry.

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4.4   Vegetative Filter Strips

Description

Vegetative filter strips (VFSs), also referred to as buffer zones or strips, grass strips, or riparian plantings, are used to filter wastewater that has been pretreated by a sedimentation process. Vegetative filter strips are created by planting dense vegetation near surface water bodies to buffer barnyard water runoff from running directly into the waterway. VFSs treat runoff through infiltration, settling, adsorption, and aeration. VFSs work by spreading the effluent flow over a wide area providing opportunity for infiltration. They allow deposition settling of suspended solids by maintaining the runoff velocity below 2 fps (0.61 m/s). Uniform shallow loading rates must be maintained to achieve optimum results (Tousignant et al, 1999; Woodbury et al, 2003). The grass and managed forest zone can be harvested for nutrient recovery. For hog operations, the likely application includes runoff from manure storage areas and runoff from fields.

The designed length or width varies depending on degree of treatment or polishing of wastewater desired. They are anywhere from 3.3 to 328 yards (3 to 300 m) long. Plantings beside fields may be as short as 3.3 yards (3 m). Design systems with pulsed discharges could be up to 328 yards (300 m) long. The width of strips varies depending on source and destination. The vegetation is typically grass with a high water requirement, such as brome grass or tall fescues. Managed and unmanaged forest zones sometimes separate the grass strip from a streambed, where available.

The vegetation reduces runoff and filters sediments and nutrients. A vegetated strip must be established down slope of the source of manure runoff, and a system must be implemented to evenly distribute the effluent from the runoff area over the entire width of the VFS. For maximum efficiency and minimum VFS size, clean water runoff should be diverted away from the VFS (Lorimor et al, 2002; Tyler, 2001).

Environmental Advantages

VFS systems effectively reduce the mass of total solids (TS) and total solids in solution (TSS) by 80% and 67%, respectively and chemical oxygen demand (COD) by 60%. Over 80% reductions in total kjeldahl nitrogen (TKN) and total phosphorus (TP) are achievable with a properly sized VFS. Typical reductions are between 65 and 75% for TKN, COD, TS, TP, NH_4, N, and fecal coliforms. There is limited volatilization of N in the system (<15%).

Environmental Disadvantages

Sediment collected in the sediment basin must be dealt with. The sediment is typically high in phosphorus (P). VFSs are not designed to meet nutrient management limits for nutrient removal in

Vegetative filter strips (VFSs) treat runoff through infiltration, settling, absorption, and aeration.
Photo Courtesy: Canadian Pork Council

many circumstances. The result is an increase in the soil nutrient levels. In some instances, the P levels at the outlet are above approved discharge levels. Currently the P cycle is under closer research. High hydraulic loading rates can lead to significant leaching of nutrients and contaminants below the root zone. If the water is coming into the VFS at too high of a rate, it can overwhelm the system and cause erosion and channelization. Knowledge of the soil characteristics related to infiltration or hydraulic conductivity is needed. The soil texture, structure, and consistency are also important in the design of the VFS. Loading rates are related to the slope of the flow surface and the depth of flow (Tyler, 2001). If the VFS is hydraulically overloaded, then the VFS is effectively short-circuited and this can lead to wastewater reaching surface water.

Costs

Developing a vegetative filter strip is similar to establishing a pasture (Nakao et al, 1999). The cost of VFS technology includes land costs, seed, fertilizer, equipment, and labour (Leeds et al, 1994). The animal capacity per year per acre needed for hog production VFS systems is in Table 4-5.

Many designed systems will include a concrete sedimentation area and designed distribution structure. The cost of seed will depend on the choice of vegetation (grass, legume, or trees). A soil test will determine the amount of fertilizer, if any, required to establish the VFS. The required equipment and labour will depend on the tillage system to be used. Table 4-6 shows estimates of costs for VFS technology for a variety of swine operation sizes.

Maintenance of VFS systems includes frequent inspection for erosion, reseeding of eroded zones and bare areas, soil testing, and weed control, either through mechanical or chemical means (Leeds et al, 1994; Harner et al, 2000). A tree-based VFS requires mowing five times per year for the first three years, and then pruning and thinning thereafter (Nakao et al, 1999). For grass-based VFSs, mowing and hay removal is required two to three times per year (Harner et al, 2000; Nakao et al, 1999). Cuttings should be removed using a process like baling to maintain the effectiveness of the VFS.

Depending upon growing conditions, irrigation may be required for seed germination and the establishment of the VFS. To avoid this added cost, VFSs should not be established in drought years. As mentioned, effluent entering the vegetative filter strip should be pre-treated with sedimentation, so those costs will also need to be considered.

Table 4-5. Estimated Land Requirement Based on Nutrient Rates for VFSs.

Size	Number of Head/Acre/Year
35 lb	100
65 lb	49
150 lb	21
200 lb	18

Based on cool season grass such as a fescue.
Modified from: Harner et al, 2000.

Table 4-6. Cost of VFSs for Pork Production.

Number of Head	Required Investment ($)	Capital/ Head ($)	Annual Operating Cost ($)
140	$2,729	$19.49	$271
300	$4,861	$16.20	$539
650	$8,884	$13.67	$1,095
1,000	$12,522	$12.52	$1,759
2,000	$21,976	$10.99	$4,567

Modified from: Featherstone, 2004

General Assessment

VFSs are an effective means of treating barnyard runoff. Significant reduction of all nutrients and contaminants that are associated with non-point source pollution of surface watercourses and groundwater is demonstrated. However, this technology does not apply to situations of large quantities of raw wastewater. The vegetation can be harvested as a biomass product. A drawback of a VFS is the lack of nutrient retention. If the producer can realize greater returns by utilizing the nutrients in the manure as a soil amendment or fertilizer additive, a VFS as the primary wastewater treatment may not be desired. Other forms of treatment with a higher emphasis on nutrient retention should be investigated.

Complementary Technologies

A VFS can be used to treat liquid effluent from some primary treatment systems such as constructed wetlands, if the treatment effectively reduces TSS. Buffer zones, which are similar to VFSs and contoured buffer strips of perennial vegetation, are a related conservation practice.

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Chapter 5   Manure Treatment

5.1   Feed Manipulation

Description

Several different methods or combination of methods of feed manipulation are available for odour control. Typically, the main goal of feed manipulation is to maximize utilization and efficiency. A reduction in nutrient excretion and emission of odour producing gases are positive secondary results. Feed should be formulated to meet the needs of the pig at each phase of the growth cycle. The logical conclusion would be to feed pigs individually according to their specific requirements. Feed rations would then be formulated on a per feeding basis. Although possible, it is not practical to monitor each pig in a large scale hog operation. An intermediate step is to separate the herd into groups with similar nutritional requirements. Phase and split-gender feeding programs have been successfully employed independently and in combination. Phase feeding is quite common where the ration is changed to meet

Feeds can be mixed according to the growth stage of the animal.
Photo Courtesy: MAFRI

the pig's requirements throughout the production cycle. Split-gender feeding separates the herd into gilts and barrows, and feeds are mixed according to the different requirements of each gender.

Feed can also be supplemented to achieve results in feed efficiency and odour control. Much of the crude protein (CP) fed to swine is digestible, and amino acids not needed for growth are excreted as urinary nitrogen (N). By lowering the CP, levels of N in the excrement can be reduced. Crystalline essential amino acids (EAA) must then be added to the feed to maintain an acceptable weight gain in the hogs. Supplements containing the crystalline EAA lysine are quite common. Threonine, methionine, and tryptophan are now available as well. As more crystalline EAA supplements become available, further reductions in manure excretion N are possible.

Control of phosphorous (P) emissions presents a different challenge. Most of the P in feed rations is locked in phytate, which is unavailable to swine. Ruminants can digest it, but pigs lack the phytase enzyme to utilize the majority of P in most feeds. Traditionally, P in a digestible form was added to the feed as a supplement and the phytate bound P was excreted. Under these herd management practices, the amount of manure that could be applied to a certain land base was limited by the P levels in the manure and the requirements of the crop, instead of N being the limiting nutrient. Phytase is now commercially available as a supplement. Researchers are also developing a genetically enhanced pig (Enviropig™) that produces phytase in its saliva. Ongoing research has also discovered less P is required if a proper calcium (Ca) to P ratio is maintained in the feed, without having detrimental effects on pig growth and development. Recent research at the University of Guelph has suggested that true bioavailability of P in feed ingredients for pigs has been underestimated by 20 to 30%. Little supplemental P is needed in a pig's diet. Low phytate feed crops, such as corn, are also coming on the market. These crops are genetically altered to reduce the amount of P locked in phytate of the plant for better bioavailability (Fan et al, 2001; Shen et al, 2002).

Feed processing is effective in improving nutrient digestibility. Research in Europe, as well as preliminary research in western Canada, have shown that grinding, pelleting, extrusion, and micronization (high energy infrared heating process that rapidly heats the feed to 230 to 239°F (110°C to 115 °C)) increase nutrient bioavailability . The increase in digestibility and retention translates into less nutrient excretion.

Environmental Advantages

Ammonia emissions can be reduced by 31 to 55%. TKN can be reduced 38 to 60% in fresh manure, and total urinary N can be reduced 28 to 36% by reducing CP and supplementing with crystalline EAA. Typically a 1% reduction in CP results in an 8% reduction in N excretion. Although the resulting reductions in odour emissions are less clear, reductions can be expected.

Environmental Disadvantages

Nitrogen and phosphorus are currently the main focus for reduced nutrient excretion. However, excretion of other minerals including potassium (K) may remain high even after diet manipulation. K is not supplemented but naturally occurs in the feed in quantities higher than required by the pig. Total VOC (volatile organic compounds) or odour emissions do not change but their profile and intensity does.

Barn design may have to be altered to accommodate separating the herd for split-gender and phase feeding requirements. Feeding equipment may have to be modified or upgraded to mix the proper rations (Heber et al, 1999).

Costs

Phase feeding can be implemented either through the addition of extra feed lines or through the movement of hogs to different feeding pens as they progress through the phases of the feeding program. Each method of implementation can result in additional capital costs in terms of feed lines or feeding pens and increased costs for the labour needed to move hogs between feeding areas. The reduction in nitrogen excretion through phase feeding is about 9% (Bactawar, 2003) and can result in savings of as much as $2/pig produced in a two phase operation. Adding phases shows a reduction in feed costs of $1/pig produced going from two phase to three phase, or $0.50 going from three phase to four phase (Murphy, 2003). In a properly designed swine facility, additional phases can be implemented without the need of extra capital investment or labour expenses.

A reduction in feed cost of $1/hog produced has been reported for the use of split gender feeding (Murphy, 2003), but as with phase feeding, additional equipment and labour costs may be necessary to use this feeding strategy.

Nitrogen excreted by hogs can be reduced through several feed additives. Crystalline amino acids such as lysine, methionine, threonine, and tryptophan have been shown to reduce excreted nitrogen by 8.5 to 20%. For diets without EAA, the use of EAA would result in a cost saving. If diets were already formulated properly, the increased cost in feed for synthetic EAA additives is $1.40 to $3.55/hog produced to further reduce N excretion. This represents an increase in feed costs of as much as 5%. Ammonia emission reductions of as much as 40% can be obtained through the addition of an organic acid, such as benzoic acid, to feed. The increase in feed cost for a benzoic acid additive is $1.49/marketed hog.

Nitrogen excretion by hogs can also be reduced by the addition of enzymes to feed. While the reduction is small at 5% for an enzyme such as xylanase, use of the enzyme may also reduce feed consumption and improve feed efficiency. It is reported that at a cost of $1.40 to $1.70/marketed hog, the reduction in feed consumption due to the enzyme while maintaining growth is valued at about $3/hog marketed (Bactawar, 2003), a net savings of $1.30 to $1.60.

The addition of phytase to a swine diet can reduce phosphorus excreted by as much as 40% at a cost of $0.47/finished pig in additional feed costs (EPA, 2001). This represents an increase in feed costs of less than 1%.

Feed processing can reduce nitrogen excretions by 20% and phosphorus excretions by 16%, with the total volume of manure produced also being reduced (Farmscape, 2003). Currently, research is underway to determine the economic feasibility of feed processing.

Recent research at the University of Guelph suggests that formulation of swine diets on true digestible P supply can dramatically reduce the use of supplemental P and phytase and save about $0.75/finisher hog.

Generally, feed mixing and feed delivery errors that may result in as little as 10% change in nutrient levels can lead to losses of as much as $2/pig produced through an increase in feed consumption (Murphy, 2003). Management and control of feed mixing and delivery is very important to avoid this potential cost increase.

Improving feed consumption by 0.1 units in finisher hogs can translate into feed savings of as much as $1.68/pig marketed (Murphy, 2003), thus any additive or feeding strategy that will result in a reduction of feed consumption without adversely affecting the gain of the hog should be considered. A break even situation can occur where the cost of additives and/or equipment and labour equals the savings in feed, and there is also a potential reduction in the amount of phosphorus and/or nitrogen excreted.

General Assessment

Feed management seems to be a win-win situation. By increasing efficiencies in the feed, the producer can optimize growth performance of the hog herd. Also, the neighbours may enjoy the added benefits of reduced odour emissions and nutrient loading in the environment if proper nutrient management procedures are followed.

Complementary Technologies

This process benefits any manure treatment and handling system. Less volume of manure and nutrient loading in the manure requires less land base for storage and application. Solid-liquid manure separation is also considered a complementary technology.

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5.2   Anaerobic Digestion

Description

The basic premise of anaerobic digestion is that raw manure is placed in a tank in the absence of air and bacteria breaks it down into other compounds. The biogas that is produced is composed of carbon dioxide, ammonia, hydrogen sulfide, and a large proportion of methane (Lorimor and Edwards, 1998). This makes the biogas combustible and useful as an energy source for heat or electrical generation. Because the digestion occurs in a closed vessel, there is no external odour during this process. The resulting liquid can be further processed to make a more concentrated fertilizer, or other processes can be used to take advantage of the nutrients in the manure in cases where there is insufficient cropland available to utilize the manure as a fertilizer.

A biodigester in operation.
Photo Courtesy: Clear-Green Environmental Inc.

There are three main types of anaerobic digestion: thermophilic, mesophilic, and psychrophilic. Thermophilic digestion's high temperatures of 104 to 158⁰F (40 to 70⁰C) destroy microorganisms and pathogens, but this type of digestion requires high heating and insulation costs. Mesophilic digestion, which occurs at 95 to 104⁰F (35 to 40⁰C), is more stable than thermophilic digestion and has lower heating costs but requires slightly longer retention times. Psychrophilic digestion is unheated, thus waste is required to remain in the digester for an extended period of time. Due to the climate, psychrophilic digestion is not recommended in Canada.

There are many types of anaerobic digesters available that have their own characteristics and strengths (Frame and Madison, 2001). The most common, well-suited digester for liquid swine manure is the complete mix digester. Plug flow digesters are not suitable for liquid swine manure, as they require manure with a lower moisture content and the solids must remain in suspension. A covered lagoon digester may not be practical, as it is difficult to continuously agitate an earthen storage. Fixed film digesters are also used in very thin manure to produce a high-methane biogas stream.

Retention time is a determining factor in the sizing and cost of a digester system. Thermophilic or mesophilic digesters have retention times of 15 to 25 days (CAEEDAC, 1999) due to the added heat, which reduces digestion time. A psychrophilic digester, such as an unheated, covered lagoon, will have longer retention times of as much as 40 or more days (Kossmann et al, 1999). Sizing of the digester should be done based upon the required retention time and daily volume of waste produced within the hog operation.

Environmental Advantages

Anaerobic digestion offers many advantages. There is little or no odour emitted, and the biogas can be burned to produce heat or electricity (Wisconsin Focus on Energy, 2002). Because of the temperature in the digester, pathogens such as E. coli, salmonella, and cryptosporidium, as well as fly eggs, are destroyed. With further processing, the effluent from the digester can be made into fertilizer or other soil amendments, or if desired, the nutrients can be reduced if cropland is not available.

Anaerobic digestion reduces the greenhouse gas emitted by the swine facility, which may generate greenhouse gas credits for the producer. For a 5,000 sow operation, a complete mix digester can reduce methane emissions by as much as 3,000 tons (2,722 t) CO_2 equivalent basis (Martin, 2003). However, this number is highly variable with the type of digester and the management of nutrients. Some systems boast a reduction of overall greenhouse gases from methane, nitrous oxide, and an offset of fossil fuels to a number that can be as high as 1 ton/finished hog/year. In some cases, the water from the process can be recycled back into the barn for flushing, which can reduce overall water requirements. In a new barn installation, a separate manure storage may not be required or a much smaller one may be adequate.

Environmental Disadvantages

A disadvantage of anaerobic digestion is that the systems must be large to be economical (Garrison and Richard, 2002). This requires a large investment by the producer. In some colder parts of Canada, supplemental heat may need to be added to some digester designs to maintain optimum temperature, and this could affect the overall energy balance and feasibility of the system. Biogas is very combustible and toxic, so safety precautions must be observed and practiced. Biogas is also quite corrosive (Wisconsin Focus on Energy, 2001), which must be accounted for in the system design and economics. Installing an anaerobic digester involves large tanks and other equipment and requires considerable land and management.

Costs

The capital cost for anaerobic digestion will depend upon operation size and type, type of digester used, and the implementation of a boiler, flare, generator, or combination. Capital costs for systems without energy generation are listed in Table 5-1. As mentioned, the choice of biogas utilization will have an effect on the overall capital required. A boiler used to heat water for use in the barns or to heat the digester has a capital cost of $15,000 to $23,000 (Moser and Mattocks, 2000; Roos and Martin, 2002), while equipment for flaring off the biogas, or excess biogas, can cost $15,000 (McNeil Technologies Inc., 2000). The cost of an engine-generator will depend partially on the energy producing potential of the digester. An engine-generator can have a capital cost of $88,000 to $158,000 (Moser and Mattocks, 2000; Iowa State University, 1998), with lower costs found in used or refurbished models. Fixed costs for anaerobic digestion are also shown in Table 5-1, assuming 15 year equipment life, 8% interest rate, 2% insurance rate, and 5% salvage value.

Table 5-1. Capital and Fixed Costs of Anaerobic Digestion Systems.

Type	Complete Mix Digester		Covered Lagoon Digester		Sequential Batch Reactor	Plug Flow
Operation	Finishing[1]	Farrow to Wean[2]	Finishing[1]	Farrow to Wean[2]	Finishing[1]	Finishing[1]
Capital Min Cost	$21.63	$63.88	$10.06	$29.41	$65.79	$21.40
Capital Max Cost	$85.53	$174.74	$142.11	$188.11	$98.68	$43.20
Fixed Min Cost	$1.11	$0.46	$0.52	$0.25	$3.37	$1.10
Fixed Max Cost	$4.38	$1.12	$7.28	$1.18	$5.06	$2.21

1 per pig space
2 per sow space
Sources: EPA, 2003; Vansickle, 1999; McNeil Technologies Inc., 2000; Danesh et al, 2000; Moser; Moser and Mattocks, 2000.

Operation and maintenance costs will vary significantly depending upon the digester design and type, the required labour, and the size of the operation. For complete mix digesters, maintenance costs run at 5 to 10% of capital costs. For covered lagoon digesters, annual operating costs average less than 5% of capital costs. For plug flow digesters, annual operating expenses are about 5 to 10% (Nelson, 2000). The addition of an engine generator to a digester does not add net cost as the generator will reduce other energy costs or add revenue from the generation of electricity.

Methane produced within the digester can be used for energy generation, water heating, or can be flared off into the atmosphere. The caloric value of biogas is from 460 to 670 Btu/ft^3 (17 to 25 MJ/m^3) (Bates, 2001). With electric generators, only about 18 to 25% of the energy is converted to electricity (McNeil Technologies Inc, 2000; NPPC, 1999). The remainder of the energy is heat, most of which can be recovered through heat exchange for heating the digester or barn. For a finishing operation, the biogas electricity produced is about 0.101 to 0.490 kWh/pig space/day (McNeil Technologies Inc, 2000; CAEEDAC, 1999), which can translate into a savings of $1.08 to $5.22/marketed hog assuming an electricity purchase cost of $0.066/kWh. This indicates that anaerobic digestion has the potential to pay for itself assuming optimal use of equipment. Based on the numbers above, the required farm size for a breakeven situation in a finishing operation using complete mix digestion with a $125,000

generator is about 6,600 finisher spaces, assuming $5.22 in electricity savings per marketed hog, if the nutrient value of the digestate is not taken into account. In a farrow-to-wean operation, the values are slightly higher since the daily effluent produced per pig space is higher.

In order to maintain optimal operating temperatures in colder climates, waste can be preheated before entering the digester but will add to costs.

Factors that affect the methanogenic bacteria can also increase costs by decreasing the effectiveness of the technology. Cleaning agents, disinfectants, salts, heavy metals, ammonia, and antibiotics that may enter, or be found in, waste can reduce methane production (NPPC, 1999; Fulhage et al, 1993) and should be monitored carefully. Excess organic material entering the system can result in a lowered pH of the material being digested, inhibiting the bacteria and halting gas production (Fulhage et al, 1993).

Manure handling changes and improvements to the barn design can greatly reduce capital costs and improve overall digester performance by more quickly removing manure for processing. Capital costs related to system insulation for maintaining operating temperature can decrease by using the insulating properties of soil, mounding it up the sides of the digester or completely burying the digester tank (Jones et al, 1980).

The fertilizer value of the digestate should also be taken into account, as the residuals of digestion still hold nutrient value. Anaerobic digestion can convert up to 70% of the nitrogen found in hog waste into ammonia (McNeil Technologies Inc, 2000).

While the cost of having properly trained personnel operating the digester and generator is higher, gas yields can increase by as much as a factor of three for a properly operated system as compared to one operated by unskilled labour (CAEEDAC, 1999). The pH of the system must also be monitored, and when the fluid becomes too acidic, costs can be decreased by using swine urine instead of water or purchased chemicals to make the system more alkaline.

General Assessment

Anaerobic digestion can be a very good method to process manure, thereby reducing the odour, producing valuable end products, and generating energy. In some cases, a complete anaerobic digestion system can be a net profit centre for the producer. However, the economics of anaerobic digesters must be determined before deciding to install a system, as there is a large capital investment required (Miranowski et al).

If electricity is to be generated, an arrangement with the local electrical utility must be confirmed before the system is finalized. It must also be recognized that operating an anaerobic digester will involve some additional management, and this must be accounted as a part of the overall decision to include anaerobic digestion as a part of the manure management scheme. The management issue is being addressed by some anaerobic digester companies that offer to finance, build, and operate the digester system. The producer pays a fee to the company, and the company owns the manure and any products generated by the system.

Complementary Technologies

After anaerobic digestion, other processes can be used to utilize the outputs, such as making fertilizer or soil amendments or using boilers for heat generation and electrical generators. If the fertilizer value of the manure must be consumed, a Sequencing Batch Reactor (SBR) can be used (Fernandes et al, 1991). A SBR uses a combination of anaerobic and aerobic reactions to process manure and consume nitrogen and carbon from the raw manure.

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5.3   Solid-Liquid Separation

Description

The objective of solid-liquid separation of swine manure is to separate the liquid fraction from the solids to make further processing easier, or for other reasons, such as reducing odour. Solid-liquid separation may be done as part of a complete manure treatment system, but it has also been used as a separate treatment.

In addition to being a step in a complete manure treatment system, solid-liquid separation has been done for two other reasons. One of these is to reduce odour. The decomposition of the solid components of swine manure contributes in a large part to odour production. In fact, fine fractions of swine manure are more readily decomposed than larger fractions and typically contribute more to odour generation (Jamieson et al, 2001). This is one incentive to remove as much solids as possible during separation. If the solids are removed, there may be fewer odours in the liquid fraction. The solids could then be treated in a way that would generate fewer odours, and the net result would be fewer odours from swine manure.

Another reason to separate liquid and solid manure components is to manage manure nutrients for land application. In some regions, phosphorous loading in the land receiving manure is an issue, and the nitrogen/phosphorous balance in the raw manure may not match the crop requirements. Because most of the phosphorus in swine manure is in the solids, separating the liquids from the solids allows more precise management of the nitrogen/phosphorus ratio in the manure applied to the land.

Solid-liquid separation is the partial removal of solids from liquid manure.
Photo Courtesy: MAFRI

Solid-liquid separation is achieved by gravitational settling or by mechanical separation. Several types of mechanical separators are available with many of them originating from other industries. They can be classified into screen separators, centrifuges, and presses (Ford and Fleming, 2002). Screen separators have a screen over which the manure is passed and particles smaller than the screen size pass through. Centrifuges use centrifugal force to separate particles of different density. Presses exert mechanical pressure on the raw manure to provide additional separation. Each type of separation performs differently in specific situations.

Because solid-liquid separation results in at least two product streams, additional storage is usually required. If the solids are dry enough, they may simply be left on a pile or moved to a separate composting facility. The liquids require another storage tank or other storage, and if desired, other treatment equipment. Two or more solid-liquid separation technologies may have to be combined in order to attain the desired moisture content and solids removal. For example, presses are often used as a secondary solid-liquid separation technology since they perform better with higher solids content effluent.

The addition of chemicals to the effluent can enhance the separation process. The chemicals act to coagulate and flocculate the particles in the effluent. The process of coagulation causes suspended solids to form into particles that will settle, while flocculation converts particles into large flocs (mass that forms in a liquid as a result of precipitation or the aggregation of suspended particles) that will also settle. Chemicals used are organic polymers such as polyacrylamide, metal salts such as ferric chloride [$FeCl_3$] or alum [$Al_2(SO_4)_3$], and lime [$Ca(OH)_2$] (Mukhtar et al, 1999; FSA Environmental, 2000). Chemicals used for coagulation and/or flocculation can increase nutrient removal from the

effluent. For example, the addition of a polymer to manure running through a centrifuge separator can increase the removal of nitrogen from 13% to 31% and phosphorus removal from 66% to 75% (HPSFG, 1994).

Environmental Advantages

When solid-liquid separators are used as a part of a complete manure treatment system, the downstream processes are normally more efficient and effective. Separation can also reduce odour due to reduction or removal of carbon compounds and nutrient elements that lead to odour generation. In some cases, the solids can be composted directly after separation. If enough solids are removed, the resulting liquid fraction will not need agitation during pump out and may be in a state that can be pumped directly into an irrigation system.

Environmental Disadvantages

When the raw manure is separated into liquid and solid fractions, two or more material streams must be handled instead of one. Introducing any type of processing equipment brings with it added complexity and management requirements. Also, solid-liquid separation is usually not the only manure treatment process in any given operation, so added processes and complexity usually accompany this treatment.

Costs

Mechanical solid-liquid separation technologies cost between $7,800 to more than $112,000 (Fleming and MacAlpine, 2003; Watts et al, 2002). These costs do not include the cost for pumps, sumps, floor channels, and heated shelters, which may be required for operation during winter months (Fleming and MacAlpine, 2003). Mechanical separation units are capable of throughputs of 26 to 7,800 gal/min (2 to 590 L/s) (Fleming and MacAlpine, 2003). Settling tanks or basins cost about $33/sow space, or $9.21 to $13.16/finisher space to construct (Lorimor and Edwards, 1998). Machinery, such as a front-end or skid steer loader, is required for the operation of sedimentation basins.

Labour for cleaning, sludge removal, and repair and maintenance is required for solid-liquid separation technologies. Many systems can be fully automated, reducing the labour required for operation (Fleming and MacAlpine, 2003). Maintenance required will depend on the type of separation. Systems with moving parts will require more maintenance than simple systems such as settling basins or inclined screens. Additional cost may occur due to the equipment being prone to corrosion, thus reducing expected lifetime (Fleming and MacAlpine, 2003).

Table 5-3 shows examples of the cost for different solid-liquid separation technologies for a 200 sow farrow to finish operation. Assumptions include an electricity rate of $0.066/kWh, interest rate of 8%, salvage value of 10% for all technologies except the settling basin, 5% salvage for the settling basin, labour cost of $12/hour, oil and lube rate of 15% of fuel cost and 3,500 hogs marketed annually. The machinery used for the settling basin includes an 80 hp (60 kW) tractor with a front-end loader attachment that is owned by the farm.

Operation costs will include energy requirements of the systems. Pumps for moving effluent are normally in the 2 to 10 hp (1.5 to 7.5 kW) size (Lorimor and Edwards, 1998) with operating costs of $0.10 to $0.49/hour of operation, assuming an electricity rate of $0.066/kWh. A list of specific capacity and utility costs is shown in Table 5-4 for a variety of separation technologies.

Costs associated with combining the technology of chemical addition with solid-liquid separation techniques include the cost of chemicals and labour or equipment for adding the chemicals. Polyacrylamide costs $13/lb ($29/kg) and can be incorporated at a rate of 5 ppm (5 mg/L) of waste (Watts et al, 2002). For a 5,000 head space finishing operation producing 0.15 ft^3 (0.004 m^3) of waste/animal/day, the annual chemical cost of adding polyacrylamide is $23.26, or less than $0.01/marketed hog.

Removal of solids makes the liquid easier to pump, thus reducing the complexity of pumping systems. The frequency of sludge removal can also be reduced, lowering associated labour and machinery costs and potentially reducing wear on storage liners and covers.

Table 5-3. Cost for Solid-Liquid Separation Technologies for a 200 Sow Farrow to Finish Operation.

	Screw Press	Belt Press	Centrifuge	Rotating Screen	Vibrating Screen	Incline Screen	Settling Basin
Capital Cost	$54,369[a]	$92,233[a]	$111,650[a]	$36,893[b]	$30,097[b]	$24,757[a]	$7,767[b]
Annual Cost							
Fixed Cost	$4,893	$8,301	$10,049	$3,320	$2,709	$2,228	$369
Lifetime(yr)	10	10	10	10	10	10	20
Energy Use (kWh/yr)	7,980	15,870	70,500	13,940	13,920	3,170	
Energy Cost	$527	$1,047	$4,653	$920	$919	$209	
Machine Use (hr)							225
Oil and Fuel Cost							$1,456
Labour/Day (hr)	0.1	0.2	0.5	0.2	0.2	0.2	0.5
Labour Cost	$438[c]	$876[c]	$2,190[c]	$876[c]	$876[c]	$876[c]	$4,890[d]
Maintenance Cost[e]	$971	$1,942	$1,942	$971	$971	$971	$0
Total Annual Cost	$6,829	$12,166	$18,834	$6,087	$5,475	$4,284	$6,715
Removed Solids (%)	20%	20%	30%	15%	20%	20%	50%
Cost/ Pig Marketed	$1.95	$3.48	$5.38	$1.74	$1.56	$1.22	$1.92

[a] Capital cost includes a shed to cover the implement and a manure collection sump with pumps and agitator.
[b] Capital cost includes a manure collection sump with pumps and agitator.
[c] Labour for monitoring and maintenance at $12/hr.
[d] Labour for front-end loader use, monitoring and maintenance at $12/hr.
[e] Routine maintenance of pumps and agitators.
Source: Watts et al, 2002.

Table 5-4. Specific Capacity and Utility Cost for Mechanical Separation Technologies.

Technology	Through-put (gal/kWh)	Cost/Million Gallons*
Rotating Drum	966	$68
Screw Press	1,052	$63
Vibrating Screen	667	$99
Screw Press with Inclined Screen	2,320	$28

* Based on electricity cost of $0.066/kWh.
Modified from: Fleming and MacAlpine, 2003.

General Assessment

Separating swine manure into solid and liquid fractions is not very easy to do effectively. This is due to the wide size distribution of manure solid particles and the resulting tendency for manure to plug filters. Any machine that is used must incorporate some method to account for this. Swine manure normally contains very little solids compared to other types of manure, such as from dairy cows, and this also makes separation more difficult. One study suggested that before using a screw press, the manure should be pre-concentrated using a machine such as an inclined screen (HPSFGF, 1994).

Most successes with separating raw manure have been with screw presses or machines that contain screen presses. In some cases, these machines could reduce the solid fraction to less than 80% moisture content. This material would form a pile and compost itself with little odour. However, the liquid fraction still emitted enough odours that further treatment was necessary to eliminate the odours.

Complementary Technologies

Solid-liquid separation can be used with composting and can also be a part of a complete manure treatment system.

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5.4   Composting

Description

The Composting Council of Canada defines compost as a solid, mature product resulting from managed bio-oxidation of solid, heterogeneous, organic substrate including a thermophilic phase (EnviroAccess, 2000).

Composting is an aerobic process requiring oxygen, moisture, carbon, and nitrogen in the proper ratios for the correct bacteria to thrive. The heat generated from microbial activity causes the initial temperature of the compost to rise to 122 to 158°F (50 to 70°C). When additional aeration activities do not result in a temperature increase, the compost is considered stable. The carbon to nitrogen ratio (C:N) in the raw material is critical to promote efficient microbial activity. The optimum ratio is 30:1 and anything less

Compost windrow turner.
Photo Courtesy: MAFRII

than 20:1 C:N can result in odour production. Swine slurry has a C:N ratio of less than 10:1 and moisture levels exceeding 90%, therefore a high carbon source or bulking agent is required. There may be advantages to using solid-liquid separation before composting the manure. Also, hog operations with solid manure systems may use enough bedding that a bulking agent is not needed.

Moisture content (MC) affects the composting process. Moisture is necessary for the microbial processes that contribute to the decomposition of manure. As the MC increases, the particles tend to agglomerate, shrinking the air spaces and limiting the supply of oxygen. If available oxygen is less than 8%, anaerobic decomposition takes over resulting in foul odour production. Oxygen consumption by microorganisms increases above 40% MC and reaches a maximum at 60% MC. The ideal range for MC is 45 to 65%. Particle size influences the ideal MC for each individual process. Smaller particle size means more available surface area, which in turn means more microbial activity and a greater oxygen demand.

The compost can either be turned or remain static. The static compost may use either forced or passive aeration to maintain oxygen levels in the pile. Mechanical turning with front-end loaders, mechanical shovels, or dedicated turners replenishes oxygen supplies and creates air space in the compost. Turning can be done daily, monthly, or any interval in between. More frequent turning reduces processing times. The compost is usually turned more frequently in the early stages of the process and less frequently as the compost cures.

There are three main composting methods: outdoor pile, windrow, and in-vessel.

The outdoor pile composting system consists of mixing and piling organic waste on an outdoor platform. An impervious base, such as a concrete pad, and drainage is required to control leachate. The leachate must be treated. Considerable land base must be set aside for a pile system. With the processing time in the 12 to 18 month range, this method can use considerable land base due to the retention time. The common arrangement for this batch process is to have multiple piles in various stages of processing. Aeration is usually passive in this system, though forced aeration may be used. Aeration could involve burying an aeration pipe in the pile or the base or using a combination of both (Tufts, 1993).

Windrowing is similar to outdoor pile composting except the compost is in several long windrows instead of piles. Again, an impervious base is recommended, and leachate must be collected and treated. It is generally estimated 35 ft³ (1 m³) of raw material requires 8.6 ft² (0.8 m²) of ground area for a windrow setup (Global Earth Products, 2005). As with piling, the windrow system is a batch process and a typical arrangement has several windrows in various stages of the composting process. Dedicated windrow turners, both self-propelled and pull-type, have been developed by several equipment manufacturers to efficiently turn and shred the compost windrows. Aeration is accomplished

by mechanical turning of the windrow, but it can be supplemented with passive or forced aeration through pipes buried in the windrows or channels in the base.

In-vessel compost systems employ a concrete channel or trough to hold the compost inside a building. The in-vessel systems have tighter quality control than windrowing or piling outdoors resulting in more consistent compost. Forced aeration is the norm and turning is more regimented, resulting in a more consistent compost (Tufts, 1993). The relative aggressiveness of the processing lowers land requirements to 20% of an outdoor windrow system. Due to its comparatively short processing time of four to eight weeks, it is best suited for continuous

The RotoKing compost turner.
Photo Courtesy: Transform Compost Systems Ltd.

treatment (Paul, 1999). Raw materials can be added at one end of the channel while finished product is removed from the other end of the channel (Bolton, 1999).

Environmental Advantages

Properly maintained compost produces minimal odour during processing, storage, or field application. With sufficient aeration, GHG emissions are significantly reduced, especially methane (CH_4) and nitrous oxide (N_2O) (Langenburg; Hao and Coulter, 2001). The sustained exposure to 140°F (60°C) destroys pathogens and weed seeds (TCSL, 2005). The resulting product can be used as an agricultural soil amendment or sold as a replacement for horticultural peat moss.

The careful monitoring and indoor facilities associated with in-vessel processing make it the most environmentally friendly compost system. There is no risk of ground or surface water contamination with in-vessel composting. It also produces a consistent, high quality end product (BCMAFF, 1996).

Environmental Disadvantages

There is some potential for odour production while establishing the pile or windrow. The passive or non-aerated systems may develop offensive odours if anaerobic pockets are allowed to develop. Pile and windrow systems require a large land base to set up and have long retention times of up to 6 months or more depending on turning frequency (Tufts, 1993). Improper maintenance of the process can lead to problems. A C:N ratio higher than 30:1 results in inefficient microbial activity, while too low of a C:N ratio (<20:1) can lead to odour production and ammonia volatilization (EnviroAccess, 2000).

Although the passive composting techniques are not as efficient and the compost itself produces more GHG, the energy requirements for turning and forced aeration are part of system emissions (CETAC-WEST, 2003).

Costs

The capital costs of composting manure depend greatly upon the method used. The capital requirements for an outdoor pile composting system consist of a front-end loader and a pad for compost storage and manipulation. A tractor and front-end loader attachment will cost approximately $100,000 and $10,000, respectively; however, such a machine is usually already available on most farms. The concrete or asphalt base, if needed, will increase the cost significantly based upon a $1.25/ft^2 ($13.50 m^2) cost to control leaching (Buckley, 2004). A base of compacted clay and gravel is less expensive and run-off treatment may only need to be a vegetated strip or field.

For windrow composting, a turner is required to manipulate the large area of compost. A self-propelled turner has a capital cost of $125,000, while a pull-type turner is about $25,000 (Paul, 1999) but also requires a tractor. The need for a roof and/or base will increase the capital costs by $6.60 and $1.25/ft^2 ($71.00 and $13.50/m^2) respectively for the outdoor pile and windrow composting.

The capital costs for in-vessel composting are significantly greater due to the increased amount of equipment and the building. For an 8 ft wide by 18 ft long (2.4 x 5.5 m) channel in-vessel compost system, the cost of the building is $20/ft² ($215/m²). A compost turner with carriage ($103,000) is also needed, plus an aeration system ($24,000). The total initial cost for processing 6,945 tons (6,300 t) of manure annually would be $260,000 for in-vessel composting.

Bulking agents are required for all three methods of composting unless the pigs are housed in a deep litter system. The cost of a bulking agent, such as straw or sawdust, is $13 to $14/ton ($14 to $15/t) of manure composted (Paul, 1999). The other cost components of the different systems are provided in Table 5-2.

Table 5-2. Annual Cost to Compost 6,945 ton of Manure/Year.

Composting System	Operating Cost*	Equipment Cost*	Pad and Housing Cost*	Total*	Unit Costs ($/ton)
Pull-type Turner	$5,815	$24,750	-	$30,565	$4.40
Pull-type Turner with Base	$5,815	$24,750	$11,392	$41,957	$6.04
Pull-type Turner with Roof and Base	$5,815	$24,750	$54,227	$84,792	$12.21
Self-propelled Turner	$5,815	$41,250	-	$47,065	$6.78
Self-propelled Turner with Base	$5,815	$41,250	$7,975	$55,039	$7.92
Self-propelled Turner with Roof and Base	$5,815	$42,150	$37,959	$82,013	$11.80
In-vessel (4 ft channels)	$8,639	$27,390	$45,984	$82,013	$11.80
In-vessel (8 ft channels)	$3,745	$33,900	$30,378	$68,113	$9.81
Modified From: Paul, 1999					

The difference in housing and pad costs between the two windrow composting systems is due to the increased space needed between windrows in the pull-type system. The use of a roof over windrows is necessary for regions of the country with high levels of precipitation, such as British Columbia. The difference between the 4 ft (1.2 m) and 8 ft (2.4 m) channel in-vessel system is due to the size requirements for the building and the time needed.

Leachate collection and treatment, not included in the evaluation, also result in increased costs for all systems except in-vessel composting.

The extent of use of the turning equipment will determine the lifespan. For 6,945 ton (6,300 t) of raw manure composted, a properly maintained compost turner should last longer than the five years used in the assumptions. This could translate into a significant decrease in annual equipment costs. For example, doubling the lifespan to ten years would halve the annual equipment cost, resulting in an annual total cost of $2.89/ton ($3.18/t) for a pull-type windrow system with no base or roof.

General Assessment

While in-vessel composting has several benefits including minimal odour, high quality end product, short compost time, year round composting, and eliminated leaching, the cost is particularly high compared to windrow composting. Despite the concerns with leaching and the lower quality of the compost produced, windrow composting, either self-propelled or pull-type, is economically more practical than in-vessel or outdoor pile composting, considering that the equipment lifespan of five years is likely underestimated. The extremely long time (12 to 18 months) needed for static composting and the lower product quality negate the attractiveness of the lower annual costs of this technology. Outdoor pile composting of livestock manure currently has limited use in Canada due to the colder climate (Hao and Coulter, 2001).

A properly maintained compost heap is an effective method for reducing odours and greenhouse gas emissions as long as there is available land base for storage and retention. It is also effective in reducing water content of the manure if the compost is to be transported long distances.

The compost can be sold in bulk, bagged, or palletized form for off farm use. All compost sold in Canada must comply with the Fertilizers Act and Regulations (Paul et al, 2001).

Complementary Technologies

A bio-shelter or deep litter operation is well suited for composting as a bulking agent may not be required.

Mechanical solid-liquid separation technologies could be used. By only composting the solid portion of the manure, less bulking agent is required and greater capacity from a smaller site would be realized. A simple settling tank works quite well and is efficient in a batch process if it is incorporated as the holding tank. Higher end technologies, such as a screw press or centrifuge, could be used when the consistency of the end product or efficient land usage is a priority (Tufts, 1993).

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5.5   Pelletizing Manure

Description

Pelleting is the process of forming fine material into pellets. These are defined as small, solid, or densely packed balls or masses. Pelleting equipment has been developed to convert dusts or powders into this homogeneous and easily transportable form.

The pellets are produced by loose pendular, funicular, and capillary bonds forming between grains of the material in the presence of moisture. Rotary action causes nucleation and the densification of the pellets, or mechanical pressure can force the material through a die.

> *Pelleting yields a stable, homogenous, granular material that is 50 to 80% of the volume of the raw material.*

Mechanical press pelleters are common in the waste processing industry and come in two main styles: extruders and roller presses. Extruders use screw conveyors to compress the material in a cylinder then through a screen or die. A rotary shear is used to cut the pellets, giving them a cylindrical shape. The speed of the extruder screw controls the process speed and pellet quality. The optimum speed of the screw is determined by the characteristics of the raw material. Optimum moisture content of the manure is 40% for an extruder machine. Its biggest limitation is that foreign debris or long fibres such as straw can easily block it. Roller presses come in many different configurations but the process is similar for each one. A roller forces the raw material through a die. Either the roller or the die may rotate. Again, pellets are sheared off at the appropriate length by a cutter. Moisture content of 20 to 25% is considered optimum for a roller press. The feed rate of the raw material dictates the process speed and the quality of the pellet. Roller presses are able to grind through the large particles that may block an extruder but foreign debris, especially rocks and metal, cause severe damage to the rollers and dies (Hara, 2001).

Drum and pan pelleters are of the rotary or tumbling style. Fine material is continuously added to a rotating pan and wetted by a fine water spray in a pan pelleter, which forms larger particles. The rotating action of the pan or drum causes small, spherical seed type particle formation. Continued rotation causes a "snowballing" effect resulting in larger particle size. The rotation speed and angle of the drum or pan control pellet size. The larger particles are forced to the outside by the rotation where they are eventually discharged. The natural selection process ensures uniform pellet size.

Pelleting requires a relatively dry raw material. Raw material moisture content must be maintained in the 20 to 45% range for optimum performance. Therefore, a dewatering process is required to handle liquid swine manure. Work has been done with pelleting compost, which is an effective moisture reduction process. A separate building will be required to house the equipment. Minimum building size for a rotating drum dryer and pelleter is 36 x 65 ft (11 x 19.5 m). For a solid manure system or if a fibrous material such as straw is used as the bulking agent, a shredder/decorticator may be required to obtain the proper input consistency. To prevent mold formation, the pellets must be dried to 20% moisture content for winter storage and 15% moisture content for summer storage. The pellets are suitable for resale as a high-end organic fertilizer for residential or commercial use.

Environmental Advantages

Pelleting yields a stable, homogenous, granular material with ammonia residue of less than 0.5 gr/ft³ (1 gm/m³) of air. The nutrients are not lost in the pelleting process, and, therefore are more concentrated in the pellets allowing for more efficient application. Also, the uniformity of the pellet size allows for more precise mechanical application. It is also more cost effective to transport and store the pellet material, as it is 50 to 80% of the initial volume of the raw material. Manure is more stable in pellet form, allowing for better handling characteristics. Pellets can be spread closer to residential areas, as they do not produce any dust. The pellets do not break down in the soil as quickly, avoiding nutrient overloading. This also creates an anaerobic environment inside the pellet, slowing the nitrification process and reducing the risk of nitrate leaching.

Environmental Disadvantages

The pelleting process requires high power input to run the machinery and a fuel source for the dryer, if used. Also, the slowing of the nitrification process leads to a greater risk of ammonium leaching compared to compost. Since the pellets retain their shape longer in the soil, care in application is required to avoid ammonium leaching and residual nutrient buildup.

Costs

The pelleting of manure and compost has several pre-processing costs that must be considered when determining the economic feasibility of this technology. Pelleting of compost should include the costs related to composting of manure, which may include solid-liquid separation, and costs of preparing the composted material to be pelleted, such as a shredder/decorticator to reduce fibrous material. With manure pelleting, a solid-liquid separation unit will be required unless the hog operation uses a deep litter system, in which case a shredder/decorticator will be needed.

Livestock manure can be pelletized using equipment such as a pin mixer. The pin mixer, capable of processing as much as 10 ft^3 (0.28 m^3) of manure (10% moisture) per hour costs \$23,160 (Hinkle, 2003). Based upon manure production figures for finishing hogs, such a unit could service a finishing production system as large as 6,000 head, operating for only one hour per day (Hamilton et al, 1997).

The annual fixed cost for a pin mixer is \$5,648, assuming a 10 year life (Hinkle, 2003), 8% interest rate, and 2% insurance rate. Annual maintenance of the unit is about \$3,829, assuming that maintenance requirements are about 10% of capital costs (Hinkle, 2003) due to the number of moving parts. Based on the 15 hp (11 kW) electric engine, electricity costs per year, assuming one hour of operation per day and an electricity cost of \$0.066/kWh, are about \$270. Labour for pelleting will involve loading and unloading the unit.

Housing for the pelleting equipment will be required and should be set up with a water supply, as the pelleting process requires the addition of water. In some cases, a binding agent such as wood liquor (lignosulfonate) (Hinkle, 2003) may be required for the formation of the pellets. If the process is performed daily, storage for the pellet product may be required.

Pellets of swine manure can be applied to fields where the pellets are slowly broken down to release the nutrient value to the soil. Pelleting can potentially avoid the reduction of the N:P ratio that is found in the composting of swine manure (Buckley et al, 2003; Freeze et al, 1999).

General Assessment

Pelleting might be an option for farms with insufficient land base for spreading. Pelleting may also be an option if there is a sustainable market for the pellets. However, there are normally more cost effective processes for handling manure for farm use. Research shows the pelleted manure is more costly than inorganic fertilizers and the market segment that will pay the premium for organic fertilizer is small. As this market segment grows and demand increases, it may become viable.

Complementary Technologies

Composting is a complementary technology as it accomplishes moisture reduction. A properly maintained compost operation can provide a consistent raw material for pelleting. However, other solid-liquid separation processes would also work instead of composting to reduce retention time and space required, although the larger volume of separated liquid would still need to be disposed.

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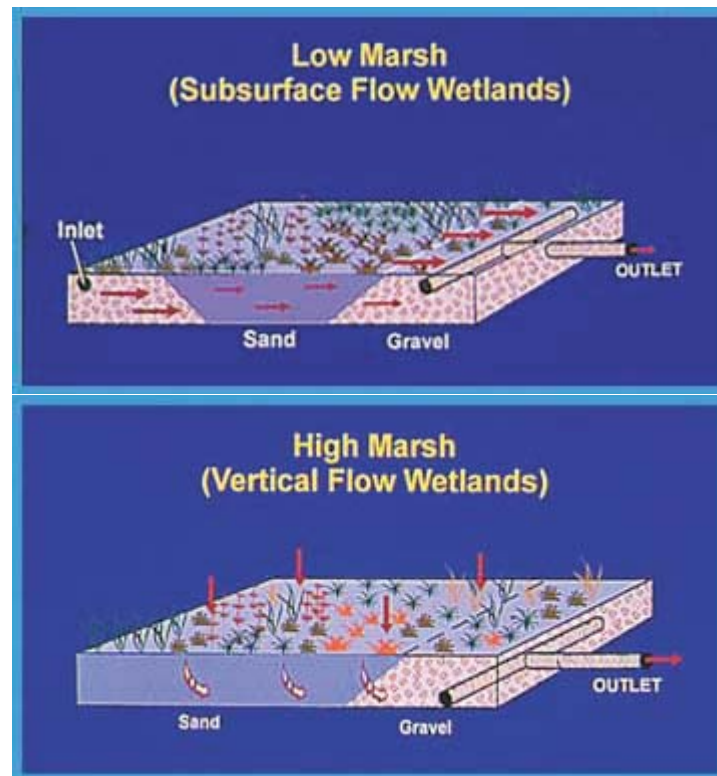
5.6   Constructed Wetlands

Description

Constructed wetlands are artificial wetlands built specifically to treat wastewater. The main design objectives for a wastewater treatment constructed wetland are to provide a system that is capable of providing a high level of treatment that discharges relatively clean water and to build an inexpensive system that is easy to operate and maintain. Constructed wetlands should not be confused with created or restored wetlands, which have the primary function of wildlife habitat.

The application of constructed wetland technology for the treatment of agricultural effluent shows promise. The design of a constructed wetland is dependent upon the volume and concentration of the incoming wastewater. Accurate determination of the various pollutants is critical in determining the size and type of constructed wetland (Tousignant et al, 1999).

Constructed wetlands can be divided into two main classes: Free Water Surface (FWS) systems and Sub Surface Flow (SSF) systems. FWS systems are

Constructed wetlands are classified based on their flow – horizontal or vertical.
Source: Water Recycling

wetlands where the water flowing through is exposed to the atmosphere. SSF systems are designed to flow through a granular media. FWS systems can be further divided into two sub classifications: emergent macrophytes (cattails and bullrushes) and free-floating macrophytes (duckweed and water hyacinth). SSF systems are sub classified based on their flow, horizontal or vertical, and by definition are all emergent macrophyte systems.

Constructed wetland systems are basins or channels lined with an impermeable liner, such as clay or geotextile, to limit infiltration. In emergent macrophyte systems, a layer of soil is provided on top of the liner in which the plants are sown. The wetland system is typically supplied with wastewater from a holding pond or lagoon that also acts as a primary settling basin. Most solids have been settled or filtered out of the suspension, lowering biochemical oxygen demand (BOD) and removing particulate forms of nitrogen and phosphorous. Plants that are typically used include: bullrushes, cattails, curly dock, duckweed, knotgrass, smartweed, spiked bulrush, reeds, sedge, and sulfuria (Woerner and Lorimor). Wastewater is pumped in or allowed to gravity drain into the cell to a level of 0.65 to 0.98 ft (20 to 30 cm) deep. A nutrient rich sludge is formed on the bottom of the wetland. The plants supply oxygen to the root zone via the root system promoting aerobic digestion. The roots also act as physical supports or substrate for microorganisms that help remove pollutants. Free floating macrophyte based wetlands use floating plants to remove nutrients and control algae. A floating barrier grid is used to support the floating plants and reduce the drifting effects of the wind. The plant mat blocks sunlight thereby preventing photosynthesis and inhibiting algae growth. SSF wetlands make use of the same removal mechanisms as FSW systems. Since the wastewater flow is below the surface, it is in continuous contact with the filter media, which provides more surface area for bacterial growth. With the higher bacterial growth rate, a higher organic loading rate can be realized. In a horizontal flow wetland, the medium is kept saturated under continuous wastewater flow. The emergent plant life

provides the oxygen flow from the atmosphere to the wetland. Vertical flow SSF systems are operated as a batch process where the wastewater is applied at timed intervals allowing the filter to drain. Since the system is not constantly saturated, oxygen is more easily transferred by diffusion (Cook and Evans, 2001).

Environmental Advantages

Several physical, chemical, and biological processes take place in a wetland system. On average, wetlands are capable of providing removal rates ranging from 60 to 90% for many pollutants and have been shown to reduce incoming pathogens numbers by up to five orders of magnitude. Typical reduction of total kjeldahl nitrogen (TKN), BOD, chemical oxygen demand (COD), total suspended solids (TSS), volitile suspended solids (VSS), and pathogens is >90% by concentration. Reduction of total phosphorus (TP) ranges from 6 to 70% (Stone et al, 2002).

Environmental Disadvantages

The phosphorous levels from the outlet of the wetland treatment systems may not meet watercourse discharge standards. Phosphorous reduction is a physical process. It binds to soil particles with a finite number of exchange/binding sites. This is offset by an effective and efficient sediment basin as a majority of the phosphorous in swine manure is in the solid portion that settles out. Nutrient treatment capacity, especially for N, is limited in cold weather. Storage is required to hold wastewater for operation of the constructed wetland in the grazing season.

Wetland managers also have to cope with the grazing and burrowing activity of native wetland species such as muskrats (Rochon et al, 1999). Fencing or other means may be required to exclude muskrats.

Costs

The cost of wetland construction is somewhat similar to the construction of simple earthen manure storage (Bayne, 1995). While the volume is not as large since the wetland acts as a treatment cell added on to a storage or lagoon, the amount of required land can be larger as the depth is not as great. The suggested size for wetlands is 1 ac/65 lb (1,000 m^2/7 kg) BOD produced per day (Rieck et al, 1993). Assuming a lagoon removes 50% of BOD, a single acre of land is large enough for 300 finishing pig spaces (Rieck et al, 1993). Costs are estimated to be between $32,000 and $45,000/ac (0.4 ha) (Phillips et al, 2001) and will depend partially on availability of equipment and clay for the lining of the wetland.

Constructed wetlands should be nearly maintenance free (NFESC, 1998). On occasion, partial pump out for application to land may be performed to lower water levels. Associated costs will be maintenance of pumping systems and water level controls.

Solids that are removed need to be stored and disposed. Storage and application equipment would be costs associated with wetland technology. Additionally, since the nutrient value of the effluent is lost (Bayne, 1995) considerations should include higher volume application rates and possibly supplemental commercial fertilizer.

General Assessment

The use of constructed wetlands is not a new idea. The most widely used wetland system in North America is the free surface (emergent macrophyte) system. This type of system is relatively simple, easy to construct and operate, and is relatively economical. However, Canada's cold climate provides some challenges to constructed wetland utilization.

Complimentary Technologies

Constructed wetlands require some form of solid-liquid separation, as they are primarily intended for wastewater systems. Constructed wetland effluent may require some phosphorous reduction before it can be discharged into a surface watercourse.

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Chapter 6   Manure Application

6.1   Swine Manure Application Method

Description

There are four main methods of swine manure land application including broadcast (no incorporation), broadcast and incorporated, high disturbance injection, and low disturbance injection (PPC, 2002).

Broadcasting of liquid manure is generally done with a tanker equipped with a dribble bar or splash plate. Irrigation is also a form of broadcasting and can utilize a pivot system, a traveling sprinkler system, or a drip system. Backflood irrigation is also sometimes used. Solid manure is broadcast using a tractor pulled or truck mounted spreader with a flail or screw system that pushes the manure to the back of the box where it is flung onto the field.

Low disturbance injection typically refers to the use of coulters to open the soil.
Photo Courtesy: PAMI

Once broadcast, both solid and liquid manure can be incorporated to increase nutrient retention. Tillage tools are used to incorporate the manure into the soil. In the case of solid manure, the tillage action may also aid in the distribution of the manure, as it tends to be deposited in non-uniform clumps.

High disturbance injection refers to the use of a tool bar equipped with a manure distribution manifold, shanks, and sweeps for opening and tilling the soil. Boots are attached to the back of the shanks to direct the manure into the opening created behind the sweeps. The sweep openers operate from 2 to 6 in (5 to 15 cm) deep in the soil depending on the manure application rates and soil conditions. The row spacing is generally 12 to 24 in (30 to 60 cm).

Low disturbance injection typically uses chisel or disk openers (angled coulters) that open the soil with a minimum of soil disturbance. Coulters penetrate the soil to a depth of 3 to 6 in (7.5 to 15 cm) and are suitable for injecting the manure into a wide range of soil and crop conditions including post emergent forage, pasture, and annual crops under zero tillage or reduced tillage systems. One specific method of low disturbance manure application is the AerWay® system. It uses a patented Shattertine® that lifts and fractures the soil as it moves forward creating a series of slots, much like a turf aerator (www.aerway.com). The manure is distributed by nozzles that are placed directly behind or in front of each row of AerWay® tines allowing the manure to enter the slots.

The chosen method of manure application will have a direct impact on nutrient retention and/or loss (Table 6-1). Losses can occur with runoff, which can affect surface water sources, and leaching where nutrients move beneath the root zone and have the potential to affect groundwater. Volatilization (gassing off) of nitrogen as ammonia is associated with odour. Compaction and soil disturbance are also issues that can be addressed with more effective manure application practices and equipment. Combined with appropriate timing and calculated rates, manure application methods can improve the agronomic performance of annual and perennial cropping systems (Schoenau, 1997).

In some situations, broadcasting manure is still an acceptable practice, and losses can be reduced with small modifications. When broadcasting liquid manure on pastureland, the use of a drop hose (rather than a splash plate or a dribble bar) that places the manure as close to the surface as possible will reduce volatilization losses. Application to pastures with good cover will also reduce losses.

Broadcasting of solid manure will be more effective if the manure is at least partially composted. Producers can do this by occasionally turning the stockpile, the result being a more consistent lower volume product, which is also less subject to losses associated with volatilization.

Nutrient loss and odour issues can result from application with irrigation equipment. Pivot systems with larger nozzles will help to reduce losses, especially when combined with practical equipment

management practices. Practices that avoid application on hot, windy days, manage rates, use larger nozzles, and apply closer to the ground will help to reduce nutrient losses and odour. Big gun irrigation systems should be avoided, as they are associated with high odour emissions and losses from runoff and leaching.

Table 6-1. Estimated Nitrogen Losses during Application.

Application Method	% of Ammonia-N Loss
Injection	0%
Broadcast (incorporation in 24 hrs)	15%
Broadcast (no incorporation)	35%
Source: Adapted from SAFRR 2004	

The use of large equipment for manure application can result in soil compaction causing a variety of issues from reduced aeration, water availability, and drainage to rutting, smearing, and soil mixing. Producers can adapt by using drag hose systems rather than tankers, restricting field and vehicle traffic, applying manure when field conditions are favourable, and maximizing the footprint by lowering tire pressures, and using larger tires or track vehicles (PPC, 2002).

Environmental Advantages

Advantages of broadcast (no incorporation) application using tank spreaders include low cost and simple application machinery that is cost effective on medium-sized livestock farms. Broadcast and incorporated application advantages include reduced risk of manure runoff, low levels of odour, and reduced potential for ammonia-N loss. Advantages of high disturbance injection include the benefits of broadcast and incorporated application plus the labour and energy savings of a one-pass operation. Advantages of the low disturbance injection system include the same advantages as for the high disturbance injection system plus the capability to inject the manure in pastures and zero till farmland.

Environmental Disadvantages

Disadvantages of broadcast (no incorporation) application include the risk of manure runoff or movement into drainage tiles, ammonia-N loss, and high levels of odour. The nutrient losses can be substantial and therefore producers are encouraged when broadcasting to incorporate in order to maximize the nutrient retention. Broadcast and incorporated application disadvantages include high energy costs to apply and incorporate the manure and no possibility of applying the manure on pasture or zero till farmland. Disadvantages of high disturbance injection are similar to broadcast and incorporated application. Disadvantages of the low disturbance injection system include higher maintenance costs for the coulter system and high down force requirements to allow coulter penetration in hard soil conditions.

Costs

Broadcast application systems would include the cost of harrows, a tank system, and tractor. The cost of harrows for incorporation of swine manure ranges from $7,400 to $45,000 (Lazarus, 1999), and the capital cost for a tank spreader without injectors ranges from $12,000 to $24,500 (Wright, 1997), so the total capital required with a 160 hp (120 kW) tractor would be between $144,600 and $194,700.

Incorporation will increase the cost for the operator by requiring an additional pass with a cultivator and will need to include the applicator's time. However, incorporation greatly increases nutrient utilization, so the benefit could be substantially more than the cost. In addition, odour is reduced significantly with incorporation, which has a number of social benefits.

Injection, either traditional or low disturbance, is very effective for conserving manure nutrients. Estimated losses with injection are often close to zero (Table 6-1), making injection a very efficient application method. Costs for a commercial applicator sized drag hose injection system can be found in Table 6-2; however, lower capital costs would occur for farm sized systems. Drag hose systems can apply approximately 1 million gal/day (4.5 million L/day) when running a 24 hour shift. Reports and information from custom applicators put liquid manure application costs at about $0.01/gal ($0.002/ L) (Table 6-3). The cost of manure application makes it seem more economical to apply higher rates;

however, rates above a two-year requirement are wasted and pose environmental concerns due to leaching (Mooleki et al, 2002).

The capital cost for a slurry tanker system would include the tractor, tanker, and injectors. The cost of a 4,200 gal (19,000 L) tanker with injectors ranges from $26,500 to $38,000 (Zulovich et al, 2001; EPA, 2001). The capital required for a 160 hp (120 kW) tractor to pull the tanker is $125,000 (EPA, 2001), resulting in a capital investment of $152,000 to $163,000. Volumes that

Table 6-2. Drag Hose Liquid Manure Injection Capital Costs (Commercial Applicator).

Equipment	Number of Items	Price	Total Cost
Tractor, 180 hp (one with 3 point hitch)	3	$150,000	$450,000
Agitators	2	$20,000	$40,000
Pump	2	$1,500	$3,000
Trucks, one ton	2	$40,000	$80,000
Hose Humper	1	$2,000	$2,000
Injection Unit with 2 miles of hose	1	$325,000	$325,000
Semi Tractor Unit (used)	1	$35,000	$35,000
Semi Low Boy (used)	1	$25,000	$25,000
Tandem Truck with Flat Deck (used)	1	$30,000	$30,000
Total			**$999,000**
Source: Halter, 2003.			

can be applied using tanker and injection systems will be limited by the size of the tanker, which can range from 1,000 to 6,000 gal (4,500 to 27,000 L).

Application systems will vary in capital cost but decisions should be made that account for site-specific conditions relating to soil, topography, and water. For instance, although surface application systems are associated with higher losses in some situations, very stony conditions will limit the use of injectors. In this example, surface application with drop hoses may be a reasonable application option. Also, the Aerway system mentioned previously worked reasonably well and soil was not turned up as with some other injection systems.

Irrigation can be quite costly with the cost of a center pivot irrigation system capable of manure application to 150 ac (60 ha) at about $80,000. Large operations producing liquid manure will require more than one center pivot irrigation device. For these operations, the amount of land available for land application (tillable acreage) must be divided into 150 ac (60 ha) per center pivot to calculate the required number of center pivots. However, the irrigation system will also be used for application of water, which will decrease the capital cost allocated to manure application.

Solid manure application can be done with a tractor pulled or truck mounted spreader. The cost of solid manure application is approximately $36/ac or $3.90/ton ($89/ha or $4.30/t) of manure. Solid manure can be composted to improve the ease of handling, reduce volume, and reduce odour, but it does add cost to the process.

General Assessment

Manure application systems that inject the swine manure directly into the soil will have lower odour and less ammonia-N loss compared to broadcast systems. All systems should be evaluated against the objectives and constraints of a particular operation and should be managed to reduce nutrient losses and minimize odour.

Complementary Technologies

The advances in direct seeding equipment technologies have resulted in seed and fertilizer opener designs that facilitated the development of minimum disturbance swine manure injection openers.

Table 6-3. Cost of Liquid Manure Injection.

Radius (miles)	Price ($/gal)
1 to 2	$0.0097
2 to 2.5	$0.0115
2.5 to 3	$0.0135
Source: Industry Standard	

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6.2   Swine Manure Application Timing

Description

The timing of hog manure application to crop and forage lands will be determined by a number of factors. These may include maximizing manure nutrient use efficiency for crop production, analyzing soil conditions to support application, maintaining surface and groundwater quality, minimizing odour production, and avoiding greenhouse gas emissions.

When selecting the appropriate time for manure applications to annual cropland, three general options exist: spring pre-plant, summer in-crop, and fall post-harvest applications. Forage lands can receive manure essentially any time after spring thaw and prior to freeze-up, depending on grazing or forage harvest frequency and soil moisture conditions. Winter spreading is a legal option in some regions of Canada but should be avoided if possible and, if necessary, only done with extreme caution to prevent manure being transferred to surface water courses. Specific regions may also regulate manure application timing. Consult local regulations for details on permitted application timing.

> *There are three greenhouse gases pertinent to the agricultural sector: carbon dioxide, methane, and nitrous oxide*

In-crop manure applications are generally possible in all regions of Canada; however, fall applications are common in western Canada due to a relatively short growing season. Tight time lines reduce the opportunity for spring application while post-harvest soil conditions are generally suitable for supporting application equipment traffic. In eastern Canada, manure application during the spring pre-plant and summer in-crop periods is recommended where possible due to the predominance of row crop and fall-seeded cereal production.

If possible, application timing should correspond to periods of rapid uptake of nutrients by developing crops or to times of minimal soil microbial activity. Applying manure when a crop is actively using nutrients will reduce the chance of environmental contamination. Applying manure when the soil is cold will minimize soil microbial action on the manure and minimize the transformation of organic and ammonium-nitrogen to nitrate-nitrogen, therefore reducing potential loss of manure nitrogen to leaching and to the production of nitrous oxide. Nitrous oxide has been shown to be a contributor to the atmospheric greenhouse effect or "global warming". When applying manure to growing crops, care should be taken to avoid contact between manure and the plant surface for crops susceptible to ammonia burning. Drop tube, Aerway®, or low-disturbance coulter injection should be considered in this application. Research in Manitoba has shown positive winter wheat responses to spring and in-crop applications of liquid hog manure (PAMI, 2004).

Cover crops can temporarily tie up manure nutrients if manure must be applied in the fall. A cover crop can be a nutrient management option if manure cannot be applied in the spring or in-crop. Cover crops can be plowed in or desiccated prior to spring planting operations, contributing organic carbon and nitrogen back into the soil system.

Inter-row applications to established row-crops, such as corn, are possible, as are applications to standing small grain crops, with negligible crop damage if proper equipment and practices are used. Care must be taken when applying manure any time throughout the year to avoid soil compaction resulting from equipment traffic on moist soils. This will be especially important for spring pre-plant and in-crop applications. Drag line systems tend to reduce the potential for soil compaction compared to tanker systems.

In-crop manure application to spring wheat using an Aerway applicator and drag line system.

Environmental Advantages

Manure application during the growing season can reduce the risk of nitrate leaching and greenhouse gas production. Both leaching and greenhouse gas production represent a loss of nitrogen from the farm nutrient cycle. Therefore, conserving manure nitrogen will reduce the need to purchase nitrogen fertilizer and minimize an operation's overall environmental impact.

Environmental Disadvantages

Applying manure during the fall will result in manure nutrients being stranded in the soil over winter and throughout the spring thaw. During this period, soil saturation is common in certain parts of Canada

Manure application in standing corn.
Photo Courtesy: Ontario Pork

resulting in the downward movement of soil water, possibly into groundwater sources. If soil nutrients are present, there is a risk of these nutrients being leached into groundwater.

The presence of soil nitrate during times of soil saturation can also result in the production of nitrous oxide. When soil becomes saturated, a lack of free oxygen exists for use by soil microbes, which instead will use soil nitrate as a source of oxygen. A bi-product of this process is nitrous oxide, a potent greenhouse gas.

Winter spreading manure significantly elevates the risk of manure entering surface water courses, as manure can be transported with the overland flow of melt water. Winter spreading and application to frozen soils should be avoided or managed carefully.

Cost

Little significant added cost is associated with altering the timing of manure application. However, if spring manure application delays planting and subsequent crop maturity, there can be significant cost consequences.

Fall seeded cover crops can help in managing the potential for nitrate leaching and nitrous oxide production from soils receiving fall applied manure. Seed and labour costs for establishing cover crops will vary with the species and method of establishment selected.

Equipment requirements generally will not vary for manure application at different times of the year. However, research has shown positive crop yield and quality responses to applying manure during the growing season (PAMI, 2003). As well as a reduced potential for environmental impact, increased nutrient use efficiency will result from applying manure during the growing season, as opposed to fall applications.

General Assessment

There are agronomic advantages to applying manure to a growing or developing crop. However, fall application will not delay spring seeding which is important in areas with short growing seasons. When applying in the fall, cool soil temperatures or application into cover crops will temporarily tie up fall-applied manure nutrients and reduce potential environmental impacts of manure application. In-crop applications will further minimize potential impacts, such as nitrate leaching and nitrous oxide production, and help to maximize manure nutrient use efficiency. In-crop applications will also tend to reduce the transfer of manure odours to the surrounding atmosphere.

Refer to local guidelines and regulations concerning allowable periods of manure application during the spring and fall, winter spreading, and manure application to frozen soils.

Complementary Technologies

New developments in machinery, such as precision automated steering, may decrease the crop damage when doing in-crop manure application into crops with narrow row spacing.

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6.3   Selecting Soils for Swine Manure Application

Description

When selecting land suitable for manure application, soil texture should be a major consideration, as soil texture along with precipitation determines the speed that crop nutrients can leach through the soil. Coarse soils with large pores allow the rapid movement of nutrients to groundwater. Conversely, fine textured soils significantly reduce the percolation of nutrients through the soil (Brasher, 2003). In areas of high rainfall and shallow water tables, application of manure to coarse textured soils should be done with caution to prevent manure movement to the water table.

Application of swine manure to agricultural soils increases organic matter resulting in improved soil structure, increased water infiltration, decreased bulk density, and improved soil tilth (Nelson et al).

Soil sampling to assess nutrient levels in the soil.
Photo Courtesy: PAMI

Sodium levels in soil are often reported as the Sodium Adsorption Ratio (SAR). This is a ratio of sodium concentration relative to calcium and magnesium. A SAR value below 13 is desirable. If the SAR is above 13, sodium can cause soil structure deterioration and water infiltration problems (Warnemuende et al, 1999).

Soils that have a high SAR should not have swine manure with a high sodium content applied, as the additional sodium can aggravate the problem. High SAR will have a detrimental effect on soil properties including soil permeability and structure (NRCS, 1996). Soils with low SAR should be monitored through soil testing to ensure that the SAR does not reach levels high enough to affect soil properties and crop production. If the SAR approaches a critical level, the field(s) should be removed from manure application. A build up of soil sodium can be recognized by spotty growth of crops, occurrence of salt-tolerant weeds such as kochia, and by white crusts of salt that accumulate on the drying soil surface.

Soils with a high salt content (saline) are also poor candidates for manure application. Salt affected soils have very low permeability to water, air, and plant roots, the soil is extremely sticky when wet, and tends to crust and become very hard and cloddy when dry. Salt affected soils may cause crops to suffer from a lack of water even when the soil is not dry. Salts will also limit crop growth and utilization of manure nutrients. High soil salt content indicates poor drainage and further additions of manure salts may increase salinity.

Swine manure may compact the soil if the manure is spread or injected when the soil is at or near field capacity. Field capacity is defined as the percentage of water remaining in the soil two or three days after the soil has been saturated and free drainage has practically ceased. Manure application to wet soils should be avoided to prevent soil compaction (NRCS, 1996).

Soils without rocks are more compatible with manure injection equipment. However, proper equipment selection will allow application of swine manure. Soil landscapes with intense topography also require special attention. Manure should be injected or immediately incorporated to prevent manure runoff and retain crop nutrients in these areas.

Environmental Advantages

Application of swine manure to agricultural soils can improve soil quality. The improvements include increased soil organic matter, better soil structure, increased water infiltration, decreased bulk density, and improved soil tilth.

Environmental Disadvantages

Excessive application of swine manure to coarse textured soils with high water tables could result in movement of manure nutrients to the water table. Manure with high sodium content added to soils with high SAR could have negative effects on soil structure. In poorly drained soils, salts contained in manure may aggravate a salinity problem.

Costs

Analysis of land prior to siting a barn is important so that manure can be applied to the land in close proximity. Poor barn siting that results in greater manure transport distances can be very costly.

General Assessment

It is good practice to determine local soil characteristics when making a decision about the location of a barn site. In high rainfall areas and regions with high water tables, avoid coarse textured soils. Land that has received or will receive repeated application of manure should be soil tested periodically to ensure that SAR and soil salinity is maintained within acceptable levels.

Complementary Technologies

New feed manipulation strategies may reduce the sodium and salts in manure, allowing more flexibility regarding soil compatibility.

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6.4   Swine Manure Application Rates

Description

Manure is a valuable source of plant nutrients and organic matter. Used as a fertilizer, it will improve annual crop and forage production and soil quality. Animal manure contains most of the nutrients that crops require, including nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, copper, manganese, zinc, boron, and iron (Bolton, 1999).

However, using manure as a fertilizer for crop production has some challenges. First, nutrient content and form is quite variable. The actual nutrient content of manure will depend on factors such as the type of livestock operation, moisture content of the manure, whether or not bedding is used, the type of bedding, the age of the animals, and the feeds and feed supplements used. Secondly, manure is not an "off-the-shelf" fertilizer and may not match the crop's relative requirements. Examples of this would be manure that contains more phosphorus relative to nitrogen than what the crop can use, or an inadequate amount of sulphur relative to nitrogen. Thirdly, nutrient content per unit weight or volume is low, which limits the economic distance that manure can be transported.

Manure application rates calculated based on soil and nutrient sampling programs and crop requirements will maximize economic returns and environmental benefits.

Understanding the nature of the manure and the availability of nutrients will help producers to calculate application rates that achieve the desired agronomic response.

In general, livestock manure can be classified as solid (<80% moisture content), semi-solid (80 to 90% moisture content), and liquid (90% moisture content) (SAF, 1999). Solid and semi-solid manure has a higher organic content than liquid manure because of the added bedding.

While tables of typical manure nutrient contents can be useful in making general interpretations about nutrient form, content, and behaviour, a laboratory analysis of a representative sample of the manure will give the best indication of the nutrient value of the manure. This will be useful in determining the appropriate rate of application for the crop to be grown.

Because of the high variability in nutrient content (Table 6-4) even within a single storage unit, several sub-samples should be taken and combined for analysis. Manure stored under covers will normally have significantly more N than if stored without a cover. Producers should check with local laboratories for sampling instructions and prices.

The total N in manure is primarily made up of two forms, ammonium N, which is in a form readily available for plant growth, and organic N. Manure contains very little nitrate-N. Nitrates, associated with manured soils, are the result of nitrification, which is the conversion of ammonium to nitrate by microorganisms in the soil. Not all of the nitrogen in the manure is readily available. The total available N is the sum of the ammonium N and that portion of the organic N that is decomposed (mineralized) into a form that is plant available.

Liquid manures are low in solids and generally contain the majority of N in the form of ammonium, which is more immediately available. For example in swine manure, the total nitrogen (N) content from earthen manure storage units typically ranges from 15 to 50 lb of total N/1,000 gal (0.15 to 0.50 kg of N/

Table 6-4. Example Nutrient Content in Liquid Swine Effluent.

	Liquid Swine Manure (lb/1,000gal)
Nitrogen (N)	15 to 50
Phosphorus (P)	1 to 20
Potassium (K)	8 to 20
Sulphur (S)	0.1 to 3
Note: Multiply P by 2.3 to convert to P_2O_5; multiply K by 1.2 to convert to K_2O Source: Bolton, 1999.	

1,000 L) (PPC, 2002). Of this total nitrogen, there is generally about 65% available as ammonium, which is a form that plants can use directly. The rest of the N is organic, and it is estimated that an additional 20 to 30% of the organic N in liquid manure is mineralized into plant-available N in the year of application. This makes liquid swine manure a very readily available form of nitrogen.

Solid manure, on the other hand, has a much higher organic N content due to the large amounts of solid fecal matter and bedding, which raises the carbon to nitrogen (C:N) ratio. Soil organisms use the added C as a food source, and as they consume C, they also consume N, making it temporarily unavailable to plants. This process is called immobilization (the conversion of inorganic N to organic N). When the organisms die, nitrogen and other nutrients are released back into the soil. This is why cattle manure characteristically behaves as a slow release fertilizer that continues to supply nutrients for some years after application. Typically, only 10 to 20% of the N in solid manure is in the form of ammonium, making availability low in the year of application.

To calculate application rates, soil type, the nutrient demand of various crops, and the nutrient content of manure all need to be considered. To calculate the optimal manure application rate, producers need a laboratory nutrient analysis of the manure and a soil test recommendation. The importance of a lab analysis is best illustrated as follows. Two producers each require 115 lb N/ac (129 kg N/ha) for a forage crop. They each receive 4,000 gal/ac (45,000 L/ha) on their forage crop from two different hog production units. Based on the nutrient analysis, the application of hog manure from the one unit results in an application of 166 lb N/ac (186 kg N/ha), whereas the application of hog manure from the second hog barn results in an application of 95 lb N/ac (107 kg N/ha). One producer is receiving more than he needs; the other producer is not receiving as much as required.

Table 6-6 illustrates how to calculate an annual manure application rate based on nitrogen using injected liquid hog manure for an 80 bu/ac (4.3 t/ha) barley crop. For the calculation, it is assumed that 30% of the organic N will be available during the growing season.

Annual records should be kept on a field-by-field basis. Good records will facilitate decision making and will improve the agronomic response on crop and pasture land. Some jurisdictions require this information to be submitted, others require the keeping of on-farm records.

Table 6-5. Estimated Nitrogen Losses During Application.

Application Method	N Loss (%)
Injection	0
Broadcast (incorporation in 24 hrs)	15
Broadcast (no incorporation)	35
Source: Bolton, 1999.	

Table 6-6. Example of Calculating a Manure Application Rate.

A – Soil Test N Recommendation (for 80 bu/ac barley)	95 lb/ac
B – Total Manure Nitrogen	30 lb/1,000 gal
C – Ammonium (NH_4) in Manure	21 lb/1,000 gal
D – Estimated Loss Factor after Volatilization (Table 6-5)	1.0 for Injection
E –NH_4 Available in Growing Season: C x D	21 x 1.0 21 x 1.0 = 21 lb/1,000 gal
F - Organic Nitrogen: B – C	30 – 21 = 9 lb/1,000 gal
G – Organic Nitrogen Available in Growing Season: F x 0.30	9 x .30 = 2.7 lb/1,000 gal
H – Total Nitrogen Available in Growing Season: E + G	21 + 2.7 = 23.7 lb/1,000 gal
Z = (Calculated manure application rate (gal/ac)) = (A/H) x 1,000 gal Z = (95/23.7) x 1,000 gal = 4,008 gal/ac	
Source: Bolton, 1999.	

Environmental Advantages

Utilizing manure for crop and forage production allows the recycling of nutrients and can effectively replace or reduce the use of commercial fertilizers. Applying manure correctly increase microbial activity, protects water resources, and increases the water holding capacity of soils. Manure also increases organic matter content, which improves soil structure, increases soil cation exchange capacity (the ability to hold nutrients), increases water infiltration, and reduces wind and water erosion (Schoenau, 1997).

Environmental Disadvantages

Over-application of manures (e.g. repeated application at rates which greatly exceed the crop nutrient removal) and improper application (e.g. surface placement without incorporation) increases the risk of manure nutrient losses to the environment and deterioration of environmental quality. Concerns include transport of nutrients to groundwater and surface water bodies, escape into the atmosphere of gases such as ammonia and nitrous oxide, and accumulation of manure salts under conditions of poor drainage (PPC, 2002).

Cost

Manure is often promoted as a valuable source of nutrients and a soil conditioner with the ability to replace, in whole or in part, commercial fertilizers. The value of manure as a fertilizer can be assessed in different ways.

One method is to give the nutrient content in the manure a monetary value based on the commercial fertilizer nutrients. For example, if a commercial fertilizer such as 46-0-0 costs \$363/ton (\$400/t). The fertilizer contains 46% nitrogen (N). The cost of nitrogen is therefore \$363/920 lb (\$400/460 kg) or \$0.39/lb (\$0.87/kg) of N. Based on typical variability of N in manure, a 500 sow farrow-to-finish barn would annually produce manure containing N valued at between \$14,000 to \$47,000.

The value of other nutrients in manure can also be calculated this way provided that they are a required nutrient. Note that the economic value of potassium (K_2O) would be zero when soils do not need added potassium. In addition, many fields, particularly those that have a long history of manure application, may no longer require phosphorus. Manure also adds benefits to the soil quality such as improved soil structure, and it is difficult to determine an economic value for these benefits. It should be stressed that this approach to calculating an economic value for manure is not to be confused with market values. It is just a means of comparing manure to commercial fertilizer.

For farmers receiving manure from a livestock operation, manure can prove to be a very low cost input. Although manure is valued differently across the country, there are a number of places where manure is sold to surrounding farmers. In the prairies, the cost ranges from \$15 to \$25/ac (\$37 to \$63/ha) for approximately 100 to 150 lb/ac (114 to 171 kg/ha) of actual N applied (Bolton, 2004). Those farmers receiving manure can estimate their actual return by considering the value of the crop yield increase. The net yield increase minus the application costs is the actual return. For example, if you fertilize your land with \$15/ac (\$37/ha) of manure and get a yield increase of 20 bu/ac (1.4 t/ha), which is sold at \$4/bu (\$147/t), the net gain is \$65/ac (\$161/ha).

General Assessment

Manure is a valuable source of plant nutrients and organic matter and, when used as a fertilizer, will improve annual crop and forage production and soil quality. Application rates calculated based on soil and nutrient sampling programs and crop requirements will maximize economic returns and environmental benefits.

Complementary Technologies

Soil and manure sample analysis services are complementary technologies to help optimize economic and environmental benefits of swine manure application.

Manure storage covers are also a complementary technology as they have been shown to retain twice the nitrogen nutrients in the manure compared to stored manure without a cover.

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6.5 Manure Application to Cropland

Description

The application of swine manure has both a short term and long term benefit of providing nutrients to crops. Studies have shown positive responses in numerous crops including wheat, barley, and canola. Manure has been successfully applied to many other crops as well, including corn, sugar beets, and potatoes. Various methods of swine manure application can be used, resulting in various levels of nutrient use efficiency, including broadcast, broadcast plus incorporation, and low or high disturbance injection with shanks or coulter injectors.

Crop responses to swine manure nutrients can be favourable when compared to the response of commercial fertilizer and in some situations can completely replace commercial fertilizers when applied at appropriate rates (Bolton, 1999).

Application of swine manure to crops has both short term and long term nutrient benefits.
Photo Courtesy: PAMI

Environmental Advantages

Applying swine manure at appropriate rates to annual crops can sustainably produce excellent crops and replace commercial fertilizers that require a great deal of energy to manufacture. In addition, the manufacture of fertilizers, particularly N, results in the release of greenhouse gases. Replacement of commercial fertilizers with swine manure has the potential to reduce overall greenhouse gas emissions based on a full life-cycle analysis.

Environmental Disadvantages

Over application or misapplication of swine manure to crops can result in gaseous N emissions into the atmosphere and nutrients leaching below the root zone and moving into the water table or drain tiles (Hilborn, 2001). The open manure storage systems used in Canada allow significant rainfall to dilute manure, increasing required application costs. These systems also allow significant release of manure nitrogen as ammonia gas, resulting in a manure phosphorus ratio of nearly 1:1 in many cases. Without proper consideration, manure phosphorus can be routinely over applied relative to crop requirements, when application rates are based solely on the manure nitrogen content.

Costs

Application costs for different manure application methods can be found in Section 6.1 Swine Manure Application Method.

The cost of applying manure to cropland includes the cost of agitating manure in storage, hauling the manure to its destination, and applying the manure to the soil, regardless of the application method used. The costs of applying manure should be compared to the costs of purchasing and applying comparable rates of commercial fertilizer.

As the cost of commercial fertilizers varies by region across Canada as well as the quantity of nutrient contained within the fertilizer product, a number of assumptions must be made. Based on April 2005 prices for commercial fertilizer, Table 6-7 outlines the value of liquid swine manure.

After establishing the unit value of your manure resource, multiply the value by the application rate required. In this case, a producer wishes to apply 75 lb/ac (84 kg/ha) of manure nitrogen. Therefore, 5,000 gal/ac (56,000 L/ha) of liquid manure must be applied to achieve the desired amount of N. Therefore, the total value of the manure nutrients applied is $121.25.

The cost of hauling manure within a 2 mile radius of the storage site can be estimated to be approximately $0.0097/gal ($0.0021/L). Therefore, to haul 5,000 gal/ac (56,000 L/ha) will cost $48.50. The total value of applying hog manure to cropland is equal to the value of the nutrients applied minus the total cost of applying the nutrients. The value of the nutrients in this example is $121.25 - $48.50 = $72.75. The value of applying liquid hog manure nutrients for annual crop production is $72.75 over the cost of application when manure nutrients are assigned an equal value to commercial fertilizers.

Table 6-7. Typical Swine Manure Nutrient Profile and Fertilizer Value.

Nutrient	Nutrient Content (lb/1,000 gal)	Fertilizer Price* ($/lb)	Value ($/1,000 gal)
Nitrogen	15	$0.52	$7.80
Phosphorus	12	$0.70	$8.40
Potassium	23	$0.35	$8.05
Total			**$24.25**

Commercial fertilizer nutrient costs, April 2005

Another important consideration when applying swine manure nutrients with an annual cropping system is that manure nutrients are generally not as readily plant available as commercial fertilizers. Therefore, assuming manure nutrients are 75% available in the year of application, applying 5,000 gal (56,000 L) of the example manure would provide 10.5, 8.4, and 16.1 lb (4.8, 3.8, and 7.3 kg) of nitrogen, phosphorus, and potassium, respectively. The manure nutrients applied would therefore be worth $90.94/5,000 gal (56,000L). The application cost does not change, so the available manure nutrient value is $90.94 - $48.50 = $42.44.

In addition to the costs of manure application, the rate of manure nutrient application is an equally important consideration. For the example presented here, Table 6-8 outlines the nutrients applied in 5,000 gal/ac (56,0000 L/ha) of swine manure and the nutrient requirements for spring wheat and grain corn. Nitrogen, phosphorus, and potassium in Table 6-8 are presented in the same format as commercial fertilizers as $N-P_2O_5-K_2O$, whereas the nutrients in Table 6-7 are presented as the value of elemental nitrogen (N), phosphorus (P), and potassium (K).

Table 6-8. Manure Nutrient Application Rates and Requirements of Spring Wheat and Grain Corn.

	Nutrient Applied in 5000 gallons manure (lb)	Spring Wheat Nutrient Requirement* (lb)	Nutrient Excess (lb)	Grain Corn Nutrient Requirement** (lb)	Nutrient Excess (lb/ac)
Nitrogen	75	85	-10	153	-78
Phosphorus (P_2O_5)	26.4	32	-5.6	63	-36.6
Potassium (K_2O)	95.45	72	23.45	202	-106.55
	40 bu/ac		**100 bu/ac*		

In this example, most commonly there is an under application of nutrients. Only the potassium in the spring wheat was over applied. However, this assumes that no soil nutrients are present as carryover from the previous crop or the potential nutrient supply from soil organic matter decomposition. A full nutrient inventory, including soil reserves and fertilizer, and manure applications will help to avoid environmentally, agronomically, and economically expensive nutrient over application.

In order to reduce the cost of manure application and maximize the efficient and cost-effective use of manure nutrients, manure should be injected or immediately incorporated after broadcast application to avoid excessive losses of manure nitrogen as ammonia. Numerous injection systems have been developed for use in no-till cropping systems that allow manure to be injected with minimal surface residue disturbance.

Effective use of barn wash water and regular management and maintenance of barn watering systems will avoid excessive quantities of manure being produced in the barn and result in reduced manure hauling and application costs.

General Assessment

At one time, liquid swine manure was considered a waste product to be disposed. With increasing fertilizer prices, environmental regulations, new research, and improved application equipment, producers are realizing that liquid swine manure is an excellent source of annual crop nutrients.

The numbers presented here represent one example of potential manure nutrient value and hauling costs, which are subject to change from year to year and throughout different regions of Canada. Each manure producer is encouraged to establish and maintain a routine manure and soil sampling protocol. This will allow a producer to make efficient use of manure nutrients, calculate the value and costs of applying manure nutrients on an annual basis, and avoid potential soil and water degradation due to the over application of manure nutrients.

Complimentary Technologies

Soil and nutrient sampling programs along with database record keeping are complementary technologies. Application rates can then be calculated based on crop requirements. Annual records should be kept on a field-by-field basis. Good records will facilitate decision making and will improve the agronomic response on crop and pasture land.

Manure injection equipment that places manure in the soil instead of broadcasting on the surface will significantly reduce the amount of ammonia lost to volatilization as well as odour production during manure application. Manure tankers equipped with narrow profile tires and narrow row-crop injection units are capable of applying liquid manure to row crops during the growing season. Applying manure during crop development provides nutrients to growing crops precisely when they are needed, maximizing the efficient use of the applied nutrients.

Manure storage cover systems will help to conserve manure nitrogen from being lost as ammonia throughout the storage period. An increase in manure nitrogen content will add significant value to a farm's manure resources. Conserving nitrogen will also help to balance the manure nitrogen to phosphorus ratio to more closely resemble crop nutrient requirements. Therefore, cover systems can help reduce the potential for over application of manure phosphorus to cropland when manure application rates are based on manure nitrogen content.

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6.6   Manure Application to Forages and Pastures

Description

Broadcasting swine manure has not typically been a viable option for forage production due to the high losses of ammonia-N from surface application (Schoenau, 1997). However, recent developments in commercial scale coulter type liquid manure injection equipment from a number of manufacturers has improved the capability of low disturbance manure injection into forages (SAF, 1999). Heavy duty coulters equipped with high trip force springs penetrate hard soil and place the manure in the root zone with minimal manure pooling on the surface. As the manure is contained within the furrow, odour and ammonia-N volatilization are minimized compared to surface application.

Coulter-type injection equipment allows low disturbance liquid manure injection into forages.
Photo Courtesy: PAMI

A disc-type injector may provide opportunity to apply liquid swine manure more efficiently to forage crops. Non-legume forage crops and grass/legume mixtures are often nutrient deficient and many types of forage have the ability to utilize large quantities of nutrients. Forages such as alfalfa, clover, and grass are high yielding and will remove in the range of 100 to 320 lb of N/ac (110 to 360 kg N/ha). Application of liquid swine effluent into forage crops will produce two types of benefits: increased forage crop production and increased soil carbon (King, 2002).

Environmental Advantages

Grass forages are typically very low in N and P and have the capacity to absorb and use large quantities of these nutrients in liquid manure. Addition of these nutrients also results in large increases in grass forage production (Hoff et al, 1981).

Environmental Disadvantages

Nitrate levels in forages are a concern when livestock graze pastures that have received a swine manure application. Under certain conditions, possibly related to grass variety, drought, or cold growing conditions, nitrates may accumulate to levels that are toxic to livestock (PAMI, 2001). To prevent problems, forages should be tested for nitrate levels following manure application.

Costs

The effects of low disturbance injection of swine manure on crested wheatgrass, alfalfa, smooth brome/alfalfa, and Russian wild rye has been studied and compared economically (PAMI, 2001).

Forage yield doubled compared to the check from a single large application of swine manure. Annual manure applications resulted in average yield increases above the check of 158 and 241%, respectively. Russian wild rye did not respond as much as the crested wheatgrass and smooth brome and produced lower forage yields than the other two. In addition, nitrate levels in the Russian wild rye at the 100 and 200 lb/ac (110 and 220 kg/ha) nitrogen application rates were above safe feeding levels.

Application costs for the injection of liquid swine manure (based on the equipment used) was valued at \$1.00/100 gal (\$2.10/1,000 L). The price for brome/alfalfa and alfalfa was calculated to be \$111 and \$105/ton (\$122 and \$116/t), respectively (SAF, 2002). The net revenue for brome/alfalfa is shown in Table 6-9. Results indicated that the yearly application of the low rate of liquid hog manure into the brome/alfalfa forage crop produced the greatest net return to the forage grower and also produced the greatest increase in soil organic carbon, a result of the large yield response to the added nutrients in this forage stand.

Table 6-9. Brome/Alfalfa Net Returns Over Three Years ($/ac).

Treatment (gal/ac)	1998 Revenue	1998 Injector Expense	1998 Net Revenue	1999 Revenue	1999 Injector Expense	1999 Net Revenue
Check	77.39	0.00	77.39	234.99	0.00	234.99
3,300	106.94	31.46	75.48	497.18	3.00	465.72
6,600	129.45	62.91	66.54	413.69	0.00	413.69
13,200	115.38	125.83	-10.32	469.04	0.00	469.04
Treatment (gal/ac)	**2000 Revenue**	**2000 Injector Expense**	**2000 Net Revenue**	**3 Yr Total Revenue**	**3 Yr Total Injector Expense**	**3 Yr Total Net Revenue**
Check	85.83	0.00	85.83	398.21	0.00	398.21
3,300	183.62	31.46	152.17	787.74	94.37	693.33
6,600	210.13	62.91	147.21	753.27	125.83	627.44
13,200	100.42	0.00	112.57	696.99	125.83	571.16

Source: King, 2002.

General Assessment

Results show that application of manure to alfalfa can be beneficial. Results also show that injection of liquid manure into brome/alfalfa was economically beneficial. Yearly effects were different mainly due to weather and amount of rainfall.

Low disturbance injection of swine manure into grass forages has the potential to sustainably expand the land base for manure application while substantially increasing forage yields.

Complementary Technologies

Nitrate testing is a complementary technology to ensure the forages are safe for livestock consumption.

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Chapter 7   Managing Mortalities

7.1   Burial

Description

Burial is the disposal of livestock carcasses into a hole or trench in the soil. On-farm burial is appropriate where soil and groundwater conditions are environmentally suitable. The regulatory authorities need to be consulted to determine if burial is a suitable option.

Burial sites should be located where low permeability soils such as clay, silt, and till exist beneath the surface. Sand and gravel locations should be avoided. The bottom of the burial pit should be separated from any present aquifer by a sufficient depth of low permeability soil to prevent contamination. Dig or drill test holes to determine if the proposed location is suitable. A consultant would assist with the soil investigation.

Partially decayed mortalities can be unsightly, attract rodents, flies and scavengers, and create odour.
Photo Courtesy: Puratone

Burial requires that earth-moving equipment be readily available for excavating the trench and covering the carcasses. The burial pit should be 6 to 10 ft (2 to 3 m) deep with straight walls to prevent access by scavengers. Carcasses should be covered immediately with at least 1 ft (0.3 m) of soil. The top surface of the carcasses should be at least 3 ft (1 m) below the natural ground surface. The final soil cover should be mounded 3 ft (1 m) above the natural ground surface to prevent water from ponding and to allow for settling. The annual land requirement for dead stock burial will depend upon the size of the operation. The average land requirement, on a per marketed hog basis, is 0.9 ft² (0.08 m²) per year (Schwager et al, 2001).

Winter makes burial difficult. However, burial pits could be prepared in the fall if the death loss is predictable. Allow 53 ft³ (1.5 m³) of burial pit per 992 lb (450 kg) of carcass. Cover the carcasses with at least 2 ft (0.6 m) of straw until a proper soil cover can be placed. A portable burial pit cover can be constructed that will keep snow from filling the pit and will keep scavengers away from the mortalities.

There may be a limit to the weight of dead stock that can be buried. This limit may vary from region to region. In Alberta, for example, the burial of dead stock is not to exceed 5,500 lb (2,500 kg) per hole (AAFRD, 2002). An alternative disposal method would be needed for larger farms.

Pests and rodent control can be accomplished by building a fence around the pit/trench. The fence would also have the added benefit of adding human safety by limiting access to the burial area.

Environmental Advantages

Burial is an appropriate method of disposal if managed properly. On-farm burial can be relatively inexpensive if existing equipment can be used. Burial is environmentally safe if subsurface soil and water conditions are suitable.

Environmental Disadvantages

Burial requires proper management to prevent nuisance and environmental issues. If burial pits are not managed properly, they can be unsightly, odorous, and an attraction to scavengers, rodents, and flies. Earth-moving equipment must be readily available to cover the carcasses with soil. A consultant may be necessary to determine if the location is environmentally suitable for burial.

Costs

Certain equipment for digging a pit/trench and loading it with dead stock is likely already available on the farm. This equipment could be a front-end loader or skid loader and a backhoe. An 80 hp (60 kW) tractor would cost about $43,000 (AAFRD, 2002), while a skid loader capable of moving 1,500 lb (680 kg) would cost $28,000. A backhoe attachment for an 80 hp (60 kW) tractor required for digging the burial trench/pit costs about $10,000, depending upon the size.

Assuming annual use of the tractor and front-end loader attachment of 600 hours, a tractor life of 13 years, and a loader life of 5 years, the annual costs associated with the equipment used to move mortalities to the pit/trench and to cover the dead stock are $11,830/year for a front-end loader attachment and an 80 hp (60 kW) tractor. For the backhoe attachment, the annual costs are about $1,400. The costs reflect the total use of the tractor for mortality management and burial, so they will be less if the equipment is used for other tasks.

The labour associated with burial of mortalities can range from 0.001 to 0.53 hours/marketed hog (Schwager et al, 2001) and will depend on the size of the operation. For example, in a 300 sow farrow to finish system, if 70 minutes/day are required for loading dead stock plus 85 minutes/day for covering mortalities, then the labour works out to 0.180 hours/marketed hog in a 2.26 turn operation (Henry et al, 2001). At a labour rate of $12, the annual labour cost is $0.01 to $6.36/marketed hog.

Depending upon the size of the operation, annual savings may occur by contracting a backhoe to dig the pit/trench, thus eliminating the costs associated with owning and operating the backhoe attachment for the tractor.

The cost of fencing to enclose the pit/trench can range from $9 to 15/ft ($30 to $50/m) plus labour for installation.

General Assessment

On-farm burial is appropriate where soil and groundwater conditions provide environmental protection. Burial requires proper management to prevent nuisance issues. Check with local authorities for any applicable bylaws associated with dead stock disposal methods.

Complementary Technologies

Rendering, composting, and incineration are complementary technologies. In addition, aquifer mapping would be helpful to determine the suitability and location for burial.

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7.2   Composting

Description

Composting is a naturally occurring process in which bacteria, fungi, and other microorganisms convert organic material in a predominately aerobic environment into a stabilized product. Composting has been widely used for the disposal of swine carcasses. The producer's role in managing the compost process is to make sure that the microorganisms have the environment they need in order to work quickly and effectively.

Two common on-farm composting systems are bins and windrows. "In-vessel" composters are also available. In-vessel systems are usually produced commercially and reduce the composting time with active aeration and heat.

Bins may be wooden, concrete, hoop structures, or bales. Alternatively, existing facilities like machine

Compost turners lift and mix the material and move the composting material along the channel.
Photo Courtesy: Transform Compost Systems Ltd.

sheds can be adapted, as long as the roof is high enough to allow the loader to lift and turn the compost. The number and size of bins required will vary depending on the type and size of operation.

Windrow composting is an outdoor system often used to compost manure. The carcasses are layered and covered with a bulking agent to form a pile roughly triangular in cross section. The windrow grows longer as more carcasses are added, and eventually the windrow will be turned to encourage further decomposition.

There are also manufactured composters available in a wide range of sizes for composting dead stock. For example, one unit can handle about 300 lb (136 kg) of mortalities per day, which is large enough for a 750 sow farrow to finish operation. Conversely, another unit can handle 30,000 lb (13,600 kg) of mortalities per day, which is suitable for several operations.

Compost production requires careful management. Moisture content, temperature, and carbon-to-nitrogen ratios are important variables that must be maintained within an acceptable range. Co-composting material (sawdust, straw, shredded paper, chives) should be used to line the bin and to cover the dead stock. Composting time varies from 6 to 18 months, depending on a number of variables including management, size of carcasses, climate, and compost pile design. The highest rates of decomposition occur at temperatures in the range of 109 to 150ºF (43 to 66ºC). Composting can take place in all weather conditions, but it is best not to start new piles during the winter. The finished compost is a stable source of nutrients and is generally weed and pathogen free.

Environmental Advantages

Properly managed composting can be a very cost-effective method of dealing with mortalities. Carcass composting is generally considered an environmentally safe, inexpensive, year-round method of disposing of livestock mortalities.

A properly managed compost pile with enough bulking agent will not produce offensive odours, promote fly problems, or be attractive to scavengers.

Compared to other disposal methods of dead stock, only composting returns valuable nutrients and organic matter to the land.

Environmental Disadvantages

Composting requires considerable management effort to ensure that the materials are properly proportioned and that the composting does not cause problems with odour, flies, pathogens, or

scavengers. Some effort may have to be made to ensure that larger bones are adequately composted prior to spreading.

Costs

Composting bins can be permanent structures of wood and concrete or be constructed by building a perimeter of round bales. Sizing of the composting facility will depend on the type and size of the operation and the mortality rate of the livestock. The volume required for composting is about 40 ft^3/lb (2.5 m^3/kg) of daily loss (AAFRD, 2002). A minimum of three bins, two for primary composting and one for secondary composting, is recommended. Table 7-1 shows suggestions of bin sizes for different operations.

There are manufactured composters available with capital costs varying largely from $20,000 that will handle 300 lb/day (136 kg/day) to $450,000 that will handle 30,000 lb/day (13,600 kg/day).

Table 7-1. Composter Sizing and Capital Costs for Different Sizes and Types of Operations.

Operation	Operation Size	Mortalities (lb/day)	Total Bins				Capital Cost	
			Primary		Secondary		With Roof*	Without Roof**
			Number	Size (ft)	Number	Size (ft)		
Farrow to Finish	100 sows	35	3	4 x 8	1	10 x 24	$4,368	$6,720
	200 sows	100	3	8 x 10	1	18 40	$12,480	$19,200
	600 sows	200	3	10 x 16	1	24 x 60	$24,960	$38,400
Farrow to Wean	100 sows	12	3	4 x 8	1	8 x 12	$2,496	$3,840
	200 sows	38	3	4 x 8	1	12 x 22	$4,680	$7,200
	600 sows	75	3	10 x 18	1	16 x 32	$13,676	$21,040
Feeder	500 head	10	2	4 x 8	1	8 x 10	$1,872	$2,880
	1,000 head	20	3	4 x 8	1	12 x 22	$4,680	$7,200
	6,000 head	117	3	8 x 12	1	20 x 40	$14,144	$21,760

* Cost at $13/sq ft
** Cost at $20/sq ft
Adapted from: Manitoba Pork Council, 2002.

Annual labour associated with the equipment used to move mortalities to the composting bins and to turn the compost are as low as only 0.0012 to 0.08 hours/marketed hog (Schwager et al, 2001; Baas et al, 2001) when dealing with livestock mortalities annually (depending upon the size and type of operation and the distance between the barn and the composting bins). For example, a 300 sow farrow to finish operation requires only 0.009 hours/marketed hog (Henry et al, 2001) or 48 hours/year of tractor operation for composting.

Labour requirements for composting mortalities range from 0.0012 to 0.08 hours/marketed hog (Schwager et al, 2001; Baas et al, 2001) and will depend upon the type of composting system used and the size of the operation. At a rate of $12/hour, the cost is $0.014 to $0.96/marketed pig. For example, in a 300 sow farrow to finish operation, the annual cost for labour is $1,300. Tasks included in labour consist of loading and unloading the system with mortalities and carbon source, daily monitoring of the compost to ensure the dead stock is covered, and turning the compost.

Carbon sources for swine mortality composting can include sawdust, straw, corn stalks, corn silage, corn cobs, grass clippings, manure, and newspaper. Sawdust has been proven to be the best choice for mortality composting due to its high C:N ratio, ability to promote high compost temperatures and bone decomposition (AAFRD, 2002), and its characteristics with respect to moisture. Table 7-2 shows the C:N ratios of materials used in carcass composting.

The amount of sawdust required for composting ranges from 0.06 to 0.10 ft^3/lb (0.0037 to 0.0062 m^3/kg) of carcass (Manitoba Pork Council, 2002; AAFRD, 2002). For a 200 sow farrow to finish operation

producing 39,000 lb (17,695 kg) of dead stock annually, the annual cost for sawdust would be $215 to $760, assuming a sawdust cost of $0.09 to $0.20/ft³ ($1.00 to $2.10/m³) (Henry et al, 2001; BCMAFF, 1996). The addition of ammonium nitrate at a rate of 3 lb/100 lb (3 kg/100 kg) of carcass can help in maintaining the C:N ratio. In most composting systems, the addition of ammonium nitrate only takes place when starting a new compost pile.

Cutting and/or grinding the carcass can reduce the processing time but at an increase in capital cost, labour, maintenance, and energy requirements for the system. A hydraulic carcass cutter costs about $2,600 and a carcass grinder costs about $7,900, each with a 10 year operating life (Foster, 1997). A benefit of reducing the processing time is that bins can be sized smaller, reducing both the capital associated with the building and the footprint of the facility.

Mortality compost is worth about $8.90/ton ($9.79/t) for its fertilizer composition (Foster, 1997).

Table 7-2. Carbon Source Materials for Swine Mortality Composting.

Material	C:N Ratio
Sawdust/Shavings	200:1 to 750:1
Straw	48:1 to 150:1
Corn Cobs	60:1 to 120:1
Cobs Stalks	70:1
Corn Silage	38:1 to 43:1
Sheep, Cattle, Swine Manure	15:1 to 20:1
Grass Clippings	15:1
Sources: Jorgensen and Pescinski, 2003; Koebel et al, 2003.	

General Assessment

Composting is biosecure, environmentally sustainable, cost-effective, and has been widely accepted as a method of disposing of swine carcasses. However, composting requires considerable management efforts to ensure that the materials are properly proportioned and that the composting does not cause problems with odour, flies, pathogens, or scavengers.

Complementary Technologies

Rendering, burial, and incineration are complementary technologies. The treatment of animal waste by means of high temperature (302⁰F (150⁰C)) and corresponding high pressure alkaline hydrolysis is an emerging technology that may also have promise for mortality disposal (EC, 2002).

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7.3   Incineration

Description

Incineration of livestock mortalities involves burning carcasses in a controlled manner at very high temperatures, which reduces the carcass to ash. Incinerators may operate on diesel, propane, natural gas, or wood, and some incinerators require a source of electrical power.

Smokeless incinerators must be properly operated and maintained to prevent smoke and odour complaints. Incineration systems may be mobile and therefore may be cost-shared with other producers.

Since there is a reduced concern regarding biosecurity as dead stock can be destroyed immediately and not stored, the incinerator can be located near the hog production facility.

A livestock mortalities incinerator.
Photo Courtesy: Dellwood Park

Size the incinerator to handle the largest expected carcass. The incinerator will not operate properly if the incinerator is overfilled because airspace is required around the carcass to achieve a proper burn. If the incinerator is too small, the carcass must be reduced to an appropriate size. Consult with regulatory authorities to determine permit requirements for incinerator use and operation.

Environmental Advantages

Proper incineration results in complete reduction of the carcass volume and the rapid oxidation of animal tissues to carbon and water. It requires no temporary storage, as carcasses can be incinerated as they are generated. Incineration can be considered environmentally safe if loaded and operated according to the manufacturer's recommendations to maximize equipment life and minimize emissions. There are biosecurity advantages to burning dead-animal carcasses thoroughly on the farm, including a reduction in the prospect of spreading disease organisms. Quick incineration also reduces odours of stored carcasses, flies, and attracting scavengers to carcass storage areas.

Environmental Disadvantages

Environmentally safe incinerators require major capital investment and must be operated and maintained properly to maintain operational efficiency. They require considerable energy, and the ash from the incineration process has no fertilizer potential and may contain trace heavy metals. Although the ash is relatively inert, disposal is required. There are fire safety hazards associated with the operation of high temperature incinerators.

Costs

Incinerators can be homemade or purchased from a manufacturer. The cost of an incinerator is between $660 to $13,250 (Schwager, 2001; Morgan et al, 2001). Incinerators will last for 5,000 hours, which results in a lifespan of 5 to 10 years.

To reduce the odour linked to incineration, an afterburner can be attached to the output of the incinerator at an additional cost of $1,320 (Henry et al, 2001), but this will also increase the fuel required in the process.

If the incinerator is established near the hog housing, labour is limited to loading and operating the incinerator. For a 600 sow farrow to finish operation, 14 min/day is required to perform these duties (Schwager et al, 2001; Henry et al, 2001), which is equivalent to $1,020/year at a rate of $12/hour.

A significant amount of energy is needed for this process. The amount of fuel required is from 1 to 4 gal/100 lb (10 to 40 L/100 kg) of dead stock (Morgan et al, 2001; Henry et al, 2001). These consumption rates will increase by 1.35 gal (5 L) per hour of operation if an afterburner is connected to the incinerator (Henry et al, 2001). An economic example of an incinerator system with and without an afterburner is shown in Table 7-3.

There will be additional costs if the incinerator is not sufficiently large enough to house a complete carcass, requiring that the carcass be either sectioned or ground.

Table 7-3. Costs Associated with Incineration of Hog Mortalities; 600 Sow, Farrow to Finish Operation.

	Incinerator without Afterburner	Incinerator with Afterburner
Capital Cost	$4,000	$5,320
Annual Cost		
Hours of Operation	1,059	1,059
Fixed Cost	$947	$1,260
Repair and Maintenance Costs	$120	$160
Fuel Costs	$2,686	$6,311
Labour Required	85 hr	85 hr
Labour Cost	$1,021	$1,021
Total Annual Cost	$4,774	$8,752
Cost/Pig Marketed	$0.48	$0.88
Fuel Cost/Pig Marketed	$0.27	$0.63
Source: Henry et al, 2001.		

General Assessment

Incineration can be a convenient and environmentally safe method for disposing of dead animals. However, expensive, smokeless incinerators must be used and properly operated and maintained. Safety and efficiency are priorities in the incineration process.

Complementary Technologies

Rendering, burial, and composting are complementary technologies. Anaerobic digestion of pre-processed mortalities is also a new technology under development.

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7.4   Rendering

Description

Rendering is the processing of carcass material into three end products: carcass meal, tallow, and water. Rendering is a convenient, clean, and waste-free solution that ultimately recycles the animal remains into usable products. Rendering companies generally offer a pick-up service but producers may have to pay for disposal. Where rendering services are available, rendering is generally considered the method of choice for disposing of mortality losses.

Nuisance issues may be eliminated if placement and pick-up of livestock mortalities are well coordinated. Carcasses should be stored securely to prevent access by scavengers prior to pick-up.

In regions where service by rendering plants is infrequent, carcasses have additional requirements

Pickup of mortalities for rendering.
Photo Courtesy: West Coast Reduction Ltd.

during the warmer months of the year. This could require refrigeration units, fermentation, or acid preservation processes. The process of fermentation controls the levels of microbial activity in the decomposition of the carcass. Acid preservation also halts the actions of microorganisms and preserves the nutrient content of the dead stock. During winter months, the lower temperatures can allow for greater times between pick ups; however, a suitable storage system must be in place to reduce the likelihood that scavengers will get at the carcass.

Peak pickup would be associated with farrowing. As dead stock is to be disposed of or refrigerated within 48 hours after death (Hannesson, 2003), the frequency of pick up could be as much as four times per week.

Environmental Advantages

Rendering requires minimal capital investment for the producer, and the rendering process results in the recovery and recycling of nutrients. On-farm environmental impact is eliminated if carcass storage is secure.

Environmental Disadvantages

Biosecurity is an important consideration, as the rendering vehicle usually stops at several farms on its route. A pickup location separate from healthy livestock is important.

The storage of the dead animals prior to pick-up may present some logistical problems for some producers. Temperature extremes may make the carcass difficult to store or handle. Heat may degrade the carcass beyond economic thresholds for the rendering facility and frozen carcasses can be difficult to handle. Carcasses must be protected from scavengers, and it is important to avoid offensive odours and unsightly carcasses visible to others who pass by the storage site. Sulfa drugs can survive the rendering process, contaminating meat meals processed for feed (AAFRD, 2002).

Costs

Capital costs associated with this technology depend greatly upon the serviceability of the farm by the rendering plant. For locations that receive frequent service, a holding pen for carcasses is all that is required. These pens are needed to keep scavengers away from the carcasses and should be located away from livestock buildings for biosecurity reasons. The cost of fencing to enclose dead stock can range from $9 to $15/ft ($29 to $49/m) plus labour for installation.

The on-site carcass preservation processes can greatly increase the capital and annual costs of using rendering to dispose of dead stock. A refrigeration unit with about 500 ft³ (14 m³) of storage space would represent a start up cost of $8,815 with annual costs of $1,275 (Foster et al, 1993). Acids and the associated equipment can be expensive and require safety procedures on the farm (AAFRD, 2002).

Mortality storage bins specifically designed for pick up, capable of holding 1,984 lb (900 kg) of dead stock, and rated for the colder climate of Canada cost about $1,000 each (Salomons, 1999). Another option would be to store the dead stock in barrels ($27 each) (Schwager et al, 2001), but this would also require an insulated storage shed if the time to pickup was going to be greater than 48 hours.

Dead animal pickup costs run at about $0.05/lb ($0.11/kg) dead weight with a minimum charge of $25 (Hannesson, 2003; Farmscape, 2003). For a 600 sow farrow to finish system, the annual cost of pickup for rendering is about $4,121 or $0.42/pig sold (Hannesson, 2003). The break down of these costs can be seen in Table 7-4.

Table 7-4. Cost of Dead Stock Pickup on a 600 Sow Farrow to Finish Operation.

	Mortality (%)	Cycle Length (days)	Calculated Dead Weight (lb)	Cost (based on $0.05/lb)
Mummies	2%	0		
Still born	7%	0	10,322	$516
Placenta	-	0		
Pre-wean	10%	21	5,106	$255
Weaner	3%	42	8,274	$414
Grower	2%	56	20,064	$1,003
Finisher	1%	56	18,570	$928
Sow	6.5%	365		
Boar	8%	365	20,099	$1,005
Gilt	1%	365		
Total			82,435	$4,121
Modified from: AAFRD, 2002; Hannesson, 2003.				

Annual costs associated with the equipment used to move mortalities to the storage area are $2,150/year for a front-end loader attachment on an 80 hp (60 kW) tractor. (Assume that the tractor is only used 20% of its annual operation dealing with livestock mortalities.)

Labour associated with transporting dead stock to the holding area for a 600 sow farrow to finish operation is about 121 hours/year. At a rate of $12/hour, the annual labour costs are $1,452.

Some facility savings may occur if several barns have a common storage area, but biosecurity procedures would be required. Transporting dead stock off the farm poses a biosecurity risks and may require special permits and licenses, so it would be more practical to have a single vehicle and operator servicing all farms in an area as opposed to a vehicle and operator for each site. The cost of such an operation shared between several farms may be less than the costs associated with refrigeration, fermentation, or acid preservation.

General Assessment

Rendering is considered an environmentally friendly method of handling livestock mortalities. Producers may want to have a storage area set aside so that the rendering pick-up vehicle is segregated from the livestock to protect the biosecurity of the farmyard.

Complementary Technologies

Composting, burial, and incineration are complementary technologies.

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Notes