DYNAMIC SPREADSHEET PROGRAMMING TO COMPARE THE EFFECT OF GEOGRAPHIC LOCATION AND ECONOMIES OF SIZE ON HOG MANURE HANDLING SYSTEMS IN OKLAHOMA

By

RITA ISABEL RODRIGUES CARREIRA

Bachelor of Science in Economics

Universidade de Coimbra

Coimbra, Portugal

1996

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2000

DYNAMIC SPREADSHEET PROGRAMMING TO COMPARE THE EFFECT OF

GEOGRAPHIC LOCATION AND ECONOMIES OF SIZE

ON HOG MANURE HANDLING

SYSTEMS IN OKLAHOMA

Thesis Approved:

Arthur Stoecker

Thesis Adviser

Francis M. Epplin

D. Sanders

Joseph E. Williams

Wayne B. Powell

Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my major advisor for supporting me in this endeavor and for providing me with his invaluable knowledge, guidance, and funds. I would also like to extend my appreciation to my other committee members Dr. Francis Epplin, Dr. Larry Sanders, and Dr. Joseph Williams for their constructive criticism and support. I am also grateful to the Faculty of the Department of Agricultural Economics, who have taught me and opened my horizons over the course of my degree. My sincere thank you is also directed at the staff of the Department of Agricultural Economics, who have been so successful in welcoming and assisting the students. It is a pleasure to study in such a dedicated department.

I would like to thank my parents, Victor Carreira and Maria Fernanda da Velha, for allowing me to have a life full of opportunities. I am eternally grateful to my late grandmother, Maria José, for taking care of me during the first nine years of my life. I feel her protection everywhere I go. I am also appreciative of all the help and inspiration Haziel has given me. Finally, I would like to thank Mark Taliaferro for giving me love, encouragement, and support when I needed it the most.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

BMP	Best Management Practices
CAFO	Concentrated Animal Feeding Operations
CWA	Clean Water Act
EPA	Environmental Protection Agency
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
OCAFOA	Oklahoma Concentrated Animal Feeding Operations Act

CHAPTER I

INTRODUCTION

1.1 Background

In recent years, the structure of the hog industry in Oklahoma evolved from many small hog farms to a small number of large hog operations. The number of pigs in Oklahoma increased from 0.19 million in 1991 to 1.98 million by September of 1998[1]. This remarkable increase is illustrated in Table 1.1.

Table 1.1 Number of Pigs in Oklahoma (numbers on December 1 of each year)

Year	Number of Animals (Thousands of Head)	Year	Number of Animals (Thousands of Head)
1987	200	1993	300
1988	240	1994	590
1989	230	1995	1.000
1990	215	1996	1,320
1991	190	1997	1,640
1992	240	1998	1,980 (1)

(1) Number of animals on September 1, 1998.

The change in the industry structure is related to two factors: first, the industry started to utilize economies of scale[2]; second, in 1991 the Oklahoma legislature (Senate bill 518) removed restrictions against corporate farming.

[1] Oklahoma Agricultural Statistics Service
[2] Kim. Chang-Gil (1997), p.97.

Larger hog farms are perceived to cause increased air and water problems. The increase in the size of the hog farms created public concern about hog manure pollution.

> Throughout the world there is an increasing concern about the generation of animal manure in volumes that could potentially pose environmental problems and inefficient use in agricultural systems. There is an increasing social dilemma over the use of manure because of the odor problems and costs of application and handling of manure compared to commercial fertilizers. These are only a few of the emerging concerns about the use of manure. (Hatfield and Stewart 1998, Preface)

Hog manure can be either an asset or a liability. Hog manure, a byproduct of hog production, is very rich in nutrients, particularly nitrogen and phosphorus, and thus may be a benefit or a cost to agriculture and the environment. The amount of nutrients present in the manure depends on the type of manure treatment facility used as well as on the method used to apply the manure to the soil. For example, lagoon treatment and application of manure to the soil surface release nitrogen to the atmosphere through ammonia volatilization. Other methods such as drag hose application minimize nitrogen loss.

The amount of nutrients regained by crops varies with location. The presence of each nutrient in the land also varies with location. Manure is rich in phosphorus and plants usually require larger amounts of nitrogen than phosphorus. The continued application of manure to the land, in amounts that satisfy the nitrogen requirements of crops, may result in a build up of phosphorus in the soil. This phenomenon increases the land area required for manure application in the case where manure applications are limited to phosphorus needs. The cost of applying manure to the land can also exceed its value. This is especially true for a large hog facility where manure has to be moved long distances to avoid applying excess nutrients.

The drawbacks associated with manure management are linked to "emissions of odour, ammonia and other gasses, pollution of ground and surface water with organic matter, nitrogen, phosphorous and pathogens and similarly to the pollution of the soil."[3] These problems are highly dependent on the location of the farm operation and on the type of swine manure management used.

According to Nowak, Shepard, and Madison,

> manure management is the use of animal manures in a way that is appropriate to the capabilities and goals of the farm while enhancing soil and water quality, crop nutrition, and farm profits. (Nowak, Shepard, and Madison. 1998, 1.)

The lagoon based management systems used in Oklahoma were developed for the North Carolina region. In North Carolina, which is a humid region, the volume of water entering a hog manure lagoon because of rainfall exceeds the volume of water evaporated. Oklahoma's weather, on the other hand, varies from humid in the east to medium rainfall in the center, and semiarid in the west (with lagoon water evaporation greater than rainfall), and with cyclical patterns from rain to wet.

1.2 The Problem

Water-intensive manure disposal technology is less cost effective in dry areas. Water is a scarce resource in the arid areas of Oklahoma. As a result and to reduce cost, hog farmers may provide insufficient amounts of water to treat the hog manure, thus creating an odor problem. It is important that farmers know beforehand how much it costs to properly manage hog manure and which is the most cost efficient hog manure management system for the particular location. This knowledge can improve hog manure

[3] Svoboda and Jones 1999, 295.

management hence decreasing negative externalities such as odor. The proper installation of the hog farm in an adequate location also may prevent future legal liabilities to the farm.

The problems associated with the current state of manure management can be traced back to the 1960s when manure started to be seen as a waste that the farmer should dispose. The negative impacts on the environment were ignored. Farmers started using industrial fertilizer as the main source of nutrients for crops. This situation lasted until mid 1980s, when manure was again viewed as a potential asset.[4] The negative perception of manure conditioned today's state of knowledge.

> If one looks through the history of agricultural research, it is easy to see that our current understanding of manure is based on research conducted in the late 1960s with a few studies in the 1970s. Much of that research focussed on supplying of crop nutrients and not on the environmental consequences of surface runoff of phosphorus or leaching of excess nitrate-nitrogen through the root zone. (Hatfield and Stewart 1998, Preface)

The problem of the manure from large hog farms needs to be addressed with urgency. There is a great need for improved estimates of costs affecting hog manure management. Such information allows not only for the comparison of total costs for different hog manure management systems, but also it can be used by policy makers in formulating manure management practices. The current study will include an analysis of most of the different types of costs associated with different size hog-manure-management systems at three different sites in Oklahoma. It also will reflect the effects of water availability (geographic location) on the cost of hog manure disposal.

[4] Nowak, Shepard, and Madison 1998, 21.

1.3 Objectives

The general objective of this study is to decrease the costs associated with hog manure handling systems. The specific objectives are:

1. To determine the effect of evaporation and rainfall on the cost efficiency of hog manure handling systems in three Oklahoma counties that face humid (Delaware), medium rainfall (Seminole), and semiarid (Texas) weather conditions.
2. To determine the impact of the predominant nutrient constraint—nitrogen or phosphorus—of each location on the cost efficiency of hog manure handling systems.
3. To improve the software available to determine the most cost effective manure management systems for specific locations.

1.4 Study Sites

Delaware, Seminole, and Texas are the three counties in Oklahoma where geographic and climatological data were collected to perform the current study. These counties were chosen to illustrate the three main climate types of Oklahoma—humid (Delaware), medium rainfall (Seminole), and semi-arid (Texas) climatological conditions. Figure 1.1 shows the counties of Oklahoma. Texas County is located in the northwest corner of the state, also referred to as the Oklahoma Panhandle. Seminole County is located in the center, and Delaware County is located in the northeast part of the Oklahoma.

These counties differ in several aspects, as illustrated by Table 1.2. In terms of geographical and climatological characteristics, and over a 30-year period (1961—1990), Delaware is the county that had the most humidity. Its net precipitation (rainfall-evaporation) averaged 2.36 inches per annum. Seminole, on the other hand, had a negative net precipitation of 13.84 inches per annum, as the average annual evaporation exceeded the average annual precipitation over the 1961-1990 period. Texas County, located in the Oklahoma Panhandle, is a semi-arid location where net precipitation averages a negative 68.09 inches per annum. Therefore, as we move from the east part towards the west part of the state, the weather conditions change dramatically from moist to dry.

Oklahoma Counties Map

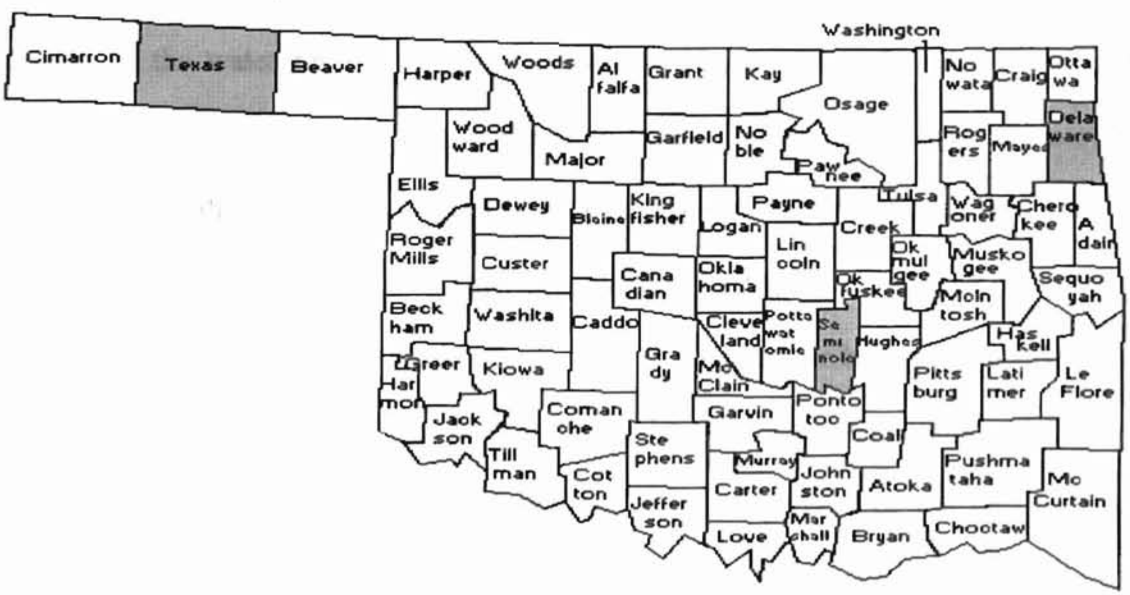


Figure 1.1 Map of Oklahoma Counties. Texas, Seminole, and Delaware counties are highlighted.

In terms of agricultural characteristics, as we move from east to west, the average farm size increases along with the amount of irrigated land. The major crops produced in Delaware County are wheat, soybeans, and sorghum. Producers in Delaware County have access to water from creeks and lakes, which is used to farm the county's 496 acres of irrigated land. In 1997, producers in Delaware held an inventory of 37,417 hogs and pigs and sold 210,113 head of swine.

Seminole is a producer of mainly wheat and soybeans. There are 1,027 acres of irrigated land in Seminole County, which is merely 0.37 percent of the county's farm land. According to the Census of Agriculture, of the three counties that are object of this study, Seminole has the smallest inventory of hogs and pigs—only 9,170 animals in 1997. The county's producers sold 66,910 hogs and pigs for that same year.

Texas County produces mainly sorghum, wheat, and hay. Texas County has limited access to water from creeks, rivers, alluviums, and terrace deposits. About 3.5 percent of the water reserves of the Ogallala aquifer are located underground in the Oklahoma Panhandle. According to the High Plains Underground Water Conservation District No. 1, this represents about 114 million acre-feet of water that is being depleted at extremely high rates. Texas County greatly benefits from the presence of this water. However, in the near future (within 50 years), it may no longer be economically feasible to extract the remaining water of the aquifer in the Oklahoma Panhandle. In 1982, the High Plains Study Council projected that by 2020, 50 percent of the Ogallala water reserves underlying New Mexico, Oklahoma and Texas will have been mined.

The production of corn and sorghum is very important to the swine industry because it is used to produce animal feed. Of the three counties considered, Texas County has the lead in the hog production (907,046 hogs in inventory) with almost one hundred times the number of hogs in Seminole (9,170). This great difference reflects the swine producers' preference for installing their operations in locations that can supply great amounts of concentrate feeds.

Table 1.2 Summary of Geographic, Climatic, and Agricultural Conditions of the Chosen Study Sites

OKLAHOMA COUNTIES: CHARACTERISTICS:	Delaware	Seminole	Texas
Geographic and Climatological Characteristics:			
Reporting Station	Kansas 1 ESE	Seminole	Goodwell
Station Number	4672	8042	3628
Location of County [1]			
Latitude	36° 12' N	35° 14' N	36 36' N
Longitude	94° 47' W	96° 40' W	101° 37' W
Soil Type[2]	Deep, cherty, loamy soil	well drained, loamy soil	clay, clay-loam
Soil pH[2]	pH 5.1~6.0	pH 5.1~7.3	pH 7.2~7.5
Source of Water [3]	-Creeks -Lakes	-Lakes -Alluviums and Terrace Deposits	-Creeks -Rivers -Alluviums and Terrace Deposits
Annual Mean Precipitation (inches) [4]	46.26 [6]	38.16	16.91
Annual Mean Evaporation (inches) [4]	43.90 [7]	52.00	68.00
Net Precipitation	2.36	-13.84	-68.09
25-year, 24-hour rainfall (inches) [4]	7.10 [7]	6.90	4.60
Annual Mean Temperature (°F) [4]	59.25 [6]	83.4	78.5
Agricultural Characteristics: [5]			
Irrigated Land (acres)	469	1,027	137,898
Farm Land (acres)	264,620	277,535	1,086,667
Percentage of Irrigated Farm Land (%)	0.18	0.37	12.69
Average Size of Farm (acres)	203	273	1,384
Major Crop Production [3] (based on bushel/acre ranking)	-Wheat -Soybeans -Sorghum	-Wheat -Soybeans	-Wheat -Sorghum -Hay
Hogs and pigs inventory (number of animals)	37,417	9,170	907,046
Hogs and pigs sold (number of animals)	210,113	66,910	1,448,807

Source: 1) NOAA (1997)

2) USDA (1970,1961,1979)

3) Oklahoma Geological Survey (1983).

4) Johnson and Duchon (1994).

5) Census of Agriculture (1997).

6)Oklahoma Climatological Data

7)Data were estimated because they were not available for the Kansas 1 ESE station.

According to Forster (1998), the developments in irrigation technology allowed the High Plains to increase its production of grain sorghum, thus making it a privileged location for hog operations. About 13 percent of the farmland in Texas County is irrigated.

CHAPTER II

LITERATURE REVIEW

During the past two decades, people have become more sensitive to environmental issues, according to Nowak, Shepard, and Madison (1998). Economic success can no longer justify the abuses forced upon the environment. The current available literature about hog manure reflects this new philosophy. The past years witnessed an increasing amount of research being done in several essential areas of environmental management concerning hog waste and its use as manure. Examples of these key research areas are: the impact of different types of manure, including hog manure, on the environment; legislation and the impact of changes in legislation; new management approaches to manure; and interactive software directed to help producers. The literature used in this study can be divided into three main areas: legislative framework, evaluation of the impacts of animal waste/manure on the environment, and budgeting models.

2.1 Legislative Framework

The early background of the present legislation on water resources protection is the 1899 Rivers and Harbors Act, which had the objectives of protecting the nation's waters and promoting commerce. In 1948, the Water Pollution Control Act was enacted to promote the protection of water quality by offering Federal assistance to States interested in protecting the quality of their water resources. The legislation was changed again, in 1965, with the enactment of the Water Quality Act (WQA), which charged the States with setting water quality standards for interstate navigable waters. Finally, in 1972, the Clean Water Act (CWA) was enacted and published under Title 33, Chapter 26 of the US Code, under the title Water Pollution Control Act. The Clean Water Act is the federal legal framework affecting hog producers today.

The 1972 CWA focused on point source pollution of surface waters. In 1977, the CWA was amended to emphasize the control of toxic pollutants. This amendment also transferred the responsibility of cleaning the nation's water from the federal to the state level. In section 1251 of the present CWA, it is declared that the CWA aims at the "restoration and maintenance of chemical, physical and biological integrity of Nation's water."[5] The instruments for achieving such goals are the states.

> It is the policy of the Congress to recognize, preserve, and protect the primary responsibilities and rights of the States to prevent, reduce, and eliminate pollution, to plan the development and use (including restoration, preservation, and enhancement) of land and water resources, and to consult with the Administrator in the exercise of his authority under this chapter. (US Code: Title 33, Chapter 26, Section 1251 (b))

The Administrator mentioned in the legal text refers to the Environmental Protection Agency (EPA). According to the CWA, and regarding the process of public participation in the development, revision, and enforcement of any regulation, etc., "the Administrator, in cooperation with the States, shall develop and publish regulations specifying minimum guidelines for public participation in such process."[6] The Clean

[5] US Code: Title 33, Chapter 26, Section 1251 (a).

[6] Ibid., Section 1251 (e)

Water Act does not intend to replace the authority of the state. Its goal is to consolidate the cooperation of federal, state, and local agencies "to develop comprehensive solutions to prevent, reduce and eliminate pollution in concert with programs for managing water resources."[7] However, the governor of each State shall prepare and submit a State management program for that State or in combination with other adjacent States, to the EPA.[8] If the EPA does not approve the program or the State fails to submit a program,

> a local public agency or organization which has expertise in, and authority to, control water pollution resulting from nonpoint sources in any area of such State which the Administrator (EPA) determines is of sufficient geographic size may, with the approval of such State, request the Administrator to provide, and the Administrator shall provide, technical assistance to such agency or organization in developing for such area a management program ... (US Code: Title 33, Chapter 26, Section 1329 (e).)

Because of the CWA, swine producers with 1,000 animal units or more must observe strict legislation to ensure that the risk of negative externalities from animal feeding operations is minimized. The Oklahoma Concentrated Animal Feeding Operations Act (Title 2 of the Oklahoma Statutes) is the legislation developed by the state of Oklahoma to accommodate the CWA. It was introduced into the legislation on June 4, 1997, as Oklahoma's House Bill 1522. According to the Oklahoma legislation:

> The purpose of the Oklahoma Concentrated Animal Feeding Operations Act is to provide for environmentally responsible construction and expansion of animal feeding operations and to protect the safety, welfare and quality of life of persons who live in the vicinity of an animal feeding operation. (Oklahoma Statutes Supplement 1999, Title 2, § 9-201)

The Oklahoma Concentrated Animal Feeding Operations Act (OCAFOA), also known as the Feed Yards Act, requires that all Concentrated Animal Feeding Operations (CAFO)

---

[7] Ibid., Section 1251 (g)

[8] Ibid., Section 1329 (b) 1.

must obtain a license for operation. The requirements to obtain this license are listed in this act and are further developed under Title 35, Chapter 17, Subchapter 3 of the Oklahoma Agriculture Rules, which were compiled by the Oklahoma Department of Agriculture.

The OCAFOA requires that producers develop a Pollution Prevention Plan before obtaining a license. Oklahoma producers also are required to obtain a National Pollutant Discharge Elimination System (NPDES) permit from the EPA, Region 6. The objective of the NPDES permits is to prevent point source pollution. Only the CAFO that meet the point source definition are subject to obtaining the NPDES permit. The act encourages the adoption of Best Management Practices (BMPs) to prevent non-point source pollution, in which the licensees "may substitute for best management practice equivalent measures contained in a site specific Animal Waste Management Plan."[9] Best Management practices are defined in the legislation as "schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the state as established by the State Department of Agriculture."[10] The Animal Waste Management Plan must be designed so that:

> (1) land application of animal waste shall not exceed the nitrogen uptake of the crop coverage or planned crop planting with any land application of wastewater or manure. Where local water quality is threatened by phosphorus, in no case shall the applicant or licensee exceed the application rates in the most current National Resources Conservation publication titled Waste Utilization Standard, and (2) timing and rate of applications shall be in response to crop needs, expected precipitation and soil conditions. (Ibid. § 9-205.3.C.4.)

---

[9] Oklahoma Statutes Supplement 1999, Title 2, §9-205.3.A.2
[10] Ibid. §9-202.B.8

The Waste Utilization Standard, Code 633 (April 1999), published by the National Resources Conservation Service (NRCS) mentioned in the OCAFOA defines waste utilization as "using agricultural wastes such as manure and waste water or other organic residues."[11] According to this document, "the use of agricultural wastes shall be based on at least one analysis of the material during the time it is to be used. In the case of daily spreading, the waste shall be sampled and analyzed at least once each year."[12] The document clearly states that the utilization of the waste is subject to minimizing the risk for contamination of surface and groundwater supplies. Therefore, liquid waste must be applied at a rate smaller than the infiltration rate of the soil.

Code 633 (NRCS, April 1999) redirects issues referring to the utilization of animal waste as a source of nutrients to Code 590 (NRCS, April 1999), entitled Nutrient Management. This document enforces the development of a nutrient budget for nitrogen, phosphorus, and potassium. The nutrient budget must consider "all potential sources of nutrients including, but not limited to animal manure and organic byproducts, waste water, commercial fertilizer, crop residues, legume credits, and irrigation water."[13] The recommended application rate of the different nutrients "shall be based on Land Grant University recommendations."[14] In the case of Oklahoma, these recommendations are made by the Oklahoma State University. Nitrogen and phosphorus application rates "shall match the recommended rates as closely as possible, except when manure or other organic byproducts are a source of nutrients."[15]

---

[11] Natural Resources Conservation Service. "Conservation Practice Standard—Waste Utilization." Code 633. 1999.
[12] Ibid.
[13] Natural Resources Conservation Service. "Conservation Practice Standard—Nutrient Management." Code 590. 1999.
[14] Ibid.
[15] Ibid.

In the case where manure or other organic byproducts are a source of nutrients, Code 590 (NRCS, April 1999) requires that the nutrient content of the manure be determined by either laboratory analysis, acceptable "book values", or historic records of the operation. Moreover, it is required that the method used provides an accurate estimation. However, it is obvious that from the three methods possible, only the laboratory analysis can be consistently accurate.

The Oklahoma State University literature[16] advises the farmer to support his or her decisions as follows depending on the type of nutrient. In the case of nitrogen, which is a mobile nutrient, the amount applied should be consistent with the crop yield goal. In the case of phosphorus and potassium, which are immobile nutrients, the decision to apply these nutrients "can best be made by having the soil tested." Therefore, we must conclude that technically, the best decision on how much animal manure to apply should be supported on a soil test for the simple reason that animal manure contains nitrogen, phosphorus, and potassium.

The legislation advises the farmer to follow the instructions of the NRCS in terms of BMPs. It also advises the farmer to follow the instructions of the Land Grant University, which is Oklahoma State University. However, the views of these two entities are not in total agreement. For this reason, we must conclude that the legislation contradicts itself.

Code 590 (NRCS) advises that the nutrient application rate when using irrigation to apply manure shall not exceed the soil's intake/infiltration rates and the total application shall not exceed the field capacity of the soil. For nitrogen application rates,

[16] Oklahoma Cooperative Extension Service. "Knowing When to Fertilize." OSU Extension Facts F-2236.

Code 590 (NRCS) foresees the possibility that manure could be applied under a phosphorus constraint. In this situation, not enough nitrogen will be applied to meet the crops needs. The standard practice is to apply nitrogen from non-organic sources. For the case of legumes, manure can be applied at a rate equal to that of the estimated nitrogen harvest removal.

According to Code 590 (NRCS), when manure is used as a source of nutrients, phosphorus application can be consistent with one of three methods: (1) Phosphorus Index (PI) rating, (2) soil phosphorus threshold values, and (3) soil test. The PI predicts that, for Low or Medium Risk Sites, manure application will be nitrogen based. In the case of High and Very High-Risk sites, manure application will be phosphorus based or there shall be no manure application.

If manure is applied according to the soil's phosphorus threshold levels and the soil test indicates soil phosphorus contents below phosphorus threshold levels, manure application will be nitrogen based. Otherwise, manure application will be phosphorus based or there will be no application.

In the third method, which is the soil test, if the soil test indicates phosphorus application, manure shall be applied according to nitrogen requirements. If there is no recommendation to apply phosphorus based on the soil test, then manure application will be phosphorus based or there will be no application.

The standard practices on phosphorus application resulting from manure application to the soil, as they are exposed in Code 590 (NRCS) [17], are a source of

[17] Natural Resources Conservation Service. "Conservation Practice Standard—Nutrient Management." Code 590. 1999. "When manure or other organic by-products are used, the planned rates of phosphorus application are consistent with any one of the following options: (1) Phosphorus Index (PI) Rating. Nitrogen based manure application on Low or Medium Risk Sites, phosphorus based or no manure

confusion for the reader. A more explicit approach would greatly benefit the users of the Conservation Practice Standards.

Additionally, and to aggravate the lack of clarity mentioned above, Code 590 (NRCS) expands the issue as follows. It predicts that manure application can be performed at a "rate equal to the recommended phosphorus application or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence."[18] Under these circumstances, the standard practice is that "manure application shall not exceed the recommended nitrogen application rate during the year of application." On the other hand, it shall "not exceed the estimated nitrogen crop removal in harvested plant biomass during the year of application when there is no recommended nitrogen application." Finally, the application rate must be consistent with the vulnerability of the location in terms of off-site phosphorus transportation. In some situations, this may entail no application at all.

As was stated above manure is rich in nutrients such as nitrogen, phosphorus, and potassium; therefore, it is an asset in agriculture. According to Crowder and Young (1988), the application of manure to the soil induces water pollution, and soil conservation practices decrease runoff and surface water pollution but increase nitrate leaching through the soil. In their study, Crowder and Young evaluate selective best management practices (BMPs) in soil conservation and nutrient management "that

application on High and Very High Risk Sites. (2) Soil Phosphorus Threshold Values. Nitrogen based manure application on sites on which the soil test phosphorus levels are below the threshold values. Phosphorus based or no manure application on sites on which soil phosphorus levels equal or exceed threshold values. (3) Soil Test. Nitrogen based manure application on sites on which there is a soil test recommendation to apply phosphorus. Phosphorus based or no manure application on sites on which there is no soil test recommendation to apply phosphorus."

[18] Ibid.

control water pollution,"[19] and the ecological and economical tradeoffs of manure. For example, for a field planted with continuous corn grain some of the BMPs evaluated were: permanent vegetative cover, contour tillage and shorter slope length, terrace system, no-till planting along the field contour with residue management, etc.

Crowder and Young used computer simulation. The CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model was used in Crowder and Young's study to "estimate edge-of-field losses of soil, surface runoff losses of N, P, and pesticides, and NO3 leached out of the root zone."[20]

Crowder and Young concluded that practices that conserve more nutrients are not necessarily the most cost-effective practices. Crowder and Young also found that a combination of conservation practices is more adequate for highly erodible land than just following one conservation practice. This implies that farmers must be aware of possible erosion and nutrient leaching problems in their fields. Their management practices should be flexible enough so that they are adequate for the characteristics of the field. The current study includes a wider variety of manure management practices, as well as a more thorough inventory of costs than that used by the above authors.

Some BMPs are specified in the Environmental Laws Impacting Oklahoma Livestock Producers (1994). Some examples of these BMPs are expansion of manure handling procedures and structures before expansion of animal facility, isolation of open lots and their waste from outside surface drainage, and disposal of dead animals within three days of their death. The Environmental Laws Impacting Oklahoma Livestock Producers aims to educate animal producers so that their practices are in accordance with

[19] Crowder and Young. 1988, p. 1.
[20] Ibid, p.4.

environmental laws. Christensen, Trierweiler, Ulrich and Erickson (1981) developed some guidelines for managing animal wastes. They too focus mainly on educating the producer and making him more aware of environmental constraints, rising energy and fertilizer costs. The present study does not attempt to educate the producer, instead it attempts to endow the producer with a tool to simulate various scenarios and calculate the best option in terms of cost.

The U.S. Department of Agriculture and the U.S. Environmental Protection Agency introduced the Unified National Strategy for Animal Feeding Operations on March 9, 1999. This document has an important role in the Clean Water Initiative. The Animal Feeding Operations Strategy provides a framework of action for the USDA and the EPA, according to the existing legislation. The strategy reflects several guiding principles including the minimization of the impacts of animal feeding operations on public health and water quality. To develop a valid study, the current study follows the guidelines of this legislation.

Some studies analyze the impact of manure disposal regulations on the income and on the economic optimum of animal operations. One of these studies is the one performed by Ashraf and Christensen (1974) who developed a linear programming model that studies the impact of regulation on twenty-five dairy farms in Massachusetts. They concluded that adoption of less polluting manure handling systems would decrease the net income of dairy farms and increase investment costs.

In 1997, Kaitibie studied the impact of environmental regulation on the growth of the United States hog industry. The author identified the main hog producing states in the nation and developed three models to study how national and state legislation affected the development of the hog industry. The first model determines the effects of environmental regulation on the size of the operations, and the second model studies the effects on the size distribution of the operations. Finally, the third model evaluates the impact of state environmental policies on total hog inventory.

From his analysis, Kaitibie concluded that the behavior of the hog industry is strongly determined by the amount of corn produced. The existence of corn also determines the location of both small and large hog farms. In terms of the impact of state legislation on the industry, the author could not find a clear relationship. Instead, Kaitibie advances the idea that since state legislation is somewhat consistent from state to state, its impact on the industry may be due to differences in state enforcement (p 53). Unfortunately, the scope of Kaitibie's study is very limited 1988-1992, especially when we consider the fact that changes in legislation take some years to be incorporated in the society and in the industries.

2.2 Evaluation of the Impacts of Waste on the Environment

Swine production produces byproducts. Zering (1996) classifies as byproducts "manure, spilled feed, additional water from washing and cooling and rainfall into lagoons. In addition there are some airborne emissions from the pigs." The byproducts are rich in nutrients: nitrogen, phosphorus, potassium, zinc, copper, etc. As it was stated before, the application of manure and other byproducts to the soil in excessive amounts may produce negative externalities.

Nitrogen is a nutrient that is mobile when applied to the soil. This implies that any nitrogen that is not utilized by the surface vegetation can leach through the soil and contaminate or pollute underground water sources as well as surface waters. In the case of surface water, an excess of nitrogen can lead to the eutrophication[21] of the aquatic environment.

The production of nitrogen as a byproduct of swine production can be reduced in several ways. Farmers can reduce nitrogen by changing the diet of the animals. They can avoid rations that contain excessive protein levels. Farmers also can choose feed ingredients that match the nutrient needs of the animals according to the animal's characteristics (sex, age, etc.).

Phosphorus is not a mobile nutrient, but there are concerns that phosphorus may become mobile if its presence in the soil reaches extremely high levels. Similarly to nitrogen, the production of the byproduct phosphorus can be reduced if the animal's diet is well managed.

Other nutrient accumulation that causes environmental concern in a lesser degree includes that of zinc and copper. The accumulation of these nutrients becomes a serious concern if manure is applied to the soil over long periods. Zinc and copper management is similar to phosphorus management for they are not mobile nutrients.

Odor is another externality that is of great concern for populations located in proximity of swine production facilities. Again, a proper diet for the animal can reduce odor. An adequate waste management system for the region where the facility is located also may be useful in reducing odor problems.

---

[21] The presence of nitrogen promotes the proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the death and sometimes extinction of other organisms.

Svoboda and Jones (1999) in their review of waste management for farms defend the idea that a proper management may significantly decrease the negative impacts of the manure on the environment:

> They (negative impacts) can be minimized, if not completely eliminated, by the correct management of the farm and livestock wastes and, by relatively new development in minimizing hog feed nutrient input in a form of enzymatic additives promoting digestion of plant phytin-phosphorus (Hoppe *et al.*, 1993) or supplementation of protein/nitrogen input by properly balancing the diet synthetic amino acids (Mordenti *et al.*, 1993). (Svoboda and Jones. 1999, 295)

Svoboda and Jones endorse a Waste Management Plan as a form of preventing pollution. They discuss several methods of collecting, storing and applying manure to the soil. Their focus is on viewing manure from an environmentally friendly perspective. Therefore, they view manure as an asset not a liability to the farm.

The negative impacts of manure on the environment can be classified as externality costs, which may be difficult or even impossible to quantify. In a report entitled "Community Perceptions of Water Quality Impacts from Large-Scale Hog Confinements," Holtkamp, O'Gorman, and Otto surveyed the community perceptions of the populations of Adams and Clarke counties in Iowa. They state that:

> In addition to the economic benefits and environmental costs to rural areas from large confinement operations, perceptions of rural residents of the risk of contamination to their drinking water will also influence policymakers and determine future political outcomes. (Holtkamp, O'Gorman, and Otto 1994,1)

Among other conclusions, these authors point out that

> over 80% of the respondents were somewhat to seriously concerned about the potential for nitrate contaminating their drinking water supplies … Respondents indicated that even at distances of 5 miles from residence they are very concerned about the risk to drinking water supplies. (Ibid.)

Therefore, the legitimate concern of populations located in areas which surround large confinement swine operations greatly endorses the need for a study where the costs associated with proper hog-manure-management systems are determined.

Malik and Shoemaker study economic incentives for farmers to adopt less-polluting agricultural practices. Taxes are one of the incentives proposed by these authors to adopt less polluting agricultural practices. To set up a tax, one needs to value the resource the tax is supposed to protect. Malik and Shoemaker fail to specify how this can be achieved.

Coote, Haith and Zwerman (1976) have developed a mathematical model that studies the effect of dairy manure management on the environment, particularly water resources, and on the total farm system. Their conclusions indicate that the regulatory system should be "sensitive to the natural resources limitations within which each farmer must operate" (p.331). This is extremely important because it indicates that regulation on this matter needs to be flexible instead of rigid, which is usually the case.

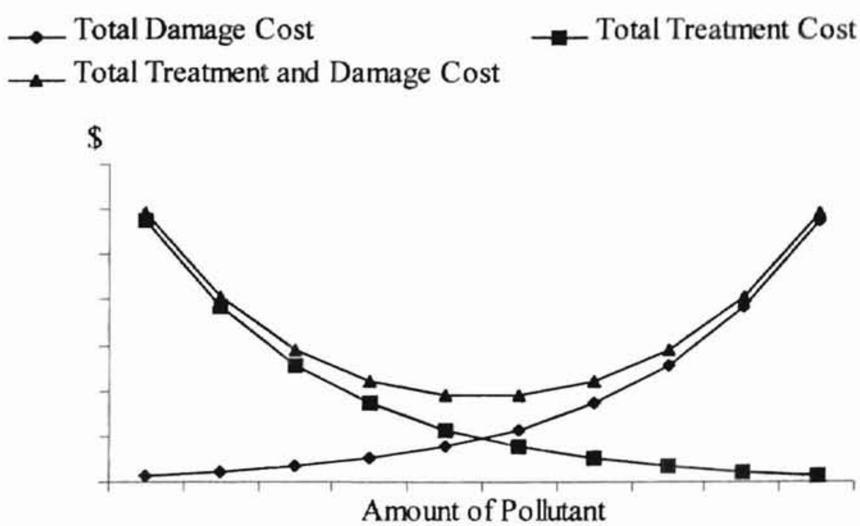


Figure 2.1 Representation of the Costs Associated with the Management of Resources that May Be Pollutants when Applied Excessively.

With regards to the last few works mentioned, this study does not account for externality costs or policy suggestions; instead, it will simply calculate the costs of properly managing hog manure. In a "social" sense, the proper manure management occurs at the point where the total cost of treatment and pollution is minimized, as is represented in Figure 2.1.

2.3 Budgeting Models

Several authors have proposed models to compare the cost effectiveness of different manure handling systems. Brundin (1994) developed a profit-maximizing model for manure handling systems in Sweden. Brundin's model has both a theoretical—the classic economic profit–maximizing model; and a more practical component—a mathematical programming model used to find the optimal portfolio of machines. Brundin's objective was "to develop a mathematical model that can find a profit maximizing design and use of a system for manure handling on a farm" (p.7).

Kim (1997) also used mathematical programming to evaluate several types of hog manure handling systems in two locations of Oklahoma—Texas and Seminole counties. Kim uses climatological data and considers geographical differences as factors that affect the cost efficiency of manure management systems. His research showed that the industry faces economies of size and that usually restrictions on the application of nitrogen are better than restrictions on the application of phosphorous. He concluded, as expected, that there is not a single manure management system that is best or optimal for all sizes and types of operation. This study is more accurate than Brundin's in terms of calculating the value and cost of manure. With respect to Kim's study, the present study develops an interactive model that producers and policy makers can use to make better decisions instead of simply evaluating different hog-manure-management systems as Kim did.

Crews, in 1987, worked on a microcomputer model, which was developed to assist producers in choosing the most economical manure handling system. Crews general objective was to "evaluate the effects of alternative waste management schemes on various swine production schemes." [22] The model developed using LOTUS-123 software, accounted for the collection, transfer, treatment, storage, and distribution phases of manure management for any type production system (feeder pig systems, feeder pig-finishing and farrow-to-finish systems).

The computer model was broken down into three major components: system design, application/distribution, and economic summary. Each component could be run independently for partial analyses or simultaneously for a comprehensive waste management analysis. Crews did not account for geographic location in his study. Other software that is user-friendly and aims at assisting the producer is available. Most of this software was developed by universities.

Zering (1996) addressed the budgeting of a swine manure operation. The author assumed that for a swine production system, the profit is given by the difference between the revenues from product and byproduct and the costs from production and waste management. According to Zering, nutrients are the largest cost in a swine operation. To minimize these types of costs, the farmer needs to select good animal waste management practices. The profitability of swine operations is related to the availability of land, to the type of crop used, and to the type of technology used. This study is helpful because the author estimates the costs of certain operations. This study uses this information as a point of reference.

Hsieh and Ho (1993) developed a linear programming model that can be used to manage solid waste. They found that linear programming is highly effective in determining the capacity of the facility, its location, transportation costs, disposal plans cost of the operation, and whether or not recycling is preferable to incineration on landfill exhaustion. This article is interesting because the authors analyze several case studies and present the most economical options.

Chang, Schuler and Shoemaker (1993) also studied how to manage municipal solid waste; to do this they used a mixed-integer-programming model. The objective function of their study was to minimize net economical and environmental costs. The authors included sub-models that were used to determine the residual value of the waste facility after the end of its useful life, to determine an air pollutant transfer coefficient, to determine more accurately the fixed and variable costs, and to determine the solid waste generation.

Although these last two studies do not analyze hog manure models, it is possible through transformation coefficients to compare municipal waste to hog manure. The study by Chang, Schuler and Shoemaker does address several issues that other studies neglect such as the residual value of the waste facility and the estimation of solid waste generation.

2.4 Rationale for This Study

---

[22] Crews. 1987, p. 218.

Most of these studies disregard many costs and benefits affecting hog manure. Some of the studies are already outdated because of the development of new technologies and new theories. These studies do not consider the effect of water availability in the comparative cost of hog-manure-management facilities. These three points are the focus of the current study.

CHAPTER III

3.1 Conceptual Framework

According to studies performed by Crews (1987) and Kim (1997), the production of swine is subject to economies of size. The production of manure as a byproduct of the production of the animals is subject to diseconomies of size due to limits on the nutrients that crops can utilize. Cost minimization theory assumes that swine producers behave as cost minimizers. Swine waste management involves costs in the collection of manure, storage method used and nutrient losses in this stage, transportation costs to field of application, and application method and nutrient losses in this stage.

The costs related to nutrient losses are sometimes hard to quantify but it is possible to include them in the cost functions associated to each method used in each stage of the hog management. The cost functions that will be used in the proposed study will also reflect the value of hog waste when applied to the land. The positive value of hog waste will be introduced in the cost functions as a negative cost.

The cost of transporting the manure to the field where it will be applied is another source of diseconomies of size. Although manure is an asset to the land because it is rich in nutrients, there will be a point when the benefits that the producer obtains from applying the manure will be outweighed by the cost of hauling the manure to the field. Beyond this point, the marginal value of an additional unit of manure will be negative.

3.2 Study Hypotheses

The effect of economies of size in the hog production activity are reduced by the counteracting role of diseconomies of size that are mostly related to hog waste management. The hypotheses of this study are:

1. The area required for land application of waste depends on the predominant nutrient constraint, the crops grown, and the geographic location.
2. The cost of hog waste management differs with geographic location and number of animals.
3. The optimal waste management system depends directly on the land available for application and on the predominant nutrient constraint.
4. Dynamic Programming can be used to select the cheapest way to dispose of hog waste for each location and production system.

3.3 Procedure

The disposal of animal waste in the form of manure can be broken into several stages. To move from one stage to the next, we need to make a decision in the previous stage. These calculations are somewhat repetitive so we can use dynamic programming by including a macro in an Excel™ 97 spreadsheet that will choose the most cost-effective method of hog waste management. A macro is a series of commands and functions that are stored in a Visual Basic module and can be run whenever we need to perform the task. The program will calculate the least cost combination of methods in the management of hog waste. The cost functions used for each method in each stage can be of any form, linear or non-linear. The proposed study aims at developing this macro, which will be inserted in a bigger spreadsheet that will include a wider variety of information concerning hog production. The animal producer can then use the spreadsheet to choose the most overall cost-effective animal production system. This option will also reflect which is the most cost effective hog-waste-system.

3.3.1 Description of Methods Used in the Excel™ 97 Program

Floor Type

The first stage of animal waste management is to choose the type of floor used in the animal house. The type of floor of a pig house greatly determines the form of the animal waste—solid or liquid—for subsequent stages. The floor can be fully slatted, have partial slats, or be a slab. When the floor is fully slated, the waste falls down to a pit. Thus, the animals are separated from the manure. The material used for the slats, their width, and their spacing depend on the type of animal and its size. Wood slats are usually used for smaller animals and have a life expectancy of two to four years. Concrete slats are more durable and are used for larger animals—swine over 75 lbs. and cattle. Steel slats are also used for small animals (hogs, calves, and sheep) and have a life expectancy of two to four years because of corrosion. Recently fiberglass "T" slats have been made available for operations involving small pigs. Slats made of this material are better for the small animals because it keeps them warmer than the concrete or metal slats. A fully slated floor requires less labor, is less stressful to the animals and keeps them in a drier environment.

A partially slated floor implies that part of the floor is solid—about two thirds, while the remaining part is slatted. This type of floor is not popular for weaned pigs because the floor becomes messy. However, the presence of the solid floor allows the animals to have more comfort when they are laying down.

The solid floor—slab—must be cleaned with a scraper. It requires more labor, the animals need to be moved around often, and the animals stay in a dirtier environment. With the solid floor, straw or other absorbent material may be placed on the floor. This allows keeping the animals in a cleaner environment and removing the waste as a solid.

In-house Waste Management System

The second stage is related to in-house waste management, i.e., to the choice of the method used in collecting the animal waste from the animal house to the storage facility. Methods include pit recharge, flushing, usage of a scraper, and a pull plug.

The pit recharge system consists of a pit, usually 32 to 36 inches deep, located under the slotted floor of the pig house. This pit contains an average of 12 inches of water that has the function of diluting the animal waste, thus allowing it to be removed as a liquid. This system requires less pumping of water than flushing and it is less costly. The default time for emptying the pit is three days.

A pull plug system implies that there is a pit located under the animal house. This pit is deeper and is emptied less often than the pit used in the pit recharge system. The animal waste falls down through the slatted floor and accumulates inside the pit. The pit is equipped with a plug that is pulled whenever the pit is to be emptied. The pit should be emptied frequently so that the plug is not clogged from the solids accumulation on the bottom of the pit. Frequent discharge of the pit is also advised because the waste that is stored under the animal house may produce toxic gases that will disturb the animals. The default time for discharge of the pit with a pull plug is 20 days. The pit recharge is employed less often than the pull plug system because there is less odor control due to the longer time interval between pit discharges.

The flushing system needs large amounts of water that flows down a sloped shallow gutter or alley. The water used for flushing can be either fresh water or water that was recycled through the system. This running water carries the hog waste to the facility where the waste will be stored and later treated and prepared to be applied as manure to the land. This system does not require much labor because the transportation of the waste from the animal house to the lagoon is done with the help of gravity.

Another system that can be used to move the animal waste from the animal house to the storage facility is a scraper. As was stated above, the scraper is the method used for cleaning full solid floors and it can be used underneath slatted floors. Scrapers can be manual or mechanical. Mechanical scrapers are helpful in reducing the need for manual labor and have low maintenance. However, the equipment for both manual and mechanical scrapers deteriorates rapidly due to the high corrosive action of the waste.

Storage and Treatment Method

The third stage of animal waste management depends on the form of the animal waste when it is ready for storage. The waste can be either in a liquid form or in a slurry form. Liquid manure is stored in lagoons that can be of several forms: aerobic lagoon, anaerobic lagoon, aerated two cell lagoon, partly aerated lagoon, facultative lagoon, and stratified lagoon. Lagoons usually require large amounts of water to work properly (minimize odor) and to preserve nutrients, especially nitrogen. Slurry animal waste is stored in other types of facilities that can take the form of: earthen storage pond, cement above ground tank, underground tank, glass lined steel tank, liquid-solid separation earthen storage pond, and liquid-solid separation concrete above ground tank. Slurry manure usually preserves nutrients better and may not cause as many odor problems as an anaerobic lagoon.

(1) Treatment of Liquid Animal Waste

Liquid manure is treated using lagoons. Lagoon size specifications vary according to the type of treatment performed. Figure 3.1 shows a representation of the different items that contribute to the total volume of a lagoon: sludge volume, treatment volume, manure volume, wash water volume, net rainfall if positive, 24-hour 25-year emergency rainfall, and freeboard volume.

The anaerobic lagoon is a treatment unit that relies on the anaerobic process for the treatment of the organic matter produced by the animals. The presence of oxygen is not required in the anaerobic process. This type of lagoon liquefies or degrades high BOD (Biochemical Oxygen Demand) wastes. These facilities are adequate for operations with high loading rates but they do give off some septic odors. Conversely, aerobic lagoons decompose less organic matter per unit volume than the anaerobic lagoons, but they significantly reduce odor problems. The bacteria inside the aerobic lagoons require the presence of free oxygen. Anaerobic lagoons are less expensive than aerobic lagoons.

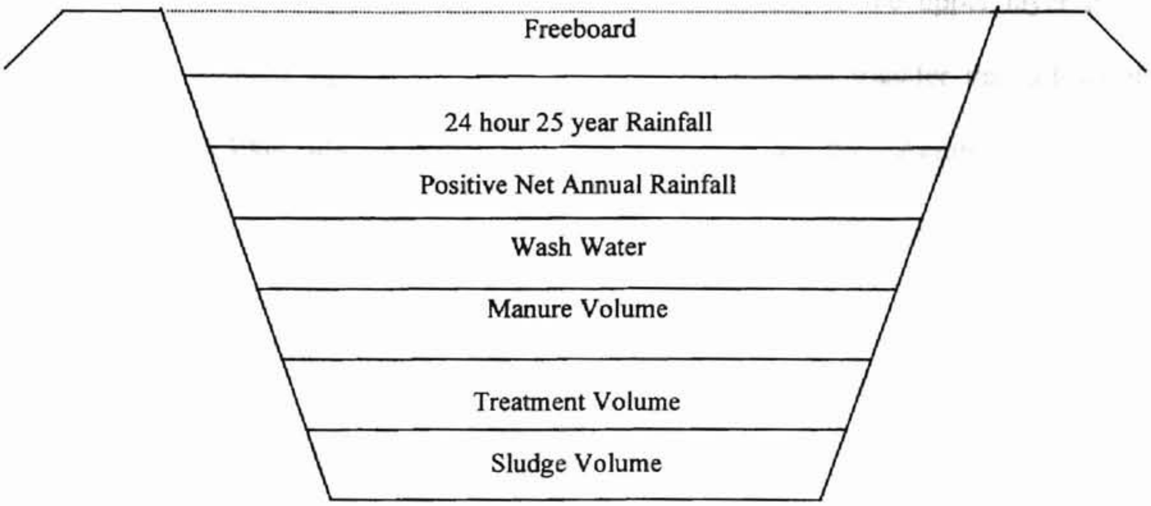


Figure 3.1 Representation of the Transversal Cut of a Lagoon to Show the Different Components of Its Volume.

A facultative lagoon unit has aerobic conditions in the upper layers and anaerobic conditions in the bottom layers. The aerobic layer of the lagoon has facultative bacteria, which tolerates small amounts of oxygen, thus controlling odor. Another form of treatment is the stratified lagoon, which works similarly to the facultative lagoon. The stratified lagoon is intermediate in size and cost between the anaerobic and the facultative lagoon.

An aerated two-cell lagoon consists of two lagoons that operate in series. This system is used to treat the organic matter before it is applied to the soil as manure. The initial cell is shallower, aerated and receives the waste first. The level of the waste in the first cell remains constant. A two-stage lagoon greatly reduces odor problems, if properly managed. Therefore, the aeration equipment must be properly selected to prevent an overload of the first cell, which may cause odor problems.

A partly aerated lagoon is a treatment unit where the aerobic conditions are maintained mechanically or by diffused aeration equipment in the upper layer of the lagoon. The aeration equipment causes a continuous oxygen transfer that allows the treatment unit to treat more wastewater per unit volume per day. Aerated lagoons are good units to treat previously untreated wastes and to control odors.

(2) Storage of Slurry Animal Waste

The animal waste that is in a solid form or slurry is usually stored in ponds or in tanks. An earthen storage pond, also called earthen storage basin, is a storage facility with sloping sides and a flat floor. This facility is used to temporarily store runoff water, wastewater, semi-solid slurry, or liquid manure. Manure can also be stored temporarily in a concrete above ground tank, which is assumed to be a circular cement structure located above ground. Similarly, slurry can also be stored in an underground cement tank, which is assumed to be a rectangular structure.

Fiberglass is another material that can be used to line a steel pipe and prevent corrosion by the animal slurry. A glass lined steel tank is a steel tank with a layer of fiberglass lining the inside surface of the tank. This facility can be used to store manure temporarily.

Finally, the spreadsheet also encompasses two storage facilities that separate the animal waste into liquid and solid waste. These facilities are the liquid-solid earthen storage pond and the liquid-solid cement above ground tank.

Application Method of Manure to the Soil

After the waste has been treated, the effluent can be applied to the soil as fertilizer. Therefore, the fourth stage in hog waste management is the application of the manure to the soil. Again, the different alternative methods used provide different options regarding nitrogen volatilization and generation of odor units. The application methods considered are irrigation, haul by tanker wagon, and drag hose application.

If the manure is in a liquid form (it has less than 15% solids), it can be applied through irrigation. Irrigation systems can be stationary or travelling units. These systems are a good process to deliver large volumes of liquid on time, but they can cause some problems concerning odor, ammonium nitrogen losses, and susceptibility to wind drift. Irrigation systems are ideal for the application of wastewater from lagoons that have little odor.

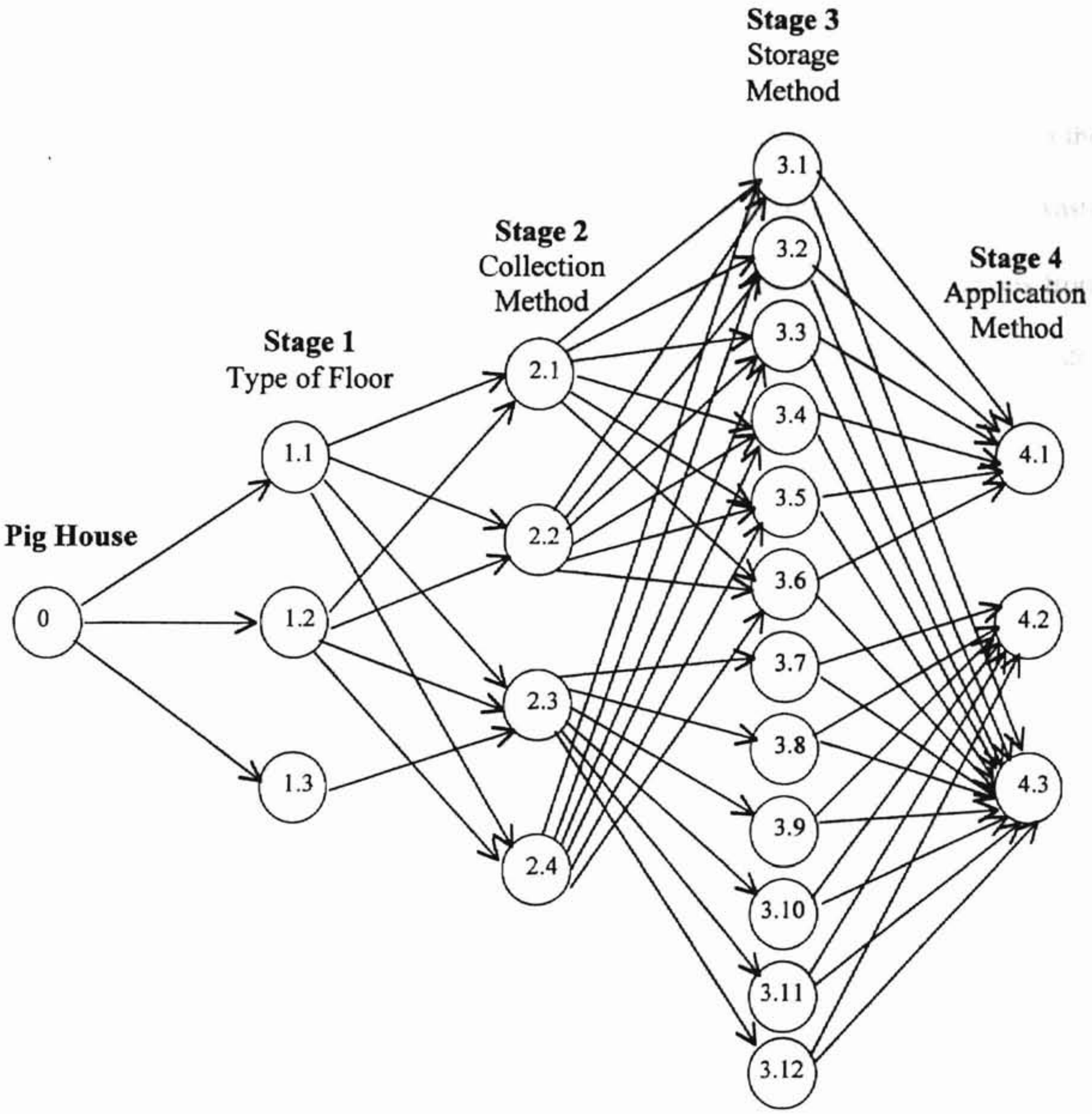
Slurry manure with up to 15 percent total solids can be applied to the soil by using a haul-tanker wagon or a drag-hose applicator. The haul-tanker consists of a tank full of manure that is moved around the field pulled by a tractor or a truck. The capacity of the tank can vary between 2350 and 9500 gallons. The bigger tanks, due to their heavy load, compact the soil when they are being moved around the field. The liquid or slurry can be either surface applied or injected into the soil with the help of cultivating rigs or concave disc incorporators. When injecting the manure to the soil, the application is even, it is possible to regulate its depth, and runoff and odor problems are minimized.

The drag-hose applicator uses a hose that connects a tractor drawn injector with a pump located at the storage site. This method provides a good uniformity of application, and odor problems and ammonium nitrogen losses are minimized. Manure application with a drag-hose takes less time than manure application with a haul tanker. Application with a haul tanker requires additional time for refilling the tank and hauling the manure back to the field.

3.3.2 Model

Associated with each method in each stage is a cost function unique to each particular waste disposal system considered and to the geographic location of the animal production facility. These functions are normal economic engineering equations that relate the cost to the equipment, time, labor, and energy required. The cost functions may be linear or nonlinear depending on the technology we are analyzing. The economic engineering cost equations are dependent on the number of animals, which allows us to express the economies and diseconomies of size associated with hog waste management.

Figure 3.2 represents the stages involved in hog waste handling. At each stage several methods can be selected. Arcs connect the methods, also called nodes. Each arc represents the flow of the waste from one stage to the next stage. Each arc is associated with a cost function. The objective is to minimize the overall cost of collecting the waste from the pig house, treating it, and applying it to the land. Node 0 refers to the beginning of the hog waste handling system. Let $f_j(x_j)$ bc the minimum path (cost) to node j at stage j, $f_0(0) \equiv 0$, and x_1 represents the methods in stage 1.



Legend:

Stage 1: Floor Type
1.1 Fully slated floor
1.2 Partial slats
1.3 Slab

Stage 2: Collection Method
2.1 Pit recharge
2.2 Flushing
2.3 Scraper
2.4 Pull plug

Stage 3: Storage Method
3.1 Aerobic lagoon
3.2 Anaerobic lagoon
3.3 Aerated two cell lagoon
3.4 Partly aerated lagoon
3.5 Facultative lagoon
3.6 Stratified lagoon
3.7 Earthen storage pond
3.8 Concrete above ground tank
3.9 Underground tank
3.10 Glass lined steel tank
3.11 Liquid-solid separation earthen storage pond
3.12 Liquid-solid separation concrete above ground tank

Stage 4: Application Method
4.1 Irrigation
4.2 Haul by tanker wagon
4.3 Drag hose application

Figure 3.2: Flow Chart of the Hog Manure from the Stage It Is Collected In the Animal House (Stage 1) Until It Is applied to the Land (Stage 4).

In stage 1, the minimum cost from stage 0 to stage 1, can be represented as:

$$(1) \qquad f_1(x_1) = f_0(0) + S_1(0, x_1),$$

where $S_1(0,x_1)$ represents the minimum cost of floor type, x_1 (1.1, 1.2, 1.3), used in the animal house, node 0. In stage 2, we proceed to find the minimum cost to take the waste from node 0 (animal house) to stage 2, where x_2 is one of the collection methods from 2.1 to 2.4. In this stage there are several possible combinations of methods, i.e., nodes have more than one incoming arc, so,

$$(2) \qquad f_2(x_2) = \min_{x_1, x_2} \{f_1(x_1) + S_2(x_1, x_2)\}.$$

Equation (2) states that the minimum cost to put the hog waste at the end of stage 2, $f_2(x_2)$, is achieved by finding the minimum cost of the sum of the cost in stage 1, $f_1(x_1)$, and the cost in stage 2, $S_2(x_1, x_2)$. This process is similarly repeated for stage 3. In stage 3, x_3 represents the type of storage method used to store the waste (cells 3.1 to 3.12). At the end of the process (stage 4) we obtain that the minimum cost to take the manure from the animal house to stage 4 after it is applied to the land is given by the following expression:

$$(3) \qquad f_4(x_4) = \min_{x_3, x_4} \{f_3(x_3) + S_4(x_3, x_4)\}.$$

In expression (3), $f_4(x_4)$ refers to the minimum cost from node 0 to one of the application methods, x_4 (4.1, 4.2, or 4.3). This path can be broken into $f_3(x_3)$, which refers to the minimum cost to take the waste from the animal house, node 0, to a storage facility, node x_3 (3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, or 3.12), and into

$S_4(x_3, x_4)$, which refers to the minimum cost to apply the waste to the land with one of the x_4 methods (4.1, 4.2, or 4.3).

The objective of the model is, therefore, to find the "shortest" (lower-cost) route from node 0 (the animal house) in the beginning of stage 1 to one of the nodes at the end of stage 4 (4.1, 4.2, 4.3, or 4.4), where the waste has been applied to the land. As said above, the labels on the arcs (cost functions) will depend on the particular region that we are studying, so we must include a geographic location option in the spreadsheet.

3.5 Data Collection

The basis for the construction of the spreadsheet is a study by Stoecker, Fulhage, Hoehne, Massey, Hamilton, and Williams, which was presented at the Animal Production Systems and the Environment International Conference in Iowa in 1998. The secondary data used to calculate the cost functions were obtained from published studies and personal communication. Information regarding equipment cost were obtained by consulting companies and by informal surveys. Geographical data were obtained from the Oklahoma climatological publications and were relative to the 1961-1990 period.[23] Technical data were obtained from the Livestock Facility handbook, the American Society of Agricultural Engineering publications, and from the Agricultural Waste Management Field Handbook.

3.6 Representative Farm Characteristics

---

[23] National Oceanic and Atmospheric Administration. *Climatological Data Annual Summary Oklahoma*. 1961-1990.

The characteristics of the representative farm in each county are illustrated in Table 3.1 (a diagram is provided in Appendix A). It was assumed that the average farm size relevant for this study corresponds to the 60^{th} percentile in terms of total farm area in the county. This means that 60 percent of the farms in each county have a size smaller than the size used in this study for the representative farm in the county. The size of the farm was interpolated using the 1997 data of the Census of Agriculture.

Furthermore, and to simplify calculations, it was assumed that the area of the farm must be divisible by 40. Consequently, the area of the representative farm of Delaware County is 440 acres; this means that 60 percent of the farmland in the county is occupied by farms that have an area less than 440 acres. The representative farm of Seminole County has an area of 640 acres; it represents that 60 percent of the farmland in Seminole County is occupied by farms that have less than 640 acres in area. Finally, the area of the representative farm for Texas County is 1920 acres; therefore, 60 percent of the farmland in Texas County is in farms that are smaller than 1920 acres.

Forty acres of land in each farm were allocated to the location of the animal operation and the respective waste management system. The remaining area of the farm was assumed to be cropland or pasture land. The proportion of area occupied by each crop and pasture in each farm follows the area proportions of the county where the farm is located.

The crops to be planted in each county are in accordance to the 1997 Census of Agriculture. It was assumed that each farm has a main crop (crop 1), which corresponds to the crop that ranked number one in terms of production in the county. The main crops selected were wheat in Delaware County, soybeans in Seminole County, and wheat in Texas County.

Table 3.1 Characteristics of the Representative Farms in Each County Selected.

Characteristics:	Delaware	Seminole	Texas
Farm Area (acres) 1)	440	640	1920
Crop 1	Wheat	Soybeans	Dryland wheat
Yield Bu/Acre 2)	32.9	25	28
Land Used for Crop 1	160	200	1400
Plant Uptake of Nitrogen lbs./A 3)	41.1	93.8	34.9
Plant Uptake of Phosphorus lbs./A 3)	12.2	9.6	10.4
Plant Uptake of Potassium lbs./A 3)	10.3	28.5	8.7
Crop 2	Soybeans	Wheat	Dryland sorghum
Yield Bu/Acre 2)	20.4	28.6	35
Land Used for Crop 2	120	160	480
Plant Uptake of Nitrogen lbs./A 3)	76.6	35.7	32.7
Plant Uptake of Phosphorus lbs./A 3)	7.8	10.6	7.1
Plant Uptake of Potassium lbs./A 3)	23.3	8.9	8.2
Pastureland	Tall Fescue	Tall Fescue	—
Yield Ton/Acre 2)	3.5	3.5	—
Land Used for Pasture	120	240	—

1) Size of farm is based on data from the Oklahoma Agricultural Statistics Service. Census of Agriculture, 1997.
2) Oklahoma Agricultural Statistics Service. Average for the period 1994-1998. Data referent to dryland sorghum in Texas County was calculated for the 1997/1998 period. Data referent to dryland wheat in Texas County was calculated for the 1995-1999 period.
3) Plant nutrient uptake was calculated based on data published in the Animal Waste Management Field Handbook, Table 6.6.

The second crop corresponds to the crop that ranked second in terms of production in each county: soybeans in Delaware County, wheat in Seminole County and sorghum in Texas County. In Texas County, it was assumed that the farm cultivates dryland wheat and dryland sorghum. In the case of Delaware and Seminole counties, it also was assumed that part of the land is used as pastureland. This assumption was made for two reasons: (1) the farm may be located in a hilly site, in which case it is too difficult to apply manure. (2) The presence of trees and/or gullies in these two counties also impairs the use of equipment in some parts of the farm. Pastureland is assumed cultivated with tall fescue. The plant uptake of nutrient was calculated according to the yields that are characteristic for the specific crop in the county.

It was further assumed that the farms in each county bought feeder pigs to sell as finished hogs. The size of the animal operation varied between 2,000 and 16,000 head capacity, at a certain point in time. The farm purchases batches of pigs monthly and the pigs stay in the farm for a period of four months. Whenever there was insufficient farmland to apply the total volume of manure within the boundaries of the representative farm, it was assumed that the remaining manure was hauled off at a cost of $0.25/cubic foot. This additional cost is included when comparing the different systems.

CHAPTER IV

FINDINGS

The different combinations of components for manure handling were tested for each representative farm and for each capacity. The representative farms were set up for a feeder-finishing operation. Eight different finishing sizes, between 2,000 and 16,000-head capacity with increments of 2,000, were tested. The model was solved with both nitrogen and phosphorus constraints. The minimum cost per animal space refers to the sum of all variable costs experienced by the animal farm in the swine waste management process, divided by the number of animal spaces.

In some cases, not enough land was available in the representative farm for the application of the total volume of manure. The indication that there was additional land used reflects this situation. The manure in excess was assumed to be hauled from the farm at a charge of $0.25 per cubic feet. The minimum costs presented in the following results already account for this additional cost. The fertilizer value of the manure was deducted from the minimum cost per animal space.

Of the combinations tested, one system excelled in obtaining the minimum cost for different operation sizes and in different locations. This system is the combination of fully slated floor/pull plug/anaerobic lagoon/irrigation (using a travelling gun) system.

4.1 Nitrogen Constraint

4.1.1 Delaware County

As is illustrated in Table 4.1, one system consistently achieved the minimum cost in Delaware County, for the different animal sizes tested, under the nitrogen constraint. This system combined a fully slated floor in the pig house, a pull plug collection method, an anaerobic lagoon to treat the manure, and irrigation with a travelling gun as the method of application of manure to the soil. The lowest cost per animal space, $6.75, was obtained for a farm with a one time capacity of 6,000 head. For this volume of swine manure, and under the nitrogen constraint, enough land was available in the representative farm of Delaware County for the application of the total volume of manure.

Table 4.1 Summary of Results for Delaware County under a Nitrogen Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$9.65	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
4,000	$7.63	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
6,000	$6.75	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
8,000	$7.42	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
10,000	$9.30	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
12,000	$10.50	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
14,000	$11.29	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
16,000	$11.89	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used

Note: Irrigation is assumed to use a travelling gun.

For operations bigger than 6,000 animal head, the cost per pig space continuously increased for the sizes tested. This was largely because, for sizes over 6,000 head, there was not enough farmland to apply the total volume of manure. Therefore, the remaining manure had to be hauled out of the farm at a cost of $0.25/cubic feet of manure. Producers in Delaware County are subject to economies and diseconomies of size in swine manure management.

Figure 4.1 represents the different costs per animal space that contribute to the total cost per animal space. A more detailed description of the costs can be found in Appendix D, Table D.1. With the exception of the cost of hauling the manure off the farm, all costs decrease as the farm capacity increases. Therefore, the increase in the total cost per animal space is due to the diseconomies of hauling the manure to a different site.

If the representative farm had more land available for manure application, the need to haul the manure from the farm would occur at a higher animal size, thus shifting the manure hauling curve to the right. Consequently, the minimum cost would be achieved with larger size operations.

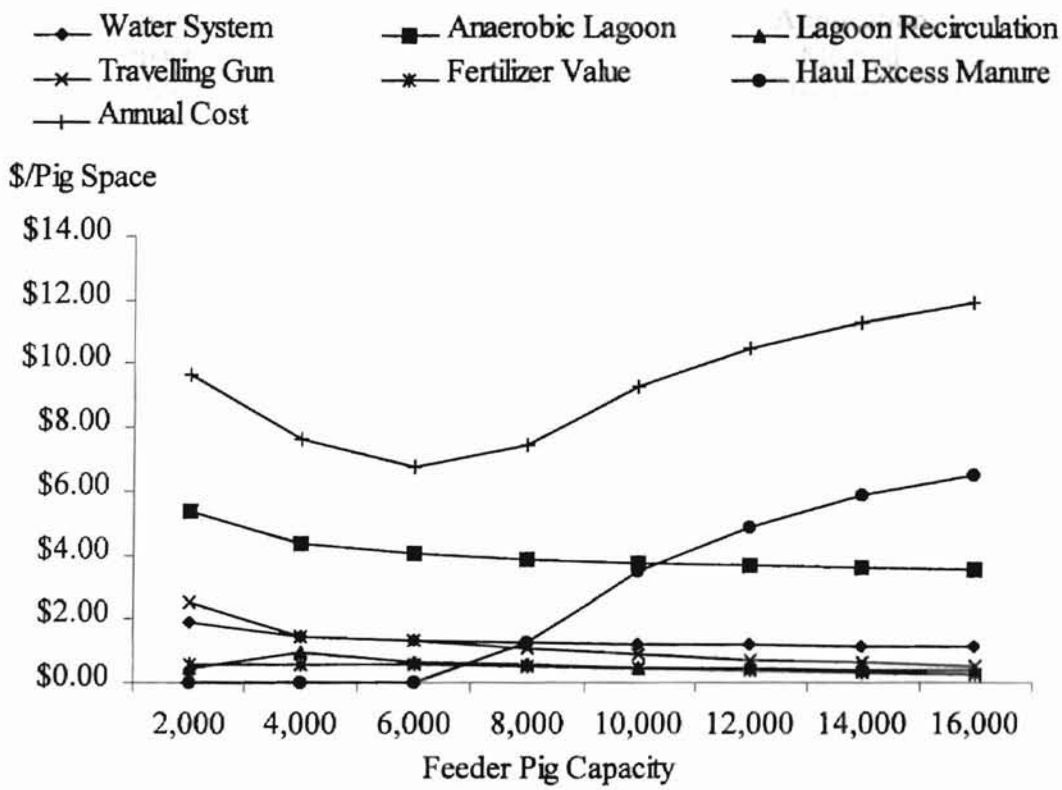


Figure 4.1. Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun in Delaware County for the Nitrogen Constraint

4.1.2 SEMINOLE COUNTY

In Seminole County, the system that performed the best was the same as in Delaware County, as is illustrated in Table 4.2. The fully slated floor/pull plug/anaerobic lagoon/irrigation (using a travelling gun) system consistently achieved the lowest cost per animal space for all sizes tested. In Seminole, the lowest cost per animal space was achieved for a 10,000 maximum animal capacity system at $5.49 per animal space.

Table 4.2 Summary of Results for Seminole County under a Nitrogen Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$9.07	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
4,000	$7.02	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
6,000	$6.14	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
8,000	$5.87	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
10,000	$5.49	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
12,000	$5.80	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
14,000	$6.69	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
16,000	$7.38	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used

Note: Irrigation is assumed to use a travelling gun.

Similarly to Delaware County, swine manure management in Seminole County clearly exhibits economies of size. Farms with a capacity larger than 10,000 head faced a higher cost per animal to handle the manure, under the nitrogen constraint, because they did not have enough farmland for the application of the total volume of manure. Excess manure was assumed to be hauled from the farm.

As is shown in Figure 4.2 (and in Appendix D, Table D.2), all costs per animal space decrease, as the number of feeding spaces in the farm increases. The exception to this trend is the cost of hauling manure to another site. At the exact point where the land availability is exhausted, the minimum cost per animal space increases because the manure handling curve also increases. The availability of additional land, in the representative farm in Seminole County, would postpone this event, allowing further economies of size.

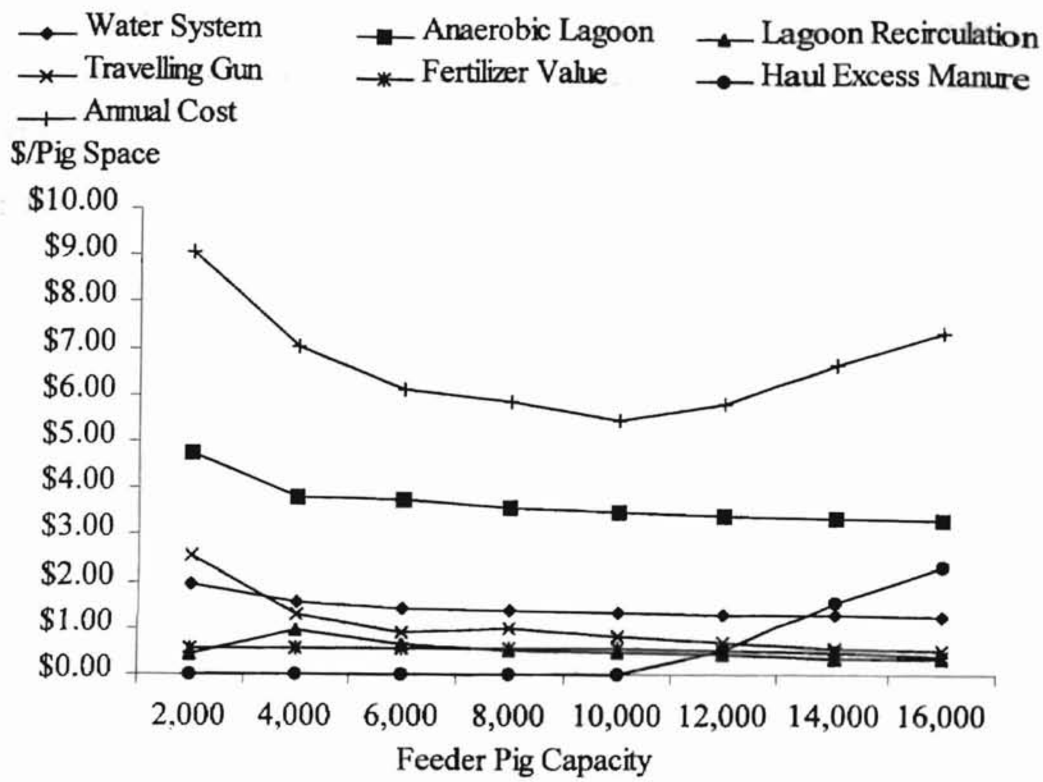


Figure 4.2 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun in Seminole County for the Nitrogen Constraint

4.3 Texas County

Swine waste management, in Texas County, under the nitrogen constraint presents some interest. Although the fully slated floor/pull plug/anaerobic lagoon/irrigation (using a travelling gun) system performed well in Texas county, there was another system that also achieved minimum costs, as can be seen in Table 4.3. For

6,000 and 8,000 maximum animal capacity, the system that performed the best combined a slab floor in the animal house, a scraper to collect the manure, an earthen storage pond, and drag hose application of manure to the soil. The minimum cost per animal space was achieved by the latter system, at $4.55 per animal space, for 6,000 animal head.

Table 4.3 Summary of Results for Texas County under a Nitrogen Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$9.67	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
4,000	$7.91	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
6,000	$4.55	Partial Slated Floor	Scraper	Earthen Storage Pond	Drag Hose	Additional land used
8,000	$6.39	Partial Slated Floor	Scraper	Earthen Storage Pond	Drag Hose	Additional land used
10,000	$6.48	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
12,000	$6.15	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
14,000	$6.00	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
16,000	$6.12	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied

Note: Irrigation is assumed to use a travelling gun.

Under this system, for a number of animal head greater than or equal to 6000, not enough farmland was available to finish the application of the total volume of manure within the representative farm boundaries. This can be seen in Figure 4.3 (and in Appendix D, Table D.4) by an increasing manure handling cost curve after this size. However, the cost of hauling the manure from the farm did not decrease the competitiveness of this system on this location because the minimum cost per pig space was achieved right at the point where the need for additional land begins.

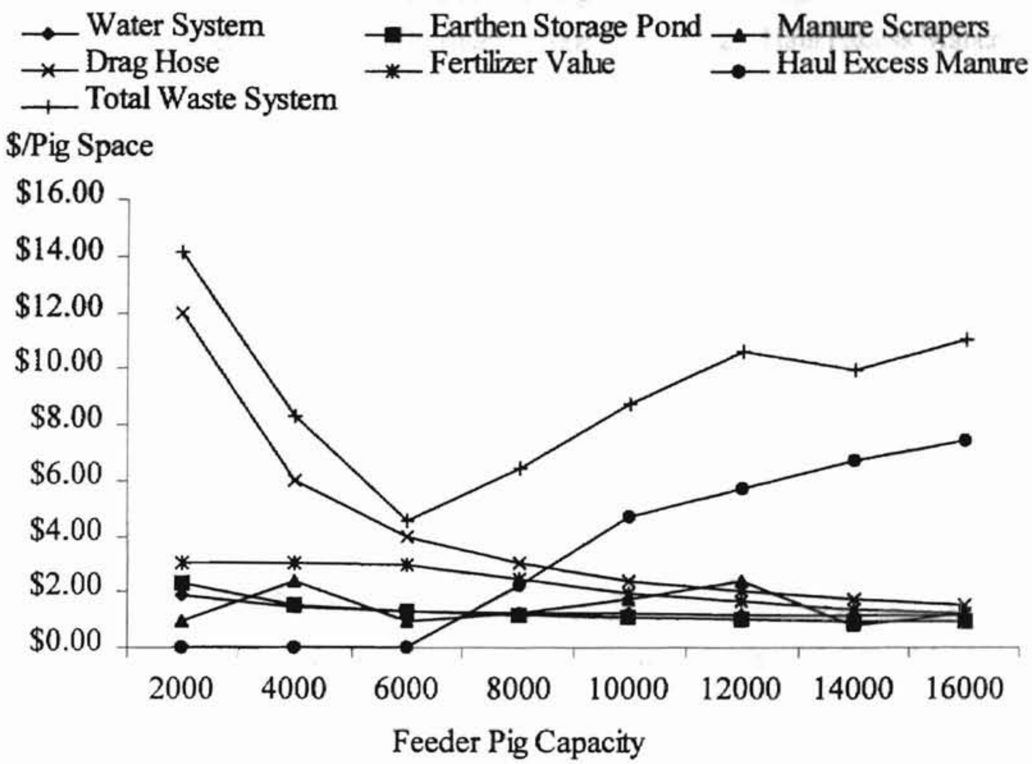


Figure 4.3 Cost Components per Animal Space for the System Partial Slated Floor, Scraper, Earthen Storage Pond, and Drag Hose Application in Texas County for the Nitrogen Constraint.

The slated floor/pull plug/anaerobic lagoon/irrigation (using a travelling gun) system achieved minimum costs for the smaller sizes (2,000 and 4,000 animal head) and for sizes greater than or equal to 10,000 animal head. As is illustrated in Figure 4.4 (Appendix D, Table D.3), the overall minimum cost per pig space is achieved at a size of 14,000 animal head, at $6.00. Although, under this system, the total volume of manure was applied within the boundaries of the representative farm of Texas County, this system faced greater costs than the system partial slated floor/scraper/earthen storage pond/drag hose.

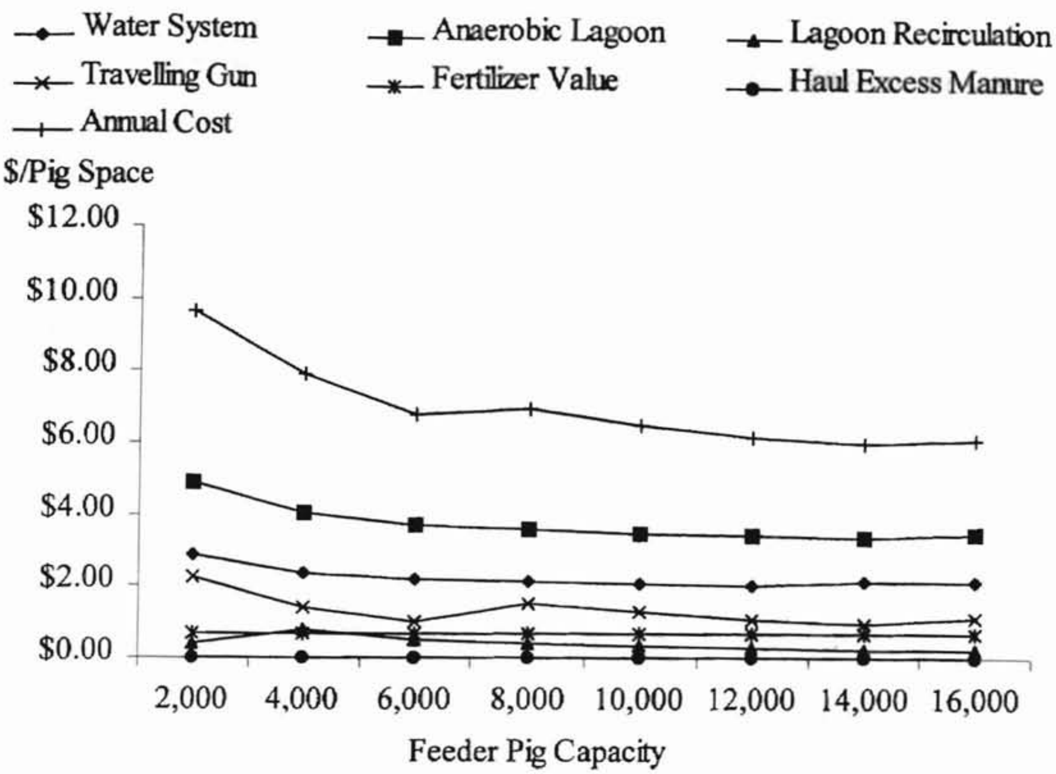


Figure 4.4 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun in Texas County for the Nitrogen Constraint.

4.2 Phosphorus Constraint

4.2.1 DELAWARE COUNTY

The cost of managing manure, in Delaware County, under a phosphorus constraint is clearly greater than that of managing the manure under a nitrogen constraint, as can be seen in Table 4.4. The most cost efficient system for all the sizes tested used a fully slated floor in the pig house and a pull plug to remove the manure from the animal house. The manure was stored and treated using an anaerobic lagoon and it was applied to the land with a travelling gun (irrigation).

Table 4.4 Summary of Results for Delaware County under a Phosphorus Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$21.63	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
4,000	$20.13	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
6,000	$18.91	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
8,000	$18.23	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
10,000	$17.80	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
12,000	$17.50	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
14,000	$17.23	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
16,000	$17.05	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used

Note: Irrigation is assumed to use a travelling gun.

For the sizes tested, this system achieved the lowest cost at $17.05, for a farm with a maximum capacity of 16,000 animal head. Since the cost per animal space decreased from size to size, there is the possibility that farms greater than 16,000 animal head may achieve lower costs. Swine manure handling in Delaware County under a phosphorus constraint is subject to economies of size. For all the sizes tested, the amount of land available for manure spreading was insufficient, consequently additional land had to be used. The manure hauling curve shown in Figure 4.5 (Appendix D Table D.5) indicates that the cost per animal space of hauling manure off the farm increases at a decreasing rate, although the cost of hauling an additional cubic foot of manure is assumed to be constant at $0.25.

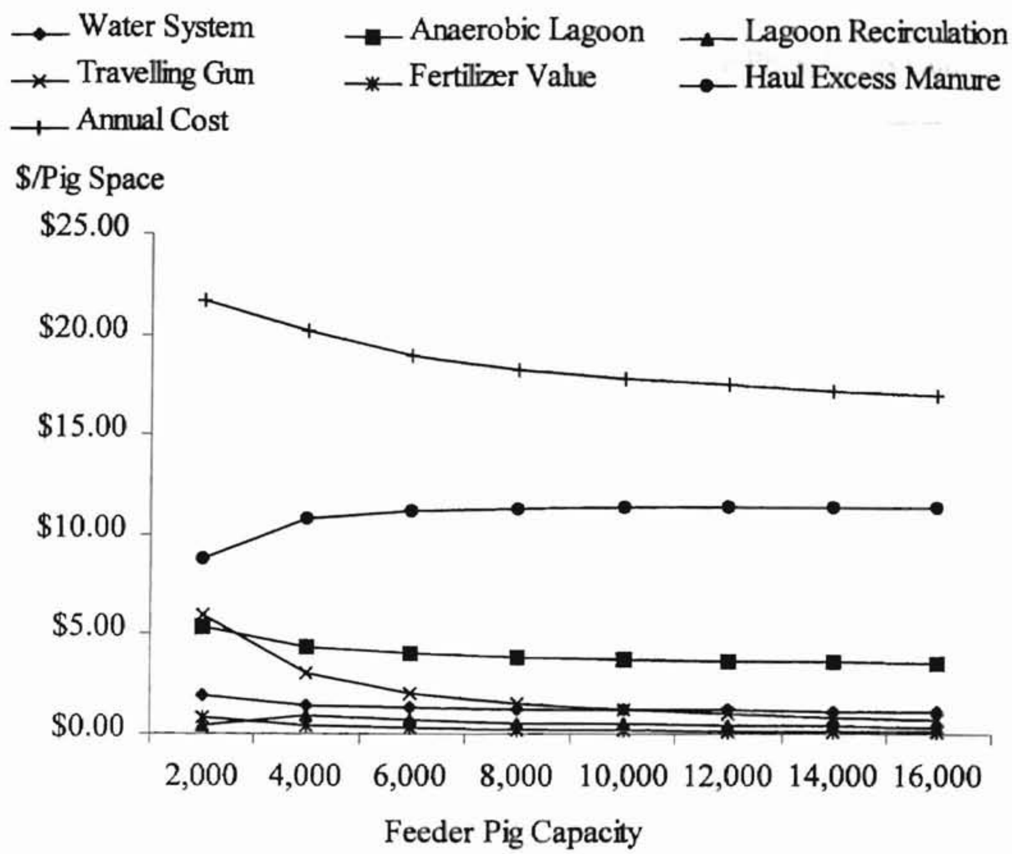


Figure 4.5 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun in Delaware County under the Phosphorus Constraint.

4.2.2 Seminole County

Similarly to Delaware County, in Seminole County, the fully slated floor/pull plug/anaerobic lagoon/irrigation (using a travelling gun) system was the system that consistently achieved the lowest cost for all sizes tested. The amount of land available in the representative farm of Seminole County for manure application using this system was also insufficient, for all farm sizes tested, as is illustrated in Table 4.5. The minimum cost per animal head was $13.12 for 16,000 animals. This cost may decrease to lower levels for farms greater than 16,000 animals.

Table 4.5 Summary of Results for Seminole County under a Phosphorus Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$18.10	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
4,000	$15.67	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
6,000	$14.66	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
8,000	$14.05	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
10,000	$13.69	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
12,000	$13.45	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
14,000	$13.25	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used
16,000	$13.12	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used

Note: Irrigation is assumed to use a travelling gun.

Figure 4.6 (Appendix D, Table D6) illustrates the evolution of the different components of the annual cost per pig space as the number of pig spaces in the farm increases. The evolution of the different costs in Seminole County is very similar to the situation portrayed for Delaware County. The cost of hauling the manure off the farm increases initially and then it appears to stabilize.

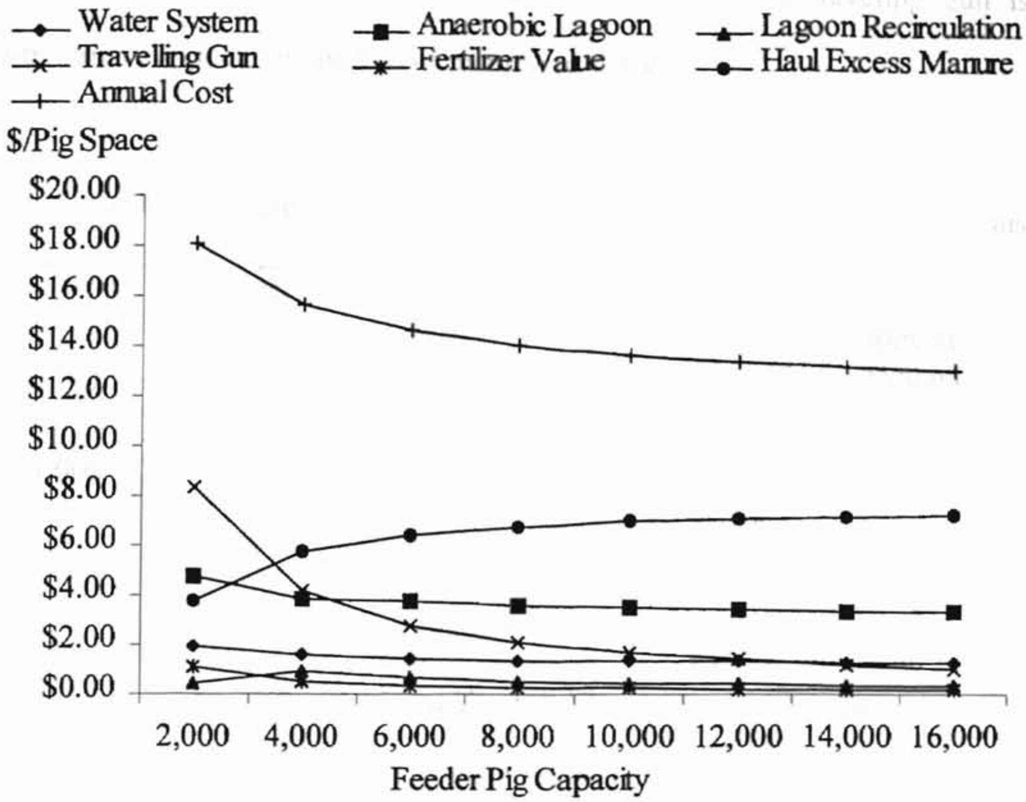


Figure 4.6 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun, in Seminole County for the Phosphorus Constraint.

4.2.3 Texas County

In Texas County, swine manure handling under a phosphorus constraint is subject to economies of scale. The system that performed the best in terms of cost per animal space combined a fully slated floor, a pull plug, an anaerobic lagoon, and drag hose application. With this system, the minimum cost per animal space was $6.81 for 12,000-head capacity.

Drag hose application of manure to the soil seems to be a competitive system for farm sizes between 10,000 and 14,000 swine head. For farm sizes smaller than or equal to 8,000 and equal to 16,000 animals, irrigation with a traveling gun is the most competitive application method of manure to the soil.

Table 4.6 Summary of Results for Texas County under a Phosphorus Constraint.

Size of Operation	Cost per Animal Space ($)	Floor Type in Animal House	In-house Collection System	Storage/ Treatment Method	Soil Application Method	Status of Application
2,000	$10.05	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
4,000	$9.06	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
6,000	$8.28	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
8,000	$7.92	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	All manure applied
10,000	$7.21	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Drag Hose	All manure applied
12,000	$6.81	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Drag Hose	Additional land used
14,000	$8.36	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Drag Hose	Additional land used
16,000	$9.36	Fully Slated Floor	Pull Plug	Anaerobic Lagoon	Irrigation	Additional land used

Note: Irrigation is assumed to use a travelling gun.

The costs per animal space for the combination fully slated floor/pull plug/anaerobic lagoon/irrigation with a travelling gun are represented in Figure 4.7 (Appendix D, Table D.8). Under the phosphorus constraint, this system achieved the lowest cost at $7.71 for 10,000-head capacity. For a larger capacity, the additional volume of manure requires additional application land. Therefore, it is the need to haul the manure from the representative farm to another location that contributes to the increase in the annual cost per animal space of the system fully slated floor/pull plug/anaerobic lagoon/irrigation with a travelling gun.

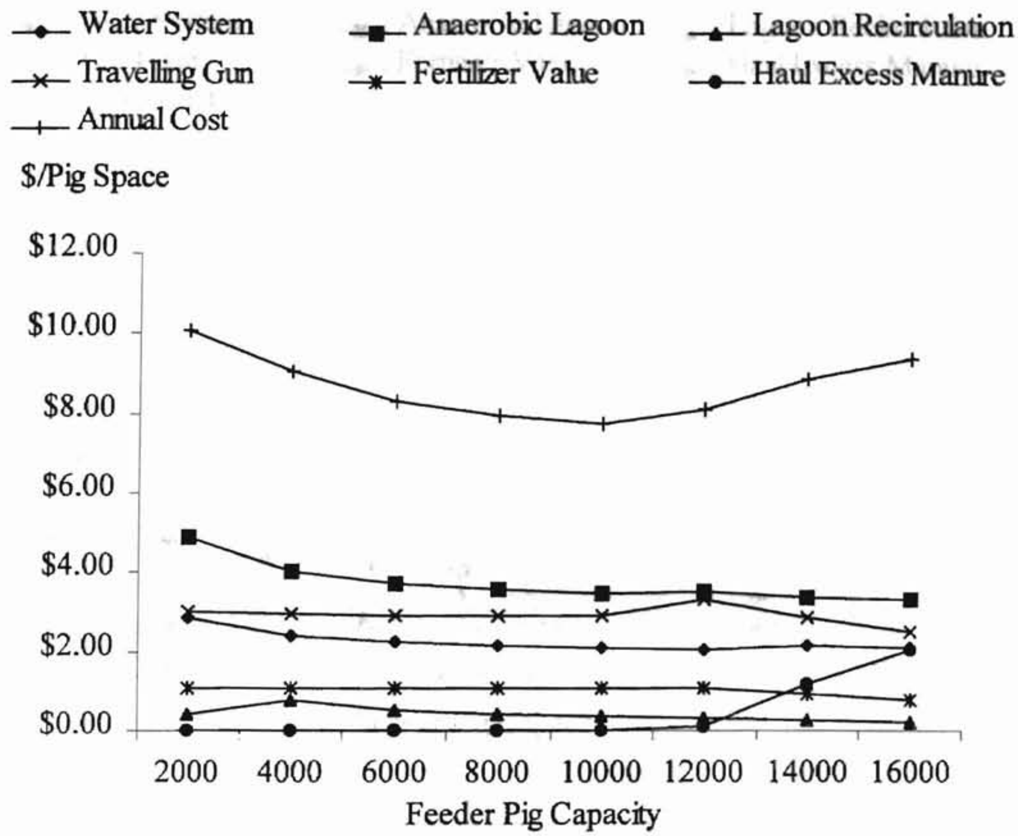


Figure 4.7 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun in Texas County for the Phosphorus Constraint.

The system that combined fully slated floor/pull plug/anaerobic lagoon/drag hose application is subject to economies of size, as can be seen by the annual cost per pig space curve in Figure 4.8 (Appendix D, Table D.7). The minimum cost per animal is achieved at $6.81 for 12,000-head capacity. Beyond this point, additional land was required to apply the remaining manure. The advantage of applying manure with a drag hose relative to applying manure with a travelling gun is that the total cost of the drag hose is kept constant as the farm size increases. The cost of the drag hose per swine animal will decrease as the number of animals increases.

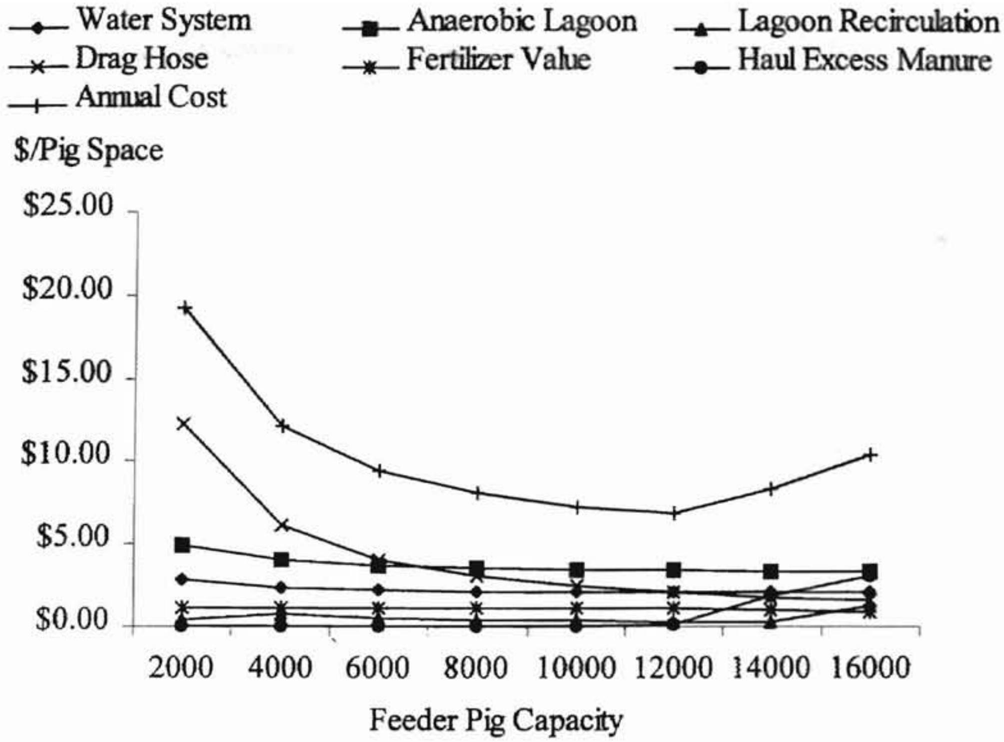


Figure 4.8 Cost Components per Animal Space for the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Drag Hose Application in Texas County for the Phosphorus Constraint.

4.4 Analysis of Findings

The results illustrated above indicate that the hypothesis that the cost of managing swine manure differs with location is supported, or at least, cannot be rejected. The same system (slated floor/pull plug/anaerobic lagoon/irrigation using a travelling gun) obtained different levels of cost across different locations, as can be seen in Figures 4.9 and 4.10. Under the nitrogen nutrient constraint, this system achieved lower costs in Seminole County for numbers of animals less than or equal to 12,000, as represented in Figure 4.9. For greater explorations, Texas County is the most competitive location.

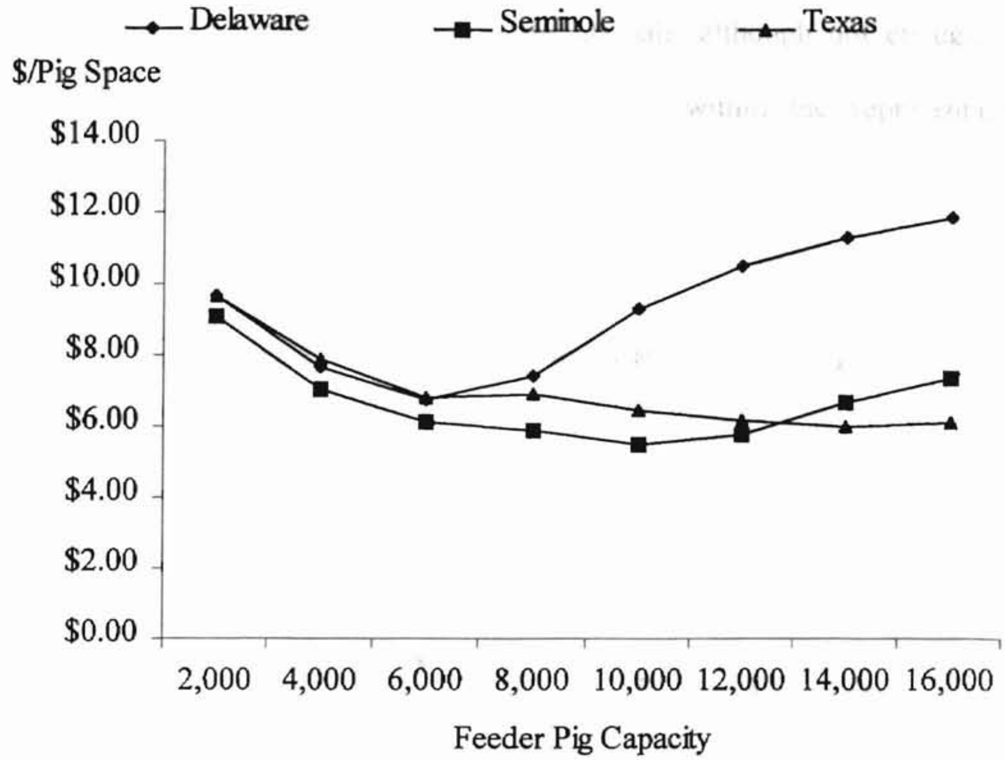


Figure 4.9 Representation of the Minimum Costs of the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun under the Nitrogen Constraint for the Three Different Locations in Oklahoma.

Under the phosphorus constraint, the system fully slated floor, pull plug, anaerobic lagoon, and irrigation with a travelling gun achieved overall minimum costs per animal space in Texas County as can be seen in Figure 4.10. It is also significant that the minimum cost per location was achieved at different sizes.

In most cases, the existence of more land to apply the remaining manure would have allowed lower costs per animal space. However, in certain locations, additional savings can be made if a different system is adopted, even if that system requires additional land. This was the case of Texas County, under the nitrogen constraint, where the partial slats/scraper/earthen storage pond/drag hose application achieved lower costs than the fully slated floor/pull plug/anaerobic lagoon/irrigation with a travelling gun system, for the sizes 6,000 and 8,000 swine animals, although not enough land was available for the total application of the manure within the representative farm boundaries.

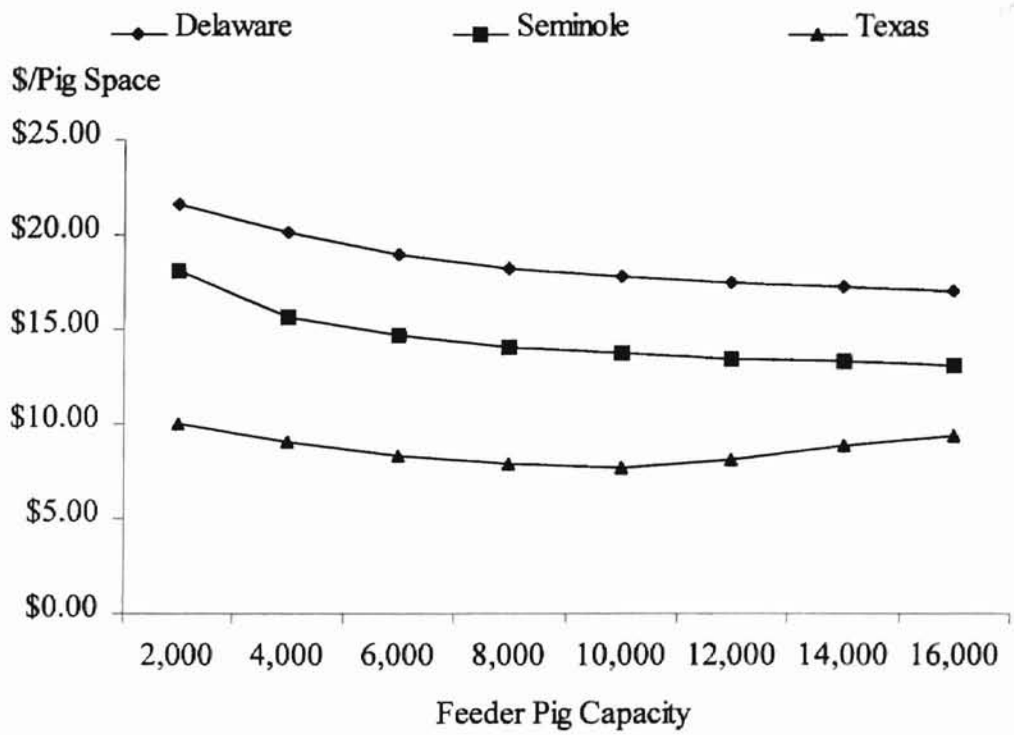


Figure 4.10 Representation of the Minimum Costs of the System Fully Slated Floor, Pull Plug, Anaerobic Lagoon, and Irrigation with a Travelling Gun under the Phosphorus Constraint for the Three Different Locations in Oklahoma

As was expected, the need for additional land differed with the predominant nutrient constraint. Under the nitrogen constraint as we moved towards west in the state the need for additional land occurred at greater sizes. Smaller size farms had enough application land to exhaust the total volume of manure. Bigger farms required additional land.

Under the phosphorus constraint, both representative farms in Delaware County and in Seminole County required the use of additional land to apply the manure for all sizes tested. The representative farm in Texas County was able to cope with volumes of manure for up to 12,000 swine animals. Beyond that size, the least expensive management system in Texas County required the use of additional land.

In Texas County, the availability of land, translated in a greater size of the farm, allowed the representative farm in this county to explore a comparative advantage relative to the farms in Seminole and to Delaware counties. This fact is substantiated by the fact that, overall, it was cheaper to manage swine manure in Texas County than in the other two locations.

CHAPTER V

CONCLUSION

The importance of hog waste management has increased significantly in the state of Oklahoma over the last ten years. The change from a large number of big farms towards a smaller number of bigger farms aggravated environmental concerns of the population over hog waste. The evolution of the legislative framework indicates that the industry will face increasingly restrictive legislation.

The main environmental negative externalities of the industry are odor nuisance, possibility of nutrient leaching to the water table, and nutrient accumulation in the soil. All these issues are connected to the disposal of the animal waste produced in the hog farm. Nevertheless, when managed properly as manure, hog waste is a source of nutrients for the crops.

Management of hog manure should take into account water availability, crop uptake of nutrient, time of application, nutrient constraints, etc. Water availability is intimately connected to the climatological aspects of the region. The proper time of application of manure to the soil is also determined by the climate. Climate variability across Oklahoma is, therefore, an interesting variable that should be considered when deciding the location of the hog production facility.

This study was performed for three different locations in Oklahoma facing humid (Delaware County), medium rainfall (Seminole County), and semi-arid (Texas County) weather conditions. Different combinations of methods were tested for each location with respect to the cost per animal of managing hog manure. One combination of systems performed well across the state for different farm sizes: slated floor/pull plug/anaerobic lagoon/irrigation using a travelling gun.

The minimum cost per animal under a nitrogen constraint ($4.55) was achieved by a 6,000 animal hog farm in Texas County using partial slated floor/scraper/earthen storage pond/drag hose application. Bigger farm sizes, in terms of animal capacity, achieved waste management costs per pig space greater than $4.55, although lower than the costs per pig space in the other two counties.

Under the phosphorus constraint, the cost per pig space of handling animal waste increased considerably in Delaware and Seminole counties due to the need to use additional land to spread the manure. The cost per animal space also increased somewhat in Texas County due to the need for additional land to apply the remaining manure occurred at 12,000 pig spaces. The minimum per pig space costs to manage manure for the different sizes tested, in Delaware and Seminole counties, were greater than the minimum costs per animal head, for the different farm sizes, in Texas County. Therefore, Texas County was the most competitive county in the management of swine waste under a phosphorus constraint.

The Visual Basic code and the method by which it interacts with the Excel™ spreadsheet are presented in Appendix C. The use of a macro in an Excel™ spreadsheet proved to be an efficient way of testing different locations for the different combinations of methods selected. The macro in the Excel™ Spreadsheet takes about three minutes and 30 seconds to run 108 combinations of systems and determine the minimum cost combination for the specified size, location, and crop selection. The computer used had 333 MHz Pentium II processor)

The program is a useful instrument for policy makers because it can provide some guidance for which size of operation and combination of methods is best for each location and size of animal exploration. The program may aid policy makers in creating legislation that orients farmers towards technologies that are adequate for the hog farm location and the particular size of the farm.

Finally, the Excel™ 97 spreadsheet program can help farmers improve their decisions. It allows farmers to test different locations prior to the farm installation, thus finding the efficient cost locations, systems, and sizes.

5.1 Limitations of This Study

Although the spreadsheet constitutes a valuable instrument for both producers and policy makers, its scope has limitations. The spreadsheet uses fixed costs, however these values are subject to change over time. The data were organized by counties, which unrealistically assumes that the characteristics of the soil are homogeneous in each county. The nutrient content of manure was also assumed to be fixed, therefore any variation in the composition of manure due to changes in the animal feed was overlooked. Finally, the spreadsheet works according to the present legislative constraints, which will most likely be changed over time.

SELECTED BIBLIOGRAPHY

The American Society of Agricultural Engineers. *Design and Operation of Farm Irrigation Systems.* Sep. 1983.

Ashraf, Muhammad, and Robert L. Christensen. "An Analysis of the Impact of Manure Disposal Regulations on Dairy Farms." *American Journal of Agricultural Economics* 56 (May 1974): 331-336.

Bowers, Wendell. *Machinery Management.* Moline, IL: Deere & Company, 1987.

Brundin, Sven. "Optimization of Manure Handling Systems under Swedish Conditions." Unpublished Masters Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden, 1994.

Chang, Ni-bin, Richard E. Schuler, and Christine A. Shoemaker. "Environmental and Economic Optimization of an Integrated Solid Waste Management System." *Journal of Resource Management and Technology* 21 (2) (Jun. 1993): 87-98.

Chistensen, L. A., J. R. Trierweiler, T. J. Ulrich, and M. W. Erickson. "Managing Animal Wastes: Guidelines for Decisionmaking." Economic Research Service, United States Department of Agriculture, Bulletin ERS-671, Nov. 1981.

Copeland, J. D., And Janie S. Hipp. "Environmental Laws Impacting Oklahoma Livestock Producers." National Center for Agricultural Law Research and Information, University of Arkansas, 1994.

Coote, D. R., D. A. Haith, and P. J. Zwerman. "Modeling the Environmental and Economic Effects of Dairy Waste Management." *Transactions of the ASAE* 19 (2) (Mar.-Apr. 1976): 326-331.

Crews, Jerry R. "An Evaluation of Swine Waste Management Systems: Utilizing an Interactive Microcomputer – Economic/System Design Program." Unpublished Ph.D. Dissertation, Auburn University, Auburn, Alabama, 1987.

Crowder, Bradley, and C. Edwin Young. "Managing Farm Nutrients: Tradeoffs for Surface- and Ground-Water Quality." Agricultural Economic Report, United States Department of Agriculture, Report 583, Jan. 1988.

Forster, D.L. "Economic Issues in Animal Waste Management." in Hatfield, J.L. *et al., Animal Waste Utilization—Effective Use of Manure as a Soil Resource,* Chelsea: Ann Arbor Press, 1998.

Hatfield, J.L., *et al. Animal Waste Utilization: Effective Use of Manure as a Soil Resource.* Chelsea: Ann Arbor Press, 1998.

High Plains Study Council. "A Summary of the Results of the Ogallala Aquifer Regional Study, with Recommendations to the Secretary of Commerce and Congress." 1982.

High Plains Underground Water Conservation District No. 1. "The Ogallala Aquifer." http://www.hpwa.com/ogallala.html

Hobbs, Bill, and Billy Tucker. Oklahoma State University, Oklahoma Cooperative Extension Service. *The Oklahoma Fertilizer Law.* OSU Extension Facts F-2233.

Holtkamp, Janice, David O'Gorman, and Daniel Otto. "Community Perceptions of Water Quality Impacts from Large-scale Hog Confinements." Staff Paper Series, Department of Economics, Iowa State University, Staff Paper No. 261, Dec. 1994.

Hsieh, Hsin-Neng, and Kuo-Hua Ho. "Optimization of Solid Waste Disposal System by Linear Programming Technique." *Journal of Resource Management and Technology* 21 (4) (Dec. 1993): 194-201.

Johnson, Gordon. Oklahoma State University, Oklahoma Cooperative Extension Service. *Knowing When to Fertilize.* OSU Extension Facts F-2236.

Kaitibie, Simeon. "The Impact of Environmental Regulation on the Growth of the United Stated Hog Industry." Unpublished Masters Thesis, Oklahoma State University, Stillwater, Oklahoma, 1997.

Kim, Chang-Gil. "An Integrated Decision Model for Evaluating Alternative Swine Waste Management Systems under Environmental Constraints in Oklahoma." Unpublished Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma, 1997.

Malik, Arun S., and Robbin A. Shoemaker. "Optimal Cost Sharing Programs to Reduce Agricultural Pollution." Economic Research Service, United States Department of Agriculture, Bulletin 1820.

Meyer, Deanne, and D. Denise Mullinax. "Livestock Nutrient Management Concerns: Regulatory and Legislative Overview." *Journal of Animal Science* 77(2) (1999) 51-62.

Midwest Plan Service, *Livestock Waste Facilities Handbook,* Iowa State University, 1993.

National Oceanic and Atmospheric Administration. *Climatological Data Annual Summary Oklahoma.* 1961-1990.

National Pork Producers Council: *Pork Industry Environmental Impact Facts.* http://www.nppc.org/PROD/EnvironmentalSection/manurefacts.html.

National Pork Producers Council and National Pork Board. *A Review of State Environmental Regulatory Enforcement Actions.* http://www.nppc.org/PROD/EnvironmentalSection/environ-regulatory-review.html. 1996.

Nowak, P., R. Shepard, and F. Madison. "Farmers and Manure Management: A Critical Analysis," in Hatfield, J.L. *et al., Animal Waste Utilization—Effective Use of Manure as a Soil Resource.* Chelsea: Ann Arbor Press, 1998.

Oklahoma Board of Agriculture. Oklahoma Statutes Supplement 1999. "Oklahoma Concentrated Animal Feeding Operations Act." Title 2, § 9.

Oklahoma Department of Agriculture. "Oklahoma Agricultural Rules—Water Quality." Title 35, Chapter 17, Subchapter 3. http://www.state.ok.us/~okag/wq/crules.pdf.

Plant and Soil Sciences Publications. Oklahoma Cooperative Extension Service. http://agweb.okstate.edu/pearl/plantsoil/soils/fertilty.htm

Public Law 92-500. Federal Water Pollution Control Act amendments of 1972 (Clean Water Act). 92nd Congress. October 18, 1972.

Schnagl, Rudy. Regional Water Quality Control Board, California Environmental Protection Agency. *Water quality and Animal Waste: What you need to Know.* http://www.cpif.org/schnagl.

Stoecker, Arthur L., Charles D. Fulhage, John A. Hoehne, Raymond E. Massey, John A. Lory, Douglas W. Hamilton, and Joseph Williams. "Spreadsheet for Design and Economic Analysis of Swine Production and Waste Management Systems." Animal Production Systems and the Environment—An International Conference on Odor, Water Quality, Nutrient Management and Socioeconomic Issues, Proceedings Volume I: Oral Presentations, Des Moines, Iowa Jul.19-22, 1998: 431-436.

Svoboda, I.F. and A. Jones. "Waste Management for Hog Farms—Review." *Asian-Australasian Journal of Animal Sciences* 12 (2) (Mar. 1999): 295-304.

Taha, Hamdy A. *Operations Research: An Introduction.* New York: MacMillan Publishing Co., Inc., 1982.

United States Department of Agriculture, Natural Resources Conservation Service (Oklahoma). NRCS Conservation Practice Standard: Nutrient Management. (Code No. 590), Apr. 1999.

United States Department of Agriculture, Natural Resources Conservation Service (Oklahoma). NRCS Conservation Practice Standard: Waste Management System. (Code No. 312), Apr. 1979.

United States Department of Agriculture, Natural Resources Conservation Service (Oklahoma). NRCS Conservation Practice Standard: Waste Utilization. (Code No. 633), Apr. 1999.

United States Department of Agriculture, Oklahoma Agricultural Statistics Service. *1997 Oklahoma Census of Agriculture.* Oklahoma, 1997.

United States Department of Agriculture, Soil Conservation Service. *Soil Survey of Delaware County, Oklahoma.* 1970.

United States Department of Agriculture, Soil Conservation Service. *Soil Survey of Seminole County, Oklahoma.* 1979.

United States Department of Agriculture, Soil Conservation Service. *Soil Survey of Texas County, Oklahoma.* 1961.

United States Department of Agriculture, Soil Conservation Service. *Agricultural Waste Management Field Handbook,* Apr. 1992.

United States Department of Agriculture, and United States Environmental Protection Agency. "Unified National Strategy for Animal Feeding Operations," http://www.epa.gov/owm/finafost.htm. Mar 9, 1999.

United States House of Representatives. Water Pollution Prevention and Control amendments of 1977 (The Clean Water Act). United States Code, Title 33, Chapter 26, http://www4.law.cornell.edu/uscode/33/1251.html.

Walkenbach, John. *Excel™ 97 Programming for Windows© for Dummies.* Foster City, IDG Books.1997.

Zering, Kelly. "What Does This Cost the Operation? Using Economics to Make Decisions on Nutrient Load." 1996 Pork Profitability Summit, Myrtle Beach, South Carolina, Dec. 11, 1996.

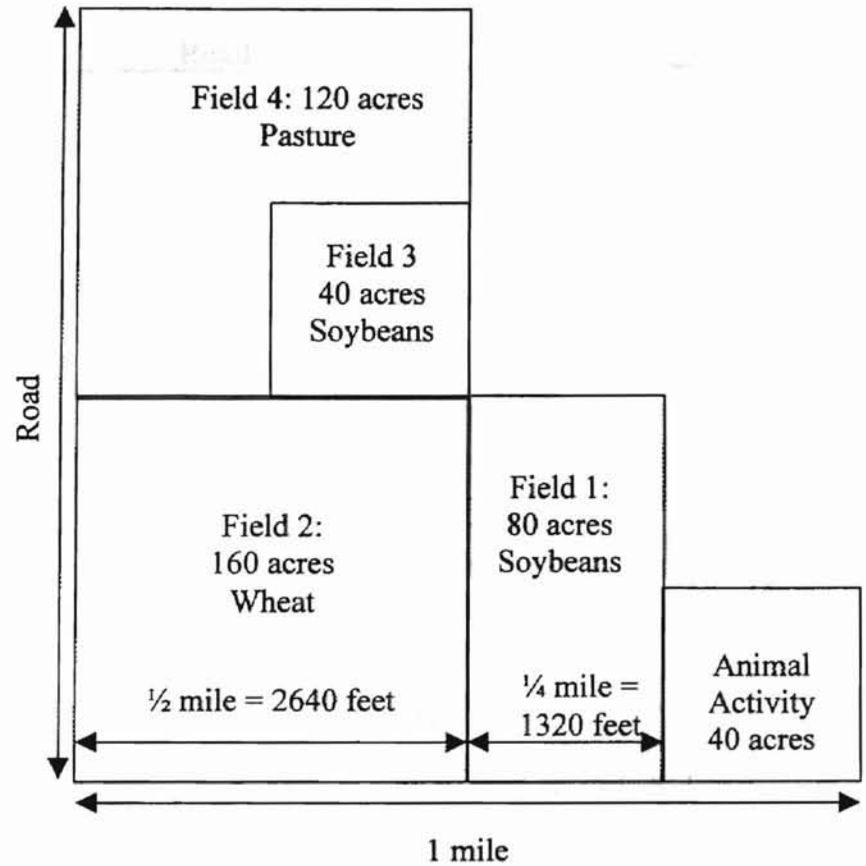
Zhang, Hailin, Bill Raun, Jeff Hattey, Gordon Johnson, and Nick Basta. *OSU Soil Test Interpretations.* Oklahoma State University, Oklahoma Cooperative Extension Service, OSU Extension Facts F-2225.

APPENDIXES

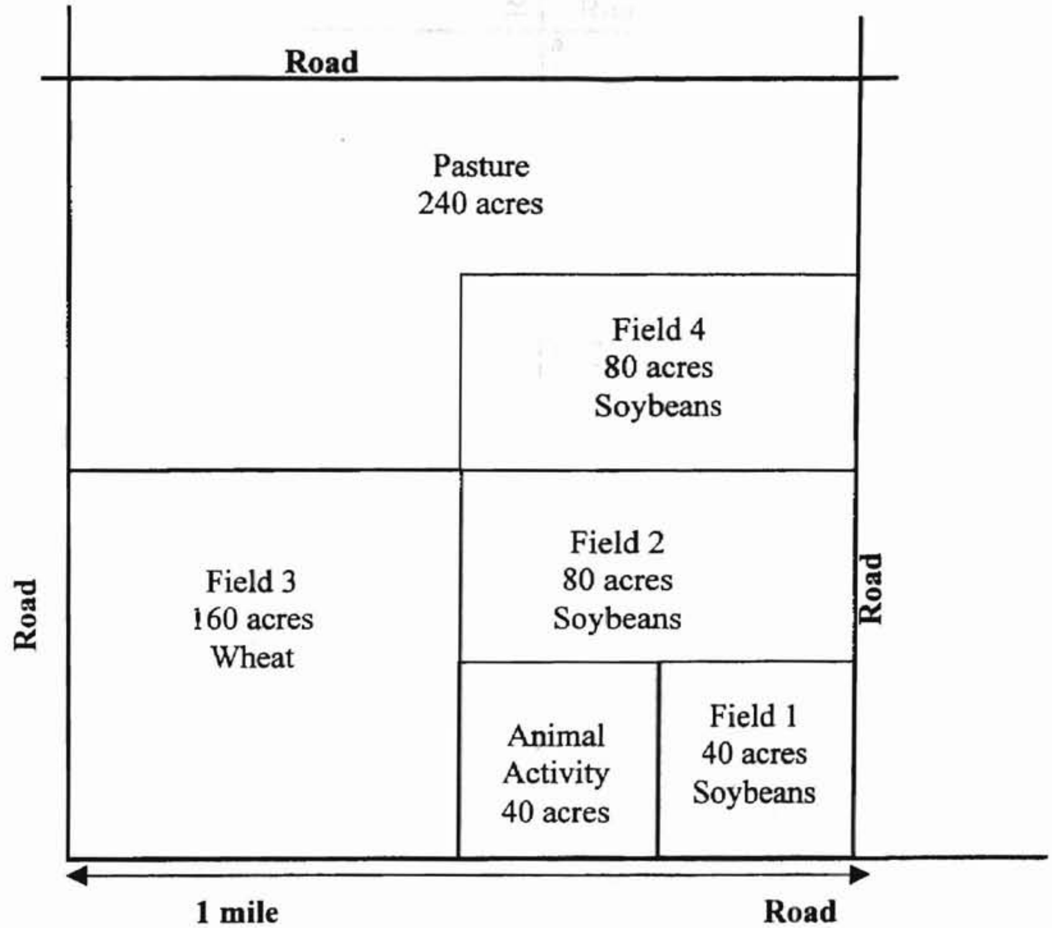
APPENDIX A—DIAGRAMS OF THE REPREPRESENTATIVE FARMS
APPENDIX B—REPRESENTATIVE FARM CHARACTERISTICS
APPENDIX C—VISUAL BASIC PROGRAM INCLUDED IN EXCEL™ 97 SPREADSHEET.
APPENDIX D—PROGRAM RESULTS

APPENDIX A—DIAGRAMS OF THE REPREPRESENTATIVE FARMS

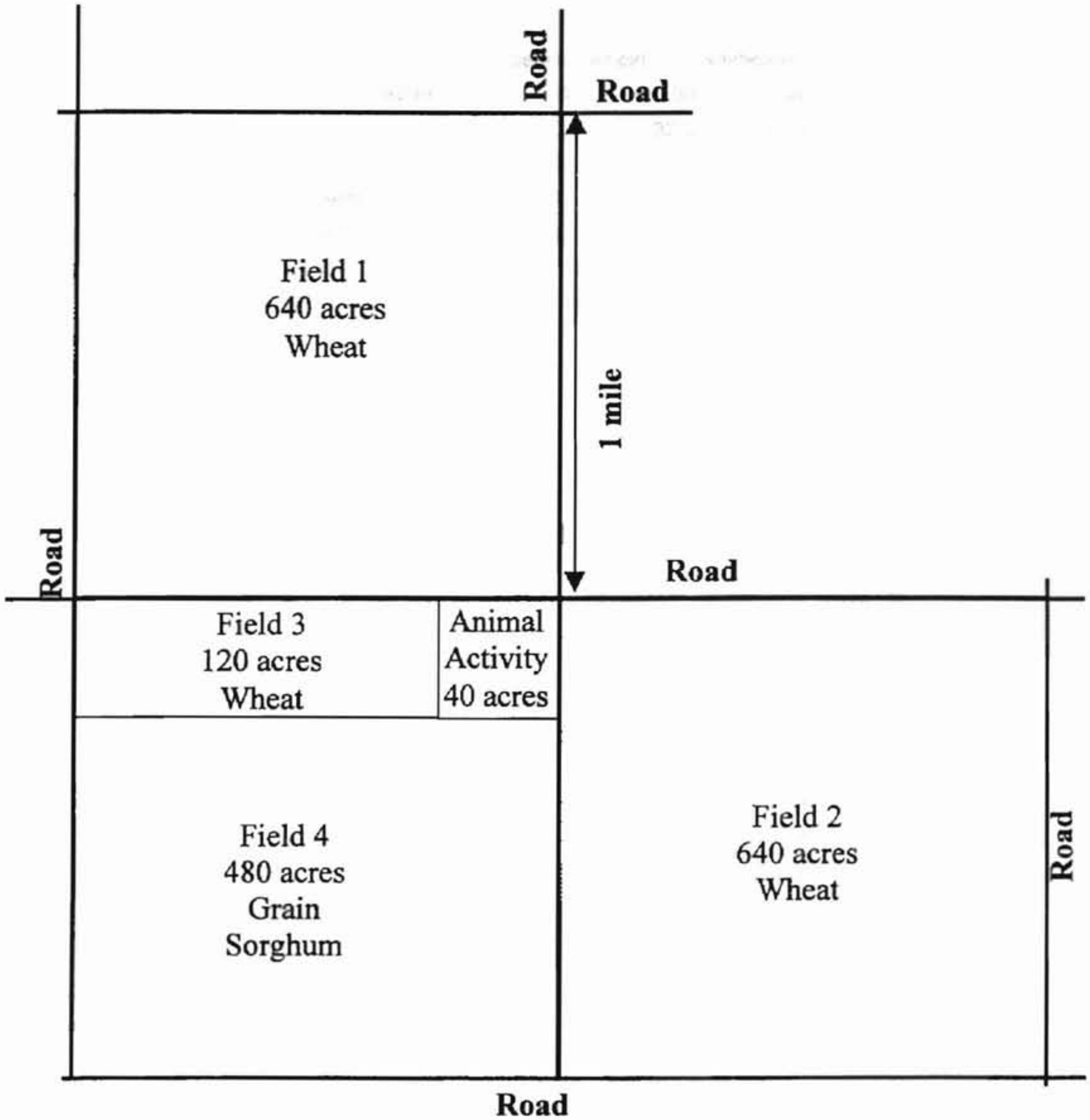
Delaware County



Seminole County



Texas County



APPENDIX B—REPRESENTATIVE FARM CHARACTERISTICS

Delaware	Field	1	2	3	4	5	6
Crop		soybeans	wheat	soybeans			
Acres in Field	Acres	80	160	40	0	0	0
Yield Goal (bushels or tons per acre)	bus/ac	20.4	32.9	20.4	0	0	0
Recommended N (blank if unknown)	lbs/ac	76.6	41.1	76.6	0	0	0
Recommended P2O5 (blank if unknown)	lbs/ac	7.8	12.2	7.8	0	0	0
Recommended K2O (blank if unknown)	lbs/ac	23.3	10.3	23.3	0	0	0
Round Trip distance in miles if hauling	miles	0	0.5	1	0	0	0
Additional Irrig. Pipe to Reach Field	feet	0	1320	1320	0	0	0
Field Width	miles	0.5	0.5	0.25	0	0	0
Long term Irrigation Infiltration Rate	inch/hr	0.3	0.3	0.3	0	0	0
Maximum Change in Elevation from lagoon	feet	25	25	25	25	25	25
Maximum Qt Per Irrigation	ai	3	4	4	4	4	4
Surface Storage Capacity	in	0.3	0.3	0.3	0.3	0.3	0.3

Seminole		1	2	3	4	5	6
Crop		soybeans	soybeans	wheat	soybeans		
Acres in Field	Acres	40	80	160	80	0	0
Yield Goal (bushels or tons per acre)	bus/ac	25	25	28.6	25	0	0
Recommended N (blank if unknown)	lbs/ac	93.8	93.8	35.7	93.8	0	0
Recommended P2O5 (blank if unknown)	lbs/ac	22	22	24.4	22	0	0
Recommended K2O (blank if unknown)	lbs/ac	34.2	34.2	10.7	34.2	0	0
Round Trip distance in miles if hauling	miles	0	0	0	0.5	0	0
Additional Irrig. Pipe to Reach Field	feet	0	0	0	1320	0	0
Field Width	miles	0.25	0.5	0.5	0.5	0	0
Long term Irrigation Infiltration Rate	inch/hr	0.3	0.3	0.3	0.3	0	0
Maximum Change in Elevation from lagoon	feet	25	25	25	25	25	25
Maximum Qt Per Irrigation	ai	3	4	4	4	4	4
Surface Storage Capacity	in	0.3	0.3	0.3	0.3	0.3	0.3

Texas (Dryland)		1	2	3	4	5	6
Crop		Wheat	Wheat	Wheat	Grain Sorghum		
Acres in Field	Acres	640	640	120	480	0	0
Yield Goal (bushels or tons per acre)	bus/ac	28	28	28	35	0	0
Recommended N (blank if unknown)	lbs/ac	34.9	34.9	34.9	32.7	0	0
Recommended P2O5 (blank if unknown)	lbs/ac	23.9	23.9	23.9	16.2	0	0
Recommended K2O (blank if unknown)	lbs/ac	0.1	0.1	0.1	0.1	0	0
Round Trip distance in miles if hauling	miles	0	0	0	0	0	0
Additional Irrig. Pipe to Reach Field	feet	0	0	0	0	0	0
Field Width	miles	1	1	0.75	1	0	0
Long term Irrigation Infiltration Rate	inch/hr	0.3	0.3	0.3	0.3	0.3	0
Maximum Change in Elevation from lagoon	feet	25	25	25	25	25	25
Maximum Qt Per Irrigation	ai	3	4	4	4	4	4
Surface Storage Capacity	in	0.3	0.3	0.3	0.3	0.3	0.3

APPENDIX C—VISUAL BASIC PROGRAM INCLUDED IN EXCEL™ 97 SPREADSHEET.

```
Sub MinCost()
Worksheets("Main").Activate
Range("C16:C19").ClearContents
Range("AO3:AO110").ClearContents
Range("Y9").ClearContents
Range("W11").ClearContents

'Reset model
Range("C16") = 1
Range("C17") = 1
Range("C18") = 2
Range("C19") = 1
Call Mcc
Calculate
Cells(3, 41) = Range("K37")

For T = 1 To 96
   'Selecting Type of Floor
   Range("C16") = Cells(T + 2, 36)
   'Selecting Inhouse Method
   Range("C17") = Cells(T + 2, 37)
   'Selecting Storage and Treatment Method
   Range("C18") = Cells(T + 2, 38)
   'Selecting Application Method
   Range("C19") = Cells(T + 2, 39)
   Call Mcc
   Calculate
   'Storing cost values:
   Cells(T + 2, 41) = Range("K37")
Next T
MCost = Application.WorksheetFunction.Min(Range("AO3:AO98"))
Cells(9, 25) = MCost
Cells(11, 23) = Application.WorksheetFunction.VLookup(MCost, Range("AO3:AQ98"),
                3, False)
MsgBox ("The minimum cost per animal is $" & Range("Y9") & ", which is achieved
                using the following methods: " & Range("W11") & ".")

End Sub
```

APPENDIX D—PROGRAM RESULTS

TABLE D.1 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN DELAWARE COUNTY FOR THE NITROGEN CONSTRAINT

Delaware–fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun

Nitrogen constraint	**Units**								
number of animals		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Acres Covered	acres	57.1	143.8	245.5	280	280	280	280	280
N Applied	ac-inch	4376	8752	13128	15768	15768	15768	15768	15768
P Applied	ac-inch	6938	13875	20813	24998	24998	24998	24998	24998
Waste Remaining	ac-inch	0	0	0	11.1	38.2	64.6	90.6	116.3
Pumps in system-size	GPM	200	200	600	600	600	600	600	600
Pumps in system	number	1	1	1	1	1	1	1	1
Days to Apply	days	11	18.5	14	19.5	19.3	19.2	19.1	19
Variable Costs									
Water System	$/year	3,737	5,798	7,859	9,919	11,980	14,041	16,102	18,162
Anaerobic Lagoon	$/year	10,768	17,509	24,145	30,727	37,273	43,794	50,296	56,784
Lagoon Recirculation	$/year	847	3,815	3,968	4,309	4,725	5,173	5,234	5,624
Travelling Gun	$/year	5,076	5,716	8,081	8,619	8,593	8,574	8,560	8,549
Fertilizer Value	$/year	1,125	2,321	3,553	4,231	4,231	4,231	4,231	4,231
Haul Excess Manure	$/year	0	0	0	10,024	34,631	58,605	82,161	104,423
Total Waste System	$/year	19,303	30,517	40,501	59,367	92,971	125,956	158,122	190,311
Variable Costs/Pig Space									
Water System	$/year	1.87	1.45	1.31	1.24	1.20	1.17	1.15	1.14
Anaerobic Lagoon	$/year	5.38	4.38	4.02	3.84	3.73	3.65	3.59	3.55
Lagoon Recirculation	$/year	0.42	0.95	0.66	0.54	0.47	0.43	0.37	0.35
Travelling Gun	$/year	2.54	1.43	1.35	1.08	0.86	0.71	0.61	0.53
Fertilizer Value	$/year	0.56	0.58	0.59	0.53	0.42	0.35	0.30	0.26
Haul Excess Manure	$/year	0.00	0.00	0.00	1.25	3.46	4.88	5.87	6.53
Annual Cost	$/year	9.65	7.63	6.75	7.42	9.30	10.50	11.29	11.89

TABLE D.2 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN SEMINOLE COUNTY FOR THE NITROGEN CONSTRAINT

Seminole--fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun

Nitrogen constraint	**Units**								
number of animals		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Acres Covered	acres	46.7	93.3	172.4	285.7	332.4	360	360	360
N Applied	ac-inch	4376	8752	13128	17504	21880	24472	24472	24472
P Applied	ac-inch	6938	13875	20813	27750	34688	38796	38796	38796
Waste Remaining	ac-inch	0	0	0	0	0	7	24.2	41.3
Pumps in system-size	GPM	200	200	200	600	600	600	600	600
Pumps in system	number	1	1	1	1	1	1	1	1
Days to Apply	days	6.1	10.7	21.5	18.8	20.3	21.1	21.1	21.1
Variable Costs									
Water System	$/year	3,882	6,171	8,577	10,923	13,273	15,626	17,981	20,338
Anaerobic Lagoon	$/year	9,469	15,211	22,406	28,630	34,837	41,033	47,220	53,401
Lagoon Recirculation	$/year	841	3,740	3,862	4,161	4,534	4,938	4,955	5,302
Travelling Gun	$/year	5,078	5,190	5,432	7,916	8,026	8,088	8,088	8,088
Fertilizer Value	$/year	1,125	2,251	3,426	4,654	5,779	6,446	6,446	6,446
Haul Excess Manure	$/year	0	0	0	0	0	6,343	21,899	37,455
Total Waste System	$/year	18,144	28,062	36,851	46,976	54,891	69,584	93,699	118,138
Variable Costs/Pig Space									
Water System	$/year	1.94	1.54	1.43	1.37	1.33	1.30	1.28	1.27
Anaerobic Lagoon	$/year	4.73	3.80	3.73	3.58	3.48	3.42	3.37	3.34
Lagoon Recirculation	$/year	0.42	0.94	0.64	0.52	0.45	0.41	0.35	0.33
Travelling Gun	$/year	2.54	1.30	0.91	0.99	0.80	0.67	0.58	0.51
Fertilizer Value	$/year	0.56	0.56	0.57	0.58	0.58	0.54	0.46	0.40
Haul Excess Manure	$/year	0.00	0.00	0.00	0.00	0.00	0.53	1.56	2.34
Annual Cost	$/year	9.07	7.02	6.14	5.87	5.49	5.80	6.69	7.38

TABLE D.3 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN TEXAS COUNTY FOR THE NITROGEN CONSTRAINT

Texas--fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun									
Nitrogen constraint	**Units**								
number of animals		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Acres Covered	acres	125.2	250.5	375.7	500.9	626.2	751.4	876.6	1001.8
N Applied	ac-inch	4376	8752	13128	17504	21880	26256	30633	35009
P Applied	ac-inch	6938	13875	20813	27750	34688	41625	48563	55500
Waste Remaining	ac-inch	0	0	0	0	0	0	0	0
Pumps in system-size	GPM	250	600	600	600	600	600	600	600
Pumps in system	number	1	1	1	2	2	2	2	3
Days to Apply	days	17.9	16.5	25.5	16.5	20.3	24.8	29.3	22
Variable Costs									
Water System	$/year	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon	$/year	9795	16067	22295	28500	34691	40871	47043	55210
Lagoon Recirculation	$/year	765	3073	3164	3254	3420	3619	3432	3576
Travelling Gun	$/year	4445	5689	6146	12133	12664	12905	13118	18287
Fertilizer Value	$/year	1358	2715	4073	5430	6788	8146	9503	10861
Haul Excess Manure	$/year	0	0	0	0	0	0	0	0
Total Waste System	$/year	19343	31621	40817	55500	64777	73779	84029	97878
Variable Costs/pig space									
Water System	$/year	2.85	2.38	2.21	2.13	2.08	2.04	2.14	2.10
Anaerobic Lagoon	$/year	4.90	4.02	3.72	3.56	3.47	3.41	3.36	3.45
Lagoon Recirculation	$/year	0.38	0.77	0.53	0.41	0.34	0.30	0.25	0.22
Travelling Gun	$/year	2.22	1.42	1.02	1.52	1.27	1.08	0.94	1.14
Fertilizer Value	$/year	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Haul Excess Manure	$/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual Cost	$/year	9.67	7.91	6.80	6.94	6.48	6.15	6.00	6.12

TABLE D.4 PARTIAL SLATS, SCRAPER, EARTHEN STORAGE POND, AND DRAG HOSE APPLICATION, IN TEXAS COUNTY FOR THE NITROGEN CONSTRAINT

Texas--partial slats, scraper, earthen storage pond, drag hose application

Nitrogen constraint	**Units**								
number of animals		2000	4000	6000	8000	10000	12000	14000	16000
Acres Covered	acres	562.6	1125.2	1707.2	1880	1880	1880	1880	1880
N Applied	ac-inch	19659	39317	58976	64633	64633	64633	64633	64633
P Applied	ac-inch	31219	62438	93657	102640	102640	102640	102641	102640
Waste Remaining	ac-inch	0	0	0	19.8	47.6	75.5	103.5	131.5
Pumps in system-size	GPM	87.1	87.1	87.1	87.1	87.1	87.1	87.1	87.1
Pumps in system	number	1	1	1	1	1	1	1	1
Days to Apply	days	10.3	10.3	10.2	10.2	10.2	10.2	10.2	10.3
Variable Costs									
Water System	$/year	3,737	5,798	7,859	9,919	11,980	14,041	16,102	18,162
Earthen Storage Pond	$/year	4,665	5,946	7,675	9,077	10,471	11,861	13,246	14,629
Manure Scrapers	$/year	1,928	9,519	5,783	9,717	16,984	28,558	11,564	19,433
Drag Hose	$/year	23,968	23,980	23,945	23,951	23,955	23,958	23,960	23,962
Fertilizer Value	$/year	6,099	12,198	17,936	19,488	19,488	19,488	19,488	19,488
Haul Excess Manure	$/year	0	0	0	17,928	47,173	68,477	93,824	119,202
Total Waste System	$/year	28,199	33,045	27,325	51,103	87,075	127,406	139,207	175,900
Variable Costs/pig space									
Water System	$/year	1.87	1.45	1.31	1.24	1.20	1.17	1.15	1.14
Earthen Storage Pond	$/year	2.33	1.49	1.28	1.13	1.05	0.99	0.95	0.91
Manure Scrapers	$/year	0.96	2.38	0.96	1.21	1.70	2.38	0.83	1.21
Drag Hose	$/year	11.98	6.00	3.99	2.99	2.40	2.00	1.71	1.50
Fertilizer Value	$/year	3.05	3.05	2.99	2.44	1.95	1.62	1.39	1.22
Haul Excess Manure	$/year	0.00	0.00	0.00	2.24	4.72	5.71	6.70	7.45
Total Waste System	$/year	14.10	8.26	4.55	6.39	8.71	10.62	9.94	10.99

TABLE D.5 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN DELAWARE COUNTY FOR THE PHOSPHORUS CONSTRAINT

Delaware--fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun

Phosphorus constrai	**Units**								
number of animals		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Acres Covered	acres	280	280	280	280	280	280	280	280
N Applied	ac-inch	1822	1822	1822	1822	1822	1822	1822	1822
P Applied	ac-inch	2888	2888	2888	2888	2888	2888	2888	2888
Waste Remaining (AI	ac-inch	19.4	47.5	74	99.9	125.3	150.6	175.6	200.5
Pumps in system--size	GPM	600	600	600	600	600	600	600	600
Pumps in system	number	2	2	2	2	2	2	2	2
Days to Apply	days	22.5	22.9	24	24	24	24	24.4	24.4
Variable Costs									
Water System	$/year	3,737	5,798	7,859	9,919	11,980	14,041	16,102	18,162
Anaerobic Lagoon	$/year	10,768	17,509	24,145	30,727	37,273	43,794	50,296	56,784
Lagoon Recirculation	$/year	847	3,815	3,968	4,309	4,725	5,173	5,234	5,624
Travelling Gun	$/year	11,897	11,906	11,931	11,921	11,915	11,953	11,949	11,946
Fertilizer Value	$/year	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545
Haul Excess Manure	$/year	17,548	43,036	67,085	90,537	113,648	136,530	159,247	181,837
Total Waste System	$/year	43,252	80,519	113,442	145,869	177,996	209,946	241,283	272,809
Variable Costs/Pig Space									
Water System	$/year	1.87	1.45	1.31	1.24	1.20	1.17	1.15	1.14
Anaerobic Lagoon	$/year	5.38	4.38	4.02	3.84	3.73	3.65	3.59	3.55
Lagoon Recirculation	$/year	0.42	0.95	0.66	0.54	0.47	0.43	0.37	0.35
Travelling Gun	$/year	5.95	2.98	1.99	1.49	1.19	1.00	0.85	0.75
Fertilizer Value	$/year	0.77	0.39	0.26	0.19	0.15	0.13	0.11	0.10
Haul Excess Manure	$/year	8.77	10.76	11.18	11.32	11.36	11.38	11.37	11.36
Annual Cost	$/year	21.63	20.13	18.91	18.23	17.80	17.50	17.23	17.05

TABLE D.6 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN SEMINOLE COUNTY FOR THE PHOSPHORUS CONSTRAINT

Seminole--fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun

Phosphorus Constrain	**Units**								
number of animals		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Acres Covered	acres	360	360	360	360	360	360	360	360
N Applied	ac-inch	2281	2281	2281	2281	2281	2281	2281	2281
P Applied	ac-inch	3616	3616	3616	3616	3616	3616	3616	3616
Waste Remaining	ac-inch	8.2	25.4	42.5	59.7	76.8	94	111.2	128.3
Pumps in system -size	GPM	600	600	600	600	600	600	600	600
Pumps in system	number	3	3	3	3	3	3	3	3
Days to Apply	days	21	21	21	21	21	21	21	21
Variable Costs									
Water System	$/year	3,882	6,171	8,577	10,923	13,273	15,626	17,981	20,338
Anaerobic Lagoon	$/year	9,469	15,211	22,406	28,630	34,837	41,033	47,220	53,401
Lagoon Recirculation	$/year	841	3,740	3,862	4,161	4,534	4,938	4,955	5,302
Travelling Gun	$/year	16,655	16,655	16,655	16,655	16,655	16,655	16,655	16,655
Fertilizer Value	$/year	2,097	2,097	2,097	2,097	2,097	2,097	2,097	2,097
Haul Excess Manure	$/year	7,448	23,004	38,559	54,115	69,971	85,227	100,783	116,338
Total Waste System	$/year	36,198	62,684	87,962	112,387	136,874	161,383	185,498	209,937
Variable Costs/Pig Space									
Water System	$/year	1.94	1.54	1.43	1.37	1.33	1.30	1.28	1.27
Anaerobic Lagoon	$/year	4.73	3.80	3.73	3.58	3.48	3.42	3.37	3.34
Lagoon Recirculation	$/year	0.42	0.94	0.64	0.52	0.45	0.41	0.35	0.33
Travelling Gun	$/year	8.33	4.16	2.78	2.08	1.67	1.39	1.19	1.04
Fertilizer Value	$/year	1.05	0.52	0.35	0.26	0.21	0.17	0.15	0.13
Haul Excess Manure	$/year	3.72	5.75	6.43	6.76	7.00	7.10	7.20	7.27
Annual Cost	$/year	18.10	15.67	14.66	14.05	13.69	13.45	13.25	13.12

TABLE D.7 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND APPLICATION WITH A DRAG HOSE, IN TEXAS COUNTY FOR THE PHOSPHORUS CONSTRAINT

Texas--fully slated floor, pull plug, anaerobic lagoon, drag hose application									
Phosphorus constrai	**Units**								
number of animals		2000	4000	6000	8000	10000	12000	14000	16000
Acres Covered	acres	290.9	581.7	872.6	1163.4	1480.1	1880	1880	1880
N Applied	ac-inch	4376	10772	16158	21544	26930	31946	31946	31946
P Applied	ac-inch	6938	13875	20813	27750	34688	41150	41150	41150
Waste Remaining	ac-inch	0	0	0	0	0	1.8	28.2	54.6
Pumps in system-size	GPM	87.1	87.1	87.1	87.1	87.1	87.1	87.1	87.1
Pumps in system	number	1	1	1	1	1	1	1	1
Days to Apply	days	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Variable Costs									
Water System	$/year	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon	$/year	9795	16067	22295	28500	34691	40871	47043	53210
Lagoon Recirculation	$/year	765	3073	3164	3254	3420	3619	3432	19433
Drag Hose	$/year	24627	24627	24627	24627	24627	24627	24627	24627
Fertilizer Value	$/year	2111	4586	6879	9173	11466	13604	13604	13604
Haul Excess Manure	$/year	0	0	0	0	0	1641	25573	49505
Total Waste System	$/year	38590	48688	56491	64252	72063	81684	117010	166838
Variable Costs/pig space									
Water System	$/year	2.85	2.38	2.21	2.13	2.08	2.04	2.14	2.10
Anaerobic Lagoon	$/year	4.90	4.02	3.72	3.56	3.47	3.41	3.36	3.33
Lagoon Recirculation	$/year	0.38	0.77	0.53	0.41	0.34	0.30	0.25	1.21
Drag Hose	$/year	12.31	6.16	4.10	3.08	2.46	2.05	1.76	1.54
Fertilizer Value	$/year	1.06	1.15	1.15	1.15	1.15	1.13	0.97	0.85
Haul Excess Manure	$/year	0.00	0.00	0.00	0.00	0.00	0.14	1.83	3.09
Annual Cost	$/year	19.29	12.17	9.42	8.03	7.21	6.81	8.36	10.43

TABLE D.8 FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN DELAWARE COUNTY FOR THE PHOSPHORUS CONSTRAINT

Texas–fully slated floor, pull plug, anaerobic lagoon, irrigation with a travelling gun

Phosphorus constrai	**Units**								
number of animals		2000	4000	6000	8000	10000	12000	14000	16000
Acres Covered	acres	290.9	581.7	872.6	1163.4	1480.1	1880	1880	1880
N Applied	ac-inch	4376	8752	13128	17504	21880	25956	25956	25956
P Applied	ac-inch	6938	13875	20813	27750	34688	41150	41150	41150
Waste Remaining	ac-inch	0	0	0	0	0	1.8	28.2	54.6
Pumps in system-size	GPM	600	600	600	600	600	600	600	600
Pumps in system	number	1	2	3	4	5	7	7	7
Days to Apply	days	28.5	27.8	27.5	27.4	28.8	27	27	27
Variable Costs									
Water System	$/year	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon	$/year	9795	16067	22295	28500	34691	41871	47043	53210
Lagoon Recirculation	$/year	765	3073	3164	3254	3420	3619	3432	3576
Travelling Gun	$/year	5950	11820	17263	22987	28778	39587	39587	39587
Fertilizer Value	$/year	2111	4223	6334	8445	10557	12526	12526	12526
Haul Excess Manure	$/year	0	0	0	0	0	1067	16622	32178
Total Waste System	$/year	20094	36244	49673	63339	77122	97147	124097	149691
Variable Costs/pig space									
Water System	$/year	2.85	2.38	2.21	2.13	2.08	2.04	2.14	2.10
Anaerobic Lagoon	$/year	4.90	4.02	3.72	3.56	3.47	3.49	3.36	3.33
Lagoon Recirculation	$/year	0.38	0.77	0.53	0.41	0.34	0.30	0.25	0.22
Travelling Gun	$/year	2.98	2.96	2.88	2.87	2.88	3.30	2.83	2.47
Fertilizer Value	$/year	1.06	1.06	1.06	1.06	1.06	1.04	0.89	0.78
Haul Excess Manure	$/year	0.00	0.00	0.00	0.00	0.00	0.09	1.19	2.01
Annual Cost	$/year	10.05	9.06	8.28	7.92	7.71	8.10	8.86	9.36

TABLE D.9 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN DELAWARE COUNTY FOR THE NITROGEN CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water System								
Initial Cost	10,020	10020	10020	10020	10020	10020	10020	10020
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28
Energy cost	2061	4122	6182	8243	10304	12365	14425	16486
Maintenance & Repair	183	183	183	183	183	183	183	183
Total Annual Cost	3737	5798	7859	9919	11980	14041	16102	18162
Anaerobic Lagoon								
Initial Cost	72256	117490	162017	206178	250103	293862	337494	381025
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	10768	17509	24145	30727	37273	43794	50296	56784
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	10768	17509	24145	30727	37273	43794	50296	56784
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	17683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	83	795	883	1177	1472	1766	2060	2355
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	847	3815	3968	4309	4725	5173	5234	5624
Travelling Gun								
Initial Cost	25585	28101	39878	40341	40306	40280	40261	40245
Annual Interest	3695	4137	5939	6024	6019	6014	6011	6008
Energy cost	102	143	422	803	783	769	758	750
Maintenance & Repair	1159	1172	1516	1516	1515	1515	1515	1515
Labor Cost	120	264	204	276	276	276	276	276
Tot. Ann. Cost Before Rec.	5076	5716	8081	8619	8593	8574	8560	8549
Less Value of Fertilizer	1125	2321	3553	4231	4231	4231	4231	4231
Total Annual Cost	3951	3395	4529	4388	4362	4343	4329	4318
Cost to Haul Manure	0	0	0	10024	34631	58605	82161	105423
Total Waste Sys. Cost	19303	30517	40501	59367	92971	125956	158122	190311
Time Req. for 10 hr Days	11	18.5	14	19.5	19.3	19.2	19.1	19
Cost/Pig Space	$9.65	7.63	6.75	7.42	9.3	10.5	11.29	11.89

TABLE D.10 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN SEMINOLE COUNTY FOR THE NITROGEN CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water System								
Initial Cost	10020	10020	10020	10020	10020	10020	10020	10020
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28
Energy cost	2206	4495	6900	9247	11597	13950	16305	18662
Maintenance & Repair	183	183	183	183	183	183	183	183
Total Annual Cost	3882	6171	8577	10923	13273	15626	17981	20338
Anaerobic Lagoon								
Initial Cost	63540	102065	150349	192110	233762	275337	316853	358323
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	9469	15211	22406	28630	34837	41033	47220	53401
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	9469	15211	22406	28630	34837	41033	47220	53401
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	19683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	77	720	777	1029	1280	1531	1782	2032
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	841	3740	3862	4161	4534	4938	4955	5302
Travelling Gun								
Initial Cost	25923	25923	25923	38030	38030	38030	38030	38030
Annual Interest	3754	3768	3795	5667	5681	5688	5688	5688
Energy cost	67	94	117	444	517	561	561	561
Maintenance & Repair	1161	1161	1161	1504	1504	1504	1504	1504
Labor Cost	96	168	360	300	324	336	336	336
Tot. Ann. Cost Bef. Rec.	5078	5190	5432	7916	8026	8088	8088	8088
Less Value of Fertilizer	1125	2251	3426	4654	5779	6446	6446	6446
Total Annual Cost	3952	2940	2006	3262	2247	1643	1643	1643
Cost to Haul Manure	0	0	0	0	0	6343	21899	37455
Total Waste Sys. Cost	18144	28062	36851	46976	54891	69584	93699	118138
Time Req. for 10 hr Days	6.1	10.7	21.5	18.8	20.3	21.1	21.1	21.1
Cost/Pig Space	9.07	7.02	6.14	5.87	5.49	5.8	6.69	7.38

TABLE D.11 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN TEXAS COUNTY FOR THE NITROGEN CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	1020	1020	1020	1020	1020	1020	20040	20040
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	2986.55	2986.55
Energy cost	4019	7831	11608	15367	19115	22854	26587	30315
Maintenance & Repair	183	183	183	183	183	183	366	366
Total Annual Cost	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon								
Initial Cost	65727	107810	149600	191237	232776	274247	315665	357042
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	9795	16067	2295	28500	34691	40871	47043	53210
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	9795	16067	2295	28500	34691	40871	47043	53210
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	17683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	1	53	79	122	166	212	259	306
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	765	3073	3164	3254	3420	3619	3423	3576
Travelling Gun								
Initial Cost	21564	28539	30282	60088	62977	62245	63365	88735
Annual Interest	3104	4135	4427	8718	9258	9089	9392	13031
Energy cost	13	25	37	206	98	325	128	278
Maintenance & Repair	993	1265	1274	2680	2660	270	2662	3921
Labor Cost	336	264	408	528	648	792	936	1056
Tot. Ann. Cost Bef. Rec.	4445	5689	6146	12133	12664	12905	13118	18287
Less Value of Fertilizer	1358	2715	4073	5430	6788	8146	9503	10861
Total Annual Cost	3088	2973	2074	6702	5876	4759	3614	7426
Cost to Haul Manure	0	0	0	0	0	0	0	0
Total Waste Sys. Cost	19343	32621	40817	55500	6477	73779	84029	97878
Time Req. for 10 hr Days	17.9	16.5	25.5	16.5	20.3	24.8	29.3	22
Cost/Pig Space	9.67	7.91	6.8	6.94	6.48	6.15	6	6.12

TABLE D.12 COST COMPONENTS FOR PARTIAL SLATTED FLOOR, SCRAPER, EARTHEN STORAGE POND, AND DRAG HOSE, IN TEXAS COUNTY FOR THE NITROGEN CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	10020	10020	10020	10020	10020	10020	10020	10020
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28
Energy cost	2061	4122	6182	8243	10304	12365	14425	16486
Maintenance & Repair	183	183	183	183	183	183	183	183
Total Annual Cost	3737	5798	7859	9919	11980	14041	16102	18162
Earthen Storage Pond								
Initial Cost	31300	39896	51499	60905	70263	79587	88884	98161
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	4665	5946	7675	9077	10471	11861	13246	14629
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	4665	5946	7675	9077	10471	11861	13246	14629
Scraper								
Initial Cost	6790	32233	20370	33178	60102	96699	41434	66356
Annual Interest	1012	4804	3036	4944	8957	14411	6175	9889
Energy cost	90	570	270	570	732	1709	466	1139
Maintenance. & Repair	826	4146	2477	4203	7295	12438	1923	8405
Total Annual Cost	1928	9419	5783	9717	16984	28558	11564	19433
Drag Hose								
Initial Cost	59214	59319	59011	59060	59095	59123	59145	59163
Annual Interest	18064	18064	18064	18064	18064	18064	18064	18064
Energy cost	1332	1339	1319	1323	1325	1327	1328	1329
Maintenance. & Repair	3894	3896	3890	3891	3892	3892	3893	3893
Labor Cost	678	682	672	673	674	675	676	677
Tot. Ann. Cost Bef. Rec.	23968	23980	23945	23951	23955	23958	23960	23962
Less Value of Fertilizer	6099	12198	17936	19488	19488	19488	19488	19488
Total Annual Cost	17869	11782	6009	4462	4466	4470	4472	4474
Cost to Haul Manure	0	0	0	17928	43173	68477	93824	119202
Total Waste Sys. Cost	28199	33045	27325	51103	87075	127406	139207	175900
Time Req. for 10 hr Days	10.3	10.3	10.2	10.2	10.2	10.2	10.2	10.3
Cost/Pig Space	14.1	8.26	4.55	6.39	8.71	10.62	9.94	10.99

TABLE D.13 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN DELAWARE COUNTY FOR THE PHOPHORUS CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	10020	10020	10020	10020	10020	10020	10020	10020
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28
Energy cost	2061	4122	6182	8243	10304	12365	14425	16486
Maintenance & Repair	183	183	183	183	183	183	183	183
Total Annual Cost	3737	5798	7859	9919	11980	14041	16102	18162
Anaerobic Lagoon								
Initial Cost	72256	117490	162017	206178	250103	293862	337494	381025
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	10768	17509	24145	30727	37273	43794	50296	56784
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	10768	17509	24145	30727	37273	43794	50296	56784
Lagoon Recirculation.								
Initial Cost	4339	17508	17367	17683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	83	795	883	1177	1472	1766	2060	2355
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	847	3815	3968	4309	4725	5173	5234	5624
Travelling Gun								
Initial Cost	58735	58742	58659	58610	58577	58732	58712	58696
Annual Interest	8619	8618	8607	8598	8592	8618	8614	8611
Energy cost	16	14	14	13	13	13	13	13
Maintenance & Repair	2542	2542	2542	2541	2541	2542	2542	2542
Labor Cost	720	732	768	768	768	780	780	780
Tot. Ann. Cost Bef. Rec.	11897	11906	11931	11921	11915	11953	11949	11946
Less Value of Fertilizer	1545	1545	1545	1545	1545	1545	1545	1545
Total Annual Cost	10352	10361	10386	10376	10370	10408	10404	10401
Cost to Haul Manure	17548	43036	67085	90537	113648	136530	159247	181837
Total Waste Sys. Cost	43252	80519	113442	145869	177996	209946	241283	272809
Time Req. for 10 hr Days	22.5	22.9	24	24	24	24.4	24.4	24.4
Cost/Pig Space	21.63	20.13	18.91	18.23	17.8	17.5	17.23	17.05

TABLE D.14 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN SEMINOLE COUNTY FOR THE PHOPHORUS CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	10020	10020	10020	10020	10020	10020	10020	10020
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28
Energy cost	2206	4495	6900	9247	11597	13950	16305	18662
Maintenance & Repair	183	183	183	183	183	183	183	183
Total Annual Cost	3882	6171	8577	10923	13273	15626	17981	20338
Anaerobic Lagoon								
Initial Cost	63540	102065	150349	192110	233762	275337	316853	358323
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	9469	15211	22406	28630	34837	41033	47220	53401
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	9469	15211	22406	28630	34837	41033	47220	53401
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	17683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	77	720	777	1029	1280	1531	1782	2032
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	841	3740	3862	4161	4534	4938	4955	5302
Travelling Gun								
Initial Cost	81506	81506	81506	81506	81506	81506	81506	81506
Annual Interest	11853	11853	11853	11853	11853	11853	11853	11853
Energy cost	13	13	13	13	13	13	13	13
Maintenance & Repair	3781	3781	3781	3781	3781	3781	3781	3781
Labor Cost	1008	1008	1008	1008	1008	1008	1008	1008
Tot. Ann. Cost Bef. Rec.	16655	16655	16655	16655	16655	16655	16655	16655
Less Value of Fertilizer	2097	2097	2097	2097	2097	2097	2097	2097
Total Annual Cost	14558	14558	14558	14558	14558	14558	14558	14558
Cost to Haul Manure	7448	23004	38559	54115	69671	85227	100783	116338
Total Waste Sys. Cost	36198	62684	87962	112387	136871	161383	185498	209937
Time Req. for 10 hr Days	21	21	21	21	21	21	21	21
Cost/Pig Space	18.1	15.67	14.66	14.05	13.69	13.45	13.25	13.12

TABLE D.15 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND DRAG HOSE, IN TEXAS COUNTY FOR THE PHOPHORUS CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	10020	10020	10020	10020	10020	10020	20040	20040
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	2986.55	2986.55
Energy cost	4019	7831	11608	15367	19115	22854	26587	30315
Maintenance & Repair	183	183	183	183	183	183	366	366
Total Annual Cost	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon								
Initial Cost	65727	107810	149600	191237	232776	274247	315665	357042
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	9795	16067	22295	28500	34691	40871	47043	53210
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	9795	16067	22295	28500	34691	40871	47043	53210
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	17683	18499	19526	17959	66356
Annual Interest	647	2542	2588	2635	2757	2910	2676	9889
Energy cost	1	53	79	122	166	212	259	1139
Maintenance & Repair	117	478	497	497	497	497	497	8405
Total Annual Cost	765	3073	3164	3254	3420	3619	3432	19433
Drag Hose								
Initial Cost	64612	64612	64612	64612	64612	64612	64612	64612
Annual Interest	18064	18064	18064	18064	18064	18064	18064	18064
Energy cost	1701	1701	1701	1701	1701	1701	1701	1701
Maintenance & Repair	3996	3996	3996	3996	3996	3996	3996	3996
Labor Cost	866	866	866	866	866	866	866	866
Tot. Ann. Cost Bef. Rec.	24627	24627	24627	24627	24627	24627	24627	24627
Less Value of Fertilizer	2293	4586	6879	9173	11466	13604	13604	13604
Total Annual Cost	22334	20041	17748	15455	13161	11023	11023	11023
Cost to Haul Manure	0	0	0	0	0	1641	25573	49505
Total Waste Sys. Cost	38590	48688	56491	64252	72063	81684	117010	166838
Time Req. for 10 hr Days	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Cost/Pig Space	19.29	12.17	9.42	8.03	7.21	6.81	8.36	10.43

TABLE D.16 COST COMPONENTS FOR FULLY SLATED FLOOR, PULL PLUG, ANAEROBIC LAGOON, AND IRRIGATION WITH A TRAVELLING GUN, IN TEXAS COUNTY FOR THE PHOPHORUS CONSTRAINT ($)

Feeder Pig Capacity	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000
Ground Water Sys								
Initial Cost	10020	10020	10020	10020	10020	10020	20040	20040
Annual Interest	1493.28	1493.28	1493.28	1493.28	1493.28	1493.28	2986.55	2986.55
Energy cost	4019	7831	11608	15367	19115	22854	26587	30315
Maintenance & Repair	183	183	183	183	183	183	366	366
Total Annual Cost	5695	9507	13284	17043	20791	24530	29939	33667
Anaerobic Lagoon								
Initial Cost	65727	107810	149600	191237	232776	274247	315665	357042
Liner Cost	0	0	0	0	0	0	0	0
Cover Cost	0	0	0	0	0	0	0	0
Annual Interest	9795	16067	22295	28500	34691	40871	47043	53210
Energy cost	0	0	0	0	0	0	0	0
Maintenance & Repair	0	0	0	0	0	0	0	0
Total Annual Cost	9795	16067	22295	28500	34691	40871	47043	53210
Lagoon Recirculation.								
Initial Cost	4339	17058	17367	17683	18499	19526	17959	18604
Annual Interest	647	2542	2588	2635	2757	2910	2676	2773
Energy cost	1	53	79	122	166	212	259	306
Maintenance & Repair	117	478	497	497	497	497	497	497
Total Annual Cost	765	3073	3164	3254	3420	3619	3432	3576
Drag Hose								
Initial Cost	28997	57571	83315	109951	135955	188146	188146	188146
Annual Interest	4216	8368	12082	15928	19686	27401	27401	27401
Energy cost	10	27	72	177	364	251	251	251
Maintenance & Repair	1268	2536	3789	5131	6423	8911	8911	8911
Labor Cost	456	888	1320	1752	2304	3024	3024	3024
Tot. Ann. Cost Bef. Rec.	5950	11820	17263	22987	28778	39587	39587	39587
Less Value of Fertilizer	2111	4223	6334	8445	10557	12526	12526	12526
Total Annual Cost	3839	7597	10929	14542	18220	27060	27060	27060
Cost to Haul Manure	0	0	0	0	0	1067	16622	32178
Total Waste Sys. Cost	20094	36244	49673	63339	77122	97147	124097	149691
Time Req. for 10 hr Days	28.5	27.8	27.5	27.4	28.8	27	27	27
Cost/Pig Space	10.05	9.06	8.28	7.92	7.71	8.1	8.86	9.36

VITA

Rita Isabel Rodrigues Carreira

Candidate for the Degree of

Master of Science

Thesis: DYNAMIC SPREADSHEET PROGRAMMING TO COMPARE THE EFFECT OF GEOGRAPHIC LOCATION AND ECONOMIES OF SIZE ON HOG MANURE HANDLING SYSTEMS IN OKLAHOMA

Major Field: Agricultural Economics

Biographical:

Personal Data: Born in Coimbra, Portugal, on May 3, 1972, the daughter of Victor Carreira and Maria Fernanda da Velha.

Education: Graduated from Escola Secundária de Jaime Cortesão, Coimbra, Portugal in July 1990; received Bachelor of Science degree from Universidade de Coimbra, Portugal in October, 1996. Completed the requirements for the Masters of Science degree with a major in Agricultural Economics at Oklahoma State University in May, 2000.

Experience: Student Assistant, Office of International Programs, Oklahoma State University, August 1995 to April 1996 and August 1997 to January 1998. Graduate Research Assistant, Department of Agricultural Economics, Oklahoma State University, February 1998 to present.

Professional Memberships: Society of Environmental Scientists at Oklahoma State University.