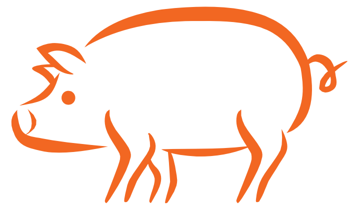
Exploring Interactions

Between Agricultural Decisions & Greenhouse Gas Emissions Using Swine Production

Part 2



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Acknowledgment

Special thanks to **Donna VanDevender**, high school teacher for Arkansas School for the Deaf and Blind, for her substantial contributions toward the development of this project.

Disclaimer

The content within this activity is for educational purposes only. Every effort has been made to ensure the accuracy of the presented information, but due to the technical nature of the subject matter, some generalizations have been made.

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Overview

The primary goal of this activity is to educate (high school) students within the state of Arkansas about the various management systems intrinsic to swine production operations. The secondary objective of this activity is to provide students with insight into the management obstacles that swine producers are challenged with through balancing carbon footprints, available resources and legal compliance with producer goals. It is **NOT** within the domain of this effort to provide an all-encompassing view of swine production, but simply to introduce the targeted audience to the general information, basic ideas and common practices associated with swine production within the United States. These goals are to be accomplished through employment of a swine production-greenhouse gas (GHG) interactive lab activity. This critical-thinking activity is intended for implementation within high school classrooms via the Farm Bureau-supported Ag in the Classroom program and others similar. This lab activity consists of introductory-level subject matter focused on swine production systems and the related scientific and regulatory issues. The content within this exercise was derived from a combination of original material and existing publications released by various agencies including the United States Department of Agriculture, National Aeronautics and Space Administration, Natural Resources Conservation Service, University of Arkansas Division of Agriculture – Cooperative Extension Service and private sources, in conjunction with the National Pork Board-sponsored Live Swine: Carbon Footprint Calculator v.1.0. The resulting information was aggregated and crafted into two complementary products.

The first product is a compilation of swine production reference materials including terminology and definitions which highlight (in layman terms) the basic dynamics of greenhouse gases (CO_2, N_2O, CH_4) and swine management (system components/functions, manure-handling options, facility options, feeding stocks/phases and types of swine operations – farrow to finish vs. feeder to finish, etc.). The included reference material also highlights some applicable regulations (summaries and key points) as they pertain to the scope of the lab activity. The reference material serves as both an introduction to basic ideas and practices native to swine production and GHGs and as a guide which aids the students in completion of the second product (lab activity).

The second product of this activity is a decision tree-building exercise which is implemented through a printable flashcard platform. The flashcards are used to represent three specific swine management systems using a three-tier hierarchy. This hierarchy is distinguished by the allocation of **Categories**, **Components** and **Options**. The **Categories** are the designated ranking class and will represent three major swine production management systems: **Feed Management**, **Housing Management** and **Manure Management**. The **Components** are the first sub-order class and are used to represent various functions/considerations that comprise each **Category** of production system. The **Options** class holds the lowest position within the hierarchy and represents the different configurations/settings for the individual **Components**. Each of the three **Categories** has its own decision tree which consists of an assemblage of both permanent and exchangeable **Components** and their accompanying **Options**, allowing the user to custom design a swine management system to the desired specifications. *(See a sample of the flashcard hierarchy in Figure 1.)* The **Options** within a management system inherently have a pre-defined carbon footprint and monetary value associated with them; i.e., **Option 2** – Insulation Material (R-value = 25, = (-) 6 GHG points and a $15 point value).

For the context of this exercise the students will act in the role of consultants hired by a producer to design the three management systems (**Categories**) to the producer's desired specifications, as defined within a pre-written scenario. Students should be separated into groups and tasked with designing a management system to the producer's specific needs/goals, while adhering to the GHG point and monetary

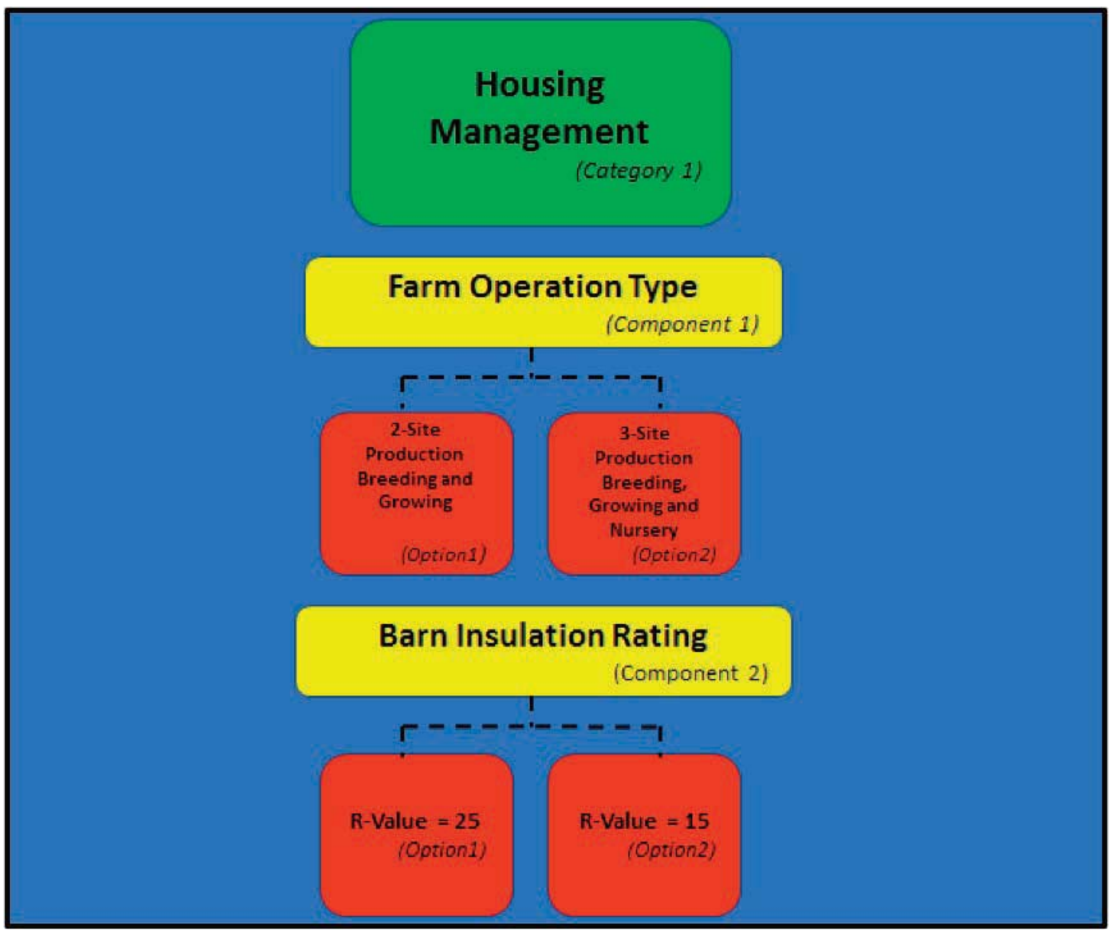


Figure 1. Flashcard hierarchy.

constraints as expressed within the (pre-defined) scenario. Essentially, the separate groups will be assigned a management system (**Category**) and charged with the task of selecting/arranging the **Components** and **Options** which best fulfill the instructions given by the producer of a selected scenario. *Student groups will work on only one management system **Category** and corresponding scenario at a time.*

The scenarios are scripted in such a way that they (1) provide clues toward the appropriate **Components** and **Options** to select and (2) allow only one configuration of components within each of the three management systems to achieve compliance with the producer's needs/constraints (functional, GHG and financial) for each given scenario. Therefore, the student groups will have to construct the appropriate management systems through a combination of comprehensive reviewing of the supplied reference material (assisted by the instructor), cross-referencing with the **Farmer Notes** and **Farmer Resources** portions of the scenario, and deductive reasoning. Upon all groups' completion of the management system design for a given scenario (approximately 20 minutes), the GHG and monetary totals should be finalized, and a last cross-referencing between scenario parameters and the constructed system design should be performed. Students should then individually fill out the **Consultant Report** portion of the scenario sheet, and each group should engage in class-level Q&A sessions and/or discussion under instructor guidance. *More detailed information can be found within the **Completion Instructions** section on page 12*.

A **Scenario Layout Key** is supplied with the exercise material to provide instructors with information to derive the correct management system configurations for each scenario and a brief justification statement. The instructor is to use this key to critique the student's compliance with the "virtual producer" instructions within each scenario.

➤ Information Delivery

The educational materials for this activity were designed to be implemented by groups of four to six students within a classroom setting. The most limiting factors will likely be the individual user's prior knowledge of any related subject information, availability of classroom resources and printing practicality (which may vary heavily from school to school). It is suggested that instructors prepare students by reviewing the instructions and resource material within the classroom setting before allowing students to begin work on the scenarios. Instructors may also choose to present other pre-prepared material that correlates to the lab activity's subject matter in addition to the lab-supplied materials.

Possible Complementary Materials

- Worksheets on topics relevant to lab activity
  - Tables, graphs, illustrations, flow charts
- Materials published by national and state agriculture agencies:
  - University of Arkansas Division of Agriculture – Cooperative Extension Service
  - Arkansas Farm Bureau
  - United States Department of Agriculture

PowerPoint Presentations

- Interactive or stand-alone materials that introduce students to basic farm production principles and practices.
  - *May duplicate some material presented within lab activity.*

A/V Demonstrations

- Interactive or stand-alone materials that introduce students to basic farm production principles and practices.
  - *May duplicate some material presented within lab activity.*

➤ Design and Completion Instructions

Design

The hands-on portion of this exercise is implemented through a cut-out flashcard platform, for the purpose of designing decision trees which are representative of various on-farm practices. The building of decision trees is achieved by selecting the appropriate on-farm practices which best meet the needs expressed by the farmer within a given scenario's **Farmer Notes** and **Farm Resources** sections.

At its core, this exercise is designed to allow students to systematically select farming practices that meet the practical and functional needs of a scenario's virtual producer, giving special consideration to the resulting carbon footprint and monetary resource commitments that change with the inclusion/exclusion of various management system **Components** and **Options**. The elements of each scenario were designed in a manner that aims to guide the student consultants into deriving scenario-appropriate management systems through a systematic approach of information-driven decision making. The flashcards were constructed to complement the information in the resource material and are intended to funnel and support the student decisions through a combination of critical thinking and an information-guided process of elimination. **The flashcard system contains three hierarchy levels:**

1. **Categories**
2. **Components**
3. **Options**

Category cards (*Figure 2*) represent the three management systems within this lab activity – **Feed Management**, **Housing Management** and **Manure Management**. **Category** cards are labeled to match the corresponding production management system and captioned with a (1) to note their position in the hierarchy. They are also distinctly rectangular to easily distinguish them from other flashcards. **Category** cards are provided for the sole purpose of providing a structural platform for the rooting of **Component** cards. The **Category** cards also provide the basic working boundaries for which each group of consultants will focus their attention in addressing the expressed limitations and needs of the virtual producer of a given scenario; i.e., *the students are to focus on how they can manipulate the options within their assigned **Category** to address the virtual producer's expressed needs and **not assume** that a group working on a different **Category** for the same scenario will address any of the virtual producer's concerns.* Furthermore,

Figure 2. Category Card

students working on a given **Category** ***<u>should not</u>*** let any collateral or incidental effects on a separate **Category** affect their management system design decisions or their approach in addressing a virtual producer's expressed needs.

Component cards (*Figure 3*) represent a particular management system's major components (i.e., Lighting and Insulation for the **Housing Category** and Feed System for the **Feed Category**). These cards are provided for the purpose of establishing a framework for the **Options**. Therefore, the cards are generic modules that feature commodities that are common on most swine operations. However, due to the unique farm specialties and goals of the virtual producers within the scenarios, the use of each **Component** card may not be necessary to achieve the system design that best suits the virtual producer's needs. So, it is very important that the expressed limitations and goals of each scenario (i.e., **Farmer Notes** and **Farm Resources**) be examined carefully in order to achieve the correct management system design. **Component** cards are distinctly rectangular and captioned to note their position in the hierarchy in the same manner as **Category** cards to easily distinguish them from other flashcards (*Figure 3*).

Option cards (*Figure 4*) are distinctly square shaped and represent the options available for the management system's **Components** [i.e., LED Lighting, Insulation (R-value=25) and Propane Fuel selections for the respective Lighting, Insulation and Fuel Source **Components**]. **Option** cards feature renderings of the various options which they are representing to provide a visual reference for users. All **Option** cards also contain a brief definition of the specific function(s) of the depicted option below the illustration for quick reference purposes (*Figure 4*). The **Option** cards are the primary class of cards which the

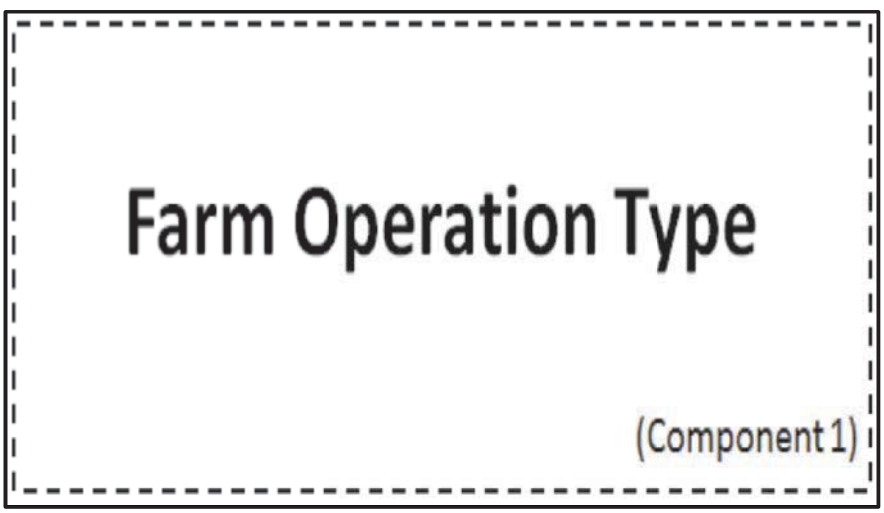


Figure 3. Component Card

Figure 4
The two options for Farm Operation type and Insulation option GHG and $ values.

student consultants will manipulate to meet the expressed needs and limitations of the virtual producers (via **Farmer Notes** and **Farm Resources**).

The back of each **Option** card features a unique greenhouse gas (GHG) and monetary ($) allocation (*Figure 4*). The depicted allocation amounts are a function of the costs and greenhouse gas emissions associated with the construction, maintenance and daily operation of each **Option**. Both the GHG and monetary values have been standardized and scaled down based on existing research to reflect the real-world costs and GHG emissions associated with each **Option**. The GHG and monetary values for each **Option** are expressed in terms of plus (+) and minus (-) and are located on the back of the Option cards. The pluses (+) in the monetary and GHG values represent the respective spending of money and the generating of GHG emissions as a result of the use of a given **Option** (i.e., +4 GHG value represents the emission of GHGs to a degree equivalent to a value of 4). The minuses (-) in the monetary and GHG values represent the respective conservation of money or mitigation of GHG emissions as a result of the use of a given **Option** (i.e., $ value of -2 represents the crediting of money to a producer's expense account). The GHG and monetary values serve as the decision support mechanism through which the student consultants can assess the associated monetary and GHG consequences of a given **Option** and compare them to the expressed monetary resources and GHG emission concerns of the given scenario's virtual producer. This decision support mechanism coupled with the guidance of the information within the reference material forms the means through which the student consultants evaluate the virtual producer's needs and suggest the appropriate management system designs.

Completion Instructions

The instructor(s) should print the activity material from the supplied PDF file and instruct the students to cut out the manipulative leaving the dotted lines as borders. (**Do not issue any content within the Instructors Only section to students.**) The students and instructor(s) should review all information within the instructional and resource material in order to familiarize themselves with the activity rules, as well as basic swine terminology and management practices. Once the students have a working understanding of the activity design and approach, the instructor should then split the students into groups of three to eight members and **assign each group a Management Category and a corresponding Scenario. Please note that the scenarios are Category specific.** *(See the the section **Classroom Implementation of Scenarios** for more details.)*

Student groups acting as swine production consultants are to collectively review the scenario for their instructor-assigned **Category** and then arrange the hierarchy of cards to construct scenario-specific management systems by interchanging and adding/removing **Component** and **Option** cards to best accommodate the virtual producer's desired specifications as detailed in the given scenario. *(**Note:** The use of all system categories is not standard and is dependent upon the resources, physical limitations, needs and goals expressed by each scenario's virtual producer; i.e., operation type, monetary limitations, farmer GHG concerns, land availability, etc.)* Once the group members have completed the arrangement of the assigned management system's **Component** and **Option** design, each member should complete the **Consultant Report Sheet** for their given scenario *(**Note: Consultant Report Sheets** are to be individually completed by each group member. However, students are allowed to consult with their group members while completing the report sheets.)*

To complete the **Consultant Report Sheet**, each group should score the GHG and monetary values of the constructed management system based on the values ascribed on the backs of the **Option** cards which they selected, and then complete the **Consultant Statements** section of the **Consultant Report Sheet**. In the Consultant Statements section, group members should write a brief statement of justification that explains the group's rationale behind why the group selected each of the **Options** used to construct the scenario's management system. The Consultant Statements portion of the exercise may also provide an opportunity for any group member(s) who disputed the use of a particular **Category** and/or **Option** to provide a statement as to why they did so. Any disputes a group member(s) may have about the final configuration should be accompanied by alternative setups and brief justification statements.

This writing exercise can also serve as a starting point in opening the dialogue between the student groups and the instructor(s) before comparing and contrasting the student's management system layouts with the **Scenario Key** provided to the teacher. After any instructor-student discussion/Q&A, the instructor can critique each group's **Consultant Report** against the **Scenario Key** and grade (if desired) the reports in a manner of the instructor's choosing.

➤ Classroom Implementation of Scenarios

For a classroom size of *15 students or less*: Students may be divided into three groups of five (or less) students per group and assigned a **Category** and common scenario. It is suggested that the assignment of the given management system be rotated among the various groups at a given interval to optimize the exercise's utility and allow participants full exposure to the subject matter.

For a classroom size of *15 students or more*: Students can be divided into groups of eight (or less) and assigned a **Category** and common scenario. The groups may then compete against other groups to achieve the highest rating for a common scenario; or construct decision trees for different scenarios.

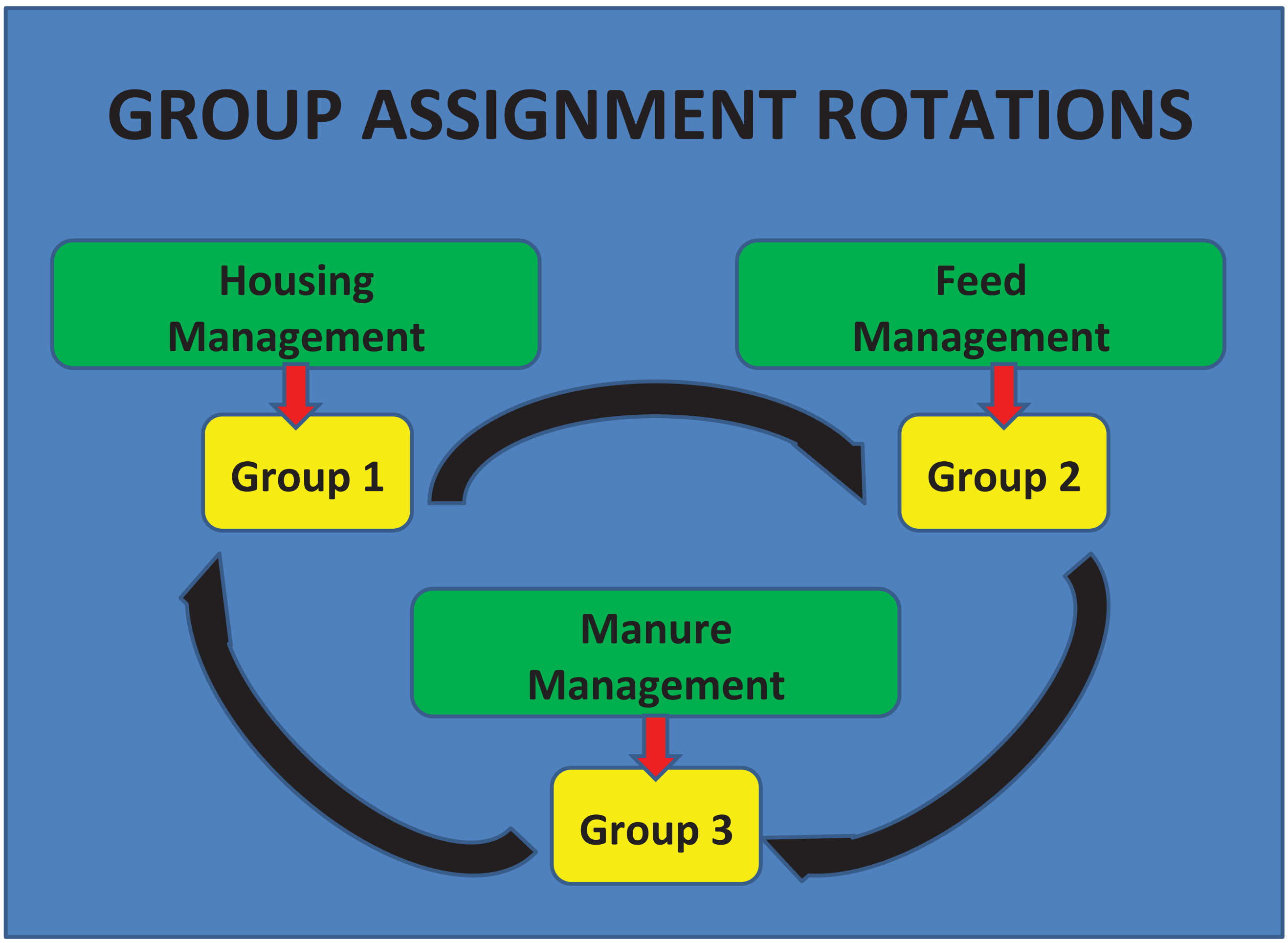


Figure 5. Group assignment rotations.

Presentation of Game and Background Information Material

Presentation Platform

- Printable (.pdf) Cards

  Cards are to be printed on paper of a standard (8.5x11 inch) size and then manually cut out by students as guided by cut-out lines.

Reference materials and Scenario Layout Key are to be printed using a standard color printer.

Arrangement of Background Information

Information within the supplied materials is color coded to match the specific management system which the information addresses to simplify reference for students. All students should review the **general information** section. The students should then review the specific section which corresponds with the **Category** for which they will be acting as a consultant. The review may be conducted independently by students or lead by the classroom instructor(s).

- **The History of Arkansas Swine Production and General Terms – RED**
- **Health and Feed Management – ORANGE**
- **Housing Management – GREEN**
- **Manure Management – BLUE**
- **Legal Compliance – BLACK**

Information for Resource Materials

The History of Arkansas Swine Production

Hernando de Soto is credited as being the father of the American pork industry. In 1539, de Soto landed in America accompanied by 13 pigs. De Soto first introduced swine into what is now Arkansas in 1541. De Soto gave pigs to the Native American chiefs as gifts. By the time de Soto and his group disbanded in 1542, the herd of pigs had grown to around 700 head. Currently Arkansas's pig population can be divided into managed herds and wild or feral hogs. The managed herds are typically smaller herds raised on a hobby or partial income basis and larger herds that provide the primary income for the farmer and employees. The wild or feral herds, which can be found in all Arkansas counties, are the descendents of escaped domestic pigs or animals introduced for hunting purposes.

General Terms/Definitions

Boars – Uncastrated male swine used for breeding.

Service Boar – Any adult male boar that is being or has been used for breeding purposes.

Replacement Boar – Any male swine intended to be used for breeding but has not yet been bred.

Barrow – Castrated male swine.

Sow – Adult female swine that has birthed (farrowed) at least one litter.

Gilts – A young female swine, up to and including the birthing of her first litter.

Replacement Gilt – A gilt that is intended to be used for breeding purposes, but has not yet been bred.

Estrus – The period during which ovulation occurs and a sow/gilt is fertile and ready to mate.

Standing Heat – The rigid stance assumed and maintained during estrus by a sow/gilt throughout servicing (insemination).

Breeding – The act of mating/inseminating a female pig.

Gestation – A term to describe swine pregnancy lasting 112-114 days in length for pigs.

Farrowing – The act of giving birth; an average of 10-12 pigs are born per litter.

Litter – Pigs born to a sow during one farrowing.

Lactation/Nursing – The period in which a sow provides milk to her recently farrowed pigs.

Recovery – The period during weaning when a sow is relocated from farrowing facilities to pens/stalls near the breeding area in preparation for further breeding.

Nursery Pig – Pigs from weaning to around 8-10 weeks of age.

Weaner Pig – Pigs from weaning up to about 40 pounds.

Feeder Pig – A young pig weighing between 30-90 pounds.

Growing Pig – A young pig weighing between 50-120 pounds.

Finishing Pig – Pigs 120 pounds to market weight.

Market Hog/Weight – Pigs weighing about 270-290 pounds. These pigs are sent to market, slaughtered and processed for the production of food products.

Nursing Phase – The time period between farrowing and weaning.

Weaning – The process of ending the nursing phase by preventing young pigs access to the lactating sow.

Grow-Finish Phase – A term referring to the multiple stages of production between the growing to finishing phases, in which unique diets are fed to closely match pigs' nutritional requirements.

Growing Herd vs. Breeding Herd vs. Nursery

The Growing Herd consists of young pigs (post-weaning) which are typically between 40-200 pounds.

The Breeding Herd consists of mated females, service boars and replacement boars.

The Nursery is the area to which pigs are moved at weaning.

Pen-Mating is the practice of placing one or more boar(s) with a group of sows for breeding purposes. This approach requires little labor, but leaves much uncertainty about when and if a sow is actually bred.

Hand-Mating is the practice of placing one boar with one sow and observing to ensure that mating occurs. This method of breeding requires significant labor, but allows for verification of mating in detail (day, time, number of occurrences).

Artificial Insemination (A.I.) is the practice of breeding a sow artificially with harvested semen. This method of breeding is very labor intensive, but allows farmers the greatest amount of control over genetic improvements while minimizing disease exposure as there is no direct contact between animals.

Greenhouse Gases (GHGs)

What are greenhouse gases (GHGs)?

GHGs can simplistically be described as gases that prevent heat radiated from the sunlit ground from escaping to space. GHGs warm the surface and lower atmosphere by re-emitting infrared radiation that would otherwise escape the Earth's atmosphere (*Figure 6*). GHGs can be produced by anthropogenic activities (man-made) or occur naturally.

How much of these GHGs are in the atmosphere?

Larger emissions of greenhouse gases lead to higher concentrations. Concentration is the relative amount of a particular gas in the air. Greenhouse gas concentrations are measured in parts per million, parts per billion and even parts per trillion. One part per million is equivalent to one drop of water diluted into about 13 gallons of liquid (roughly the fuel tank of a compact car). It is impossible to precisely quantify all GHGs in the atmosphere. However, atmospheric scientists can make estimates of overall GHG concentrations based on a combination of atmospheric sampling and emission inventory datasets.

How is the environmental impact of GHGs measured?

Some GHGs are more effective global warmers than others due to differences in the amount of time each GHG remains in the atmosphere, its concentration in the atmosphere and how strongly it absorbs energy. This phenomena is accounted by assigning each GHG a Global Warming Potential (GWP), where a GHG's ability to warm the earth is standardized through comparison to the global warming potential of CO_2. Gases with a higher GWP absorb more energy,

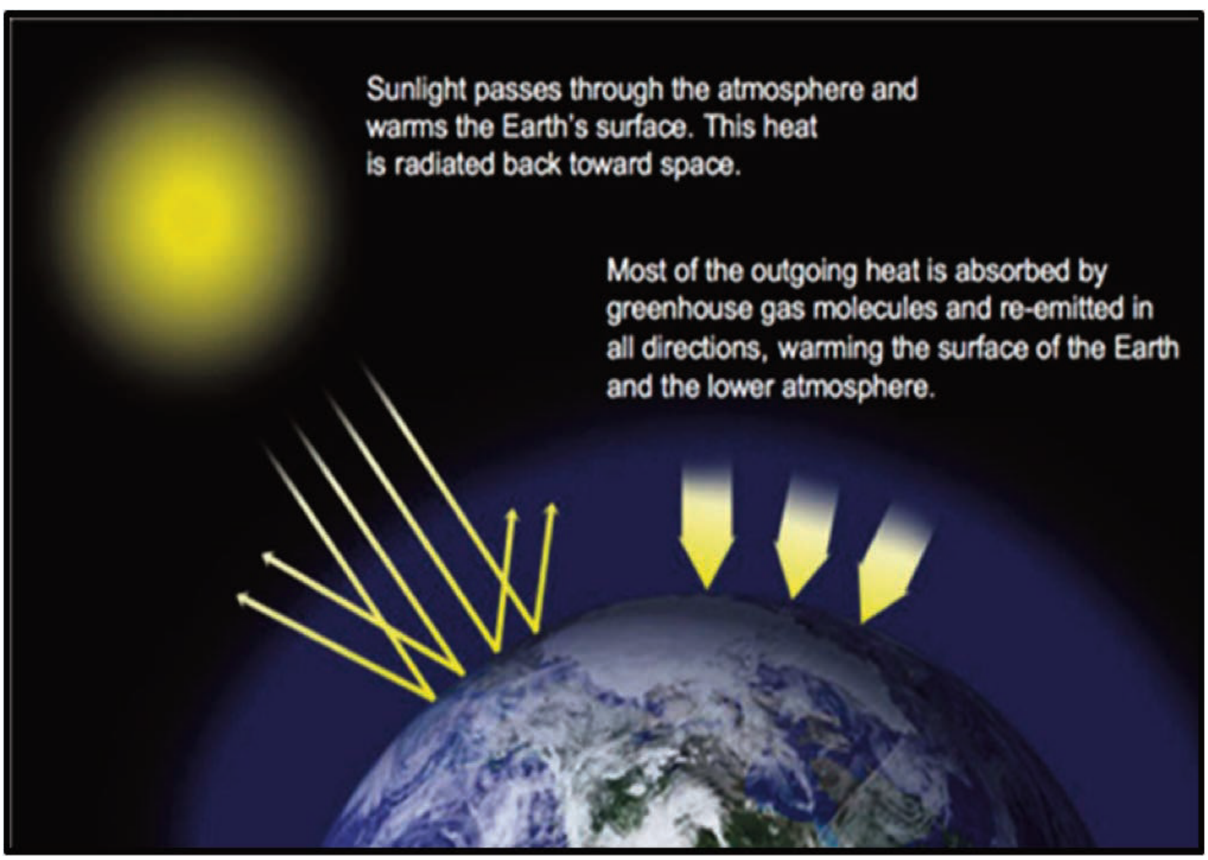


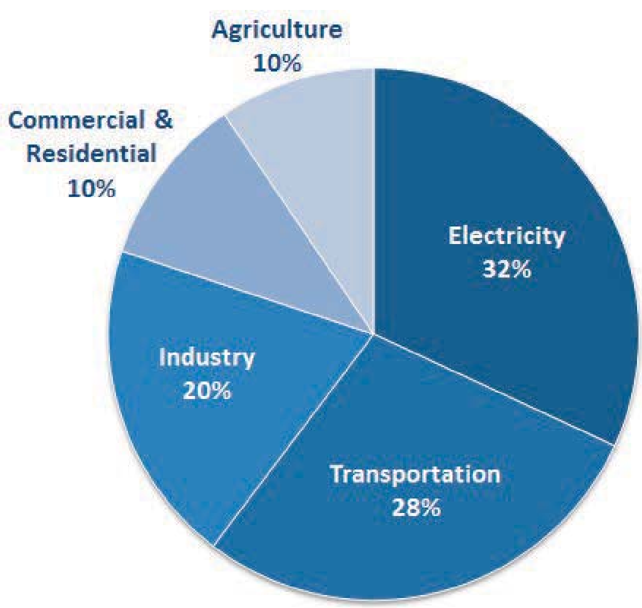
Figure 6. *(Source: NASA Earth Observatory)*

per pound than gases with a lower GWP and thus contribute more to global warming. For example, methane's 100-year GWP is 21, which means that methane will cause 21 times more warming compared to an equivalent mass of carbon dioxide over a 100-year time period.

Sources of GHGs

Though agricultural processes produce a significant amount of GHGs, the largest source of GHGs in the U.S. is the burning of fossil fuels for electricity, heat and transportation (*Figure 7*). Greenhouse gas emissions from agriculture generally come from the cultivation of crops and livestock for food.

Figure 7. Total U.S. Greenhouse Gas Emissions by Economic Sector in 2012



Total Emissions in 2012 =
6,526 Million Metric Tons of CO_2 Equivalent

*Land Use, Land-Use Change and Forestry in the United States is a net sink and offsets approximately 15% of these greenhouse gas emissions.

All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012.*

Major GHG emission sources from swine operations:

- **Manure storage and treatment** – CH_4 and small amounts of N_2O
- **Land application of manure** – N_2O
- **Enteric fermentation (digestion)** – CH_4

Methane – CH_4 (GWP = 21) – Methane is produced during anaerobic (in the absence of oxygen) decomposition of organic material within the pig's digestive system. The amount of methane swine emit during digestion is relatively lower than that of other livestock (ruminants) with more complex digestive systems (i.e., cattle). Methane is also produced during the management (collection, transport, storage and land application) of manure, with emission amounts dependent upon factors such as the pig's diet [which directly affects the manure physical/chemical characteristics (i.e., the amount of excreted volatile (able to be vaporized) solids], manure handling and manure storage methods.

CH_4 Emission Reduction Strategies – The most prevalent method of mitigating methane emission from swine manure is the capture of methane emissions from anaerobic digestion of manure held in a lagoon or formed structure digester such as a plug-flow digester. During anaerobic digestion, microorganisms convert the organic matter within the manure into methane through biochemical decomposition in an oxygen-absent environment. To prevent the emission of the methane by-product, a capture-and-utilize technique is used. In the case of the lagoon digester, an airtight cover is placed over the lagoon to capture the gaseous by-products. Once captured, the methane gas can be utilized. Typically the captured gas is burned off by controlled feeding of the gas via a system of valves to an open flame. In other cases, the captured gas can be used on-site as a fuel source in boilers to produce hot water or burned in engines to power electrical generators *(see the Manure Management section for more information on anaerobic digestion and methane biogas)*.

Carbon Dioxide – CO_2 (GWP = 1) – The CO_2 emitted from the production of swine is generally associated with the combustion of fossil fuels for electricity, transportation and equipment use on the farm. However, one of the largest sources of CO_2 related to swine farming is the production of fertilizer used to grow crops. There is also a smaller amount of CO_2 released from soil activities related to the production of swine feed grains. Soil CO_2 is emitted as a result of soil disturbance practices (such as tilling) that expose organic material in the soil to warmer temperatures and increase microbial activities. The warmer and microbe-rich soil conditions promote decomposition of the soil's organic material, and CO_2 is released as a natural by-product.

CO_2 Emission Reduction Strategies – Carbon dioxide is removed from the atmosphere (sequestered) when it is absorbed by plants as part of the biological carbon cycle. One way that crop-producing swine farmers can reduce CO_2 emissions is through soil carbon sequestration, meaning reducing the amount of CO_2 released into the atmosphere by increasing the amount held by the soil. There are a variety of ways to sequester CO_2 in soil, but generally they include implementing conservation tillage/no-till practices, using biofuels and grassland conversion. Conservation tillage/no-till practices involve minimal or no disturbing/turn-over of the soil between crop plantings to allow soil carbon to accumulate. Grassland conversion refers to converting cropland to grassland or pasture. By converting the land cover from a one-season type (annual) to a year-round type (perennial), the amount of soil carbon retained is increased through preventing erosion. Grassland conversion also reduces the amount of atmospheric CO_2 through supplying plants to absorb CO_2 during the photosynthesis process year round. The use and/or production of biofuels on farms is another strategy which focuses on minimizing or eliminating the addition of GHGs to the atmosphere. Biofuel use mitigates GHG emission by utilizing GHGs that were removed from the atmosphere through photosynthesis and stored in the plant matter (biomass). In essence, the plants are capturing and harvesting GHGs which will be used in further energy production processes.

Nitrous Oxide – N_2O (GWP = 310) – Most of the N_2O emitted by swine production is associated with fertilizer applications and the microbial decomposition of manure during the collection, storage and land application. If manure is land applied to soil-crop systems, the biochemical processes of nitrification and denitrification produce nitrous oxide emissions. Nitrification occurs when NH_4+ (ammonium) is converted to NO_3- (nitrate) by microbes in the presence of oxygen (aerobic environment). Denitrification occurs in anaerobic environments (in the absence of oxygen) and is the microbial reduction of NO_3 to N_2 (nitrogen gas). *(See Figure 8 for an illustrated summary of the Nitrogen Cycle.)*

N_2O Emission Reduction Strategies – Implementing a nutrient management plan can make a significant impact in the reduction of N_2O emissions through enabling more precise managing of the on-farm nutrients. Improved nitrogen management translates into adjusting of nitrogen-based fertilizer applications to give more consideration in trying to meet the N-P-K needs of the soil and the plants. Reducing N content of animal feed can also make a significant impact on reducing the amount of N_2O emitted from swine manure. By carefully balancing the amount of proteins and amino acids in feed to match the swine nutrient requirements, the amount of nitrogen excreted in the pig's manure can be minimalized. Another strategy for managing the N in manure is the mitigation of the nitrogen lost to volatization. Altering the land application of manure from topical spreading to incorporation into the soil can help manage the amount of nitrogen lost to volatization. The time of year which the fertilizer is applied can also play a role in the amount of volatization that occurs. During warm-weather fertilizer applications, the nitrogen loss to volatization can be substantial. But if fertilizer is applied during cool weather, less nitrogen is converted to gas and therefore less nitrogen is volatized.

Nitrogen Cycle – *See chart below.*

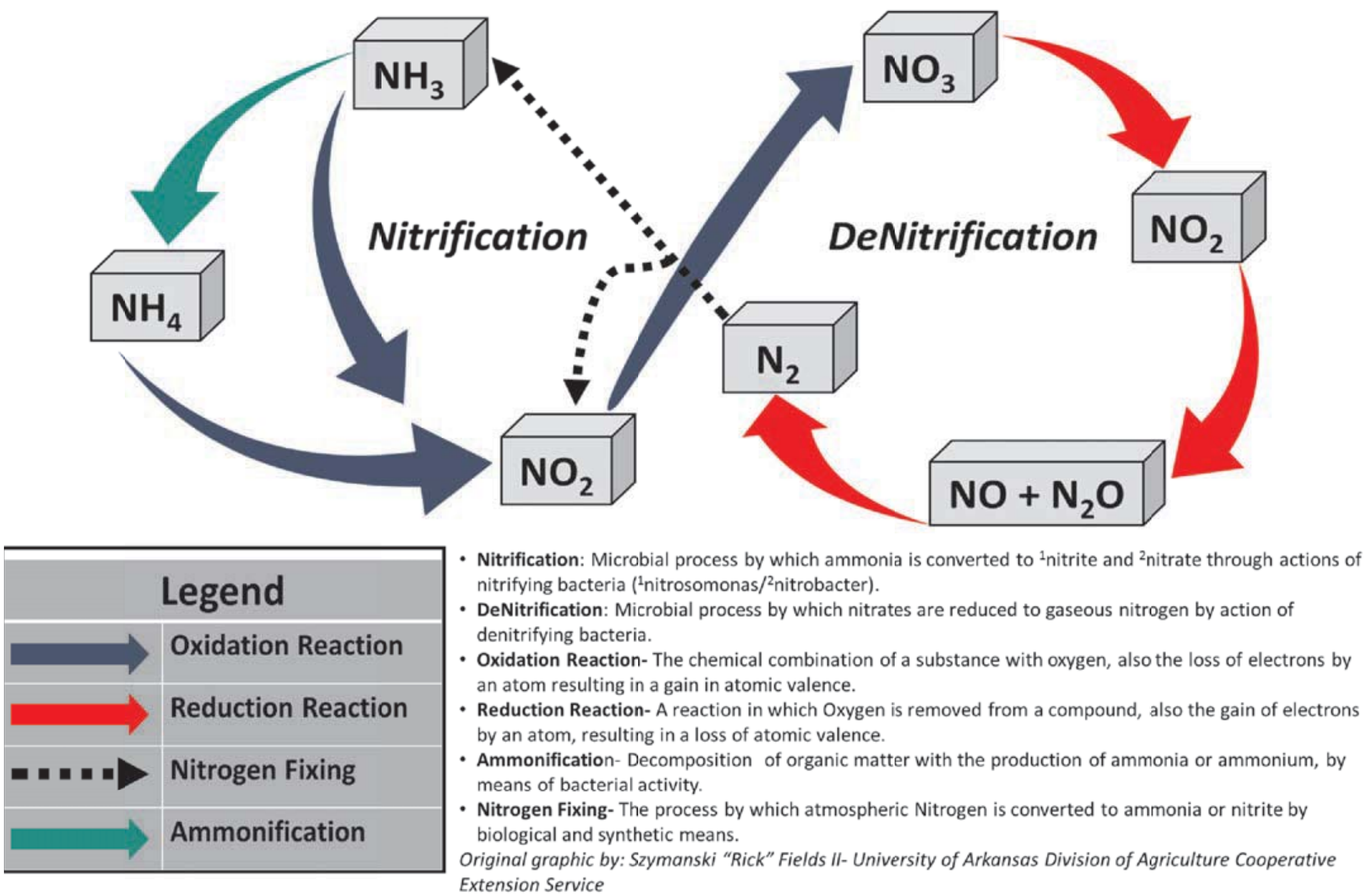


Figure 8. Simplified Nitrogen Cycle. *(Source: Fields, 2013)*

Phosphorous Cycle – Though phosphorous (P) does not directly contribute to GHG emissions, it plays a critical role in the balance of nutrient inputs and outputs in swine production operations and is important to discuss. Phosphorous is a naturally occurring element that can be found in all living organisms, as well as in water and soil. Swine get part of their P needs from feed materials. However, much (around 70%) of the P ingested by pigs is excreted in the manure. As a result, swine manure is a good source of P and also the nutrients N and potassium (K). These nutrients (N, P and K) are essential nutrients which are necessary for healthy plant growth and development. Therefore, the nutrient-rich manure is often land applied as a fertilizer which crops and grassland can use to fulfill their nutritional needs. Because animal manure nutrients are not balanced like those of commercial fertilizers (mixed at a specific N, P and K ratio to meet the needs of the desired crop), the use of manure as a fertilizer tends to result in applying more P than is needed. The repeated over-application of P causes the soil to accumulate P. This buildup of soil P is a major environmental concern, as it is harmful to plant growth and has negative effects on the environment due to the potential transportation of the P into waterbodies through runoff, erosion and nutrient leaching. *(More information on the environmental interactions of phosphorous can be found in the* ***Manure Management*** *section.) (See Figure 9 below for an illustration of the Phosphorous Cycle.)*

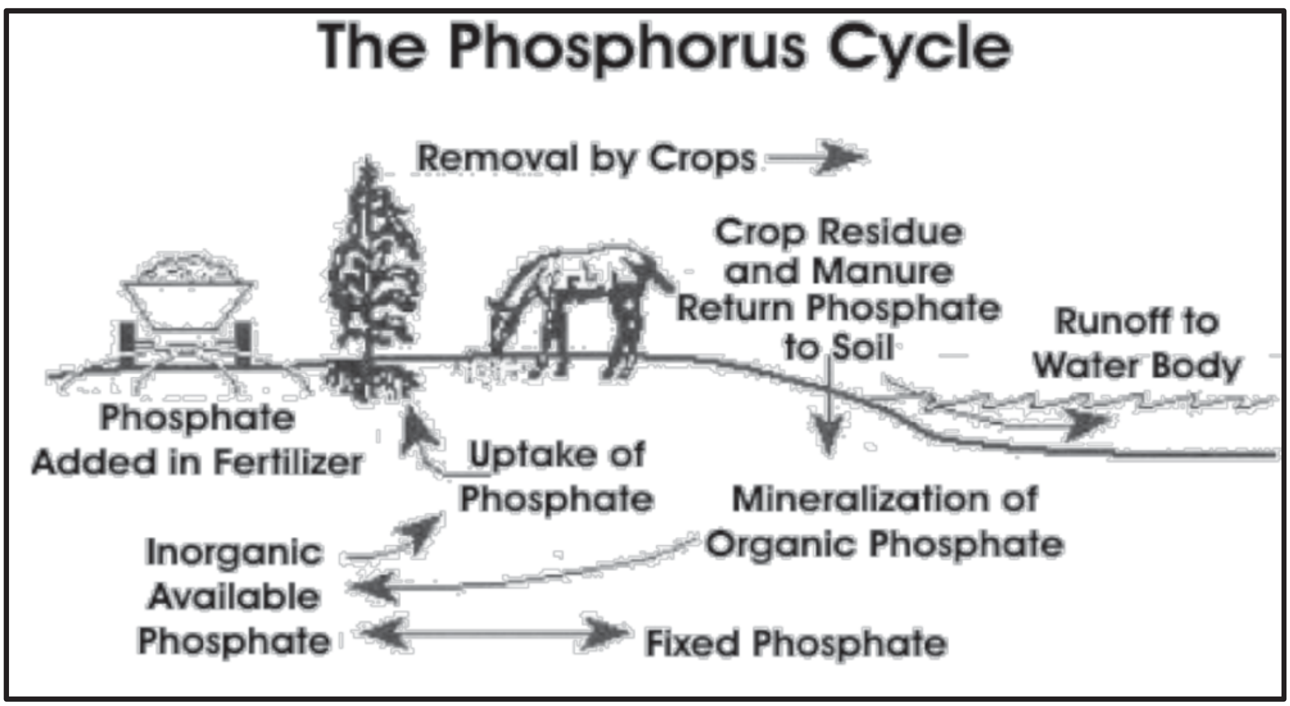


Figure 9. The Phosphorus Cycle. *(Source: EPA, 2012)*

Feed Management Systems

Feed is the major production input of the pork production process. In fact, feed accounts for 65% (or more) of all swine production expenses. A variety of feed ingredients are used in proper proportions to produce "balanced" diets for pigs which meet their nutritional needs during each stage of development. The energy content of "feedstuffs" and the energy requirements of the pigs are expressed as metabolized energy (ME). The ME is calculated by subtracting the energy lost in feces, urine and gases from the gross energy supplied by the feedstuffs [i.e., total energy supplied by food – energy losses (feces, urine and gases)]. The majority of the pig's energy needs are met by carbohydrates and fats, while the other ingredients support the functioning of internal biological processes (i.e., immune systems) as well as promote healthy organs and tissues. Traditionally, the major challenge facing the producer is to manage all the feed variables in such a way that profitability and productivity are optimized.

Feeding Programs

Complete Diet System – In this feeding system, complete commercially mixed diets are purchased from a feed manufacturer and delivered to the farm. This system is best suited for smaller farm operations and hobby farmers. This system may also be appropriate for very large operations where large amounts of mixed feed can be stored in bulk.

Advantages

1. Eliminates the need for on-farm feed processing.
   a. Ideal for specialty diets.
2. Reduces need for separate storage facilities, as all ingredients are pre-mixed and stored together.

Disadvantages

1. Offers no feed formulation flexibility (changing the ratio of grains and proteins to vitamins and minerals).
2. Very expensive, as all feed must be purchased and transported frequently or stored in bulk.

Base-Mix System – In this system, farmers purchase vitamins and minerals in a mixed pre-measured form to be added to on-farm grains and protein sources.

Advantages

1. Offers a high level of feed formulation flexibility (control of the relative ratios of proteins and carbohydrates to vitamins and minerals).
2. Allows high degree of ingredient quality assurance, as the producer supplies the grain and protein sources.
3. Most economical option for producers who have readily available grains/soybeans and the appropriate storage/processing capabilities
   a. Large operations require a big storage capacity.
   b. Small operations need very little storage capacity.

Disadvantages

1. Not economical for specialty diets, as these ingredients are expensive and often must be obtained from off-farm sources.

2. Requires on-farm feed processing capabilities.

3. Requires appropriate storage facilities, as grains and soybean meal must be stored on-farm.
   a. Large operations require a big storage capacity.
   b. Small operations need very little storage capacity.

Basic Swine Feed Components

Carbohydrates

Corn and grains are the major ingredients in swine feed and supply carbohydrates, which are an essential energy source. Carbohydrates play an important role in regulating body temperature, reproduction and can serve as laxatives (fiber). The most commonly used carbohydrate sources include corn, barley and oats.

Fats

Fats are an important part of a balanced swine diet as they play key roles in growth and internal biological processes. Fats act as a carrier of nutrients by transporting fat-soluble vitamins. Fats also serve as a source of essential fatty-acids, which cannot be produced by the body and must be ingested. Fats are mainly supplied by feed ingredients containing animal fat and soybean oils, but may be added through a supplement in some cases.

Proteins

Proteins are necessary for muscle and milk production. Proteins are broken down into amino acids during digestion and then absorbed into the body to build new tissues and repair old/torn tissues. Pigs must continually consume sufficient amounts of protein to maintain proper muscle growth and weight gain. The most common sources of proteins in adult swine feed are soybean meal and meat/bone meal. Starter swine feed commonly uses more expensive/digestible protein sources such as blood meal, fish meal and dried whey.

Amino Acid Categories

Indispensable Amino Acids – Must be directly supplied to the pig's diet and/or cannot be synthesized from other amino acids.

Dispensable Amino Acids – Can be produced from biological action on other amino acids or other nutrients to meet body's needs.

Minerals and Trace Minerals

Minerals play a support role for many biological functions, such as fortifying the pig's structural components (bones and teeth). Minerals also support healthy cell development and function and are involved in the functions of enzymes. Special care must be taken when balancing mineral supplies to the needs of the pigs, because many minerals can be toxic at very high concentrations.

Vitamins

Vitamins are most simply described as organic compounds that are necessary in small amounts for normal growth, reproduction and health of animals. The vitamin categories are as follows:

Fat-Soluble Vitamins – Vitamins that are dissolved and stored in fatty tissue. The stored vitamins are very slowly excreted from the body, and need not be consumed regularly. *Fat-soluble vitamins include vitamins A, D, E and K.*

Water-Soluble Vitamins – Vitamins that are dissolved in water and not stored in the body for long periods of time. These vitamins are routinely excreted though urine and manure, so they must be consumed regularly to maintain health. *Water-soluble vitamins include vitamins C, B_{12}, thiamin, riboflavin and niacin.*

Additives

Feed additives are ingredients that provide no nutritional value, yet may enhance production and profitability under the right circumstances. Feed additives are regulated by the U.S. Food and Drug Administration (FDA), and their use is overseen by strict guidelines. There are many classes of food additives including antibiotics, anthelmintics, Ractopamine HCL (Paylean®), fats and enzymes.

Antibiotics – Compounds extracted from living organisms (bacteria and molds) that can inhibit the growth of microorganisms. Antibiotics can be useful in the treatment of bacterial infections and, in low doses, can be used to prevent bacterial infections altogether.

Anthelmintics – Compounds that are used to expel parasitic worms from the body. Different parasitic infections are targeted by specific anthelmintics, and pigs may be re-infected if exposed to parasites after completing the cycle of anthelmintics.

Ractopamine HCL (Paylean®) – This compound is a beta-antagonist and is used to alter the pig's metabolism by shifting nutrients to lean muscle growth and away from fat development. The nutrient shift results in an increased rate of muscle weight gain, improved feed efficiency and increased carcass leanness (less fat). Because of the increased muscle growth and protein buildup, pigs fed Ractopamine must ingest more amino acids than otherwise and need a dietary minimum of 16% crude protein. Ractopamine's effects are dose dependent, and dosing guidelines are closely adhered to by pork producers. Ractopamine is allowed to be administered to pigs in a maximum dietary level of 4.5-9.0 grams/ton of feed in live pigs from 150-240 pounds and only during the last 45-90 lbs of weight gain before slaughter.

Crude Protein (CP) – Term used to describe the total amount of nitrogen content in food. CP is calculated by multiplying the total nitrogen content by (6.25). This provides an estimate of the amount of protein within a food.

Fats – Fats can be added to any diet to raise the Lower Critical Temperature (LCT) of a pig. The LCT is the lowest temperature environment that a pig can tolerate without suffering a significant loss in growth and productivity due to thermal stress (i.e., pigs with lower LCTs can tolerate cooler temperatures). Fats can also be removed from the diet to increase the Upper Critical Temperature (UCT). The UCT represents the highest temperature environment that a pig can tolerate without suffering a significant loss in growth and productivity due to thermal stress. The practice of limiting fats should be used cautiously, as lowering the fat contents in feed is known to decrease the feeds palatability and cause the pigs to consume less feed. Any lowering of the pig's feed intake could be counter-productive. Fats are also added to some specialty diets to alter the caloric intake and increase energy value. Fats are used because they provide increased energy (caloric density) value to a feed without significantly altering the other ingredient amounts.

Enzymes – These microorganisms are essential for the pig's digestion of feed. Enzymes stimulate the pig's digestive system and aid in breaking down feed components. Enzymes are most commonly used when feed ingredients contain a high amount of fiber (cereal grains), such as barley. Enzymes can also be used to release minerals (i.e., phytase releases phosphorous) that are bound in unusable forms, therefore making them available to be used by the pig. The use of phytase can reduce the amount of phosphorous excreted in the manure by 20%-40%. This reduces the amount of mineral supplements needed. This can be important on swine farms where manure is land applied to soils and phosphorous buildup is a concern.

Nutritional Requirements by Swine Type

Breeder Boar Diets

Boar nutrition is very important due to the boars influence on the swine-breeding program. Boar nutrition can affect litter size and farrowing rates. Therefore, the objective of this diet is to supply sufficient nutrients to meet requirements and support healthy reproductive performance. Boars used for mating (service boars) are limit-fed a grain-soybean meal (14% CP) diet with mineral and vitamin contents very similar to those fed a gestating sow. The limit-feeding helps minimize mature body weight in order to allow boars to mate with smaller sows/gilts. Though feeding goals differ with production situations and priorities, some important factors which affect boar nutrient requirements include age (stage of maturity), body condition, environmental conditions and breeding frequency.

Age – Incoming boars are quarantined from the rest of the breeding herd for 45-60 days to allow for health status evaluation and time to adjust to their new environment. Feeding management goals vary between younger (300-400 lbs) and mature (400-700 lbs) breeding boars (*see Table 1*). Younger boars must be fed enough to allow for a healthy rate of weight gain as they are still growing (i.e., 5-5.5 lbs of balanced corn-soybean diet). Mature boars should be fed a diet that meets nutritional needs and allows for optimal reproductive performance (i.e., 5-6.5 lbs of balanced corn-soybean diet).

Body Condition – As boars become older the amount of nutrients provided for body maintenance increases and the amount provided for weight gain decreases *(see Figure 10)*. The feeding goal for mature boars is to maintain body weight while restricting weight gain. The feeding goal for younger boars is to achieve gradual weight gain while maintaining fertility and libido. This is accomplished by restricting energy (carbohydrates and fats) intake while feeding high mineral, vitamin and protein amounts through a limit-feeding program.

Table 1. Feeding Guidelines for Breeding Boars. ***(Adapted from Whitney and Baidoo, 2010)***

Body Weight (lbs)	Pounds of Feed for Maintenance	Target Gain Per Day (lbs)	Pounds of Feed for Gain	Total Feed Per Day (lbs)
300	3.42	1.2	1.5	4.9
350	3.78	1.1	1.38	5.2
400	4.14	1	1.25	5.4
450	4.47	0.9	1.13	5.6
500	4.8	0.8	1	5.8
550	5.11	0.7	0.88	6
600	5.72	0.6	0.75	6.2
650	5.71	0.5	0.63	6.3
700	6	0.4	0.5	6.5

Breeding Frequency – The amount/rate of mating that a service boar participates in is often referred to as the boar's "workload." Boars that are mated more than twice per week are considered to have a fairly high workload and should be fed an additional 0.2 lb per day. The increase in feed consumption helps maintain the boar's libido and preserves fertility.

Environmental Conditions – Increases in feed intake should be made when boars are exposed to cold weather or exhibit an extremely high libido (sex drive). Increase feed by 0.1 lb for each 1°F below 68°F.

Grow-Finisher (Market Hog) Diets

Market hogs are mature pigs that are intended for slaughtering and processed for the production of pork products. Since companies purchase market hogs based on carcass weight and lean meat content rather than live weight, this diet is formulized to optimize lean muscle growth. High muscle gain is achieved by the use of dietary ingredients that contain higher nutrient contents and energy density (i.e., fats). The amount of lean tissue on a carcass varies, but is usually calculated based on measurements of backfat and loin area, or loin depth and yield. There are some important factors that limit the lean gain such as feed management, age, gender and environmental conditions.

Age – Muscle deposits increase as a pig's body weight increases and peaks at around 125-140 lbs. Fat deposition increases as the pigs age and happens at a faster rate as pigs mature.

Gender – Barrows grow faster than gilts but tend to have more fat deposition.

Feed Management – These diets are frequently adjusted to meet the pig's changing nutrient needs and can be mixed on farm or purchased as a complete diet ration. If a diet is high in carbs and fats (energy dense), the pigs require less feed. However, if the energy density of the feed is lowered (contains high fiber content only), the pigs will require more feed. Because of this trend, it is critical to ensure that sufficient nutrient (vitamin and mineral) amounts are being provided by adjusting their concentrations to complement the feed's energy content.

Phase Feeding – Grow-finisher diets are phase-fed in order to sync nutrient supplies with the growth stage of the pig. Phase feeding minimizes underfeeding (not meeting nutritional needs) and overfeeding (wasting nutrients). There are typically two to four phases (different diets) fed to a grow-finish pig.

The greatest benefit from using a phase feeding occurs when changing from a single to a two-phase feeding program. Additional phases will improve profitability and reduce nutrient excretion, but at a much lesser rate.

Ractopamine is included in finisher diets to reduce fat deposition and increase lean tissue (muscle) by 25%-35%. Ractopamine is approved to be fed during the last 45-90 lbs of weight gain at 4.5-9 grams/ton in finishing feed containing at least 16% crude protein.

Environmental Conditions – Maintaining the proper temperature is critical to the growth rate of market hogs. The comfortable temperature zone ranges from approximately 55°-75°F. Pigs housed in temperatures below 55°F (too cold) will consume more food in order to maintain body heat. The feed intake is increased approximately 0.03-0.05 lb of food per 1°F below 55°F. This increase in feed consumed will not increase growth rates and results in poorer feed efficiencies. Pigs housed in temperatures of more than 75°F (too hot) will have a reduced feed intake. Feed intake will decrease by approximately

0.05-0.08 lb per 1°F above 75°F. In hot environments the growth rate is expected to decrease by approximately 0.03-0.04 lb/day for every 1°F above 75°F. The decreased growth rate reduces feed efficiencies and lengthens the time needed to achieve market weight.

Gestating Sow Diets

The objectives of this diet are to promote the sow's targeted weight gain, to support optimal litter development and lactation. This diet is grain-soybean meal based (around 14% CP) and contains higher levels of vitamins and minerals than the grow-finish diets in order to ensure nutrient requirements are met under the limit-feeding program. The gestation diet is limit-fed in order to avoid over-consumption and obesity, which will decrease the sow's reproductive performance and feed efficiency. Under-feeding is also a major concern as it contributes to poor reproductive performance and lactation. Therefore, it is critical that a balanced diet be maintained during all stages of a sow's life cycle. Important factors that affect the nutrient requirements of the gestating sow include feed management, body condition and environmental conditions.

Feed Management – During gestation, the pregnant sow requires nutrients and energy to maintain her bodily functions and to supply the developing litter. The sow's body maintenance represents 75%-85% of her total energy requirements, while maternal weight gain accounts for the remaining 15%-25%. The actual feed allowances needed to meet these requirements are influenced by factors including the sow's weight, energy density of the diet and the amount of weight gained. Because so many factors influence the sow's feed requirements, a successful feeding strategy will be based on each individual sow's needs. Accordingly, each sow's feeding program is based on some estimate of that sow's body condition at the time of breeding.

Limit-Feeding – A feeding strategy in which pigs are fed a specific amount of food in a time period to keep body weight and nutrient levels within a given range.

Body Condition – Achieving the proper weight gain during gestation is very important. Sows that experience excessive weight gain during gestation are prone to lowered feed consumption and greater weight loss during lactation. In general, healthy weight gain ranges are 60-85 lbs for sows and 75-100 lbs for gilts. In many operations, a "body condition score" is used to determine feed allowances for each sow based on prior experience and observations. The condition score basically assumes the level of fatness of a sow. The condition score is assigned by visual assessment and ranges from 1-5 (*see Figure 10*). A score of 1 signifies a very thin sow, while a score of 5

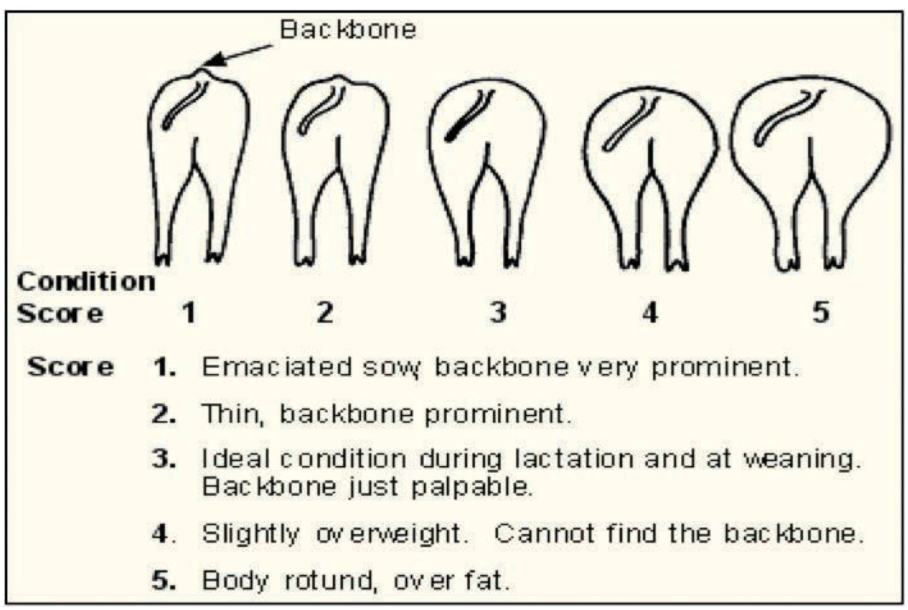


Figure 10. Example of Body Condition Scoring for swine.
(Source: Muirhead et al., 1997)

means a very fat sow. A condition score of 3-3.5 is the ideal/targeted score. Though the condition score system is widely used, it is not without its limitations, the most significant being the lack of scientific basis for loose correlation between feeding levels for particular scores.

Environmental Conditions – Barn temperatures should be kept within the range of 68°-70°F for sows kept on slated floors. A feed allowance increase of 2-3 oz per day is required for each 2°F below the optimal temperature range.

Lactating Sow Diets

The objective of this feeding program is to ensure that sows consume enough nutrients to maintain adequate body condition and optimize litter and reproductive performance. Lactating sows are fed to appetite (fed what they are expected to consume) a grain-soybean diet with around 19% CP. These diets are fed stair-wise (in increasing amounts) per day until the 7th day of lactation. This feeding system is designed to keep pace with the sow's increasing nutritional needs due to lactation. Generally, a feed allowance of 4.0 lbs + 1.25 lbs for each piglet is a good baseline for the minimum amount a lactating sow should be fed. Some of the most important factors that affect a lactating sow's nutritional requirements include feed management, parity, milk yield/composition and environmental conditions.

Feed Management – Generally, lactation diets should contain ingredients that are concentrated sources of energy (corn and soybean meal). Supplemental fats can be added to a diet in order to increase caloric density. Increasing caloric density when feed intake is insufficient due to lactation demands and heat stress helps maintain adequate body condition of the sow. Feeding fat supplements also increases the daily gain of nursing pigs, which translates into higher weaning weights. Special caution should be use to avoid the long-term storage of feed with high fat content, as the increased fat levels will cause bridging and caking in bulk storage bins.

Parity – Parity is the number of times a sow has given birth. Gilts are in their first parity as it is their first time giving birth. First parity sows can make up to around 35% of litters farrowed on a farm. Research has shown that gilts in their first and second parity mobilize more than 12% of their protein during lactation if they are not receiving sufficient nutrients. Sows with nutrient deficiencies in early parities will have decreased future reproductive performance, and the weaning weights of their future piglets will be reduced. Thus, it is very important that lactating sows intake enough nutrients to avoid excessive weight loss.

Milk Yield and Composition – Lactating sows produce up to 3 gallons (25 lbs) of milk per day. Relative to body weight, a sow produces more milk than a dairy cow. Because of this high milk production, the lactating sow's nutrient requirements are three times higher than during gestation. If nutrient needs are not met, the body will mobilize nutrients from the sow's muscle and bone support to milk production.

Environmental Conditions – Barn temperature in the farrowing rooms should be kept between 66°-70°F. High barn temperatures will decrease the feed intake of lactating sows, making them vulnerable to nutrient deficiencies. Generally, feed intake per day will decrease by 0.2 lb for every 1°F above 66°F. Flooring type will also greatly affect the sow's ability to shed excess body heat. Lighting can also affect the sow's feed intake; research has shown that exposure to 16 or more hours of light per day increased sows' feed intake, litter weaning weight and rebreeding performance.

Weanling/Nursery (Starter) Diets

These diets are the first dry feeds that a weaned pig consumes. Accordingly, weanling diets require more expensive/digestible sources of protein such as blood meal, fish meal and dried whey because of the reduced ability of weanlings to use complex proteins (soybean meal). Starter/weanling diets are grain based and fortified with specialty ingredients such as antibiotics and fats. These diets are phase-fed (usually three phases) with less complex and decreasing levels of crude protein in each subsequent phase. Starter-1 (weanlings) feed contains 21% CP and is fed until the pig weighs about 15 lbs. Starter 2 and 3 diets commonly contain a soybean protein source with lactose, dried milk and whey being reduced or eliminated due to the more mature digestive systems of nursery pigs. Starter 2 feed contains 20% CP; this diet is fed until the pig weighs about 25 lbs. Starter 3 feed contains 19% CP, and this diet is fed until the pig weighs about 50 lbs. Because of the complex ingredients in these diets, it is recommended that they be commercially purchased. However, Starter 2 and 3 diets can be mixed on-farm with the purchase of commercial base-mixes given the right conditions. Starter 2 and 3 diets typically include fats and antibiotics as growth promoters. Factors that affect the growth and performance of nursery pigs include feed management and environmental conditions.

Feed Management – Dietary formulation is critical to the growth and performance of newly weaned pigs. Weanlings require very specialized diet formulations due to their immature digestive systems. However, as the weanlings develop, so do their nutritional needs. Therefore, a nutritionally balanced phase feeding program must be used to keep nutrient supplies in step with needs. There are also economic advantages to synchronizing nursery diets to the pig's needs. Because the weanling diets are so complex, the ingredients are more expensive than the Starter 2 and 3 diets. By promptly adjusting dietary ingredients to match the pig's maturing digestive system, the producer will save a considerable amount of money through feeding the less complex diets.

Environmental Conditions – In addition to a good diet, proper temperature and ventilation promote pig development. Young pigs are extremely temperature sensitive, and exposure to stressfully low or high temperatures will severely impede growth performance. Nursery pigs have a general desirable temperature range of 70°-80°F, with an optimal temperature of 75°F. No amount of rations increases can make up for energy lost due to thermal stress in nursery pigs. The best way to remedy thermal stress-induced growth reductions is through proper environmental management.

Housing Management Systems

In Arkansas, the overwhelming majority of swine production is performed within controlled-environment buildings. These facilities make production easier through allowing greater control of the thermal environment and providing more direct observations of the pigs. Controlled-environment facilities also have the added advantage of taking up small amounts of land, leaving more available for crop production. Most controlled-environment facilities are operated in an “all-in/all-out” fashion, where pigs are moved in groups as they progress through the various phases and buildings are disinfected and cleaned in-between each group. The facility arrangement and in-door conditions constitute the environment of a given swine production system and have a great impact on both the production performance and health status of the pigs and workers. Each production type has its own unique features and environmental controls. But regardless of the type of facility used, the objective is the same: To provide the proper environment to maximize the productivity and well-being of the pigs and workers. Therefore, each type of facility requires a skillful balancing of capital investment, labor requirements and management decisions.

2-Site and 3-Site Production – Two-site production facilities typically consist of separate breeding and growing production systems. Three-site production facilities typically consist of separate breeding, nursery and growing production systems.

All-In/All-Out (AIAO) – This is the practice of housing pigs of the same age and size together in order to decrease disease-spreading opportunities. The groups of pigs are moved throughout the various rooms designated for each stage of swine development as a unit, hence the name all-in/all-out. This practice gives the housing managers the opportunity to thoroughly clean and disinfect all rooms in-between uses.

Thermal Environment – The thermal environment involves all factors that affect the energy (heat) exchange between the pig and its surroundings. Energy (heat) exchange is transferred between a pig and its surroundings by four basic methods: convection, conduction, radiation and evaporation. Understanding how the pig loses and gains heat is the key to understanding the interactions between the pig and its environment.

Conduction – Heat transfer through physical contact with another surface that has a temperature different from the pig’s core temperature. An example of heat transfer through conduction is when pigs lose/gain heat through contact with the floor (assuming floor temperature is different from the pig’s surface). Standing pigs will lose/gain less heat from the floor than lying pigs due to less contact area with the floor. Pigs use this to their advantage and adjust the amount of contact with the floor to suit their needs (i.e., sprawling on a cool floor when they are too hot).

Convection – Heat transfer through physical contact with air or water that is at a temperature different from the pig’s surface. A practical example of convection is the use of fans to blow cool air on pigs to reduce heat stress. Another example of convection heat transfer in action is when pigs experience cold drafts.

Radiation – Heat transfer through non-physical contact with surfaces that have temperatures that differ from the pig’s surface. An example of heat transfer through radiation is when a standing pig loses heat to a nearby barn wall with a temperature lower than that of the pig’s surface. This same principle applies to all surfaces that are within a pig’s surrounding environment.

Evaporation – Heat transfer through the conversion of water to vapor. As pigs lack sweat glands, most of their environmentally induced water loss is through respiration. Some major environmental components that affect evaporation rates are the humidity (amount of water vapor in the air), ambient temperature, speed of moving air and the pig's rate of respiration.

Optimal Thermal Environment – An optimal thermal environment is an environment that does not require an extraordinary physiological response from the pig to maintain comfortable body temperature. Temperatures that are outside of the optimal temperature range will induce "thermal stress" (*Table 2*). Facility managers must be very careful when assessing and troubleshooting the pig's thermal environment. All factors that affect energy exchange should be considered in order to correctly alter the thermal environment.

Table 2. Optimal Thermal Environment Ranges by Swine Type.

Breeder Boar – 68°F
Grow-Finisher – 55°-75°F
Gestating Sow – 68°-70°F (for sows kept on slated floors)
Lactating Sow – 66°-70°F
Nursery Pig – 70°-80°F, with an optimal temperature of 75°F

*Younger pigs are more susceptible to thermal stress than older pigs. Nursery pigs are especially prone to drafts from high airflow, and need environmental control systems that address this issue.

Thermal Stress – Exposure to temperatures outside of the pig's optimal temperature range induces a physiological response from pigs to maintain body temperatures. Temperatures above the optimal temperature are the Upper Critical Temperature (UCT), and temperatures below the optimal temperature are the Lower Critical Temperature (LCT).

Lower Critical Temperature (LCT) – The effective thermal environment where pigs need to consume more feed and apply other extraordinary measures to keep warm. Behavior responses that indicate cold stress include huddling, shivering and excessive feed consumption.

Upper Critical Temperature (UCT) – The effective thermal environment where pigs lower feed intake and take other extraordinary measures to cool off. Behavior responses that indicate heat stress include panting, lowered feed intake and lying spread-out on cool floors.

Assessments of the Thermal Environment – Pigs are highly adaptable to their environments, but it is often at a cost. The cost may be in the form of extra feed intake from cold stress or lowered feed intake due to heat stress. Properly evaluating the environment regularly and keeping the environment within optimal temperature ranges will reduce the likelihood of thermal stressors, conserve resources and promote swine productivity.

Ambient Air Temperature – An important environmental factor is ambient air temperature. The ambient air temperature is the air temperature inside of the enclosed housing facility. The air temperature relative to the pig's body temperature governs the level of heat exchange between the pig and its environment through convection, evaporation and radiation. The ambient temperature is significantly modified by changes in air moisture, airflow and the insulation of the barn walls.

Airflow – Another important factor is the speed of air (airflow) moving over the pigs. The airflow directly affects heat transfers from convection and evaporation.

Water Vapor – The amount of water vapor in the air and the air temperature control the evaporation of water during pig respiration.

Surface Temperatures – The surrounding surface temperatures are good indicators of the pig's thermal environment. The surface temperatures contacting the pig affect conduction heat transfer, while surface temperatures surrounding the pig affect radiation heat transfer.

Fan Ventilation Concepts

Fans are important components of mechanically ventilated facilities, as they are the driving force behind air exchange. Air exchange (replacing stale air with fresh air) is necessary for odor control, controlling moisture levels and establishing a healthy environment for pigs and workers. Several concepts must be understood in order to make sound decisions about proper fan usage, including static pressure, air delivery and fan efficiency. Fans should be selected based on air delivery and efficiency ratings. It is important to match the fan performance with the ventilation needs in order to optimize energy inputs with returns. The ventilation rate (for mechanically ventilated enclosure) is based on moisture removal (cold weather) or heat removal (mild and hot weather). Under-ventilation due to insufficient air exchange will result in poor air quality and is harmful to animal health, while over-ventilation wastes heat and is uneconomical.

Static Pressure – Static pressure is the difference in pressure that a ventilation fan creates between the inside and outside of the building. This concept is very important because ventilation fans are used to create a negative pressure indoors and therefore draw air into the building. In most animal barns, the static pressure operates in the range of 0.04-0.08 inch of water.

Air Delivery – Air delivery is the amount of air that a fan will move under different conditions and is expressed as the volume of air movement per unit of time (cubic feet per minute, cfm).

Fan Efficiency – Fan efficiency is the amount of air delivered per unit of electricity used, expressed as cfm per watt (cfm/W). Generally, small fans are less efficient than large fans.

Tunnel Ventilation – A system of large outward-facing fans used to pull air down the length of the house to provide the desired air exchange within a building. Tunnel fans have a larger air movement capacity and create "wind tunnels" to cool animals in summer. Tunnel fans also have the added advantage of being easily fitted with evaporative cooling pads on air inlets to provide further cooling of the air. Typically, air exchange rates vary by swine type (*Table 3*) and are manipulated by controlling the number of fans in operation at a given time.

Table 3. Ventilation Rate Recommendations by Swine Type.

Boars and Sows (cfm)
50 cfm/pig for cold weather
200 cfm/pig in hot weather
Nursery Pigs (by weight)
10-30 lbs – 2 cfm/pig
30-50 lbs – 4 cfm/pig
50-75 lbs – 7 cfm/pig
75-180 lbs – 9 cfm/pig

Barn Insulation Concepts

Insulation material slows down the conduction of heat through walls, ceilings and floors. Insulation is rated by "R-value," which is a measure of thermal resistance. The higher the insulation's R-value, the better its ability to slow down heat flow. The total R-value equals the rated "R" (per inch) multiplied by the thickness in inches;

i.e., and insulation with an R-value of 15 per inch is applied to a thickness of 4 inches for a total R-value of 60 (15x4). Adequate insulation is one of the most important and cost-effective measures available for improving the energy performance of heating/cooling systems housed within enclosed structures.

Barn Heating and Cooling Energy Sources

The choice between different heating and cooling energy sources is among the most important decisions producers face. Energy source decisions have a lasting effect on the practical functionality, finances and greenhouse gas emissions associated with swine operations. The two most common energy sources for heating barns in Arkansas are natural gas and propane. Both propane and natural gas are fossil fuels, meaning that they are generally formed through the compression and heating of organic matter within the depths of the earth.

Propane Basics – Propane (C_3H_8) is a hydrocarbon that is produced as a by-product from both the processing of natural gas and the refining of crude oil. Propane naturally occurs in a gaseous state; however. it can be changed to a liquid state as liquefied petroleum gas (LPG) when pressurized within a container. In its liquefied state, propane is 270 times more compact; therefore, it is more efficient and economical for propane to be stored and transported in its liquid state. The stored LPG will vaporize into a gas once the pressure in the container is released by opening a valve. This gaseous form of propane is what is used as a fuel source for heaters and other appliances.

Natural Gas Basics – Natural gas is a combustible mixture of hydrocarbon gases. The primary component of natural gas is methane (CH_4), but it also contains ethane (C_2H_6), butane (C_4H_{10}), carbon dioxide (CO_2) and propane (C_3H_8). Natural gas is colorless, odorless and tasteless, so the chemical mercaptan is added to the gas prior to distribution. Mercaptan has a distinct rotten-egg smell and is added to aid in leak detection. Natural gas is classified as being either "wet" or "dry." "Dry" natural gas is almost pure methane, while "wet" natural gas still contains significant concentrations of the other hydrocarbons. It is also important to note that "dry" natural gas (methane) can also be formed through the decomposition of organic matter (such as manure) by microorganisms. Natural gas is processed and refined to extract the non-combustible contaminants.

Comparison of Propane vs. Natural Gas

Energy Content Comparison – The energy content of propane and natural gas is measured in British Thermal Units (BTUs). A BTU is a measure of the amount of energy (heat) it takes to raise the temperature of 1 lb (approximately 1 pint) of water by 1°F. Per cubic foot, propane and natural gas contain 2,516 and 1,030 BTUs, respectively. By applying these numbers in various scenarios, the difference in energy content can be further expressed. For example, the differences in BTU affect the amount of fuel needed to provide the same amount of heat from a 100,000 BTU/hr furnace. A 100,000 BTU/hr furnace will use about 97 cubic feet of natural gas (100,000 ÷ 1,030 = 97.1) in one hour. The same 100,000 BTU/hr furnace will use about 40 cubic feet of propane (100,000 ÷ 2,516 = 39.7) in one hour. Propane has roughly twice the energy content of natural gas.

Cost Comparison – The cost comparison of propane and natural gas is easily made by considering the BTU energy and cost per unit of each fuel. Assuming the cost of natural gas is $15 per 1,000 (cubic feet) and propane costs $3 per 1,000 (cubic feet), the following is true. For $15, natural gas provides 1.03 million BTUs (1,030 BTUs x 1,000 cubic feet) of energy (68,666 BTU/$1), while propane provides over 2.5 million BTUs (2,516 x 1,000) of energy for $3 (833,333 BTU/$1). It is common practice to sell LPG propane by the gallon. Therefore it is important to know that 1 gallon of LPG is equal to 36 cubic feet of propane gas. For conversion simplicity, consultants should note that roughly 28 gallons of LPG propane is equal to 1,000 cubic feet of gas propane.

Environmental Impacts – According to the Environmental Protection Agency (EPA), natural gas is classified as a greenhouse gas when it is discharged directly into the atmosphere before combustion. A comparison of the toxicity of emissions from propane and natural gas reveals no significant difference, as both release minimal levels of toxins and cause no harm to air, soil and water resources if released into the atmosphere before combustion. Both fuels are considered to be clean-burning alternative fuel sources to coal-generated energy.

Biogas – Methane, the major component of natural gas, has the added availability of being able to be produced on-farm through anaerobic digestion of swine manure. The anaerobic digestion process requires specialized equipment to capture the methane as it is released from manure during microbial decomposition. This option is only suitable for producers with sufficient land and seed money to allocate toward digester placement and purchase. Producers who choose to utilize anaerobic digestion can significantly lower the carbon footprint and long-term energy costs of their operation if the CH_4 is captured and utilized.

Lighting Fixtures

The choice between different barn lighting sources also provides an opportunity for farmers to conserve energy and financial resources. Lighting is essential to the practicality of a barn and also can have major implications for both the animals and workers. Inadequate lighting in a barn presents a safety hazard for workers due to lowered visibility. There are also recommendations for the amount of light exposure for the different swine types. Breeding gilts are recommended to receive 14-16 hours of light exposure/day to promote healthy estrus cycling. Gestating sows are also recommended to receive 14-16 hours of light per day to assist in restarting estrus. Nursery pigs are recommended 24 hours of light exposure per day. Because lighting is so important to the production and economic efficiency of a swine operation, it is equally important to select the light source that best meets the farmer's energy and lighting needs. Two potential light bulb options for swine barns are light-emitting diodes (LED) and halogen lights.

Light-Emitting Diodes (LED) Basics – LEDs use diodes instead of traditional filament semi-conductors to generate light. A semiconductor is a material with the ability to conduct electrical current. In the case of LEDs, the conductive material is typically aluminum-gallium-arsenide (AlGaAs). When introduced to electrical current, the electrons within the AlGaAs become excited and release light (photons) as the major by-product of their rapid movement. LEDs are constructed to release a large number of photons outward. Additionally, they are housed in a plastic bulb that concentrates the light in a particular direction.

Halogen Light Basics – Halogen light bulbs emit light in a similar manner to traditional incandescent bulbs, through conduction of electricity through a semiconductive tungsten filament. The major difference is that the halogen bulb's filament is encased inside a small halogen gas-filled envelope. The gas (usually Argon) has a very interesting property; it combines with tungsten vapor. When the temperature inside the bulb is high, the halogen gas combines with the evaporating tungsten atoms and re-deposits them on the filament. This filament recycling process both extends the life of the bulb and allows the filament to emit more light, as it can be excited to a hotter temperature.

Comparison of Halogen vs. LED

Energy Efficiency – Halogen light bulbs give off 90% of their energy in the form of heat, only about 10% of the light produced is in the visible spectrum. This wastes a lot of electricity. LEDs only loose about 5% of their energy to heat production. The brightness of the light generated from light bulbs is measured in lumens, with higher amounts of visible light given off by bulbs with more lumens. Because of the high energy loss to heat, the halogen bulbs have less energy emitted as visible light, only about 10 lumens per watt. Conversely, the high energy efficiency of LEDs results in a light emission of about 55 lumens per watt. This means that a much higher percentage of the electrical input of LEDs is going directly to generating light, which cuts down on electricity demands considerably.

Cost Comparison – Halogen light bulbs have a significantly lower upfront cost than LEDs. However, due to halogen light's higher energy consumption, lower photon emissions per watt and shorter lifespan, the money saved during initial purchase is soon overcome by the money loss due to inefficiency.

Environmental Impacts – From an energy conservation standpoint, halogen lights have an indirectly negative impact on the environment because they waste energy. The lowered energy efficiency from unnecessary electricity consumption results in a proportionately higher release of GHG emission from the electricity source. From a practical perspective, the comparatively shorter lifespan of halogen lights means that per unit of time more halogen lights will be produced and discarded. Therefore, conceptually the energy use associated with the production, transport and replacement of halogen lights will be higher than that of LEDs on a per unit basis.

Manure Management Systems

Agricultural manure management systems (AMMS) are planned systems to control and use agricultural by-products in a manner that sustains and/or enhances the quality of natural and energy resources. AMMS must be developed using a total system approach which accounts for all manure associated with a given agricultural enterprise. Because manure varies in consistency, AMMS techniques and handling equipment will also differ accordingly. Swine in Arkansas are typically raised in a total confinement system, which allows for more automation in manure management. Manure is generally collected using slatted flooring and then handled as a liquid with either temporary or permanent storages underneath the production facility. Long-term storage and treatment are usually handled in a nearby anaerobic lagoon or holding pond.

Six Basic Functions of Swine Manure Management

1. **Production** – Production is a function of the amount and nature of the agricultural manure generated. The manure requires management if the amount produced is enough to become a resource concern.

2. **Collection** – Collection refers to the capture of manure from the point of origin. Swine manure can be collected by scraping or flushing. Scraped manure is collected as a solid or slurry, while flushed manure is handled as a liquid. The most common manure collection process in Arkansas is the practice of raising swine on slatted floors over manure storage pits.

3. **Transfer** – Transfer refers to the movement of manure throughout the management system. It includes the transfer of manure from the collection point to the storage facility, to the treatment facility and to the utilization site. Liquid and slurry manure may be transferred using pipes and portable tanks. Solids and semi-solids can be transported using mechanical equipment.

4. **Storage** – Storage is the temporary containment of manure. The storage facility is the tool that gives the manager control over the timing and scheduling of system functions. The manure storage period is ideally determined by the utilization schedule. Swine manure can be stored as solid, slurry or liquid. Solid manure should be protected

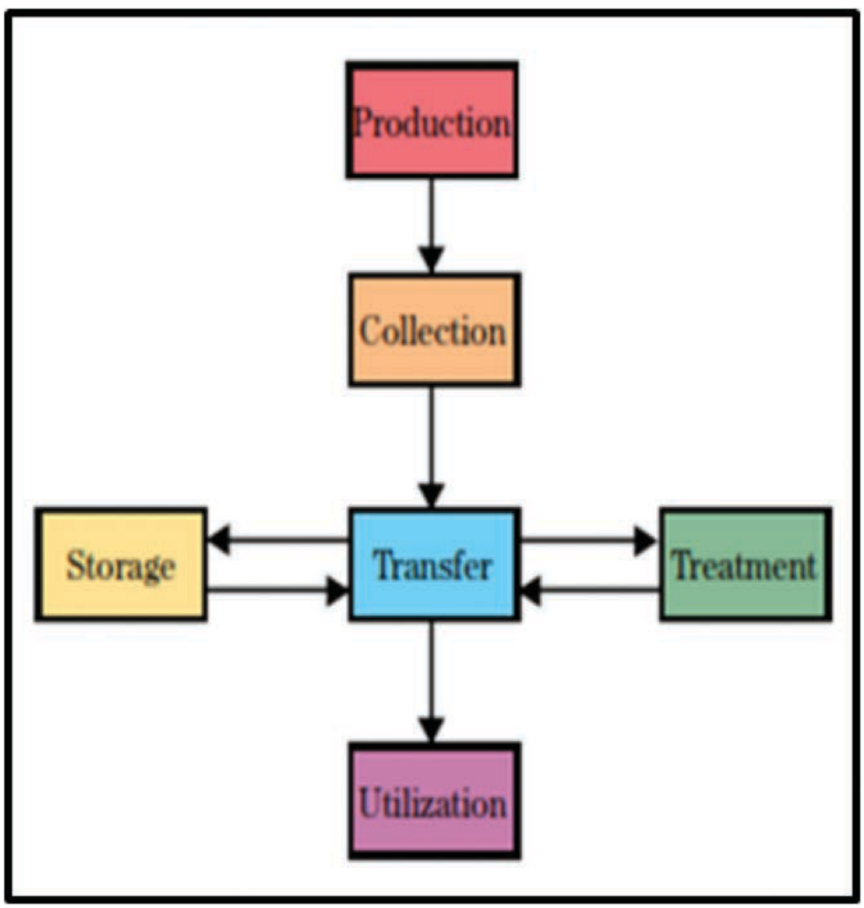


Figure 11. The six basic functions of swine manure management.
(Source: USDA-NRCS Agricultural Waste Management Handbook)

from precipitation and housed in a covered/closed structure. Slurry and liquid manure are stored in aboveground tanks or earthen storage ponds.

5. Treatment – Treatment is the function designed to reduce the pollution potential or modify the physical/chemical characteristics of the manure. Manure treatment consists of physical, biological and chemical processes. It also includes pretreatment activities, such as solids separation. Liquid swine manure is commonly treated in an anaerobic lagoon/digester. Solid swine manure can be composted.

6. Utilization – Utilization includes the reuse and recycling of manure products. Manure may be used as a source of energy, organic matter or plant nutrients. Swine manure can be used as an energy source through the anaerobic digestion process. Solid manure can be composted, and the heat generated from decomposition used as a supplemental heat for a building. The most common use of the nutrients in swine manure is land application. During land application, manure is hauled and distributed onto the land with a spreading device.

Swine Manure Chemical and Physical Composition

The physical and chemical composition of swine manure is dependent upon many factors including the pig's diet, age and health status. Listed below are manure characteristics and some common descriptive terms.

Solid Manure – Manure with higher than 20% solids content. Solids are usually collected with a scraper and stored in a drying facility.

Semi-Solid Manure – Manure with between 12% and 20% solids content. It can be pumped with a large-diameter manure pump. Solids separation may allow for easier management of the solids and liquids separately.

Liquid Manure – Manure with less than 10% solids content. Liquid manure is usually collected and transported by pumping into a storage pond or lagoon.

- Weight (Wt) – Quantity of mass, measured in lbs.
- Volume (Vol) – The space occupied in cubic units, measured in ft^3/gallon.
- Moisture Content (MC) – The liquid part of manure removed by evaporation and oven drying, measured in percentages.
- Total Solids (TS) – The residue remaining after water is removed through drying or evaporation, measured in percentages.
- Volatile Solids (VS) – The part of total solids driven off as volatile (combustible) gases when heated, organic matter, measured in percentages.
- Fixed Solids (FS) – The solids remaining after volatile gases are driven off, measured in percentages.
- Dissolved Solids (DS) – Part of total solids that pass through a filter during filtration, measured in percentages.
- Suspended Solids (SS) – Part of total solids that are removed by a filtration process, measured in percentages.
- Total Nitrogen (TN) – The amount of nitrogen within manure from all various nitrogen compounds, measured in percentages.
- Total P (TP) – A measure of all forms of phosphorous within manure, measured in percentages.
- Soluble Reactive Phosphorous (SRP) – A measure of orthophosphate (filterable and water soluble) fraction of phosphorous which is able to be taken up by plants.

Manure Collection and Transfer Options

Manure must be stored so that it can be used when conditions are appropriate. Storage facilities for manure of all consistencies must be designed to meet the needs of a given swine operation. Determining the storage period for a storage facility is important to the proper management of manure. If too short a period is selected, the storage capacity may be reached before the material can be used. Too long a storage period may result in excessive loss of nutrients (nitrogen) to volatilization. Many factors are involved in the selecting of storage periods. These factors include weather, crop(s), soil condition, equipment availability and labor requirements. Generally, when manure is land applied, a storage facility must be large enough to store the manure through a non-growing season (typically winter). A longer storage period allows for more flexibility in managing the manure. All swine manure storage facility designs must comply with NRCS Standard 313. Manure transfer systems should conform to NRCS Standard 634.

Flush – This storage option is for liquid manure only. Flushing is the practice of placing alleys below rows of slatted flooring. The animal's hoofs work the manure through the slats and into the alleys below. The manure is then collected by flushing the alleys below with large amounts of water. The amount of water used is critical, as it must be adequate to remove the manure. Water resources must be frequently replenished if flush tanks are used as the water supply. Flush systems may also rely on recycled lagoon water for the flushing liquid. This option is also labor intensive as flush alleys must be cleaned twice a day.

Shallow Pit then Storage Pond – This option is typically utilized to store liquid manure. In this storage option the manure is collected through slatted flooring and temporarily stored in shallow reception pits. The manure is then transported to a storage pond via centrifugal pumping or gravity pipes. The storage pond is an earthen containment unit used to retain manure and runoff liquid. Storage ponds are generally rectangular, but may be designed to any shape that is practical for the given operation. Pond liners made of clay or concrete are used to reduce permeability and improve the pond's operation. Earthen storage is very economical, as it is generally the least expensive type of storage. However, limited space availability, high precipitation and permeable soils can limit its practicality. Semi-solid manure placed in a storage pond will most likely have to be removed as a liquid unless precipitation is low or there is a means of draining the pond. If the pond is drained, the removal of solids requires extracting the settled solids with the appropriate equipment (backhoe-scrapper). If draining the pond isn't an option, the semi-solids can be re-suspended with agitation and pumped out. The re-suspension of solids is very time, labor and energy intensive. Liquid and slurry manure in ponds is typically stored for a given period prior to being transported for treatment or utilization. Storage ponds are designed in accordance with NRCS Standard 313.

Shallow Pit then Formed Storage – This storage option accommodates liquid manures. In this storage option the manure is collected through slatted flooring and temporarily stored in shallow reception pits. Liquid and slurry manure utilize formed storages such as aboveground or belowground tanks. Formed storages for liquid and slurry manure are expensive, as tanks are constructed from concrete, metals and other durable materials. The liquid and slurry manure is held in formed storage and then transported for treatment or utilization. The semi-solid manure can be mechanically or gravity separated and transported to a storage structure where it is allowed to further dry prior to utilization. The solids storages are accessible for loading and unloading and are often roofed. As the solid manure dries in storage, a portion of the nitrogen content will be lost to volatization. This nitrogen loss will lower the concentration of nitrogen in the manure in relation to the other major nutrients phosphorous (P) and potassium (K). Formed storages for manure require a relatively small amount of land availability and a moderate amount of labor, as the manure can be transported to the formed storage and held for relatively long periods. Factors to consider when designing formed storages for solids include the number and size of animals and the number of storage days desired.

Deep Pit – In this storage option the liquid manure is collected through slatted flooring and stored in deep reception pits. The deep reception pits are circular or rectangular and are often constructed of reinforced concrete. The pits are typically sized to hold all the manure produced over 180 days. The manure is removed from the pit using centrifugal or gravity pumps. This option is less labor intensive than shallower pits, as it allows for longer storage periods. There are also smaller secondary storage requirements because the manure can store in pits for longer periods of time. Once the manure has accumulated in the pits, it is transported for treatment or utilization.

Manure Treatment and Storage Options

In many cases, treatment is necessary before final utilization of manure. Treatment practices are designed to reduce the pollution potential of the manure through biological, chemical and physical means. The goals of treatment processes widely vary, as different treatments may target reductions in nutrients, harmful microorganisms or Total Solids (TS). Any manure treatment process is management intensive because treatment facilities require close monitoring.

Primary Treatments – Primary treatments include physical processes such as solid and liquid separation. Primary treatments are usually followed by secondary treatment prior to storage or land application. Swine manure contains solid materials that can be physically recovered. Solid separators are used to reduce the Total Solids (TS) content of the manure through mechanical or gravitational recovery methods.

Manure Separation Styles

Mechanical Separation (Screw Press) – Several kinds of mechanical separators can be used to remove solids from manure. One common mechanical separation device is the screw press. The screw press is a device that is designed to mechanically separate solid and liquid portions of animal manure. Slurry is pumped into the separator, and initial separation is achieved by gravity, as the screw forces the manure slurry through a tube and past a cylindrical wedge wire screen. The screen's port size ranges between 0.1 mm and 1.0 mm (0.04 inch). Solids are retained on the screen and transported by a screw auger toward a conical ejection port. Manure solids build up in the cylinder of the ejection port and are compressed before being discharged as manure solids (up to 80%). The separated liquids are transported to storage or utilization.

Gravity Separation (Settling Basin) – A settling basin is the most common device used to separate manure solids and other materials from liquids. A settling basin is a shallow pond that is designed for the gravity-driven accumulation of settled material. Once the slurry is deposited into the settling basin, the solid material is pulled to the bottom of the basin by gravity. After the solids have been allowed to settle, the upper liquid portion is removed from the basin via submerged pumps or pull-plugs, and the solids are manually collected. Generally, settling basins have access ramps and outlets that allow the removal of the settled solids by tractors and other equipment.

Secondary Treatments – Secondary treatment includes biological and chemical treatments such as lagoons and vegetative treatment areas. These additional treatment steps reduce the pollution potential of the manure prior to land application by reducing the nutrient contents.

Biological Treatment Options

Anaerobic Lagoons (Earthen) vs. Anaerobic Digesters (Container)

Anaerobic Lagoons (Earthen) – Anaerobic lagoons are widely utilized in Arkansas for the treatment of animal manure. In the lagoon, the manure is digested by microorganisms and methane gas is released as a by-product. The microbes within the lagoon break down the organic contents of the manure and leave behind mineral solids. Lagoons can also be used to reduce manure odors. Anaerobic treatment lagoons are designed on the basis of volatile solids' loading rate per area (1,000 cubic feet). The volatile solids are the portion of solid manure materials that will decompose. Anaerobic lagoons must be managed if they are to function properly. Regular lagoon maintenance includes monitoring of liquid levels and pH. Liquid levels must be maintained either below or at the maximum operating level. The optimal pH for a lagoon is 6.5. If the pH falls below the optimal levels, methane-producing bacteria are inhibited and gas production decreases. A lagoon should be constructed to avoid leakage and potential groundwater pollution. Anaerobic lagoons should be designed and planned in accordance with NRCS Standard 359.

Anaerobic Digesters (Container) – Anaerobic digestion is the process of storing liquid manure in airtight containers to be decomposed by microbes into methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S); i.e., biogas. Anaerobic digestion in itself is not a pollution control practice. The digester effluent (liquid manure discharge) must be managed similarly to undigested manure by storing in storage ponds or further treating in lagoons. A commonly used tank digester in Arkansas is the Plug and Flow Digester. The Plug and Flow Digester is used to facilitate more efficient and effective handling of thick manure (sludge). The manure enters through one end and moves as a "plug" to the other end. Achieving the appropriate TS content in the incoming manure is crucial, because if TS content is too low, the biogas production will be lowered as well. Because it provides complete containment, the Plug and Flow Digester is also useful in assisting with the management of manure odors.

Biogas – Anaerobic digestion for biogas productions is considered a utilization function because the manure is being managed for use. Although the relative abundance of CH_4 varies, biogas from animal manure is typically 65% CH_4. The amount of CH_4 produced from animal manure depends on the livestock type, manure handling method and climate. Biogas can be burned in boilers to produce hot water, in engines to power electrical generators and in heaters and air conditioners. Appropriate management of the produced biogas goes hand-in-hand with biogas production management. The most frequent problem with anaerobic digestion systems is related to the economical usage of the biogas. Because the biogas production is constant and storage of gas is expensive, the best utilizations of biogas as an on-farm energy source occur in situations where gas production closely matches with gas usage.

Manure Utilization

Land Application of Manure – Typically, manure is applied to land as a source of nutrients for plant growth. Manure can also be land applied to improve the soil's organic matter content, water-holding capacity and to control erosion. When applied at rates and times that match the needs of the crop to be grown, manure can significantly reduce the amount of commercial fertilizer needed for crop production. Animal manures vary widely in nutrient content due to rations fed to the animal, nutrient losses during storage and moisture content of the manure during storage. To accurately use manure, samples of the manure should be analyzed to reveal concentrations of the nutrients nitrogen (N), phosphorous (P) and potassium (K). The soil in the fields where the manure is to be applied should also be analyzed to reveal nutrient recommendations (nutritional needs of the soil). The soil nutrient recommendations coupled with the nutrient content of the manure indicate the rate at which the manure (nutrients) should be applied on a given field. The scheduling of land application of manure is very important, and several factors must be considered, including the availability of land and equipment, the amount of available manure storage and the weather conditions. NRCS Standard 590 provides detailed planning and design considerations for the land application of manure.

Manure is land applied using a variety of equipment. The main factors that determine the method of application are the Total Solids (TS) content of the manure and the availability of equipment. For solid manure from settling basins and solids storages, box spreaders are used for application. Slurry manures are applied using slurry spreaders such as tank wagons, “honey wagons.” Slurry spreaders are generally used to spread slurry manure that was stored in above/below-ground storage structures, earthen storages and lagoons. Liquid manure is usually applied using tank wagons or irrigated using large-diameter nozzles. The irrigation method is used to land apply liquid stored in tanks, lagoons and storage ponds.

Phosphorus Concerns and Manure Application – The phosphorous (P) content of manure intended for land application is of particular concern to farmers. Phosphorous is important for root development and is a key element in all energy functions within the plant. Arkansas soils are typically low in available P unless high amounts have been applied as fertilizer or manure. This is because P will accumulate in soils when application rates from fertilizer and manure exceed the removal rate in pasture, hay or other crop. Phosphorous accumulates at higher rates than N and K because most forms of phosphorous are readily absorbed by soil particles in a very stable chemical bond. For this reason, phosphorous is considered less prone to runoff unless moved with soil particles during erosion.

Phosphorous is a naturally occurring nutrient, and at high levels, it is usually not harmful to crop production. However, phosphorous is the nutrient that most often limits biological activity in aquatic plants within lakes and streams. In fact, very small increases in freshwater phosphorous levels can trigger excessive algae and aquatic vegetation growth. This increased rate of biological activity in response to increased supplies of nutrients is called “eutrophication.” Eutrophication can cause drinking water to have a foul odor and “off” taste. Advanced eutrophication can reduce aquatic wildlife populations by lowering the biological oxygen demand (BOD) to levels that deplete the available oxygen.

➤ Legal and Compliance

Federal Agencies

Food and Drug Administration (FDA) – The FDA is responsible for protecting public health by assuring the safety, efficacy and security of human and veterinary drugs, biological products, medical devices, our nation's food supply, cosmetics and products that emit radiation.

Environmental Protection Agency (EPA) – The mission of the EPA is to protect human health and the environment. To accomplish this mission, the EPA develops and enforces regulations, gives grants, sponsors partnerships, teaches people about the environment and publishes information.

Natural Resource Conservation Service (NRCS) – The mission of the NRCS is to provide national leadership in the conservation of soil, water and related natural resources. The NRCS provides balanced technical assistance and cooperative conservation programs to landowners and land managers throughout the United States as part of the U.S. Department of Agriculture (USDA).

State Agencies

Arkansas Soil and Water Conservation Commission (ASWCC) – Focal points are to manage and protect our water and land resources for the health, safety and economic benefit of the State of Arkansas.

Nutrient Management Plans (NMPs) – A nutrient management plan is a legal document that should be written by a certified planner in the format specified by the regulations that require it. In Arkansas, the format for NMPs evolved from the ASWCC's Title 22. Under Title 22, nutrient management plans should be written in accordance with NRCS Standard 590: Nutrient Management. Each nutrient plan will be different because the natural resource concerns and farm characteristics will be different. However, each plan should contain the same general elements and be in the same general format. Sections include:

1. Operation Design
2. Summary of Management Plan Actions
3. Legal and Compliance Requirements
4. Collected Information
5. Nutrient Application Calculation/Analysis
6. Recommendations
7. Record Keeping

Arkansas Act 1059 and Act 1061 – These acts identify nutrient-sensitive areas in the state and designate them as "Nutrient Surplus Areas" (NSA). NSAs require all nutrient applications (manure or fertilizer) to be done in accordance with a nutrient management plan. These acts are overseen by the ASWCC.

University of Arkansas Cooperative Extension Service (CES) – The Cooperative Extension Service is part of the University of Arkansas Division of Agriculture. The mission of the Division of Agriculture is to advance the stewardship of natural resources and the environment, cultivate the improvement of agriculture and agribusiness, develop leadership skills and productive citizenship among youth and adults, enhance economic security and financial responsibility among the citizens of the state, ensure a safe, nutritious food supply, improve the quality of life in communities across Arkansas and strengthen Arkansas families.

Arkansas Department of Environmental Quality (ADEQ) – The Department of Environmental Quality strives to protect and enhance the state's environment through regulatory programs, proactive programs and educational activities. While this overview focuses primarily on the Department's regulatory activities, almost every area of the agency also devotes time and personnel to outreach and education efforts.

Arkansas Regulation 6 – This law mandates that permitted CAFOs must implement a nutrient management plan that meets EPA standards. This regulation is overseen by ADEQ.

Arkansas Regulation 5 – This law requires that all livestock and poultry operations with liquid manure-handling systems obtain a nutrient management plan as a partial requirement for receiving a permit for operation. This regulation is overseen by ADEQ.

Arkansas Natural Resource Commission (ANRC) – The commission establishes policy and makes funding and regulatory decisions relative to soil conservation, nutrient management, water rights, dam safety and water resources planning and development.

AFO/CAFO Summaries and Guidelines

Animal Feeding Operations (AFOs) are agricultural operations where animals are kept and raised in confined situations. AFOs generally congregate animals, feed, manure, dead animals and production operations on a small land area. Feed is brought to the animals rather than the animals grazing or otherwise seeking feed in pastures. Animal manure and wastewater can enter waterbodies from spills or breaks of manure storage structures (due to accidents or excessive rain) and nonagricultural application of manure to crop land.

AFOs that meet the regulatory definition of a concentrated animal feeding operation (CAFO) may be regulated under the NPDES permitting program. The NPDES program regulates the discharge of pollutants from point sources to waters of the United States. CAFOs are point sources, as defined by the CWA [Section 502(14)]. To be considered a CAFO, a facility must first be defined as an AFO.

The National Pollutant Discharge Elimination System (NPDES) is a national program under Section 402 of the Clean Water Act for regulation of discharges of pollutants from point sources to waters of the United States. Discharges are illegal unless authorized by an NPDES permit.

In swine production, an Animal Feeding Operation (AFO) is a lot or facility where the following conditions are met:

- Pigs have been, are or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period.

- Crops, vegetation, forage growth or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

In swine production, a Concentrated Animal Feeding Operation (CAFO) is defined as an AFO that meets the following conditions:

- Contains at least 2,500 swine weighing 55 lbs or more.

- Contains at least 10,000 swine weighing 55 lbs or less.

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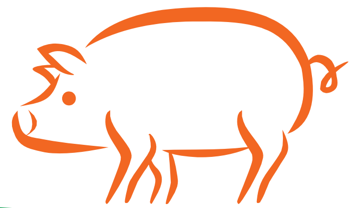
University of Arkansas System

Exploring Interactions Between Agricultural Decisions & Greenhouse Gas Emissions Using Swine Production



For Instructor Use Only

This section is for the use of instructors only. It is intended to assist instructors with supervising the lab exercise and *should not be distributed to students*.

The tables in this section contain the **Farm Management Option Guide**, which lists all **Components** and **Options** for each management system of this exercise. The Options Justification column details the expressed conditions under which each **Option** should be selected for the various **Components**.

These tables are included to assist instructors in critiquing the student's **Options** selections and **Consultant Report** statements.

Farm Management Option Guide

Pig Type Options	Feed System Options	Option Justifications (Feed Management)
Grow-Finisher	● **Base-mix (limit-fed)**	**Ractopamine HCL** (To increase growth rate and/or leanness)
	● Operations with corn grain/ soybean meal production/access	**Fats** (In response to thermal stress; to promote increased feed consumption)
	● Operations with appropriate storages	**Antibiotics** (In response to confirmed or suspected bacterial infections)
	● **Complete diet (limit-fed)**	**Anthelmintics** (In response to confirmed or suspected parasitic infections)
	● Operations without corn grain/ soybean meal production/access	**Enzymes** (To address manure P concerns, to improve P digestion)
	● Operations with appropriate storages	
Breeder Boars	● **Base-mix (limit-fed)**	**Fats** (In response to thermal stress; to promote increased feed consumption)
	● Operations with corn grain/ soybean meal production/access	**Antibiotics** (In response to confirmed or suspected bacterial infections)
	● Operations with appropriate storages	**Anthelmintics** (In response to confirmed or suspected parasitic infections)
	● **Complete diet (limit-fed)**	**Enzymes** (To address manure P concerns, to improve P digestion)
	● Operations without corn grain/ soybean meal production/access	**Ration increase** (In response to environmental. stress, or increase in workload)
	● Operations with appropriate storages	**Ration decrease** (In response to environmental. stress, or decrease in workload)
Gestating Sows	● **Base-mix (limit-fed)**	**Fats** (In response to thermal stress; to promote increased feed consumption)
	● Operations with corn grain/ soybean meal production/access	**Antibiotics** (In response to confirmed or suspected bacterial infections)
	● Operations with appropriate storages	**Anthelmintics** (In response to confirmed or suspected parasitic infections)
	● **Complete diet (limit-fed)**	**Enzymes** (To address manure P concerns, to improve P digestion)
	● Operations without corn grain/ soybean meal production/access	**Ration increase** (In response to environmental. stress)
	● Operations with appropriate storages	

Farm Management Option Guide (cont.)

Pig Type Options	Feed System Options	Option Justifications (Feed Management)
Lactating Sows	● **Base-mix (limit-fed)**	**Fats** (In response to thermal stress; to promote increased feed consumption)
	● Operations with corn grain/ soybean meal production/access	**Antibiotics** (In response to confirmed or suspected bacterial infections)
	● Operations with appropriate storages	**Anthelmintics** (In response to confirmed or suspected parasitic infections)
	● **Complete diet (limit-fed)**	**Enzymes** (To address manure P concerns, to improve P digestion)
	● Operations without corn grain/ soybean meal production/access	**Ration increase** (In response to environmental. stress)
	● Operations with appropriate storages	
Weanlings/ Nursery Pigs	● **Base-mix (phase-fed)**	**Fats** (In response to thermal stress/Phase 2 and 3 Base-mix)
	● Operations with corn grain/ soybean meal production/ access (Phases 2 and 3 only)	**Antibiotics** [In response to confirmed or suspected bacterial infections (any phase), or as a growth promoter Phase 2 and 3]
	● Operations with appropriate storages (Phases 2 and 3 only)	**Anthelmintics** (In response to confirmed or suspected parasitic infections)
	● **Complete diet (phase-fed)**	**Enzymes** (To address manure P concerns, to improve P digestion)
	● Operations without corn grain/ soybean meal production/ access (all phases)	
	● Operations with appropriate storages (all phases)	

Farm Management Option Guide (cont.)

Housing Options	Option Justifications (Housing Management)
Barn Type	**This category of options is designated based on operation type and goals.**
2-site	Growing and Finishing operations.
3-site	Breeding, Nursery and Growing operations.
Ventilation	**The main objective in this category of options is to balance ventilation needs (pig need based upon designated cfm), efficiency, $ expenditures, climate (N., mid, S.).**
Tunnel lg. 1	This option has lower energy consumption per cfm of air movement. Suitable for operations that (1) desire energy efficiency, (2) have long-term energy conservation goals, and (3) have GHG footprint concerns and can handle higher upfront costs (without immediate $ limitations). This option provides a higher immediate return for operations located in hotter climates due to their increased need for cooling ventilation in the summer.
Tunnel lg. 2	This option has higher energy consumption per cfm of air movement. This option is suitable for operations that (1) do not place a high emphasis on energy efficiency, (2) have no long-term energy conservation goals, (3) have no GHG footprint concerns, and (4) cannot handle higher upfront costs (have immediate $ limitations). This option may be more suitable in milder/cooler climates with less need for heat dissipation in summer.
Insulation	**The main goal in this category of options is to match insulation needs with each operation's local climate (N., mid, S.) and energy usage concerns (losses w/previous system).**
R-value 15 (low)	This option provides mid-level insulation. This option is suitable for operations that (1) do not report any serious problems with heat retention/indoor climate control, (2) are not concerned with maximizing the barn's energy efficiency, (3) are not concerned with GHG footprint emissions caused due to low energy efficiency, and (4) operations with small budgets which cannot afford the upfront costs (and still address other issues). This insulation option may be more suitable for operations located in milder climates (mid-state) which do not frequently experience very hot or cold temperatures.
R-value 25 (high)	This option provides the highest level of insulation. This option is suitable for operations that (1) have reported excessive energy usages and/or issues with indoor climate control, (2) are concerned with maximizing the barn's energy efficiency, (3) are interested in lowering GHG footprint through improved energy efficiency, and (4) operations with large budgets which can afford the upfront costs (and still address other issues). This insulation option may be more suitable for operations located in harsher climates that are prone to freezes and heat waves (northern and southern regions).
Heating	**The main considerations for this category of options are: the on-farm energy usage, GHG footprint, and $ expenditures.**
Propane and Natural Gas	Given that the virtual fuel prices, operation resources and concerns are detailed in the scenarios, allow students to calculate which fuel source is more economical at the given price per BTU output. Also ensure consideration is given to any physical limitations supplied, such as no gas lines being available on operation to guide consultant decisions. Pay special attention to interests in anaerobic digestion and methane capture technologies to hint toward natural gas energy (CH_4).

Farm Management Option Guide (cont.)

Housing Options	Option Justifications (Housing Management)
Lighting	**The main considerations are energy usage, GHG footprint and $ expenditures.**
LED	This lighting option provides maximum energy efficiency. This option is suitable for operations with (1) GHG footprint concerns, (2) long-term energy/$ conservation goals, and (3) an expressed need for emitted light increases based on a physiological recommendation (i.e., light exposure improves feed intake, rebreeding performance and litter wean weight in lactating sows).
Halogen	This lighting option provides low energy efficiency. This option is suitable for operations with (1) no GHG footprint concerns, (2) no long-term energy/$ conservation goals, and (3) an expressed interest in cutting upfront costs.
	Notes: Allow students to calculate monthly (i.e., 30 days) usage costs for LED vs. Halogen with scenario given the quotes on cost of electricity per kWh, amount of light bulbs per house, energy use per light (LED and Halogen) and lighting hours per day (from resource materials' lighting recommendations). *Although the calculations may not be necessary for scenario completion, the calculations are suggested as a tool to help reinforce the concepts of energy usage and efficiency as they relate to appliance selection.* The basic equation is: kW x hours = kWh Example: Power usage = 56 lights x 100 W/light = 5600 W or 5.6 kW On time = 7 am to 5 pm = 10 hours per day Monthly usage = 5.6 kW x 10 hrs/day x 30 days/month = 1680 kWh Monthly cost = 1680 kWh x $0.10/kWh = $168/month

Farm Management Option Guide (cont.)

Manure Options	Option Justifications (Manure Management)
Collection	**The main considerations for this category of optins are the producer's labor availability, storage time preferences and water availability**.
Deep-Pit	This option provides longer storage periods (180 days) and has the added advantage of allowing manure to be removed and go straight to utilization, storage or treatment. This option is suitable for producers with major labor limitations, manure-handling limitations (equipment) and land availability limitations. This option is not appropriate for producers interested in capturing gaseous emissions from manure through later treatment during anaerobic digestion.
Shallow-Pit	This option provides shorter storage periods (2-10 days). The wastes stored in this option can only proceed to further storages and/or treatment (not to utilization, as the storage period is not long enough to make direct utilization practical). This option is most suitable for producers with moderate labor availability and adequate land availability for placement of long-term storages and/or treatment facilities. This option is also appropriate for producers interested in capturing gaseous emissions from manure through later treatment during anaerobic digestion.
Flush Alley	This option provides very short storage periods, as the wastes must be cleaned out (flushed) several times a day. This option is most suitable for producers with high labor availability and adequate land available for placement of long-term storage and/or treatment facilities. This option is also appropriate for producers interested in capturing gaseous emissions from manure through later treatment during anaerobic digestion. This option requires a substantial amount of water for flushing the alleys; any restrictions on water availability would allude to avoiding this option.
Separation	**The main considerations are the producer's labor availability and manure application/utilization preferences (solid or liquid).** ***NOTE:** *Solid separation is only necessary for producers who express or have a need for it. Producers may have various reasons for wanting manure separated, such as a preference to land apply manure as a solid. Producers who intend to transport manure for off-site utilization will benefit from the moisture removal of solid separation (which lowers the weight of the transport costs).*
Screw-Press	This separation option is highly mechanically automated; therefore, it is a practical separation method for producers with limited labor resources.
Settling Basin	This separation option requires moderate labor availability, as there is a relatively higher manual labor requirement due to the frequent handling of the settled solid manure. Solid manure is generally manually removed from the basin by scrapping and loading into a backhoe or into a liquid storage/treatment facility.
Treatment	**The main considerations for this category of options are producer's preferences for manure utilization, land availability for placement of treatment facilities and methane capture and utilization.** ***NOTE:** *Anaerobic treatment is only necessary for producers who express or have a need for it. Anaerobic digestion is the only mechanism presented in this exercise that allows for the capture and recovery of methane emissions from manure.*
Earthen Lagoon	The earthen treatment platform is relatively cheaper than concrete/metal-constructed storages due to the need for fewer construction materials. This treatment option requires moderate land availability for lagoon placement. Earthen lagoons can accommodate solid/liquid mix or liquid manure. Methane capture and recovery is possible with this option.
Plug-Flow Digester	The metal construction of the plug-flow digester makes this option more expensive than earthen storage. This treatment option requires less land for installment and provides odor control because it is a sealed containment system. Plug-flow digesters accommodate solid/liquid mix or liquid manure. Methane capture and recovery is possible with this option.

Farm Management Option Guide (cont.)

Manure Options	Option Justifications (Manure Management)
Storage	**The main considerations for this category of options are the producer preferences/goals, manure type (solid/liquid), cost availability, land availability, labor availability and GHG production.**
Earthen (Liquid)	This option has the capacity for liquid manure only, so it is a storage option that requires no pretreatment (solids separation). This option is relatively the cheapest storage method. This option also has the largest land commitment requirement of the presented storage methods, but has a moderate labor requirement (solids agitation/re-suspension). This storage option releases minimal gaseous emissions from nitrogen volatization.
Aboveground Liquid	This option has the capacity for liquid manure only, so it is a storage option that requires no pretreatment (solids-separation). This option has a relatively small land requirement and low amount of labor needs. There is a high material/construction cost associated with this option, which makes it the most expensive storage option. This storage option releases minimal gaseous emissions from nitrogen volatization.
Aboveground Solid	This option can only receive solid manure, so manure must be pretreated (solid separation) before storage. This option requires a relatively small amount of land and a moderate level of labor due to low frequency of manure handling. There is also a moderate material/construction cost associated with this option, making it a relatively inexpensive storage option for solids. There is a moderate amount of nitrogen volatization that can occur, but this should not deter GHG-consciencious producers from this storage option.
Utilization	**The main considerations for this option category are producer preferences/goals, land availability, manure production rate and storage capacity, application equipment availability and GHG production.**
Land Applied	The on-site land application of manure requires land availability. Therefore, this option is only appropriate for producers with crop-land or pasture available. This option also provides revenue for the operation as the cost of operating the spreading equipment is less than the money saved by not having to purchase commercial fertilizer. There are moderate levels of nitrogen volatization that can occur when manure is land applied, but this should not deter GHG-concerned producers from land applying manure.
Transported	This option is appropriate for producers without any crop-land or pasture available. This option is relatively more expensive than on-site utilization because of the transportation costs associated with manure transport. This option generally releases more GHG emissions than on-site manure use, as the manure is often transported large distances before utilization on another farm or energy conversion center.

Name ______________________________

Date ______________________________

Scenario #1 – Feed

Farm Resources:

- Farmer expressed a modest budget allocated toward feed management renovations.

  $ Range: (-3) -3

- Farmer expressed need to conserve the operation's Feed Management System Greenhouse Gas emissions.

  GHG Range: < (-2)

Farmer Notes:

- The farm is a 2-site grow-finish operation with consultation focus on the finishing herd.
- Manure is intended for on-farm land application on phosphorous-sensitive soils.
- Farmer is on a tight deadline for pigs to reach market weight.
- Average observed barn temperature is 54°F.
- Farm has capacity to supply corn grain and soybean meal components of feed.
- Farm has appropriate feed storage available.
- Farmer observed white discharge from snout of pigs and later confirmed it to be a bacterial infection.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #1 – Housing

Farm Resources:

- Farmer expressed a moderate budget allocated toward barn renovations.

  $ Range: 21-25

- Farmer expressed a sincere need to mitigate the operation's Greenhouse Gas emissions.

  GHG Range: < (-2)

Farmer Notes:

- Farm is a 2-site grow-finish operation and operator requested that the consultant make general recommendations.
- Farmer wants to lower the long-term electricity budget and expressed a desire to explore energy saving options.
- Farmer expressed a concern about regulating the barn's climate and requested that the consultants make insulation recommendations.
- Farmer expressed that the farm is located in a climate that experiences modest summer heat followed by moderate winter temperatures. The farmer views the barn's ventilation needs as modest and requested that the consultants make ventilation recommendations.
- Farmer has pre-existing accommodations for natural gas and propane and requests that the consultants make recommendations for heating fuel source.
- Farmer wants to use the most economical fuel source, local fuel prices as follows:

  Propane – $16.20 per cubic foot
  Natural Gas – $8.15 per cubic foot
  Note: The barns furnace uses 100,000 BTU/hour.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #1 – Manure

Farm Resources:

- Farmer expressed a moderate budget allocated toward manure handling system renovations.

  $ Range: 7-15

- Farmer expressed need to conserve operation's Greenhouse Gas emissions.

  GHG Range: < (-2)

Farmer Notes:

- Farm is a 2-site grow-finish operation and operator requested that the consultant make general recommendations.
- Farmer wants to collect manure using the most carbon footprint conservative method available.
- Farmer expressed a concern about the amount of land available for liquid manure storages and requested that consultants make recommendations on the most appropriate storage type.
- Farmer advises that all manure is to be applied to on-site pastureland using a truck spreader.
- Farmer expressed a desire to invest in any energy recovery technologies that would allow him to reduce the farm's Greenhouse Gas emissions and requested that the consultants make recommendations.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #2 – Feed

Farm Resources:

- Farmer expressed a moderate budget allocated toward feed management renovations.

  $ Range: 5-10

- Farmer expressed little focus on moderating the Feed Management System Green-house Gas emissions.

  GHG Range: (-3) -3

Farmer Notes:

- Farm is a 3-site grow-finish operation with consultation focus on the finishing barn.
- Manure is intended for off-farm utilization as a fertilizer.
- Farmer is on a tight deadline for pigs to reach market weight.
- Average observed finishing barn temperature is 54°F.
- Farm has no corn or soybean production to supplement feed.
- Farm has appropriate feed storage available.
- Farmer confirmed parasitic earworm infections in the finishing herd.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #2 – Housing

Farm Resources:

- Farmer expressed a moderate budget allocated toward barn renovations.

  $ Range: 17-20

- Farmer expressed little focus on moderating barn's Greenhouse Gas emissions.

  GHG Range: -3 to +3

Farmer Notes:

- Farm is a 3-site grow-finish operation with consultation focus on the nursery barn.
- Farm is located in a climate characterized by mild temperatures in summer months followed by moderate winter temperatures.
- The nursery barn experiences frequent drafts during the winter months, with an average observed nursery barn temperature of 65°F.
- Farm can accommodate propane or natural gas. Farmer wants to use the most economical fuel source, local fuel prices as follows:

  Propane – $13.50 per cubic foot
  Natural Gas – $5.25 per cubic foot
  Note: The barn's furnace uses 180,000 BTU/hour.

- Farmer expressed wishes to furnish the barn's lighting fixtures with as little upfront costs as possible.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #2 – Manure

Farm Resources:

- Farmer expressed a modest budget allocated toward manure management system renovations.

  $ Range: 8-13

- Farmer expressed little focus on moderating barn's Manure Management System Greenhouse Gas emissions.

  GHG Range: 4-8

Farmer Notes:

- Farm is a 3-site grow-finish operation and operator requested that the consultant make general recommendations.
- Farmer has five sons on-hand to assist with daily manure management and requested that consultant make recommendations to help accommodate his situation.
- Farmer intends to sell manure as a packaged dry fertilizer and give liquids to a neighbor for utilization.
- The farmer mentioned that there are several acres available for placement of manure management structures.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #3 – Feed

Farm Resources:

- Farmer expressed a modest budget allocated toward feed management renovations.

  $ point range: 4-8

- Farmer expressed some interest in moderating operation's Greenhouse Gas emissions.

  GHG point range: -3 – (3)

Farmer Notes:

- Farm is a 3-site nursery-finish operation with consultation focus on Gestating Sow barn.
- Manure analysis reported high phosphorous content.
  - Farmer intends to sell manure as fertilizer and desires a reasonably balanced nutrient content.
- Average observed barn temperature is 69°F.
- Farm has no corn or soybean production to supplement feed.
- Farm has appropriate feed storage available.
- Recently the gestating herd was assessed and averaged a body score of 2.
- Farmer confirmed the presence of roundworms in the gestating herd.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #3 – Housing

Farm Resources:

- Farmer expressed a modest budget allocated toward barn renovations.

  $ point range: 12-17

- Farmer expressed some interest in moderating operation's Greenhouse Gas emissions and will not object if the consultant finds a way to conserve GHG emissions while not exceeding the budget.

  GHG point range: 0 – (2)

Farmer Notes:

- Farm is a 3-site nursery-finish operation with consultation focus on Gestating Sow barn.
- Lighting preferences were not specified. Farmer requests consultant recommendations.
- The farmer expressed little concern with internal climate regulation, but wanted to invest in steps to ensure proper air mixture to avoid cold/hot zones within the barn.
- Average observed barn temperature is 69°F.
- Farm has pre-existing accommodations for natural gas and propane. Farmer wants to use the most economical fuel source, local fuel prices as follows:

  Propane – $11.00 per gallon
  Natural Gas – $9.00 per cubic foot
  Note: The barn's furnace uses 120,000 BTU/hour.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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Consultant Recommendation Statements *(cont.)*:

Name ______________________________

Date ______________________________

Scenario #3 – Manure

Farm Resources:

- Farmer expressed a modest budget allocated toward manure management renovations.

  $ point range: 8-10

- Farmer expressed some interest in moderating the operation's Manure Management System Greenhouse Gas emissions.

  GHG point range: 2-5

Farmer Notes:

- Farm is a 3-site nursery-finish operation and operator requested that the consultant make general recommendations.
- Farmer is mobility impaired due to a recent health issue and has little help on-hand to assist with daily manure management. Farmer wants to collect manure once every 3-4 months.
- Farmer intends to sell and transport the majority of the manure off site as a solid fertilizer, but also wants to land apply a portion as a liquid fertilizer.
- Farm has limited space available for the placement of manure management structures, but expressed an interest in methane recovery technologies.

Consultant Report

Operation's Greenhouse Gas (GHG) Score: ______________

Operation's Monetary ($) Score: ______________________

Consultant Recommendation Statements:

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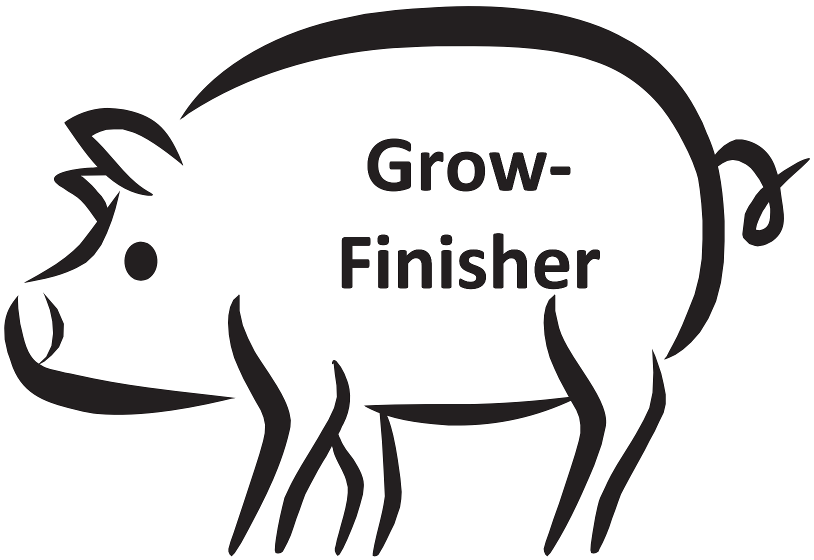
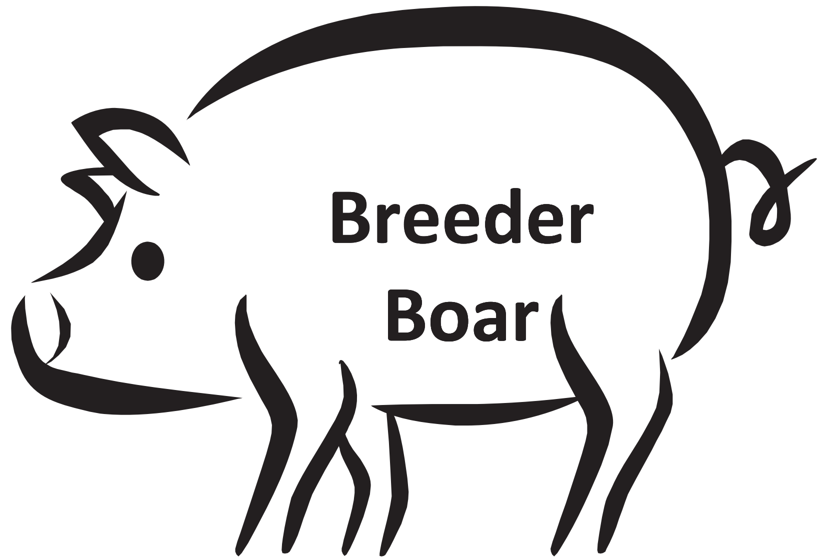
Consultant Recommendation Statements *(cont.)*:

Health and Feed
(front only)



Definition:
Mature pigs (50 – 290 lbs.) intended for market and processing into food.
Things to consider:
Age (body condition), Gender, Environment (temperature), Feed management (additives and feed practices)

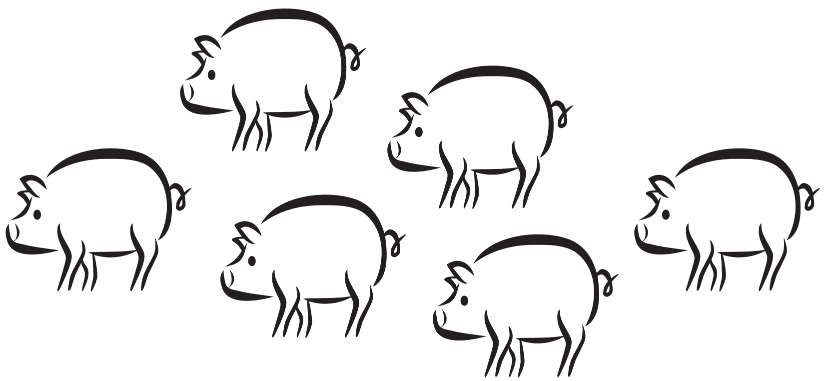


Definition:
Adult male pigs used for natural of artificial mating purposes.
Things to consider:
Age (body condition), Environment (temperature), Workload

Health and Feed
(front only)

Definition:
A pregnant adult female pig.
Things to consider:
Body condition (condition score), Feed management, Environment (temperature)

Definition:
Adult female pig that is producing milk to supply nutrients to a recently farrowed litter
Things to consider:
Feed management, Parity, Environment (temperature), Milk yield/ composition.



Weanlings/Nursery Pigs

Definition:
Pigs from weaning to about 8-10 weeks of age.
Things to consider:
Feed management (age) and Environment (temperature),

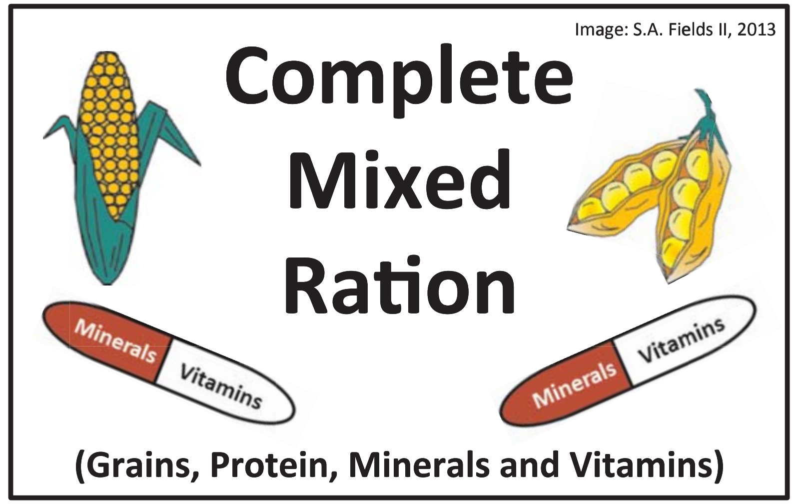
Health and Feed
(front)

Base-mix System

Mineral and Vitamin Basemix

In this system, pre-mixed vitamins and minerals are purchased and added to farmer supplied grains and soybean meal (protein source). This system is best for larger producers, or those whom have access to bulk soybean meal/ grain supplies and need dietary flexibility.

Complete Diet System



In this system, completely commercially mixed diets are purchased from a manufacturer and delivered in bulk. This system is best suited for small operations without access to bulk grain/soybean meal supplies. Specialty feeds, such as starter diets are best served by this ration type.

Health and Feed
(back)

Base-mix System

GHG: -2 (Net)

- Lowered feed transport emissions, (-)(-)(-)
- Less precise diet mix, (+)

$: -2 (Net)

- Lowered feed transport costs, (-)(-)(-)(-)
- Feed mixing labor, (+)
- Feed storage maintenance, (+)

Complete Diet System

GHG: +3 (Net)

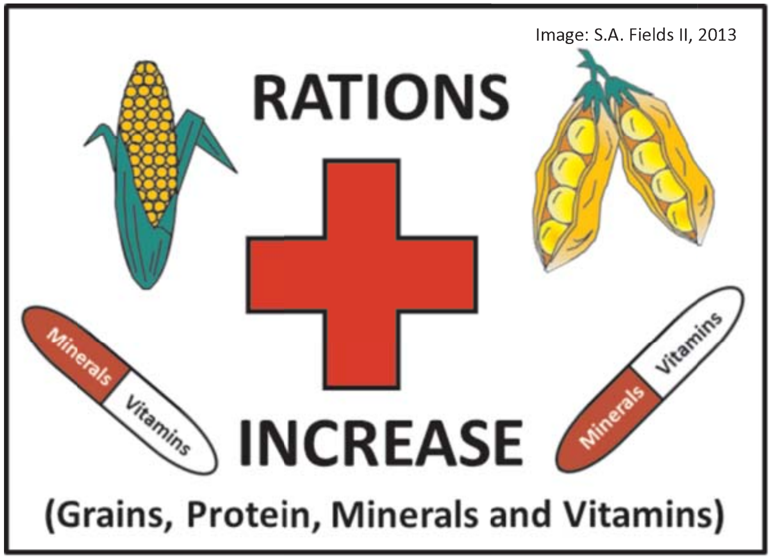
- Increased feed transport emissions, (+)(+)(+)
- Precisely mixed diets, (-)

$: +3 (Net)

- Feed purchase and transport costs, (+)(+)(+)
- Feed mixing labor, (-)
- Feed storage maintenance, (+)

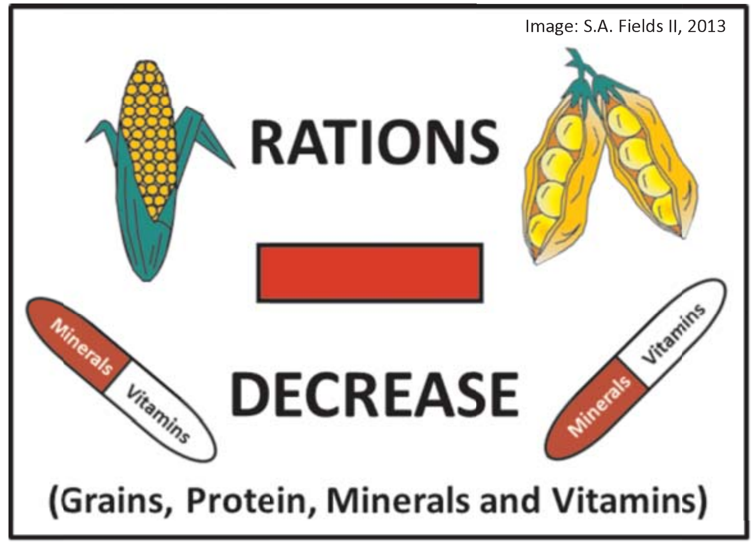
Health and Feed
(front)

Feed Additive



Increase the rations for a given swine type by an amount recommended by the dietary consultant.

Feed Additive



Decrease the rations of a given swine type by amount recommended by dietary consultant.

Health and Feed
(back)

Rations Increase

GHG: -2[work] **or +2**[thermal] **(Net)**

- **If changed due to workload; balancing nutrients improves feed efficiency, (-)(-)**
- **If changed due to thermal stress; decreased feed efficiency, (+)(+)**

$: 0 [work] **or +4** [thermal] **(Net)**

- **Increased feed usage, (+)(+)**
- **If changed due to workload; increased feed efficiency, (-)(-)**
- **If changed due to thermal stress; decreased growth performance and feed efficiency, (+)(+)**

Rations Decrease

GHG:-2[work] **or +2** [thermal] **(Net)**

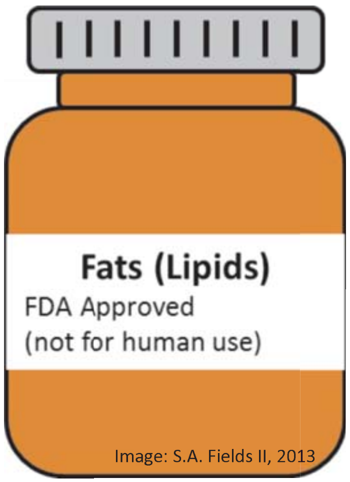
- **If changed due to workload; balancing nutrients improves feed efficiency, (-)(-)**
- **If changed due to thermal stress; decreased feed efficiency, (+)(+)**

$: 0 [thermal] **or -4** [work]**(Net)**

- **Decreased feed usage, (-)(-)**
- **If changed due to thermal stress; decreased growth performance, (+)(+)**
- **If changed due to workload; increased feed efficiency, (-)(-)**

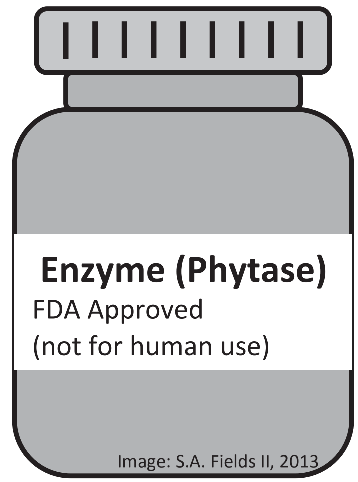
Health and Feed
(front)

Feed Additives



Fats are used when special dietary requirements need to be met due to changes in the pig's environmental or physiological conditions.

Feed Additives



Enzymes stimulate the pig's digestive system and aid in breaking-down feed components. Enzymes can also be used to release minerals (i.e. Phytase releases Phosphorous) that are bound in unusable forms, therefore making them available to be used by the pig.

Health and Feed
(back)

Fats

GHG:-2 or +2 (Net)

- If fed to boost energy intake; balancing nutrients improves feed efficiency, (-)(-)
- If fed due to thermal stress; decreased feed efficiency, (+)(+)

$: -1 or +3 (Net)

- Purchase and mixing, (+)
- If changed to boost energy; increased feed efficiency, (-)(-)
- If changed due to thermal stress; decreased growth performance, (+)(+)

Enzyme (Phytase)

GHG:-3 [land] or 0 (Net)

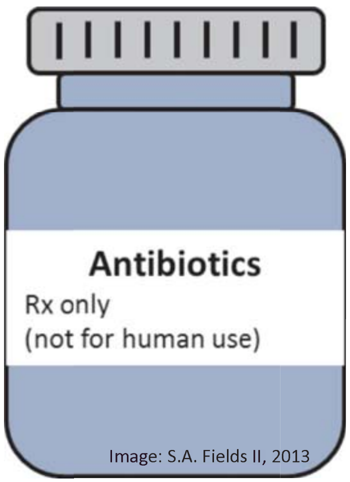
- If manure is land applied; improved nutrient management, (-)(-)(-)
- If manure is transported off-site, 0

$: -1 [land] or +2 (Net)

- Purchase and mixing, (+)(+)
- If manure is land applied on farm; improved nutrient management, (-)(-)(-)
- If manure is transported off-site, 0

Health and Feed
(front)

Feed Additives



Definition:
This feed additive is made from bacteria and mold extracts and is used to inhibit the growth of harmful microorganisms that cause sickness.

Feed Additives

Definition:
This additive is a compound that is used to expel parasitic worms from the body.

Health and Feed
(back)

Antibiotics

GHG:-2 (Net)
- Improved feed efficiency, (-)(-)

$: +1 (Net)
- Purchase and administration of medicine, (+)(+)(+)
- Improved feed efficiency, (-)(-)

Anthelmintic

GHG:-2 (Net)
- Improved feed efficiency, (-)(-)

$: +1 (Net)
- Purchase and administration of medicine, (+)(+)(+)
- Improved feed efficiency, (-)(-)

Feed Additives

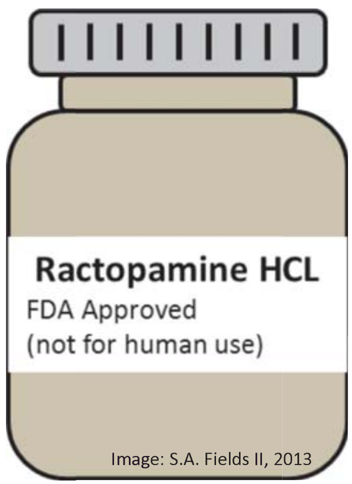


Image: S.A. Fields II, 2013

Definition:
This feed additive is a beta-antagonist used to decrease fat depositions and increase lean tissue (muscle). It is added to feed at very specific amounts to meet federal guidelines.

Ractopamine HCL

GHG:-2 (Net)

- Improved feed efficiency [growth performance and leanness], (-)(-)

$: -2 (Net)

- Purchase and administration of supplement, (+)(+)(+)
- Improved time to market weight and leanness, (-)(-)(-)(-)(-)

Housing Management
(front)

2-Site Production

The Breeding herd and the Growing herd are separated onto two individual sites.

3-Site Production

The Breeding herd, Nursery, and Growing herd operations are separated onto three individual sites.

Housing Management
(back)

2-site Production

GHG:0 (Net)

- No GHG points are assessed for this option

$: 0 (Net)

- No $ points are assessed for this option

3-site Production

GHG:0 (Net)

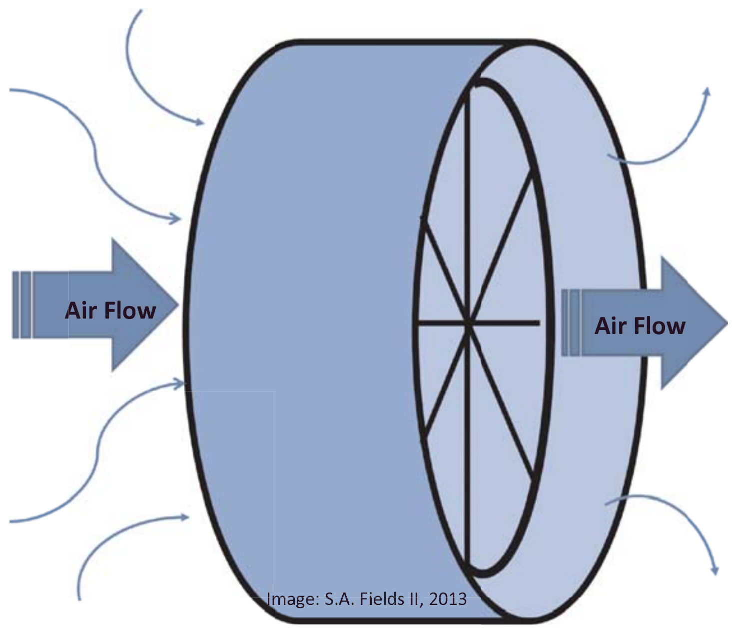
- No GHG points are assessed for this option

$: 0 (Net)

- No $ points are assessed for this option

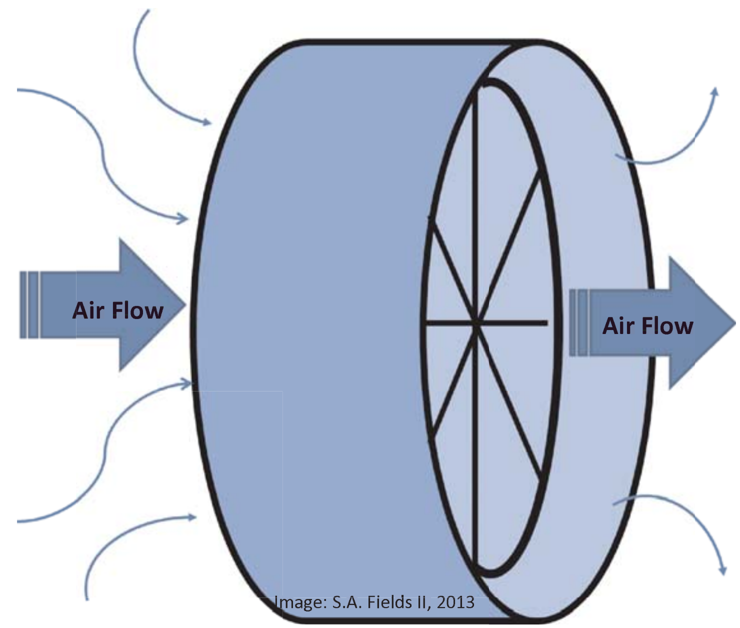
Housing Management
(front)

Tunnel Ventilation 1



Barn ventilation is performed using a sequence of strategically placed Tunnel Fans. Fan specifications, (20,000 cfm & 25 cfm/W).

Tunnel Ventilation 2



Barn ventilation is performed using a sequence of strategically placed Tunnel Fans. Fan specifications, (20,000 cfm & 12 cfm/W).

Housing Management
(back)

Tunnel Ventilation 1

GHG:-3 (Net)

- Energy efficient ventilation, (-)(-)(-)

$: +6 (Net)

- Higher up-front cost, (+)(+)(+)(+)(+)(+)
  - This option will save the farm operation a significant amount of money over the long-term through high energy efficiency.

Tunnel Ventilation 2

GHG:+2 (Net)

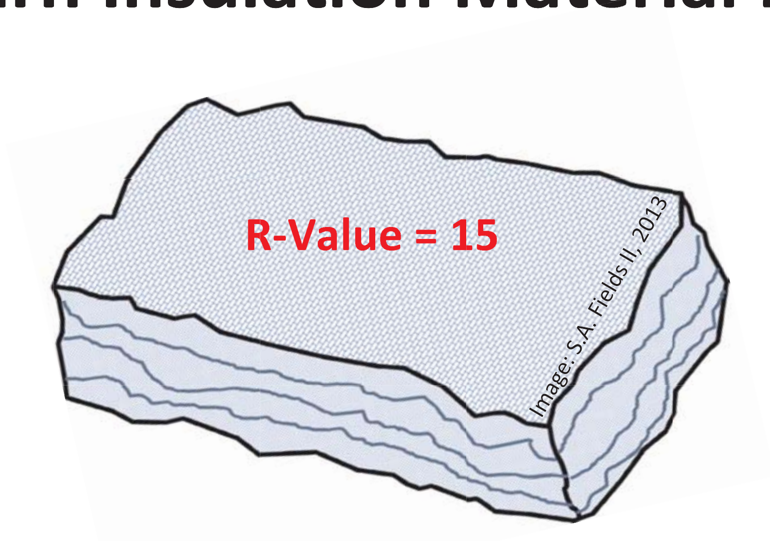
- Energy inefficient ventilation, (+)(+)

$: +3 (Net)

- Lower up-front cost, (+)(+)(+)
  - This option will cost the farm operation a significant amount of money over the long-term through poor energy efficiency.

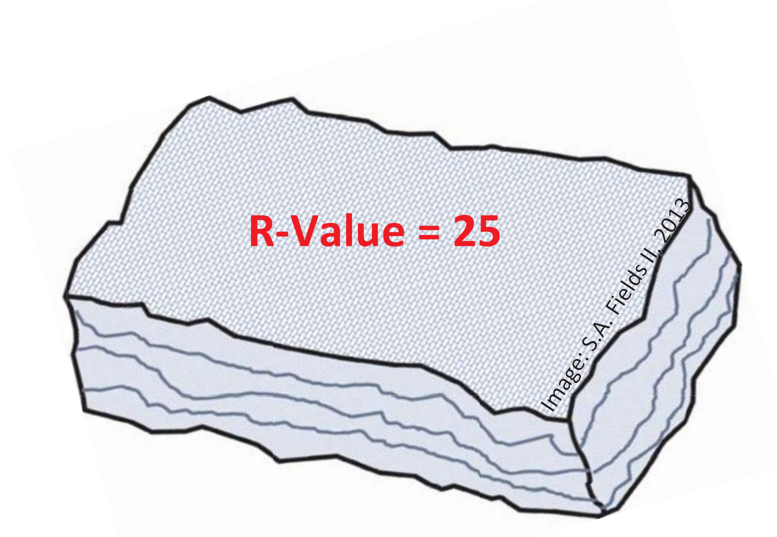
Housing Management
(front)

Barn Insulation Material 1



The efficiency rating of the insulation material is expressed as the “R-value”. The Higher the value, the better the performance of the insulation material. Conversely, the lower the R-value the less efficient the insulator.

Barn Insulation Material 2



The efficiency rating of the insulation material is expressed as the “R-value”. The Higher the value, the better the performance of the insulation material. Conversely, the lower the R-value the less efficient the insulator.

Housing Management
(back)

Insulation Material 1

GHG:+2 (Net)

- Energy inefficient insulation, (+)(+)

$: +10 (Net)

- Lower up-front cost, (+)(+) (+)(+)(+)(+)(+)(+)(+)(+)
    - This option will cost the farm operation a significant amount of money over the long-term through poor energy efficiency.

Insulation Material 2

GHG:-6 (Net)

- Energy efficient insulation, (-)(-)(-)(-)(-)(-)

$: +15 (Net)

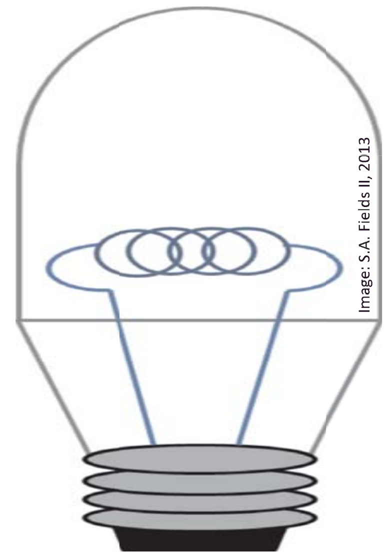
- Lower up-front cost, (+)(+) (+)(+)(+)(+)(+)(+)(+)(+) (+)(+) (+)(+)(+)
    - This option will save the farm operation significant amounts of money over the long-term through poor energy efficiency.

Housing Management
(front)

LED Lighting

Light Emitting Diode lights are filament free light sources that utilize aluminum-gallium-arsenide (AlGaAs) as electrical conductive material. LEDs are highly energy efficient light sources

Halogen Lighting



Halogen lights are filament based light bulbs that use Halogen infused envelopes to extend the bulbs temperature range and lifetime.

Housing Management
(back)

LED Lighting

GHG:-2 (Net)

- Energy efficient lighting, (-)(-)

$: +3 (Net)

- Higher up-front cost, (+)(+)(+)
  - This option will save the farm operation a moderate amount of money over the long-term through high energy efficiency.

Halogen Lighting

GHG:+2 (Net)

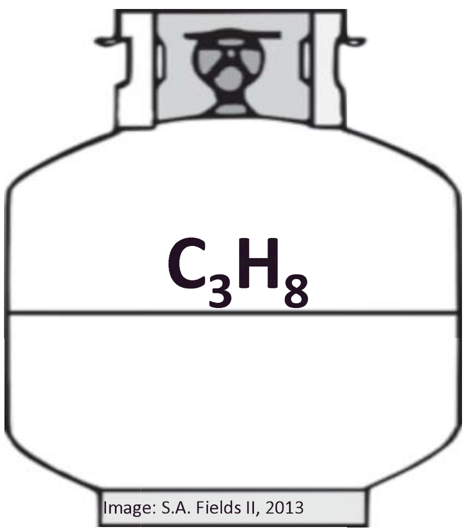
- Energy inefficient lighting, (+)(+)

$: +1 (Net)

- Lower up-front cost, (+)
  - This option will cost the farm operation a moderate amount of money over the long-term through high energy efficiency.

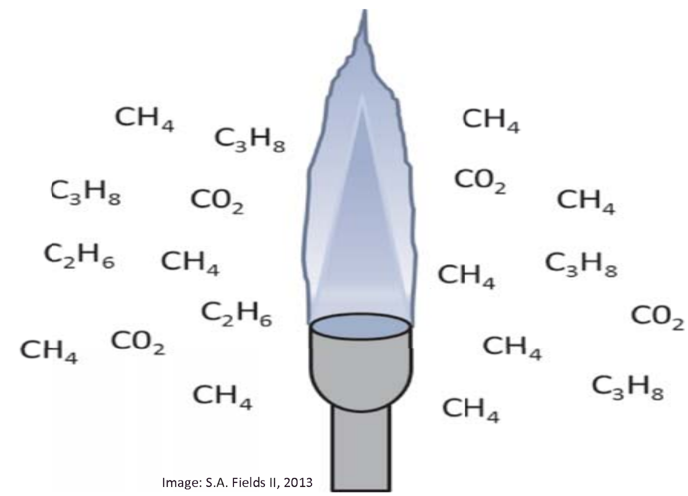
Housing Management
(front)

Propane Fuel Source



Propane (C_3H_8) is a hydrocarbon that is produced as a by-product from both the processing of natural gas and the refining of crude oil.

Natural Gas Fuel Source



Natural gas is a combustible mixture of hydrocarbon gasses. The primary component of natural gas is methane, but it also contains ethane, butane, carbon dioxide and propane.

Housing Management
(back)

Propane Fuel Source

GHG:0 (Net)

- Producers are not penalized or rewarded for fuel selection alone.

$: TBD (Net)

- Costs associated with this option are determined by the virtual fuel prices listed within the scenarios.

Natural Gas Fuel Source

GHG:0 or -4 (Net)

- Producers are not penalized or rewarded for fuel selection alone.
- If combined with Methane captured from anaerobic digestion, (-)(-)(-)(-)

$: TBD (Net)

- Costs associated with this option are determined by the virtual fuel prices listed within the scenarios.

Manure Management
(front only)

Manure Management Process

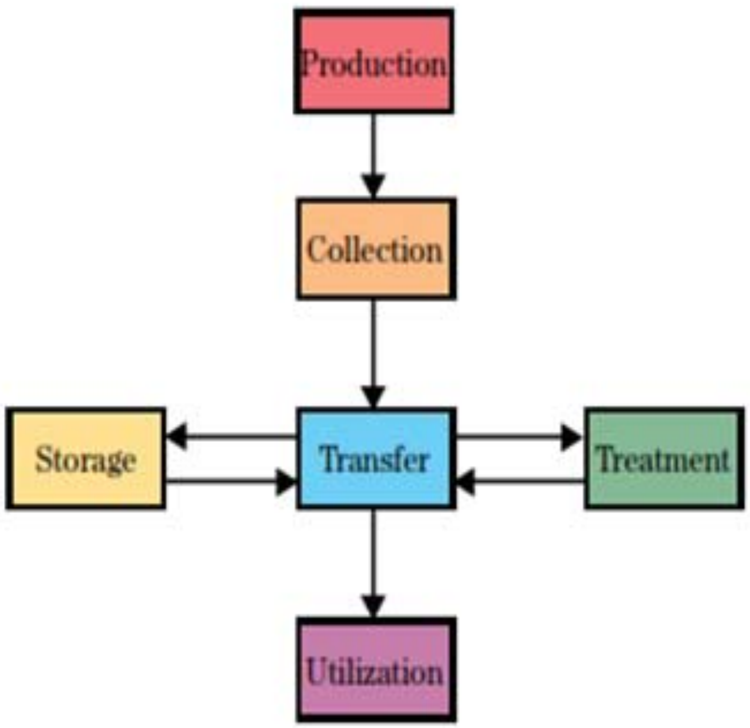


Image: USDA, 2008

Swine Manure Management Process

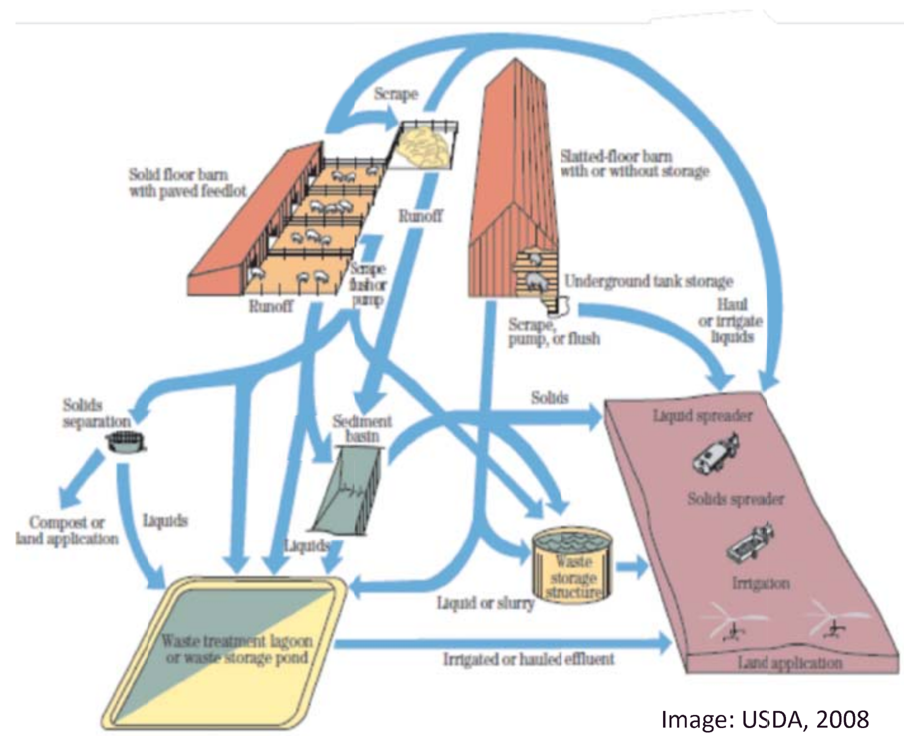


Image: USDA, 2008

Manure Management
(front only)

Slatted Floor Collection

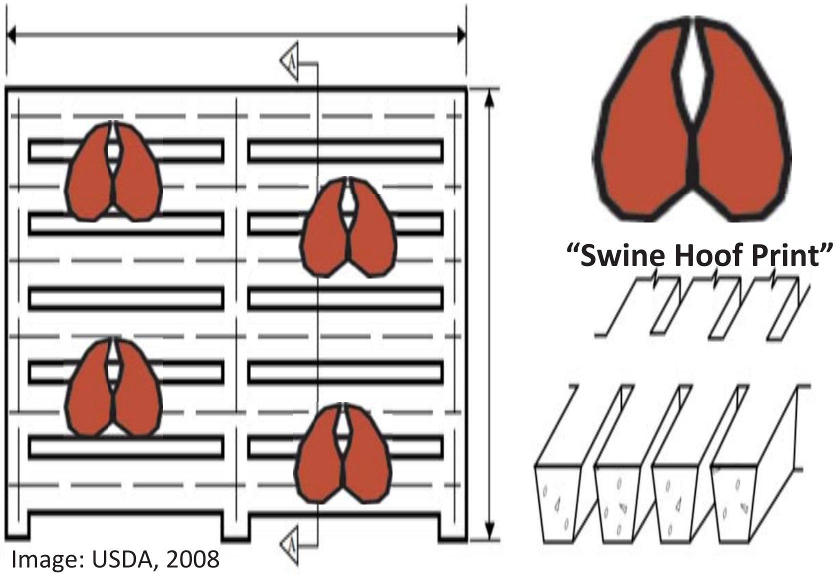


Image: USDA, 2008

Definition:
Manure is transferred into pits located below stalls through slats in flooring via action of pig's hoofs.

Manure Management
(front)

Flush Alley Collection

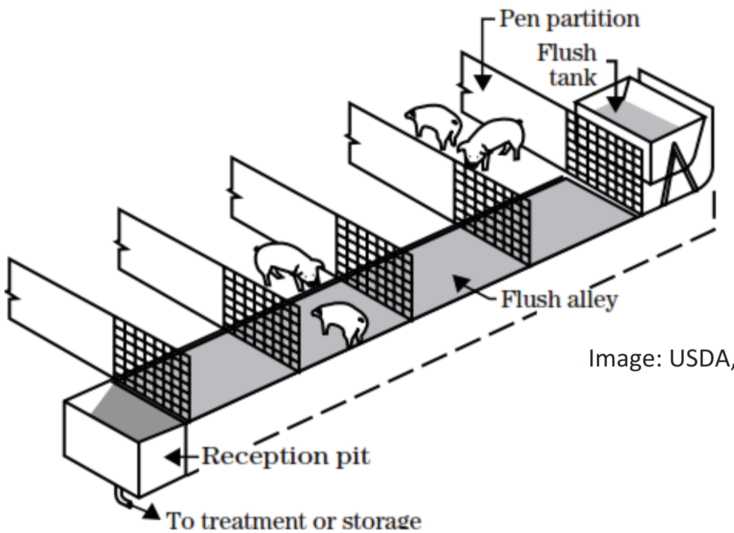


Image: USDA, 2008

Definition:
Liquid manure collection into alleys below stalls. Captured manure is then transported to treatment or storage by flushing the alleys with water several times a day.

Shallow-Pit Collection

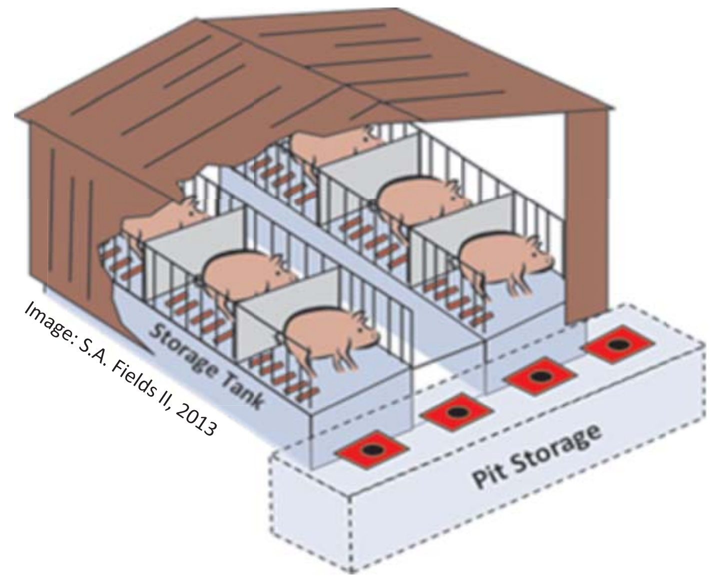


Image: S.A. Fields II, 2013

Definition:
Liquid manure storage option that collects manure through slatted flooring for temporary (2-10 days) storage prior to treatment, long-term storage or utilization.

Manure Management
(back)

Flush Alley Collection

GHG: +2 (Net)

- Low volatization/emissions levels per residence time, (+)
- Frequent pump use, (+)

$: +4 (Net)

- Frequent pump use, (+)
- Materials & construction, (+)
- High clean-out labor, (+)(+)

Shallow-Pit Collection

GHG: +1 (Net)

- Low volatization/emissions levels per residence time, (+)

$: +3 (Net)

- Frequent pump use, (+)
- Materials & maintenance, (+)
- Moderate clean-out labor, (+)

Manure Management
(front)

Deep-Pit Collection

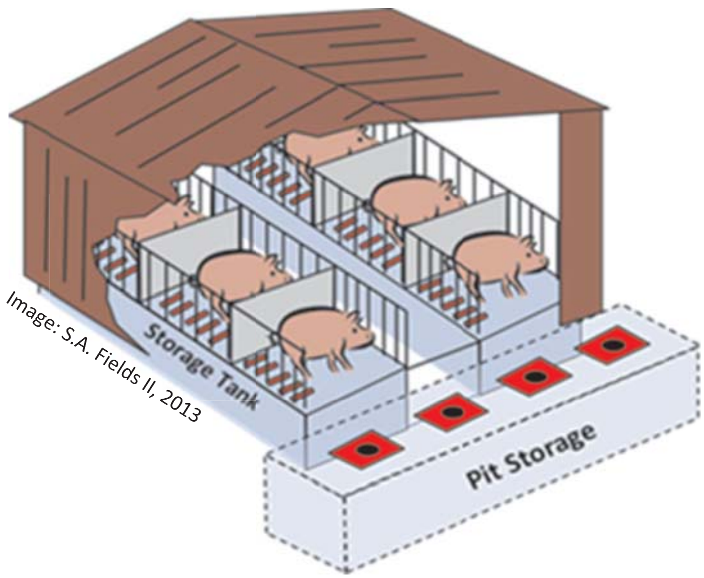


Image: S.A. Fields II, 2013

Definition:
Liquid manure storage option that collects manure through slatted flooring for temporary (up-to 180 days) storage prior to treatment, long-term storage or utilization.

Gravity Separation (Settling Basin)

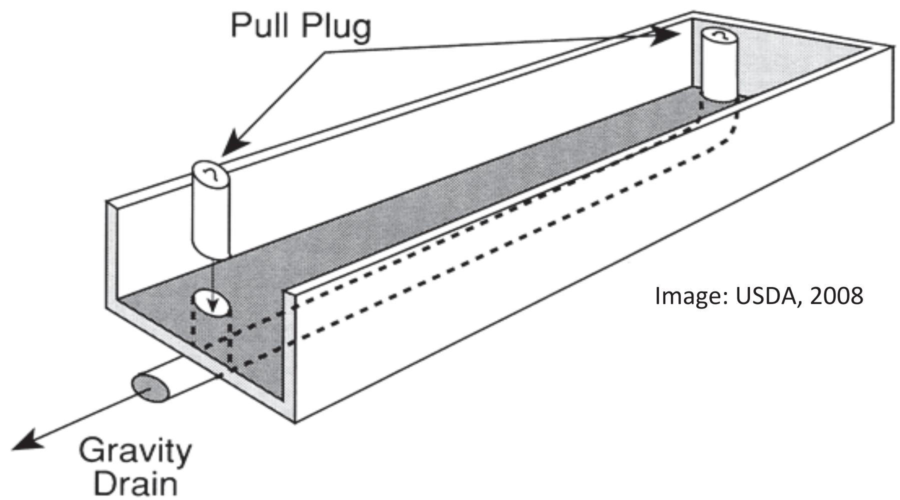


Image: USDA, 2008

Definition:
A shallow flow-through basin designed to allow enough residence time for some solids to accumulate at the bottom. The separated liquids are then transported for further treatment or storage. The remaining solids flow through to long-term storage.

Manure Management
(back)

Deep-Pit Collection

GHG: +2 (Net)

- Moderate volatization and emissions levels per residence time, (+) (+)

$: +3 (Net)

- Materials & maintenance, (+) (+)
- Low clean-out labor (+)

Gravity Separation

GHG: 0(Net)

- At this time insufficient research data exists to evaluate the difference in GHG emissions for the two separation options presented in this exercise.

$: +3 (Net)

- Materials & maintenance, (+) (+)
- Moderate clean-out labor, (+)

Manure Management
(front)

Mechanical Separation (Screw Press)

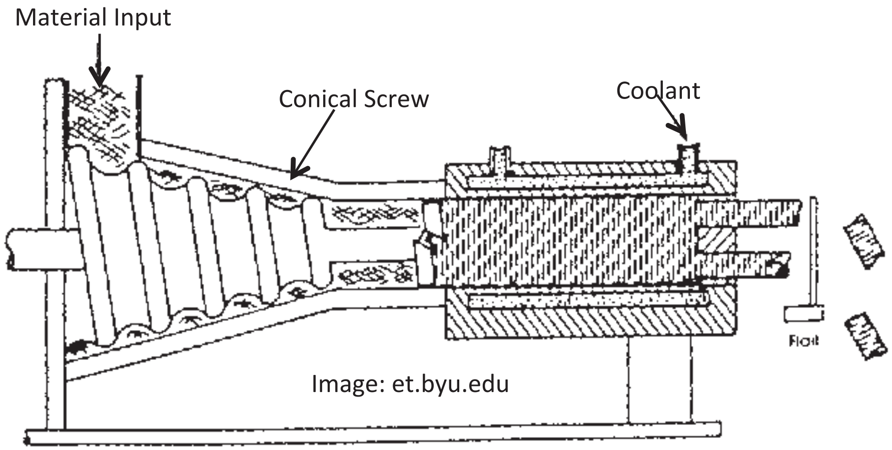


Image: et.byu.edu

Definition:
A device designed to mechanically separate solid and liquid portions of animal manure. The screw press is used to squeeze water from solids. The resulting liquid and solid manures are then transported to the appropriate storage or treatment.

Earthen Storage (Liquid & Solid/Non-Treated)

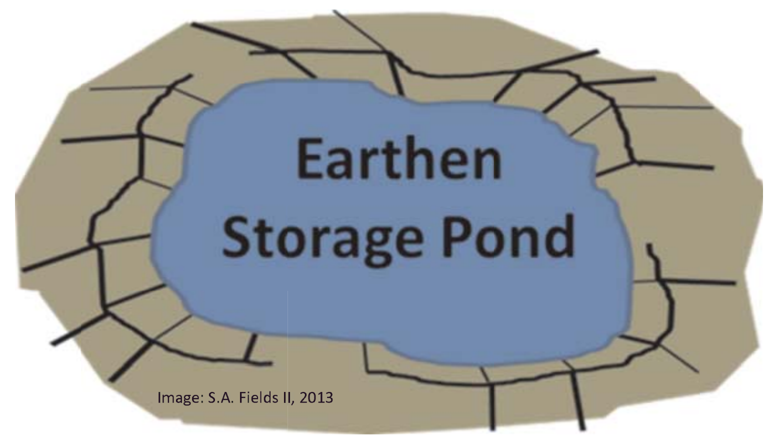


Image: S.A. Fields II, 2013

Definition:
Earthen storage ponds are liquid manure storages which use concrete/clay lined ponds for long-term storage.

Manure Management
(back)

Mechanical Separation

GHG: 0 (Net)

- At this time insufficient research data exists to evaluate the difference in GHG emissions for the two separation options presented in this exercise.

$: +3 (Net)

- Purchase & maintenance, (+) (+)
- Motor and pump operation, (+)

Earthen Storage

GHG: +1 (Net)

- Low volatization and GHG emissions levels per given residence time, (+)

$: +1 (Net)

- Materials, construction & maintenance, (+)
- Low clean-out labor (+)

Manure Management
(front)

Above-ground Storage (Liquids/Non-Treated)

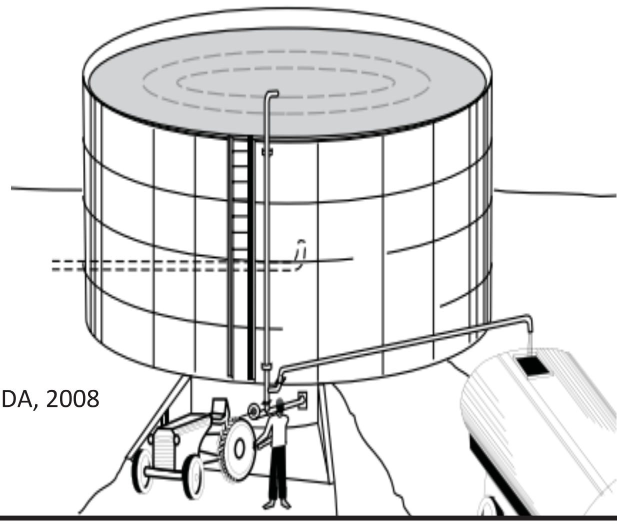


Image: USDA, 2008

Definition:
Above-ground steel-lined storages for liquids are containers designed for long-term storage of manure.

Above-ground Storage (Solids/Non-Treated)

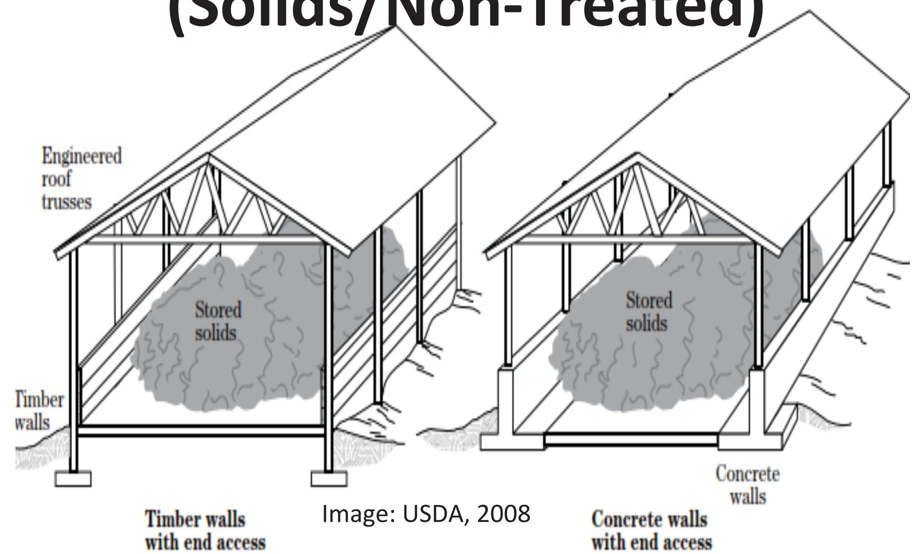


Image: USDA, 2008

Definition:
Above-ground storages are roofed structures designed for long-term manure storage. During storage the solid manure is allowed to dry-out.

Manure Management
(back)

Above-ground Storage (liquid)

GHG: +1 (Net)
- Low volatization and GHG emissions levels per given residence time, (+)

$: +4 (Net)
- Materials, construction & maintenance, (+)(+)(+)
- Low clean-out labor (+)

Above-ground Storage (solid)

GHG: +2 (Net)
- Moderate volatization and GHG emissions levels per given residence time, (+)(+)

$: +3 (Net)
- Materials & maintenance, (+) (+)
- Low clean-out labor (+)

Manure Management
(front)

Lagoon Digester (Earthen Treatment)

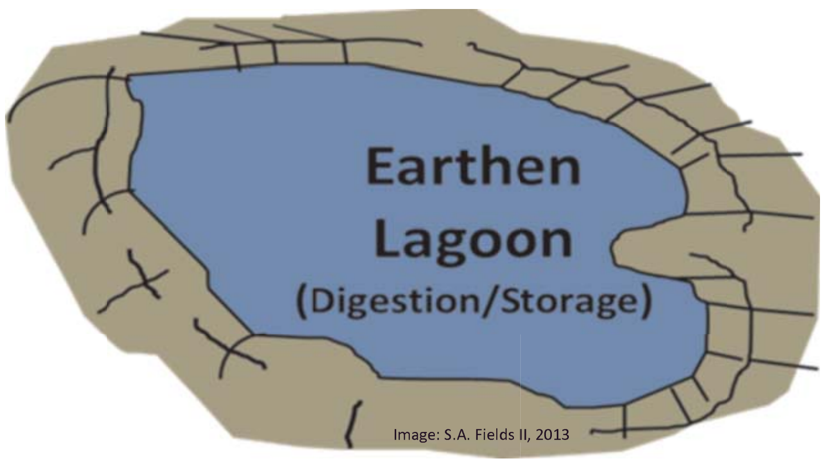


Image: S.A. Fields II, 2013

Definition:
Earthen lagoons are anaerobic waste treatments that utilizes microbes to produce Methane from the Carbon and Hydrogen in manure. Earthen clay liners are typical; If covers are installed to capture gas and/or reduce odor, they are usually a plastic fabric material.

Mixed Digester (Tank Treatment)

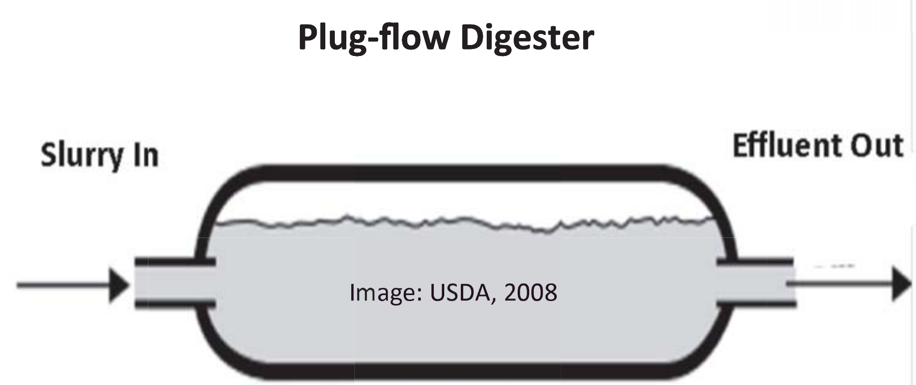


Image: USDA, 2008

Definition:
Anaerobic waste treatment that utilizes microbes to produce Methane from the Carbon and Hydrogen in manure. Concrete construction is typical and the containment is also an effective strategy for odor management.

Manure Management
(back)

Earthen Digester (solid)

GHG: -3 or +2 (Net)

- If methane is captured and used, (-)(-)(-)
- If methane is not captured, (+)(+)

$: +2 (Net)

- Materials & maintenance, (+)(+)

Mixed Digester (solid)

GHG: -3 or +2 (Net)

- If methane is captured and used, (-)(-)(-)
- If methane is not captured, (+)(+)

$: +4 (Net)

- Materials & maintenance, (+)(+)(+)(+)

Manure Management
(front)

On-farm Manure Application

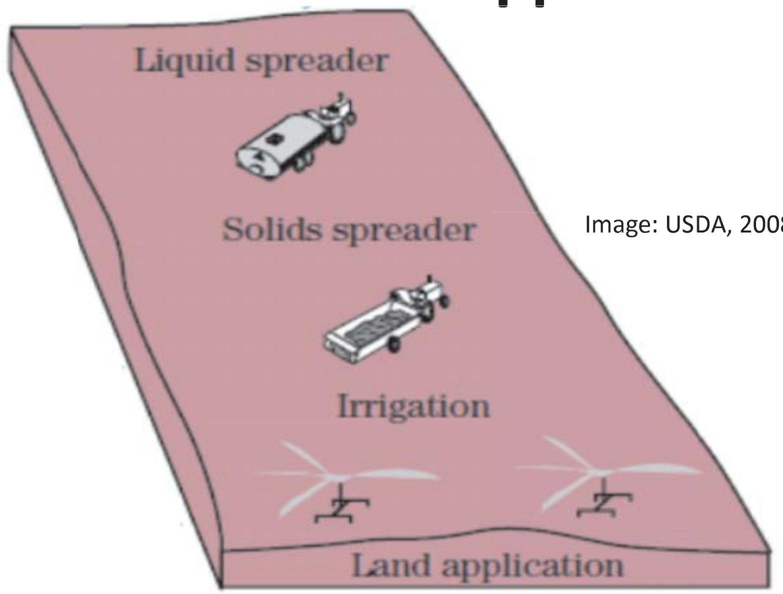


Image: USDA, 2008

Definition:
Manure is applied to land at rates and times that meets the nutrient needs of crop(s) to be grown. Solids are applied using manure spreaders. Liquid and slurry manures are usually applied using tank wagons, or irrigation.

Off-farm Manure Transport

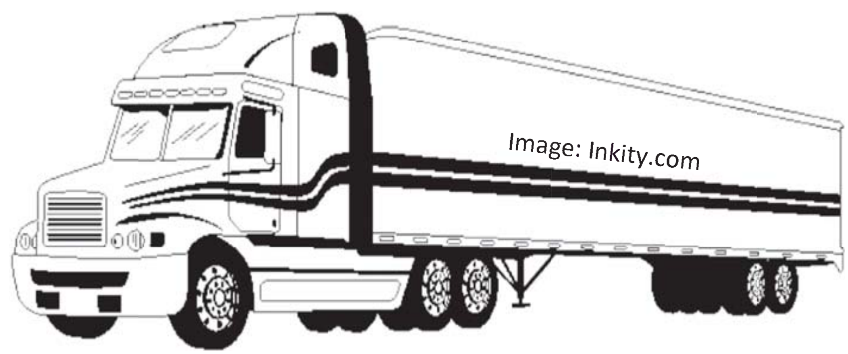


Image: Inkity.com

Definition:
Manure is transported for off-site utilization. The manure may be applied as fertilizer on another farm or utilized as an energy source at an energy conversion facility.

Manure Management
(back)

On-farm Application of Manure

GHG: +1 (Net)

- Variable levels of volatization after manure application, (+)

$: -2(Net)

- Lowered need for commercial fertilizer, (-)(-)(-)
- Application equipment operation, (+)

Off-farm Manure Transport

GHG: +2 (Net)

- Manure loading and transport , (+)(+)

$: -1(Net)

- Manure sold as fertilizer, (-)(-)
- Manure loading and transport, (+)