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Cost Comparisons Considering Herd Size, Transport Distance, and Nitrogen versus Phosphorus Application Rates for Liquid Dairy Waste Transport and Application Systems

Adam Shane Daugherty
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To the Graduate Council:

I am submitting herewith a thesis written by Adam Shane Daugherty entitled "Cost Comparisons Considering Herd Size, Transport Distance, and Nitrogen versus Phosphorus Application Rates for Liquid Dairy Waste Transport and Application Systems." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Robert T. Burns, Major Professor

We have read this thesis and recommend its acceptance:

Tim L. Cross, D. Raj Raman, George F. Grandle

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Dr. Anne Mayhew______
Vice Provost and
Dean of Graduate Studies

(Original signatures are on file in the Graduate Student Services Office.)

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A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Adam Shane Daugherty

December 2001

DEDICATION

This thesis is dedicated to my parents

Patrick Shane Daugherty

and

Cherry Warner Daugherty

who taught me about the important things in life (how to show respect for my elders, earn respect from my elders, deal with disappointment, strive for success, identify fresh tracks from old, how to tell if the dogs are bayed or trailn', some firewood won't burn the duration of the night, and the world will not meet you half-way) before I ever entered a university.

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ABSTRACT

A cost estimation model was developed that compares the economics associated with different animal waste transport and application systems used by confined animal operations. The model was constructed from data collected from individual farmers, equipment manufacturers, and gleaned from waste management system manuals. The model was developed to provide animal waste transport and application cost estimates for both liquid and dry waste management systems. The model was developed in Microsoft Excel. Using facility specific information, the model estimates the costs associated with various components of manure transport and application systems. Specifically, the model enables comparisons of capital costs, annual operating costs, and annual fixed costs for the components of various manure transport and application systems.

This study provides cost comparisons for the transport and application of dairy waste slurries based on both phosphorus and nitrogen application rates. Cost estimates are made for several common dairy waste transport and application systems. Five dairy herd sizes ranging from 50 to 2,000 cows using 19 transport and application systems were evaluated. For each dairy herd size, the costs associated with the transport and application system combinations were determined for transport distances of 0.5, 1.5, and 4.5 miles for both nitrogen and phosphorus-based application rates. Total annual economic cost, transport and application cost per acre, annual cost per cow, and net fertilizer value per acre based on nutrient requirements for a 20-ton per acre corn silage crop were calculated.

Results indicate that depending on transport and application system choice, transport distance, and operation herd size, transport and application costs were at times

different between phosphorus and nitrogen-based applications. No differences between transport and application costs were found between nitrogen and phosphorus-based applications when using individual hauling and drag hose systems for a given herd size and transport distance. Phosphorus-based applications costs were estimated to be from 5 to 60% more than nitrogen-based applications when using irrigation systems for the transport and application of the animal manure. While phosphorus-based applications were more expensive than nitrogen-based applications in some cases, the less expensive application standard did not always produce the greatest net fertilizer value. The greatest net fertilizer value produced by a given transport and application system varied between phosphorus and nitrogen-based applications depending on application method, transport distance, and herd size. Dairy operations larger than 200 cows economically favored the implementation of phosphorus standards for all applications of animal manures over small dairy operations. Pumping systems were found to be less sensitive to increases in transport distance than hauling systems once herd size exceeded 200 cows. Overall, hauling systems produced the lowest costs and highest net fertilizer values for operations of 200 cows or less. The waste volume produced by these operations produced an annual transport and application operational time that was justifiable. Once herd size exceeded 200 cows it was not justifiable to handle the larger waste volume using hauling systems, and the pumping systems began to produce lower transport and application annual costs and higher net fertilizer values.

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CHAPTER I

INTRODUCTION

Due to increasing concern over air and water pollution from agricultural operations, state and federal agencies have developed laws and guidelines pertaining to the transport and application of animal wastes from concentrated animal feeding operations. To abide by these laws and guidelines, many animal producers must implement new animal waste transport and application systems or upgrade existing systems on their operations.

Land application is the most prevalent method of utilizing animal manures. Manure applications increase soil organic matter, improve soil tilth, and increase water holding capacity and solar heat absorption capacity (Roka et al., 1995). More importantly, manure contains significant amounts of plant nutrients and can therefore substitute for commercial fertilizers. If the utilization of manure in lieu of commercial fertilizer increases farm profits, manure is an economic resource; if the management and operating costs outweigh the benefits, it is a waste. Determining whether manure nutrients are an economic resource or waste has environmental implications. In cases where manure is a waste, a producer's economic incentives are to simply minimize disposal costs. This approach encourages over-application and increases the potential for water quality degradation from surface runoff or leaching. On the other hand, in cases where manure nutrients are a resource, economic incentives encourage nutrient conservation and efficient application rates. An efficient application rate matches manure

applications with crop nutrient requirements, and as a result, decreases the likelihood that nutrients would move into either ground or surface waters (Roka et al., 1995).

Livestock and poultry producers in the United States are subject to concentrated animal feeding operation (CAFO) regulations. To remain in compliance with CAFO regulations, producers must make decisions concerning the transport and application of animal wastes at their operation. It is essential that these systems be designed to operate in a cost effective manner for producers to remain economically viable. Most animal waste applications are currently based on crop nitrogen requirements. When applications are based on nitrogen, phosphorus is typically applied in excess. Phosphorus, an essential nutrient for crop and animal production, can accelerate fresh water eutrophication (Carpenter et al., 1998). In 1996, the US Environmental Protection Agency identified eutrophication as the main problem in waters of impaired quality in the United States (Weld et al., 2001). Accelerated eutrophication restricts water use for fisheries, recreation, industry, and drinking due to the increased growth of undesirable algae and aquatic weeds and shortages of oxygen caused by algal death and decomposition (Carpenter et al., 1998). To reduce environmental impacts, it has been suggested that comprehensive nutrient management plans (CNMP's) be developed on phosphorus rather than nitrogen standards (Sharpley et al., 1996; US Department of Agriculture and Environmental Protection Agency, 1999).

An additional benefit of manure is that long-term soil productivity can be enhanced because manure is a rich source of organic material (Cassman et al., 1995). Many argue that an integrated crop and livestock system is the best example of an economically and environmentally sustainable farming system (Fleming et al., 1998).

However, delivering manure nutrients to a field at the right time and in the right amount can be costly. If delivery and application costs are low enough, then substituting manure for fertilizer can increase profits from crop production. If the delivery costs are too high, then only a portion of the delivery cost can be recovered by reduced fertilizer cost, and farmers will not have a strong incentive to adopt technologies that match manure application rates to crop nutrient requirements.

Phosphorus-based applications require more land area than nitrogen-based applications. Concentrated animal feeding operators are concerned that phosphorus-based application regulations will incur their operations large economic transport and application costs. The objectives of this study are to develop a research tool that will accurately estimate the costs associated with various animal waste transport and application systems and to investigate the economic impacts of nitrogen-based land applications versus phosphorus-based land applications. This research tool can be used to generate data that extension and farm planning personnel can use to assist farm operators in making better economic decisions when choosing manure transport and application equipment for given concentrated animal feeding operations. Farm operators are interested in how much a manure transport and application system will cost their operation and what economic returns will be received from this investment. The out-of-pocket cost that a farm operator incurs annually without receiving any monetary returns is identified as the transport and application economic cost. The only monetary return that a farm operator will receive will come from the value of the applied manure in lieu of commercial fertilizer. This monetary value is identified as the fertilizer value. The net fertilizer value is defined as the fertilizer value minus the transport and application

economic cost. Hypotheses were developed to test the impacts of nitrogen versus phosphorus-based applications. The hypotheses tested in this study are as follows:

1. Phosphorus-based manure applications have higher transport and application economic costs than nitrogen-based applications.

2. Phosphorus-based manure applications have higher transport and application net fertilizer values than nitrogen-based applications.

3. Regulations proposing the implementation of phosphorus standards for all land applications of animal waste economically favor large dairy operations over small dairy operations.

4. Hauling system transport and application net fertilizer values are more cost sensitive to increases in transport distances than are pumping system transport and application net fertilizer values.

To address these issues, costs estimates were determined for five dairy sizes, 19 transport and application system combinations, three transport distances, and two application requirements (N or P). Each hypothesis was tested for the scenarios mentioned above. Each hypothesis was designed to investigate issues that frequently arise concerning economic and environmental impacts surrounding land application of animal manures. Hypothesis 1 was designed to investigate whether or not there were economic cost differences between phosphorus and nitrogen-based applications and to evaluate these differences if present. Hypothesis 2 was designed to evaluate which application standard produced the highest net fertilizer value for a producer. Hypothesis 3 considers which sized operations would be more economically viable under regulations that require all land applications of animal manure to be phosphorus-based. Hypothesis 4

was designed to evaluate the sensitivity of net fertilizer values for hauling systems and pumping systems and to investigate if there are break points at certain transport distances between the separate transport methods.

CHAPTER II

REVIEW OF LITERATURE

Previous Studies

Most previous studies concerning the economics of animal waste transport and application have focused their attention on the fertilizer value of animal manure. This is understandable because the main monetary value of animal manure is its value as fertilizers for production crops. One such study was conducted in Iowa. This investigation considered the cost of delivering manure nutrients from Iowa swine production facilities from two forms of manure storage, using two target nutrients, two crop rotations, and two levels of field incorporation (Fleming et al., 1998). This study was designed to answer the questions: Should manure nutrients be conserved and applied to crops? What is the impact of a policy requiring that manure applications be soil incorporated? What is the impact of a policy requiring that manure applications be based on phosphate? The study reported that the cost of delivering nutrients is always greater than the value of the nutrients; that incorporating manure increases production returns while improving air quality, however, incorporation affects the timeliness and flexibility of application; that basing applications on phosphate levels rather than nitrogen increases the value of the manure nutrients because the phosphate applied nutrients better match crop requirements; and while manure management is important, other production considerations drive management decisions. The study did represent various costs associated with the transport and application of animal manure. However, all of the costs

presented were derived from custom manure applicator fees producing results based on parameter values consistent with conditions in Central Iowa. Costs associated with personally owned and operated systems and various geographical locations were not investigated. Additionally, the economic model developed for the investigation was designed for use with only swine production facilities.

Various microcomputer worksheets and assessment tools have been developed to assist farm operators in certain areas of the operation's waste management system. Iowa State University developed a microcomputer worksheet to assist animal producers in estimating manure production, calculating manure storage structural dimensions, providing guidelines for application, and providing cost estimates for storing and handling liquid manure (Stewart et al., 1994). The Iowa worksheet dealt only with applying liquid manure using slurry tanks. Transport distance was not an input into the worksheet and irrigation, drag hose, and dry manure transport and application systems were not considered.

An existing dairy forage system model (DAFOSYM) was expanded to provide a tool for evaluating and comparing the long-term performance and economics of alternative manure systems for dairy farms and their interaction with field crop production. The model is capable of comparing various semi-solid, slurry, and liquid handling systems (Bickert et al., 1993). It was designed to focus primarily on crop production benefits associated with different manure storage and application techniques. The model can be used to predict manure transport and application costs, but is not designed as a complete transport and application cost estimation model. The study concentrated on a limited array of transport and application equipment for each type of

manure storage. In reality, there are many combinations of transport and application equipment that can be used to transport and apply a given manure type and costs will vary depending on equipment selection. Evaluation of manure transport and application costs should focus equally on the equipment selection possibilities rather than total emphasis on manure storage. The DAFOSYM study reported that injection of manure directly into the soil or immediate incorporation of manure reduce nitrogen losses with little additional cost to the farmer; manure handling costs increase with herd milk production level, but the difference in performance and costs among manure systems is affected little; and manure handling costs are highly sensitive to transport distances. The model was designed only for use with dairy operations and only herd sizes of 60 and 250 cows were evaluated.

Researchers at The Ohio State University completed an economic comparison of three manure-handling systems (Rausch et al., 1998). Each manure handling system was designed for an 80 to 100-cow dairy. Land type, land area, and transport distance were identical for these three systems. The systems compared were (1) earthen holding pond using a dragline for direct injection; (2) earthen holding pond using a liquid slurry tank and; (3) a stack pad using a conventional box spreader. The two liquid systems were identical, except for the method of application (Rausch et al., 1998). This study did represent many of the costs associated with these three systems under specific conditions. However, this study did not allow comparisons of system(s) costs when distances to application sites varied between the systems. In addition, this study only evaluated three specific systems for a given dairy size. There are many variations of these systems and dairy sizes that were not evaluated. However, the Ohio study showed that the liquid

slurry tank system was cheaper to operate for this size operation as compared to a drag hose system. Overall the stack pad using a box spreader was the lowest cost manure handling system that was evaluated in this study. Application rates were based on phosphorus as the limiting nutrient and the land mass needed for this application was not present, therefore, excess manure remained in the storage facility. The cost estimates that were presented included adjustments for selling the excess nutrients, giving excess away, or over applying the excess. Additionally, such scenarios as evaluating the cost and benefits of broadcast and broadcast with incorporation for the slurry tank and box spreader systems as well as basing applications on nitrogen crop requirements were not discussed in the Ohio study.

A cooperative project between The University of Tennessee Agricultural Extension Service and The University of Kentucky Cooperative Extension Service led to the development of a Sustainable Dairy Systems Manual and Training Guide (Sustainable Dairy Systems Manual, 1997). The Sustainable Dairy Systems Manual, Spreadsheets, and Training Project was developed to help Tennessee and Kentucky dairy producers make better management decisions (Sustainable Dairy Systems Manual, 1997). The manual examines the costs, returns, investment, and labor requirements for alternative dairy production systems. Chapter 10 of the manual is focused on manure management. This chapter includes many of the costs associated with the transport and application of animal waste (Taraba, et al., 1996). It, however, is not a complete cost estimation tool that can be used to estimate the costs of many different transport and application systems. This manual was designed for use only with dairy operations and contains limited resources for the selection of a wide array of manure transport and application equipment.

Need for an Economic Model

While various studies have been performed concerning the economics associated with certain animal waste transport and application systems, these studies have yet to lead to the development of a complete analytical tool that extension and farm planning personnel can use to assist individual farm operators in estimating the costs that are associated with each component of their transport and application system(s). This need motivated the development of cost estimation tool built on engineering designs and principles. Significant variability exists among concentrated animal feeding operations including number of animals, storage type, cropping systems, and animal species which demands a tool with the versatility to accommodate these site-specific situations. The cost estimation tool developed for this study can produce cost estimates for all components of a wide range of transport and application systems. In addition, this tool is capable of providing cost estimates for many livestock species utilizing both wet and dry manure management systems and can be used in conjunction with any cropping system.

Waste Characteristics

Dairy, swine, and beef manures are excreted at about 88% moisture and poultry broiler manure at approximately 75% moisture (Midwest Plan Service, 1985). In order to handle manure as a solid material it should be no more than 70% moisture (Loehr, 1974). Bedding materials such as sawdust or shavings are usually added to manures to absorb moisture which will bring it to a solid consistency (Burns, 1999). At 88% moisture, manure requires significant moisture addition to be handled as a liquid (Burns, 1999). In order to handle manure as a pumpable liquid it should be at least 90% moisture. For liquid manure to be applied using standard irrigation equipment, it should have a

minimum moisture content of 96% (Burns, 1999). Moisture additions to animal manures generally come from water used to clean confinement and milking areas and from rainfall that is collected from the confinement area and that falls directly into the manure storage area. In rainfall surplus areas it may be easier to adjust manure to a liquid state, where as in rainfall deficit areas it may be easier to adjust manure to a solid state (Burns, 1999).

For most crops, dairy manure is a nutrient-rich, unbalanced fertilizer. A 1,000-pound lactating dairy cow excretes approximately 0.45, 0.16, and 0.31 pounds of N, P_2O_5, and K_2O respectively per day (Burns et al., 1998). The N:P ratio for manure is different from the N:P ratio required by most crops, making balanced crop nutrient requirement applications difficult to achieve. When applications are based on crop nitrogen requirements, phosphorus and potassium are typically applied in excess of crop needs. When applications are based on phosphorus, nitrogen and often potassium crop requirements are not met. Historically, nutrient management plans have been developed based on crop nitrogen requirements. This management method is not desirable on land that already has high concentrations of soil phosphorus, and it has environmental implications due to the potential for surface runoff of phosphorus into surface waters.

Nutrient Availability

The primary nutrients (N, P, & K) contained in animal manures, composts or other organic materials are typically much less readily available to plants than the nutrients of most inorganic fertilizers. In addition, the nutrient content of animal manures may be highly variable from species to species (Midwest Planning Service, 1985). Manure is a slow release nitrogen fertilizer. Nitrogen available to a crop from the application of livestock manure is less than the total nitrogen produced by the livestock

(Burns et al., 1998). This difference is due to nitrogen's ability to volatize and be released into the atmosphere. In addition to volatilization, nitrogen can be lost by leaching and runoff, and organic nitrogen requires time to become plant available. To account for the storage, handling, and application losses and the rate of transformation from an organic form to the plant-available forms of nitrate and ammonia, plant-available nitrogen is typically estimated by using a nitrogen-availability factor. Nitrogen-availability factors are usually found in a matrix consisting of storage system types and application methods (Burns et al., 1998). Table 2.1 presents the nitrogen availability factors that were used for this study.

Approximately 75 to 100% of the total phosphorus and potassium content of animal manures will be available to the crop within a year of application (NRCS, 1992). For this study, phosphorus and potassium are assumed to be conserved and to become completely available for crop uptake over the long term in cropping systems.

Table 2.1. Nitrogen availability following handling, storage, and application losses.

	Application Method			
Storage System Type	Broadcast / no incorporation	Broadcast / incorporated within 12 hours	Knife or sweep injected	Irrigate / no incorporation
Daily Haul	0.40	0.50	NA	NA
Dry Stack	0.40	0.50	NA	NA
Litter	0.40	0.50	NA	NA
Slurry Pit	0.45	0.60	0.65	0.45
Holding Pond	0.40	0.50	0.60	0.40
Anaerobic Lagoon	0.15	0.25	0.25	0.15

Adapted from PB 1635 *Nutrient Management Plan Assistance Guide for Tennessee Class II Concentrated Animal Feeding Operation Permit*

Comprehensive Nutrient Management Plans (CNMP)

A Comprehensive Nutrient Management Plan (CNMP) is a group of conservation practices and management activities that help to ensure that both production and natural resource protection goals are achieved (NRCS, 2000). Comprehensive Nutrient Management Plans are designed to utilize animal manure and organic by-products as a beneficial resource while ensuring environmental protection. A CNMP addresses natural resource concerns dealing with soil erosion, manure, and organic by-products and their potential negative impacts on water quality that may derive from animal feeding operations. The objective of CNMP's is to provide animal feeding operation operators with plans to manage manure nutrients by combining conservation practices and management activities into conservation systems that, when implemented, will protect or improve water quality while disposing of manure.

Manure is phosphorus rich, so application of manure based on nitrogen may result in application of phosphorus in excess of crop uptake requirements. Traditionally, this has not been a cause for concern, because the excess phosphorus does not usually cause harm to plants and can be absorbed by the soil where it was thought to be strongly bound and thus environmentally benign (EPA, 2001). The capacity for a soil to absorb phosphorus varies among soil types. Recent observations have shown that soils can and do become saturated with phosphorus (EPA, 2001). Continued manure application on phosphorus-saturated soils, in amounts greater than what can be used by the crops and absorbed by the soil, results in phosphorus leaving the application site with storm water via leaching or runoff (EPA, 2001). In addition, phosphorus that is bound to soil particles may also be lost from application sites through erosion.

In many geographic locations across the United States, repeated manure applications based on nitrogen crop uptakes have resulted in areas with high to excessive soil phosphorus concentrations (EPA, 2001). Because of the increasing environmental concerns surrounding phosphorus, The United States Environmental Protection Agency has developed regulations pertaining to the application of animal wastes from concentrated animal feeding operations (CAFO). Option 1 is that all CAFO's must implement a CNMP where manure application rates will not exceed crop nitrogen requirements. This option will address application sites where soil phosphorus and runoff potential is low. Option 2 will address application sites where the potential for phosphorus leaving the application site is high. Option 2 would impose a best management practice (BMP) that requires manure application rates be based on phosphorus crop uptake requirements where necessary, depending on the specific soil conditions at the application site(s). For these sites, phosphorus application rates will be determined by (1) Phosphorus Index, (2) Soil Phosphorus Threshold Level, or (3) Soil Test Phosphorus Level (EPA, 2001).

While various models have been developed to estimate the costs and benefits of transporting and applying animal manures, these models are not applicable for a wide variety of transport and application systems. Manure has proven to be a good source of plant nutrients, but it is an unbalanced fertilizer and the costs for delivering manure to production fields can be high. More stringent regulations are being developed for animal manure management. Operator costs associated with these regulations have not been fully investigated. Currently, there is no single source of cost estimates available covering the wide range of manure transport and application systems for an array of herd

sizes, application rates, and transport distances. This study presents a variety of cost estimates to aide farm planning personnel, farm operators and regulatory agencies in making better management decisions.

CHAPTER III

MATERIALS AND METHODS

Cost Estimation Model

User input facilitated spreadsheets were developed to calculate operational cost per hour for various pieces of manure transport and application equipment. Capital costs for various pieces of manure transport and application equipment were obtained from surveys of equipment manufacturers. Operational costs were calculated based on equipment capital cost (purchase price), useful life, salvage value, annual hours of use, fuel type, wage rates, and interest cost. Depreciation, interest, insurance, repairs and maintenance, fuel, and labor costs per hour were estimated using these factors. Annual hours of use and equipment age must be entered into the spreadsheet for the equipment considered. Annual hours of use are calculated in one of five spreadsheets designed to estimate total loading, transport, application, and incorporation time for the transport and application system selected. Users select from solid manure hauling systems, liquid manure hauling systems, big gun irrigation systems, drag hose direct injection systems, or center-pivot irrigation systems. Users must input a manure volume, manure nutrient content, crop requirement application rate (N, P_2O_5, or K_2O), and transport distance. Depending on the system choice, users also enter other variables such as loading rate, discharge rate, pumping rate, transport speed, tank capacity, application width, incorporation width, incorporation speed, and gun throw diameter.

Machinery cost calculation methods followed methods and parameters used in estimating machinery costs for enterprise budgets constructed by The University of Tennessee Agricultural Extension Service (Cross et al., 1999). Whenever possible, American Society of Agricultural Engineers (ASAE) standards were followed. All operational costs were estimated on a cost-per-hour basis. Equipment depreciation costs were estimated using straight-line depreciation methods. Fuel cost was calculated based on the price of fuel, fuel type, and estimated fuel consumption rates of tractors and self-propelled machinery. Fuel consumption rates were approximated from Nebraska Tractor Test Data, as reported in ASAE Agricultural Machinery Management Standard 6.3.2.1 (ASAE Standards, 2000). The price of diesel fuel at the time of this study was $1.20/gallon. All self-propelled machinery and engines evaluated in this study operated using diesel fuel.

The costs incurred in keeping a machine operable from normal wear, parts failure, accidents, and natural deterioration are calculated as repair and maintenance expenses: Annual repair and maintenance costs were calculated based on annual and accumulated hours of use, following ASAE Agricultural Machinery Management Standard 6.3.1 (ASAE Standards, 2000). Labor costs were determined assuming a total labor cost of $10.00 per hour including employment taxes and other payroll overhead. Equipment salvage value was estimated by using a salvage value percentage of the equipment's capital cost. Insurance provides protection from risks associated with theft, fire, flood, or other natural disasters. The cost of insurance was based on the initial cost of machinery and an insurance rate. An insurance rate of 1.0% was assumed. Interest is calculated as an opportunity cost using the average value of machinery at the mid-point of its useful

life. For this study, all equipment was assumed to have a useful life of ten years. The interest rate for all equipment was assumed to be 10%. The equations used for calculating operational cost per hour for individual pieces of equipment for this study follow. Additional calculations performed in this study appear at the end of Chapter III.

Depreciation
= (Capital Cost – Salvage Value) / (Useful Life * Annual Hours of Use)

Interest
= {[(Capital Cost + Salvage Value) / 2] * Interest Rate} / (Useful Life * Annual Hours of Use)

Insurance
= (Capital Cost * Insurance Rate) / Annual Hours of Use

Fuel
= Fuel Price * 0.73 (0.06 * Maximum PTO Horsepower)

Salvage Value
= Capital Cost * Salvage Value %

Repairs and Maintenance
= (((((Accumulated Hours of Use + Annual Hours of Use) / 1000)^RF2) * Capital Cost * RF1) – (((Accumulated Hours of Use / 1000)^RF2) * (Capital Cost *RF1))) / (Annual Hours of Use)

Where:
RF1= Repair factor 1 from Appendix 35 Machinery Cost Calculator
RF2 = Repair factor 2 from Appendix 35 Machinery Cost Calculator

The model calculates total annual system cost, system cost per acre, and system cost per gallon or cubic foot of manure depending on manure type (solid or liquid). Other information calculated by the model includes application rate per acre (gallons/acre or tons/acre), acreage required, acres covered per hour, equipment speeds, and incorporation rate. In addition to producing total annual economic system cost, the

model presents the individual loading, transport, application, and incorporation costs. No attempts were made to estimate land costs in this study. Tables A-1 thru A-27 located in Appendix A contain the capital cost (purchase price) for each individual piece of manure transport and application equipment that was evaluated in this study. For each general piece of transport and application equipment, a spreadsheet was developed to calculate an operational cost per hour for that piece of equipment based on the equations listed above. Not all equations were used in determining the operational cost per hour for some pieces of equipment. For example, incorporation disks, box spreaders, slurry tanks, etc. do not use fuel. However, the tractors used to pull and power these pieces of equipment do; therefore, the fuel charge is assigned to the tractor being used with the equipment.

The first decision in operating the model is do decide what type of manure will be transported and applied. The user has two choices of manure type: (1) solid or (2) liquid. Next, the user must calculate the manure volume that must be transported and applied. Figures 3.1 and 3.2 represent the spreadsheets that were developed to calculate these volumes for dairy operations. To calculate manure volume the user will simply enter the appropriate values in the user input columns. No spreadsheets were developed to calculate volumes for other species since this particular study was to focus on dairy operations. However, if the user is interested in using this model to estimate transport and application costs for other livestock species, hand calculations can be performed to estimate a manure volume and nutrient content(s) and these values can be entered into the transport and application total annual cost spreadsheet.

Liquid Waste Management System Volume Calculation Worksheet

User Input Column

Number of Lactating Cows	2000	
Average Weight of Lactating Cows	1,400	pounds
Volume of Raw Waste Produced per Cow per Day	1.82	cubic feet
Volume of Bedding Used per Cow per Day	0.181	cubic feet
Days of Storage for Waste	365	days
Milking Center Waste Volume per Cow per Day	1.96	cubic feet
Loafing Lot Area per Cow	20	square feet
Annual Rainfall for Operation's Location	50	inches
Annual Rainfall *minus* Evaporation for Operation's Location	20	inches
24 hour / 25 year Storm for Operation's Location	6	inches
Desired Holding Pond Depth	16	feet
Desired Holding Pond Lenth for One Side	200	feet

Waste Volume to be Stored for Desired Storage Period	**26,146,363**	gallons

Number of Lactating Cows	Average Weight of Lactating Cows (pounds)	Volume of Raw Waste Produced per Cow per Day (cubic feet)	Volume of Bedding Used per Cow per Day (cubic feet)	Days of Storage for Waste (days)	Milking Center Waste Volume per Cow per Day (cubic feet)	Loafing Lot Area per Cow (square feet)	Annual Rainfall for Operation's Location (inches)	Annual Rainfall*minus* Evaporation for Operation's Location (inches)	24 hour / 25 year Storm for Operation's Location (inches)	Desired Holding Pond Depth (feet)	Desired Holding Pond Lenth for One Side (feet)
2000	1,400	1.82	0.181	365	1.96	20	50	20	6	16	200

Raw Waste + Bedding + Milking Center Waste Volume for Desired Storage Period (gallons)	Runoff Volume from Loafing Lot Area (gallons)	Lenth of Other Side of Holding Pond (feet)	Holding Pond Surface Area (square feet)	Rainfall Volume Which Must be Stored in Holding Pond (gallons)	Total Waste Volume to be Stored for Desired Storage Period (gallons)
21,631,536	1,396,453	962	192,387	3,118,374	26,146,363

Some Useful Numbers from MWPS-18	
Sawdust Bedding	3.1 lb/day/1000lb cow
Lactating Cow Manure Production	1.3 cubic feet/day/1000lb cow
Sawdust Bedding Density	12.00 lbs/cubic foot
Milking Center Waste Volume	1.40 cubic feet/day/1000lb cow

Figure 3.1. Liquid waste management system manure volume calculation spreadsheet.

Dry Waste Management System Volume Calculation Worksheet

User Input Column

Number of Lactating Cows	50	
Average Weight Of Lactating Cows	1,400	pounds
Volume of Raw Waste Produced per Cow per Day	1.82	cubic feet
Volume of Bedding Used per Cow per Day	0.181	cubic feet
Days of Storage for Waste	365	days

Waste Volume to be Stored for Desired Storage Period	**36,518** cubic feet

Number of Lactating Cows	Average Weight of Lactating Cows (pounds)	Volume of Raw Waste Produced per Cow per Day (cubic feet)	Volume of Bedding Used per Cow per Day (cubic feet)	Days of Storage for Waste	Amount of Material Produced per Cow per Day (cubic ffet)	Waste Volume to be Stored (cubic feet)
50	1,400	1.82	0.181	365	2.001	36,518

Some Useful Numbers from MWPS-18	
Sawdust Bedding	3.1 lb/day/1000lb cow
Lactating Cow Manure Production	1.3 cubic feet/day/1000lb cow
Sawdust Bedding Density	12.00 lbs/cubic foot

Figure 3.2. Dry waste management system manure volume calculation spreadsheet.

Once the user has determined the volume of manure to be transported and applied, the nutrient content of the manure is estimated. This can be accomplished by using values found in many waste management manuals or through laboratory analysis of the manure. Most often, producers are interested in N, P, or K, however, the model can be used to calculate application rates and cost estimates for any nutrient desired for any given cropping system. The next step in producing transport and application cost estimates is to determine the annual hours of use for each piece of equipment using the transport and application total annual cost spreadsheets. Tables 3.1 thru 3.5 list the user inputs needed and the calculated values produced from the spreadsheet designed for each type of manure transport and application system. The default values will be determined from the spreadsheets used to determine the operational cost per hour for each piece of transport and application equipment.

Table 3.1. Solid manure hauling system transport and application total annual cost spreadsheet.

Solid Manure Hauling Systems		
User Inputs	Calculated Values	Default Values
Manure Volume (cubic feet)	Number of Loads Required	Loading Cost per Hour ($/hour)
Spreader Capacity (cubic feet)	Time to Load Spreader Once (hours)	Transport Cost per Hour ($/hour)
Loading Rate (cubic feet/minute)	Total Loading Time (hours)	Application Cost per Hour ($/hour)
Transport Distance + Return Trip (miles)	Total Loading Cost ($)	Incorporation Cost per Hour ($/hour)
Average Transport Speed (mph)	Total Transport Distance (miles)	
Nutrient Application Rate (lbs/acre)	Transport Time for One Trip (hours)	
Pounds of Nutrient per ton of Waste	Total Transport Time (hours)	
Equipment Application Rate (cubic feet/minute)	Total Transport Cost ($)	
Application Width (feet)	Transport Cost per Mile ($/mile)	
Incorporation Speed (mph)	Total Tons of Waste (tons)	
Incorporation Width (feet)	Application Rate (tons/acre)	
	Application Speed (mph)	
	Acreage Required (acres)	
	Application Rate (acres/hour)	
	Total Application Time (hours)	
	Total Application Cost ($)	
	Incorporation Rate (acres/hour)	
	Total Incorporation Time (hours)	
	Total Incorporation Cost ($)	
	Total Transport and Application System Cost ($)	
	System Cost per Acre ($/acre)	
	System Cost per Cubic Foot ($/ft3)	

Table 3.2. Liquid manure hauling tank system transport and application total annual cost spreadsheet.

Liquid Manure Tank Hauling Systems		
User Inputs	Calculated Values	Default Values
Manure Volume (gallons)	Number of Loads Required	Loading Cost per Hour ($/hour)
Tank Capacity (gallons)	Time to Load Tank Once (hours)	Transport Cost per Hour ($/hour)
Loading Rate (gpm)	Total Loading Time (hours)	Application Cost per Hour ($/hour)
Transport Distance + Return Trip (miles)	Total Loading Cost ($)	Incorporation Cost per Hour ($/hour)
Average Transport Speed (mph)	Total Transport Distance (miles)	
Nutient Application Rate (lbs/acre)	Transport Time for One Trip (hours)	
Pounds of Nutient per 1000 Gallons of Waste	Total Transport Time (hours)	
Equipment Application Rate (gpm)	Total Transport Cost ($)	
Application Width (ft)	Transport Cost per Mile ($/mile)	
Incorporation Speed (mph)	Application Rate (gallons/acre)	
Incorporation Width (ft)	Application Speed (mph)	
	Acreage Required (acres)	
	Application Rate (acres/hour)	
	Total Application Time (hours)	
	Total Application Cost ($)	
	Incorporation Rate (acres/hour)	
	Total Incorporation Time (hours)	
	Total Incorporation Cost ($)	
	Total Transport and Application System Cost ($)	
	System Cost per Acre ($/acre)	
	System Cost per Gallon ($/gallon)	

Table 3.3. Big gun irrigation system transport and application total annual cost spreadsheet.

Big Gun Irrigation Systems		
User Inputs	Calculated Values	Default Values
Manure Volume (gallons)	Total Pumping Time (hours)	Application Cost per Hour ($/hour)
Gun Flow (application) Rate (gpm)	Application Rate (gallons/acre)	Incorporation Cost per Hour ($/hour)
Nutrient Application Rate (lbs/acre)	Acreage Required (acres)	
Pounds of Nutrient per 1000 Gallons of Waste	Tow Path Spacing (ft)	
Gun Throw Diameter (ft)	Length of Pull Needed to Cover One Acre (ft)	
Incorporation Speed (mph)	Time to Cover One Acre (minutes)	
Incorporation Width (ft)	Gun Tow Speed (feet/minute)	
Time For One Set-Up (minutes)	Application Rate (acres/hour)	
Total Length for One Pull (feet)	Number of Set-Ups Required	
	Total Set-Up Time (hours)	
	Total Application Time (hours)	
	Total Application Cost ($)	
	Incorporation Rate (acres/hour)	
	Total Incorporation Time (hours)	
	Total Incorporation Cost ($)	
	Total Transport and Application System Cost ($)	
	System Cost per Acre ($/acre)	
	System Cost per Gallon ($/gallon)	

Table 3.4. Drag hose direct injection system transport and application total annual cost spreadsheet.

Drag Hose Systems		
User Inputs	Calculated Values	Default Values
Manure Volume (gallons) Nutrient Application Rate (lbs/acre) Pounds of Nutrient per 1000 Gallons of Waste Equipment Application Rate (gpm) Application Width (ft)	Application Rate (gallons/acre) Application Speed (mph) Acreage Required (acres) Application Rate (acres/hour) Total Application Time (hours) Total Transport and Application System Cost ($) System Cost per Acre ($/acre) System Cost per Gallon ($/gallon)	Application Cost per Hour ($/hour)

Table 3.5. Center-pivot irrigation system transport and application total annual cost spreadsheet.

Center-Pivot Systems		
User Inputs	Calculated Values	Default Values
Manure Volume (gallons) Nutrient Application Rate (lbs/acre) Pounds of Nutrient per 1000 Gallons of Waste Equipment Application Rate (gpm) Total Length of Span (feet) Total Length of Transport Pipe Needed (feet) Additional Hours Needed for Set-Ups Incorpoaration Speed (mph) Incorporation Width (feet)	Application Rate (gallons/acre) Acreage Required (acres) Number of Set-Ups Required Total Application Time (hours) Total Application Cost ($) Incorporation Rate (acres/hour) Total Incorporation Time (hours) Total Incorporation Cost ($) Total Transport and Application System Cost ($) System Cost per Acre ($/acre) System Cost per Gallon ($/gallon)	Application Cost per Hour ($/hour) Incorporation Cost per Hour ($/hour)

The user needs adequate knowledge of manure transport and application systems in order to calculate cost estimates using this tool. Although manure transport and application systems contain many individual pieces of equipment, not all of these pieces of equipment may produce the same annual operational hours. It is essential to understand what the function of each piece of equipment is and how to assign the appropriate operational times to it in order to estimate an accurate operational cost per hour for that piece of equipment. For example, loading liquid manure into a slurry tank will require different pieces of equipment than incorporating the manure after it has been land applied. Although both of these operations tally into the total system cost, their

individual operational costs must be calculated separately and then added for a total cost. The same is true for determining annual operational times for individual pieces of equipment. If the total transport and application system annual operational hours is 100 hours and this total comes from 25 hours loading time, 25 hours transport time, 25 hours application time, and 25 hours incorporation time, the user must have knowledge of how to assign these operational times or combinations of operational times to the individual pieces of equipment. In addition, the user must comprehend issues such as injection systems will not use other incorporation methods, solid manure cannot be pumped, irrigation systems cannot use injection methods, etc. General common sense must also be used in order to produce accurate cost estimates: A 40 HP tractor cannot be used to pull a 8,000 gallon liquid slurry tank, and one diesel engine driven pump unit will not be able to pump liquid manure an infinite distance.

Once the annual operational hours have been determined for the various operations of the transport and application system from the transport and application total annual cost spreadsheet, these values are used to determine the operational cost per hour for the desired pieces of transport and application equipment using the equipment operational cost per hour spreadsheets. These values are then used to calculate the default values in the transport and application total annual cost spreadsheet. No spreadsheet has been designed to do this automatically for the user. Once the user has hand tabulated the individual default value operational costs then these values can be entered into the appropriate locations in the transport and application total annual cost spreadsheet to calculate the total annual transport and application system cost, transport and application system cost per acre, and transport and application system cost per gallon

or cubic foot (depending whether solid or liquid system is chosen). Figure 3.3 represents the overall operational steps for use of the cost estimation model.

Transport and Application Systems Evaluated

There are many different equipment choices for the transport and application of animal manures. Each system combination is best suited for certain operational parameters. The cost estimation model is capable of calculating cost estimates for all commonly used manure transport and application systems. In this study, six common liquid transport and application systems were evaluated for use with dairy waste. Two separate liquid slurry tank and liquid vacuum tank systems were evaluated to compare the advantages and disadvantages of tank sizes and to illustrate some of the model's versatility. Table 3.6 lists the systems with all their components that were analyzed. A transport and application system is typically comprised of an array of individual pieces of equipment. Some systems are more expensive than others and capital cost for certain transport and application systems will vary with transport distance. Table 3.7 presents the initial investment (capital cost) for each system type. These cost estimates were based on 2000 M.S.L.R.P values. A brief description of each system type considered for this study follows.

Liquid Slurry Tanks (LST)

Liquid slurry tanks (LST) range in size from 2,300 gallons to 12,000 gallons, and are classified as liquid hauling systems. Liquid waste from the storage area must be loaded into the tank. Agitation of the storage area is not required to load the tank. However, to gain maximum nutrient value from the waste, agitation is recommended. Typically, a PTO agitation and loading pump attached to a tractor is used to load the tank.

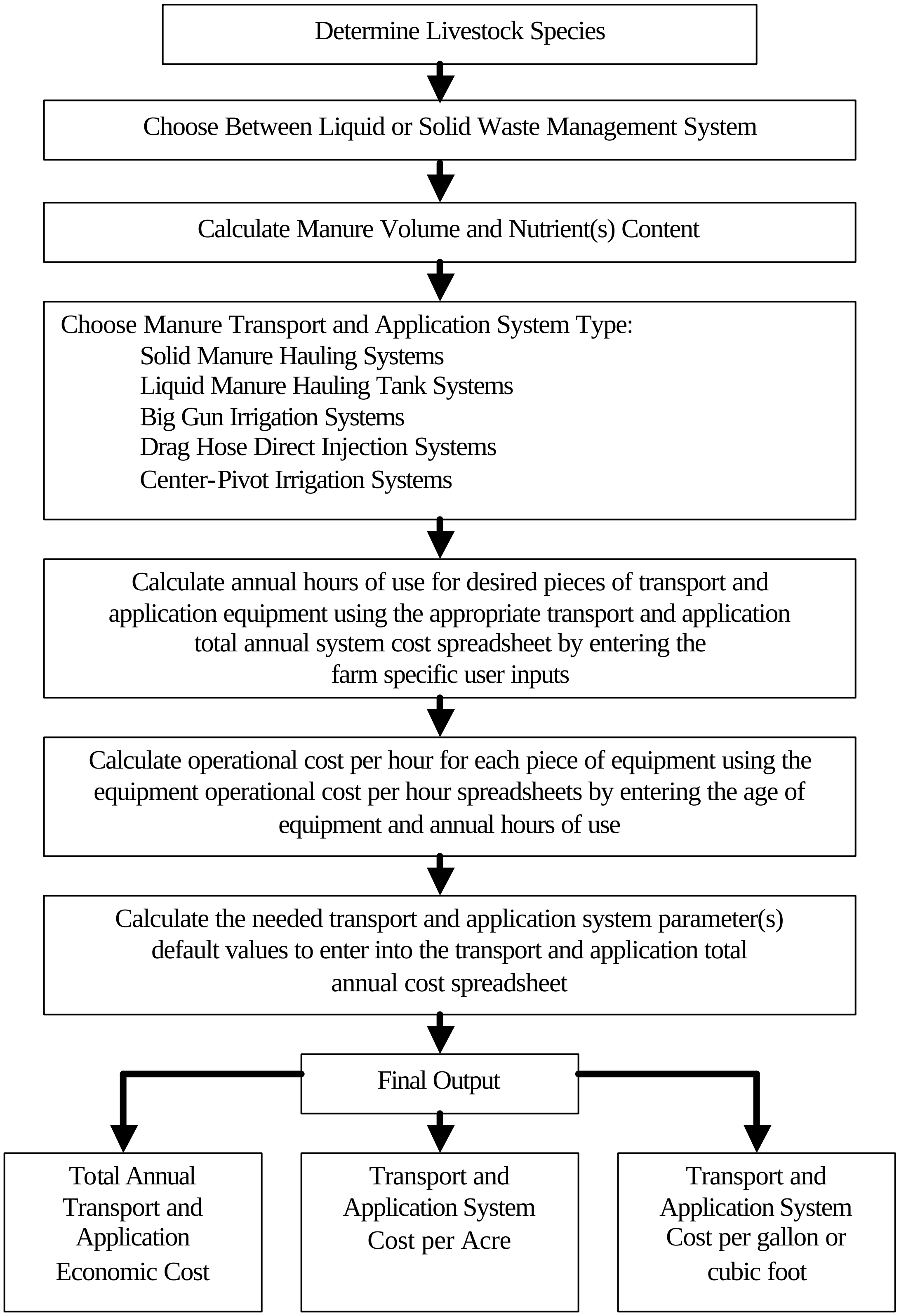

Figure 3.3. Operational steps for use of the cost estimation model.

Table 3.6. Transport and application systems evaluated.

System Type	System Components
5,000 Gallon Liquid Slurry Tank (LST5) (liquid hauling system)	125 HP 4WD Transport and Application Tractor, 100 HP 4WD Incorporation and Loading Tractor, 32' PTO Agitator-Loading Pump, 20' Incorporation Disk, 14' Injection Toolbar
10,000 Gallon Liquid Slurry Tank (LST10) (liquid hauling system)	250 HP 4WD Transport and Application Tractor, 100 HP 4WD Incorporation and Loading Tractor, 32' PTO Agitator-Loading Pump, 20' Incorporation Disk, 24' Injection Toolbar
5,000 Gallon Liquid Vacuum Tank (LVT5) (liquid hauling system)	125 HP 4WD Transport and Application Tractor, 100 HP 4WD Incorporation and Agitation Tractor, 32' PTO Prop Agitator, 20' Incorporation Disk, 14' Injection Toolbar
8,500 Gallon Liquid Vacuum Tank (LVT8) (liquid hauling system)	225 HP 4WD Transport and Application Tractor, 100 HP 4WD Incorporation and Agitation Tractor, 32' PTO Prop Agitator, 20' Incorporation Disk, 24' Injection Toolbar
Drag Hose System (DHS) (liquid pumping system)	225 HP 4WD Application Tractor, 6" Aluminum Transport Pipe, 18' Injection Toolbar, 157 HP @ 2400 rpm Pumping Unit & Diesel Engine Driven Pump **
Big Gun Hard Hose Traveler (BGHH) (liquid pumping system)	4.5" X 1310' Hard Hose Traveler, 100 HP 4WD Agitation, Pumping, & Incorporation Tractor, 124 HP @ 2200 rpm Pumping Unit & Diesel Engine Driven Pump **, 32' PTO Agitator-Loading Pump, 6" Aluminum Transport Pipe, 20' Incorporation Disk
Big Gun Soft Hose Traveler (BGSH) (liquid pumping system)	4.0" X 1310' Soft Hose Traveler, 100 HP 4WD Agitation, Pumping, & Incorporation Tractor, 124 HP @ 2200 rpm Pumping Unit & Diesel Engine Driven Pump **, 32' PTO Agitator-Loading Pump, 6" Aluminum Transport Pipe, 20' Incorporation Disk, 80 HP 4WD Reel Tractor
Center-Pivot System (CPS) (liquid pumping system)	124 HP @ 2200 rpm Pumping Unit & Diesel Engine Driven Pump **, 100 HP 4WD Agitation, Pumping, & Incorporation Tractor, 6" Aluminum Transport Pipe, 20' Incorporation Disk
** for transport distances of 4.5 miles two pumping units were used	

Table 3.7. Total capital investment costs for each system.

System Type and Application Method	Transport Distance (miles)		
	0.5 mile	1.5 mile	4.5 mile
LST5 No Inc	$157,000	$157,000	$157,000
LST 5 Inc	$172,000	$172,000	$172,000
LST 5 Inj	$165,000	$165,000	$165,000
LST10 No Inc	$250,000	$250,000	$250,000
LST 10 Inc	$265,000	$265,000	$265,000
LST10 Inj	$275,000	$275,000	$275,000
LVT5 No Inc	$158,000	$158,000	$158,000
LVT 5 Inc	$173,000	$173,000	$173,000
LVT5 Inj	$165,000	$165,000	$165,000
LVT8 No Inc	$240,000	$240,000	$240,000
LVT8 Inc	$255,000	$255,000	$255,000
LVT8 Inj	$265,000	$265,000	$265,000
DHS	$233,000	$248,000	$313,000
BGHH No Inc	$132,000	$147,000	$212,000
BGHH Inc	$147,000	$162,000	$227,000
BGSH No Inc	$147,000	$161,000	$226,000
BGSH Inc	$162,000	$176,000	$241,000
CPS No Inc	$128,000	$143,000	$207,000
CPS Inc	$143,000	$158,000	$222,000

Note: No Inc (no incorporation system), Inc (incorporation system), Inj (injection system)

A PTO agitator-loading pump consists of a bladed propeller connected to a drive shaft driven by the tractor's PTO. The rotating propeller agitates the storage area. The PTO agitator-loading pump also transfers the liquid waste through a pipe mounted to the frame of the device that can be used to load the tank. A tractor is used to pull the tank to the application site and then through the application field. Tanks can be used to broadcast the liquid waste or can be equipped with an injection toolbar to directly inject the liquid waste beneath the soil surface.

Liquid Vacuum Tanks (LVT)

Liquid vacuum tanks (LVT) range in size from 1,500 gallons to 8,500 gallons, and are classified as liquid hauling systems. Liquid waste from the storage area must be loaded into the tank. Agitation of the storage area is not required to load the tank.

However, to gain maximum nutrient value from the waste, agitation is recommended. The storage area is agitated using a prop agitator that is attached to the PTO of a tractor. This device is similar to the PTO agitator-loading pump except it lacks a PTO driven pump. The vacuum tank contains a vacuum pump that is used to load and unload the tank. To load the tank, the vacuum pump pulls air out of the tank that causes a vacuum. This process of pulling the air out of the tank will at the same time pull the liquid waste into the tank. The tank contains a loading arm, which is placed into the storage area and the vacuum created by the tank transfers the liquid from the storage area into the tank via the loading arm. A tractor is used to pull the tank to the application site and then through the application field. The liquid waste is discharged from the tank by reversing the vacuum and the vacuum pump forces air back into the tank. The air pressure in the tank is used to discharge the liquid waste from the tank. Vacuum tanks can be used to broadcast the liquid waste or can be equipped with an injection toolbar to directly inject the liquid waste beneath the soil surface.

<u>Drag Hose Systems (DHS)</u>

Drag hose systems (DHS) are classified as pumping systems. The storage area is agitated with a PTO agitator-loading pump and a high-volume, high-pressure pump is used to transport the liquid through pipe to the application site. At the application site, the pipe is attached to an umbilical application hose, which is attached to an injection toolbar mounted to the rear of the tractor. The hose is commonly 660 ft long and is pulled by the tractor through the application field where the liquid waste is directly injected under the soil's surface. Injection toolbars for drag hose systems range in width from 10 ft up to 40 ft wide.

Big Gun Hard Hose Traveler (BGHH)

Big gun hard hose travelers (BGHH) are classified as pumping systems. The storage area is agitated and a high-pressure, high-volume pump is used to transport the liquid through pipe to the application site. At the application site the pipe is attached to a hard hose reel. The vertical reel houses a flexible hose, which is usually 1,100 ft to 1,300 ft long. The hose is attached to a big gun irrigation sprinkler that is mounted on a retractable-wheeled cart. The hose is unwound by pulling the cart along a desired towpath perpendicular to the reel. This can be accomplished using a truck, tractor, ATV, etc. Once the hose has been unwound, liquid is pumped to the big gun sprinkler, where it is sprayed onto the application site. The cart is pulled along the towpath by a motor which turns the reel and rewinds the hose. Some reels are driven by an internal hydraulic turbine, but for animal waste slurries, engine driven reels are preferred to accommodate the faster tow speeds needed to apply at lower rates.

Big Gun Soft Hose Travelers (BGSH)

Transport of waste to the application site is identical for both big gun hard hose (BGHH) and big gun soft hose (BGSH) systems. The transport pipe is attached to a soft flexible hose that is usually 660 ft long. This hose is wound on a horizontal reel and must be completely unwound for any pull. The reel is only used to transport the hose. A big gun irrigation sprinkler mounted to a retractable-wheeled cart is connected to the drag hose. The cart is then hooked to a cable, which is mounted to a PTO driven reel. The cable is usually 1,300 ft long. The cart is pulled along the towpath by the cable as it is wound around the reel.

Center-Pivot Systems (CPS)

Center-pivot systems (CPS) are classified as pumping systems. The storage area is agitated and a high-volume high-pressure pump is used to transport the liquid through pipe to the application site. The pipe is connected to a long boom which rotates around a fixed center point. The boom is comprised of individual spans. The individual spans can range in length from 109 ft to 205 ft. Center-pivot systems may include from one individual span up to many spans. The maximum length of a pivot which can be pulled and relocated without complete disassembly is ¼ mile.

Operation Description

For this study, five lactating dairy herd sizes were considered; 50, 200, 400, 800, and 2,000 cow operations. All cows were assumed lactating, average cow weight was assumed to be 1,400 pounds, and cows were assumed to be continuously confined in freestall barns with open loafing lots. The bedding material was assumed to be sawdust. All excreted waste, parlor cleaning water, flush water, and lot runoff was assumed to be stored for 365 days in a 16-foot deep holding pond. Flush water was assumed to be recycled from the holding pond. All runoff from roofed structures was assumed to be collected by gutters and diverted away from the operation and storage area. Uncovered loafing lot area considered to receive rainfall that would be handled as waste was based on 20 square feet of loafing lot per cow. Annual rainfall for the study was set at 50 inches. Net annual rainfall (annual rainfall minus evaporation) for the study was set at 20 inches. The 24-hour/25-year storm for the study was 6 inches.

Determining Manure Volumes

Manure volumes from the Natural Resource Conservation Service (NRCS) part 651 Animal Waste Management Field Handbook were used for this study (NRCS, 1992). Bedding, excreted waste, and milking center clean-up water were combined to produce a total daily waste volume excluding rainwater per cow. This daily volume was multiplied by the number of cows and by the desired storage period. Lot runoff was then added to this volume. This total volume was then used to estimate the waste volume to be applied from the dairy under test. A holding pond surface area was calculated and used to determine additional storage volume needed to store net annual rainfall plus a 24-hour/25-year storm event. Table 3.8 presents the variables used for these calculations and the annual amount of waste produced from each operation.

Determining Nutrient Contents

The nutrient content of the liquid waste was estimated based on pounds of nutrients excreted per pound of live weight per day (Burns et al., 1998). For this study, it was estimated that a 1,400-pound dairy cow excreted 0.63, 0.22, and 0.43 pounds per day N, P_2O_5, and K_2O respectively. These values were used to determine the mass of nutrients per year to be land applied considering handling, storage, and application nutrient losses (refer to Table 2.1) associated with each system type. This information is presented in Table 3.9. These nutrient masses and estimated manure volumes were used to determine the pounds of nutrients per 1,000 gallons of waste for each nutrient and each application method and to determine the application rate per acre as shown in Table 3.10. Application rates for this study were based on a 20-ton per acre corn silage crop. This

Table 3.8. Variables used for manure volume calculations and total manure volumes for each operation.

Sawdust Bedding 12lb/ft^3 Lactating Cow Excreted Manure Milking Center Waste	0.18 ft^3/day/1,400lb cow 1.82 ft^3/day/1,400lb cow 1.96 ft^3/day/1,400lb cow
Total Volume Excluding Rainwater	3.96 ft^3/day/1,400lb cow 29.6 gallons/day/1,400lb cow 10,800 gallons/year/1,400lb cow
Uncovered Loafing Lot Area per cow Annual Rainfall Annual Evaporation Net Annual Rainfall 24-hour/25-year storm Event Holding Pond Depth	20 square feet 50 inches 30 inches 20 inches 6 inches 16 feet (plus 1 ft freeboard)
Number of Cows	Annual Amount of Waste Produced (gallons)
50	650,000
200	2,600,000
400	5,200,000
800	10,450,000
2,000	26,000,000

Table 3.9. Pounds of nutrients available per year following handling, storage, and application losses.

Number of Cows	PAN Broadcast w/ no Incorporation	PAN Broadcast w/ Incorporation	PAN Injected	P_2O_5 all applications	K_2O all applications
	Pounds of Nutrients				
50	4,599	5,749	6,899	4,088	7,921
200	18,396	22,995	27,594	16,352	31,682
400	36,792	45,990	55,188	32,704	63,364
800	73,584	91,980	110,376	65,408	126,728
2,000	183,960	229,950	275,940	163,520	316,820

Note: PAN (plant available nitrogen)

Table 3.10. Pounds of nutrients per 1,000 gallons of waste following handling, storage, and application losses and corresponding application rates.

	Pounds of Nutrients per 1,000 Gallons of Waste	Application Rate (gallons/acre)
PAN Broadcast w/ no Incorporation	7.0	21,000
PAN Broadcast w/ Incorporation	8.8	17,000
PAN Injected	10.6	14,000
P_2O_5 all applications	6.3	9,600
K_2O all applications	12.1	9,900

Note: PAN (plant available nitrogen)

yield was assumed to require 150 pounds of N, 60 pounds of P_2O_5, and 120 pounds of K_2O per acre per year (Savoy and Hamilton, 1994).

Determining Costs

For each dairy size, the total annual economic costs associated with the transport and application system combinations were determined for transport distances of 0.5, 1.5, and 4.5 miles for both nitrogen and phosphorus-based applications. Using the total annual economic cost, a transport and application cost per acre was determined based on the acreage required for each system. In addition, a cost per cow was determined based on the number of cows in that operation. Using the cost per acre value for each system and each dairy size, a net fertilizer value per acre was determined based on crop requirements for a 20-ton per acre corn silage crop. Current prices (at the time of this study) for N, P, and K were used to determine the value of the manure nutrients per acre. For this study, N, P_2O_5, and K_2O values of \$0.30, \$0.25, and \$0.15 per pound respectively were used. No monetary credit was given to P and K when these nutrients were applied at rates greater than those needed to meet crop requirements. Table 3.11

Table 3.11. Manure nutrient value per acre for a 20-ton per acre corn silage crop.

Application Standard	Application Method	Manure Nutrient Value ($/acre)
Nitrogen	All	$78.00
Phosphorus	Broadcast w/ No Incorporation	$52.68
Phosphorus	Broadcast w/ Incorporation	$57.74
Phosphorus	Injected	$62.81

presents the manure nutrient value per acre for nitrogen and phosphorus-based applications for a 20-ton per acre corn silage crop.

Equations Used for Calculations

Total Annual Economic Cost
= Total Loading Cost + Total Transport Cost + Total Application Cost + Total Incorporation Cost

Annual Cost per Cow
= Total Annual Economic Cost / Number of Cows

Transport and Application Cost per Acre
= Total Annual Economic Cost / Application Acreage

Transport and Application Cost per Gallon or per Cubic Foot
=Total Annual Economic Cost / Manure Volume (gallon or cubic foot)

Total Transport and Application Annual Hours of Operation
= Total Loading Time + Total Transport Time + Total Application Time + Total Incorporation Time

Net Fertilizer Value
= Manure Value as Fertilizer per Acre – Transport and Application Cost per Acre

Manure Value as Fertilizer per Acre
= Pounds of N applied per acre * Value of N per pound
+
Pounds of P_2O_5 applied per acre * Value of P_2O_5 per pound
+
Pounds of K_2O applied per acre * Value of K_2O per pound

Note: No monetary credit given to nutrients when applied in excess of crop requirements

Pound of Nutrients Available

= Pounds of Nutrient Excreted per animal per day * Number of Animals * Days of Storage

Note: If calculating nitrogen appropriate availability factor must be used

Pounds of Nutrients per 1,000 Gallons of Waste

= (pounds of nutrient available / manure volume)*1000 gallons

Application Rate (gallons/acre)

= pounds of nutrient required by crop per acre *(1000 gallons / pounds of nutrient per 1000 gallons of waste)

CHAPTER IV

RESULTS AND DISCUSSION

For this study total economic cost is defined as the total operational cost for transporting and applying manure. Net fertilizer value is defined as the total value of the land-applied manure as fertilizer per acre minus the total cost per acre to transport and apply the manure. If an operation's objective is to land apply manure by the cheapest means possible, total economic cost is a valid figure of merit to aide in the selection of equipment and application method. However, if the objective is to receive maximum benefits (returns) from land applied nutrients, then net fertilizer values are the correct figure of merit. In many instances, the transport and application system that produces the lowest operational cost will not produce the highest returns. The following sections present the hypotheses that were developed to evaluate the impacts of nitrogen versus phosphorus-based animal waste applications. Each hypothesis was designed to investigate and provide conclusions to issues that arise when discussing the implications of basing manure applications on phosphorus rather than nitrogen. In addition, detail is presented comparing the economic performance among the various transport and application systems.

Hypothesis 1: **Phosphorus-based manure applications have higher transport and application economic costs than nitrogen based applications**

This hypothesis was developed to determine if transport and application economic cost differences between phosphorus and nitrogen-based applications exist and to evaluate cost differences if present. If phosphorus-based applications incur higher transport and application economic costs to concentrated animal feeding operations, regulatory agencies may develop strategies that could ease these cost increases. In addition, evaluation of the annual economic costs of various transport and application systems operating under different nutrient management plans will aide in making management decisions.

This hypothesis proved to be false for all hauling and drag hose systems. There were no economic cost differences between phosphorus and nitrogen-based applications for hauling and drag hose systems. However, the hypothesis proved to be true for the irrigation systems evaluated in this study (big gun hard hose, big gun soft hose, and center-pivot). Phosphorus-based applications were more expensive for irrigation systems due to the increased amount of labor that is needed to set up the irrigation equipment on the additional land area required for phosphorus-based applications. A detail description of each transport and application system that was evaluated in this study follows with an explanation of why their annual economic costs were or were not different for phosphorus and nitrogen-based applications. Land requirements for each operation are presented in Table 4.1.

Table 4.1. Land requirements for a 20-ton per acre corn silage crop (acres) for each operation, for each nutrient, and each application method.

Limiting Nutrient	Nitrogen	Nitrogen	Nitrogen	Phosphorus
Application Method	Broadcast with no incorporation	Broadcast with incorporation	Injected	All application methods
Number of Cows	Acres			
50	31	38	46	68
200	120	150	180	270
400	250	300	360	550
800	500	600	740	1,100
2,000	1,200	1,500	1,800	2,700

Liquid Slurry Tank Systems (LST)

The model produced identical cost estimates for both nitrogen-based and phosphorus-based applications when liquid slurry tanks were used. When these systems were used to either broadcast the waste without any incorporation or to directly inject the waste into the soil they produced identical cost estimates. These costs were identical because these systems were able to operate within a speed range that effectively allowed them to apply the waste at a desired application rate for both nitrogen and phosphorus-based applications. For phosphorus-based applications, where the waste was broadcast onto the application site, the slurry tanks could be towed at 2.5 mph and this produced the desired application rate of 9,600 gal/acre. When basing the application on phosphorus and the waste was to be injected into the soil, the tanks could be towed at 4.4 mph (5,000 gallon tank) and 2.6 mph (10,000 gallon tank) and meet the desired application rate of 9,600 gal/acre. For nitrogen-based applications with desired application rates of 21,000 (no incorporation), 17,000 (incorporated), and 14,000 (injected) gal/acre the tanks could

be towed at 1.1 mph for broadcast applications with no incorporation. For broadcast applications implementing incorporation, the tanks could be towed at 1.4 mph. Liquid slurry tank injection systems could be towed at 3.0 mph (5,000 gallon tank) and 1.7 mph (10,000 gallon tank) and match the desired application rate of 14,000 gal/acre. Liquid slurry tank injection systems' speeds differed for the two tank sizes because they were equipped with different width injection toolbars. The 5,000 gallon tanks were equipped with a more narrow toolbar and therefore had to be towed faster to meet the application rate requirements. The broadcast width for these systems was assumed to be 25 ft. The injection application widths were assumed to be 14 ft for the 5,000 gallon tanks and 24 ft for the 10,000 gallon tanks. The liquid slurry tank systems' total economic costs only differed when the land-applied nutrients were incorporated into the soil. Phosphorus-based applications had higher total economic costs than nitrogen-based applications when the land-applied nutrients were incorporated into the soil. This cost difference was due to the increased cost associated with operating incorporation equipment over a larger land area. The largest observed difference was a 4.5% ($3,000) increase when the application was phosphorus-based using a 5,000 gallon liquid slurry tank for a 2,000-cow operation.

<u>Liquid Vacuum Tank Systems (LVT)</u>

Cost estimates for nitrogen and phosphorus-based applications were identical when liquid vacuum tanks systems were used. Like the slurry tank systems, their costs only differed when the application was incorporated into the soil. However, the vacuum tank systems incurred significantly higher total annual economic costs than the slurry tank systems. Figure 4.1 compares total annual economic cost for a 400-cow operation

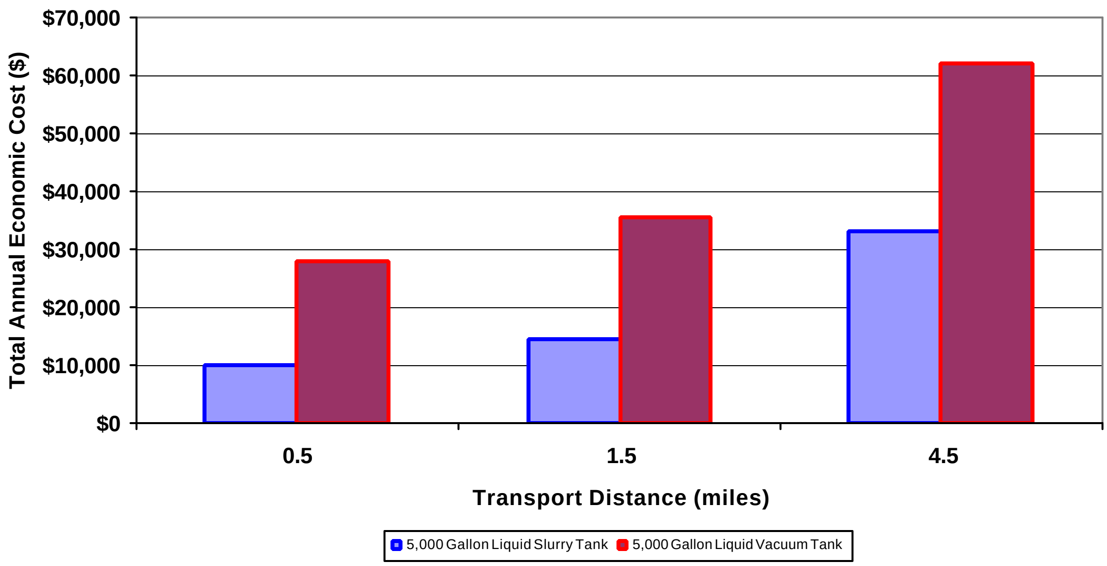

Figure 4.1. Total annual economic cost comparison for a 400-cow operation with a phosphorus-based no incorporation application.

using a 5,000 gallon liquid slurry tank and a 5,000 gallon liquid vacuum tank, with the application based on phosphorus with no incorporation. This cost difference was attributed to the liquid vacuum tank's slower loading and discharge rates. The maximum rate at which the vacuum tanks could load themselves was a rate of 600 gal/min. The maximum discharge rate for these tanks was 400 gal/min. The slurry tanks could be loaded at a rate of 1,000 gal/min and unloaded at a rate of 1,200 gal/min. The vacuum tanks could still operate at a speed to achieve the desired application rates, although the times were greater for these systems than for the slurry tank systems. Phosphorus-based broadcast applications required the vacuum tanks to be towed at 0.8 mph to achieve an application rate of 9,600 gal/acre. Phosphorus-based injection applications required the 5,000 gallon vacuum tank equipped with a 14 ft injection toolbar to be towed at 1.5 mph.

The 8,500 gallon vacuum tank equipped with a 24 ft injection toolbar had to be towed at 0.9 mph to achieve the 9,600 gal/acre application rate. Broadcast with no incorporation nitrogen-based applications required the tanks to be towed at 0.4 mph for an application rate of 21,000 gal/acre. Broadcast with incorporation nitrogen-based applications required a 0.5 mph tow speed for a 17,000 gal/acre application rate. Nitrogen-based injection applications required tow speeds of 1.0 and 0.6 mph for the 5,000 and 8,500 gallon vacuum tanks respectively. These speeds produced the desired application rate of 14,000 gal/acre.

Drag Hose System (DHS)

Drag hose systems produced identical total annual economic costs for both phosphorus and nitrogen-based applications. The drag hose systems evaluated in this study were all equipped with direct injection toolbars. However, toolbars have been designed to broadcast liquid waste onto the soil surface. Future studies should consider these systems and evaluate their costs and returns. The drag hose systems for this study were equipped with an 18 ft injection toolbar and were assumed to discharge 900 gal/min. For this application width and discharge rate, the systems had to travel at 2.6 mph to achieve a 9,600 gal/acre application rate for phosphorus-based applications. For nitrogen-based applications the systems were required to travel at 1.7 mph to meet the 14,000 gal/acre application rate.

Big Gun Hard Hose Traveler System (BGHH)

For big gun hard hose systems, phosphorus-based applications had higher total annual economic costs than nitrogen-based applications. Phosphorus-based applications

had higher costs for two reasons. Phosphorus-based applications require more land area, which results in more equipment set-ups needed to cover the additional land and a lower discharge rate is required to maintain equipment operation capabilities. Big gun hard hose travelers' maximum tow speed for this study was assumed to be 7.0 ft/min (Ag-Rain, 2000). For phosphorus-based applications, gun flow rate had to be set at 550 gal/min to achieve a tow speed not exceeding 7.0 ft/min. Gun flow rate for nitrogen-based applications could be set at 600 gal/min which was assumed to be the maximum flow rate for big gun hard hose travelers. However, this flow rate difference was not the significant reason for phosphorus-based applications to have higher total annual economic costs. Phosphorus-based applications required significantly more labor than did nitrogen-based applications. After the big gun sprinkler has been pulled the entirety of its tow path, the system must be set up for another pull. The time to set up the system again for another pull for this study was assumed to be 45 minutes (Ag-Rain, 2000). Since typical phosphorus-based applications require approximately twice as much land as nitrogen-based applications, twice the number of set-ups is required. Figure 4.2 compares annual operational times for phosphorus and nitrogen-based applications using a big gun hard hose traveler.

Phosphorus-based applications resulted in total annual economic cost increases of 2% to 25% over nitrogen-based applications. These cost differences were greater for larger operations. As operation size increases so does the amount of land needed to satisfy application requirements. The phosphorus-based applications will require more

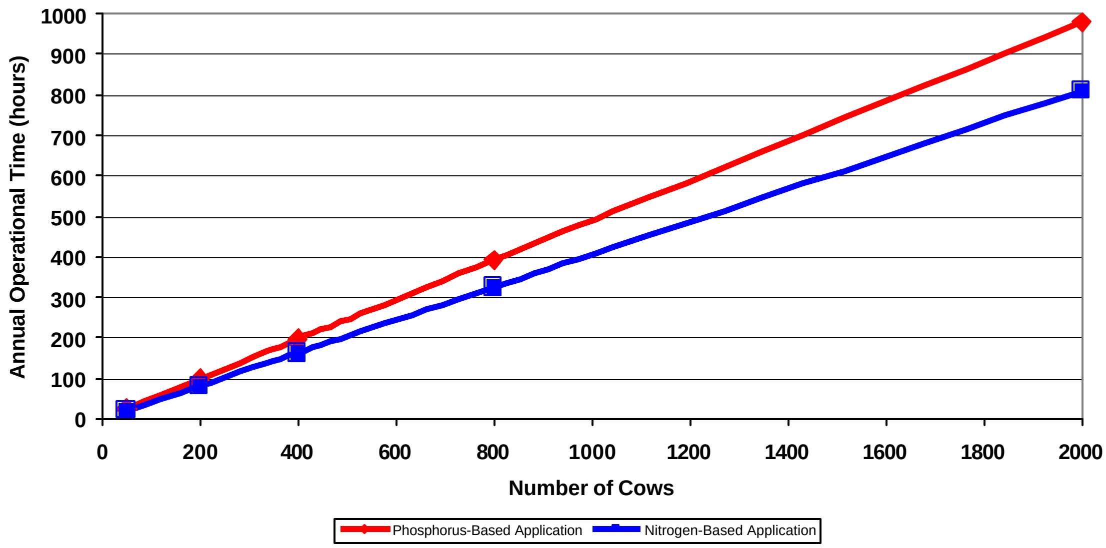

Figure 4.2. Annual operational time comparison for big gun hard hose systems using a no incorporation application.

land, which results in more labor needed for additional set-ups. For BGHH systems, as herd size increased, the cost difference between phosphorus and nitrogen-based applications also increased. For a 50-cow operation with a 4.5-mile transport distance, the total transport and application costs were lower to apply based on phosphorus crop uptake requirements than nitrogen if the waste was incorporated into the soil. The extra operational time required for the phosphorus-based application lowered the equipment's hourly operational costs enough that annually it was $65 less ($20,905 versus $20,970) to apply based on phosphorus standards than implementing a nitrogen-based application. This was the only situation where a phosphorus-based application proved to have a lower total annual transport and application economic cost than a nitrogen-based application using a big gun hard hose traveler system.

Big Gun Soft Hose System (BGSH)

Phosphorus-based applications produced higher total annual economic costs for big gun soft hose systems than did nitrogen-based applications. These higher total annual economic costs were attributed to phosphorus-based applications requiring more land area and a reduced gun flow rate. Maximum tow speed for these systems was assumed to be 7.0 ft/min. Unlike the big gun hard hose systems, gun flow rate did have a significant effect on cost. Phosphorus-based applications required a gun flow rate of 550 gal/min. Big gun soft hose systems can accommodate a higher flow rate than big gun hard hose systems. For this study the maximum flow rate was assumed to be 800 gal/min (Tuckasee, 2000). This flow rate could be implemented for nitrogen-based applications and tow speed would remain below the operational maximum of 7.0 ft/min. The time to set up the big gun soft hose system for each pull for this study was assumed to be 60 min (Tuckasee, 2000 CFW, 2000). As with the big gun hard hose system, big gun soft hose system phosphorus-based applications require twice the land area needed for application. Big gun soft hose systems require more set-up labor than big gun hard hose systems. This increase of labor and gun flow rate discharge difference attributed to cost increases of 60% for phosphorus-based applications over nitrogen-based applications. Figure 4.3 compares annual operational times for phosphorus and nitrogen-based applications using a big gun soft hose system.

There were no situations where phosphorus-based transport application costs were less than nitrogen-based transport and application costs when using a big gun soft hose system. Figure 4.4 presents the total annual economic cost comparison for a big gun soft

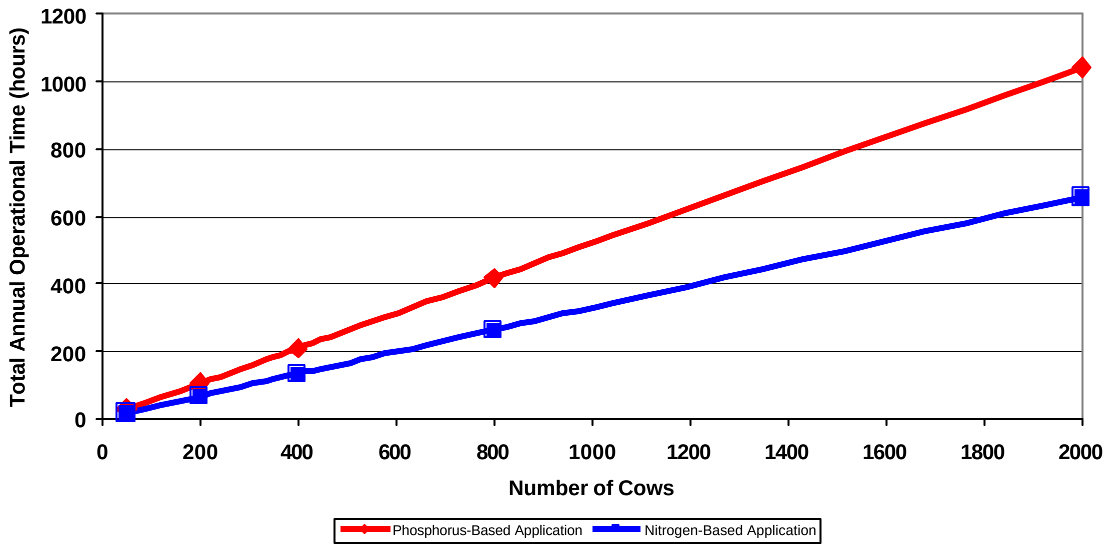

Figure 4.3. Annual operational time comparison for big gun soft hose systems with a no incorporation application.

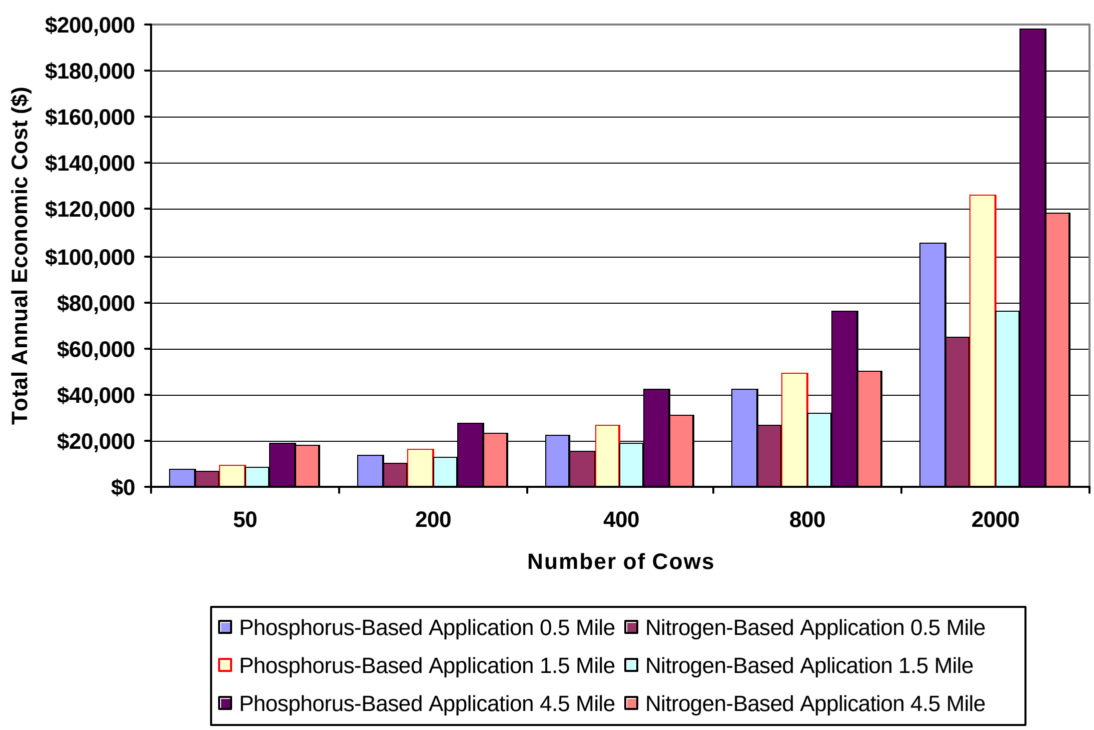

Figure 4.4. Total annual economic cost comparison for a big gun soft hose system with a no incorporation application.

hose system with a broadcast, no incorporation application for each transport distance. The results show that once herd size reaches 200 cows, it becomes more cost effective to apply based on nitrogen at a 1.5 mile transport distance than to apply based on phosphorus at a 0.5 mile transport distance. As herd size increases to around 1,000 cows, nitrogen-based applications at a 4.5 mile transport distance are cheaper than phosphorus-based applications at a 1.5 mile transport distance. The large differences in application area requirements and gun flow rate between phosphorus and nitrogen-based applications caused significant differences in total annual economic costs when using a big gun soft hose system.

Center-Pivot System (CPS)

Phosphorus-based applications had slightly higher total annual economic costs for center-pivot systems than did nitrogen-based applications. The largest cost increase observed was around 18% for a 2,000-cow operation. Center-pivot systems were not as labor demanding as the big gun systems and therefore the total annual economic costs between phosphorus and nitrogen-based applications were not as large. For this study it was assumed that a ¼-mile center-pivot system was the largest unit that could be maneuvered from one application area to another without complete disassembly. A ¼-mile center-pivot system is capable of covering an application area of 126 acres each time it is set up. Each set-up of the system was assumed to take 8 hours of labor. For each 8 hours of set-up labor a center-pivot system was capable of covering 126 acres of application area in a full revolution. In order to cover this same application area, 9 and

12 hours of set-up labor were required for a big gun hard hose and big gun soft hose system respectively.

Cost differences between phosphorus and nitrogen-based applications were attributed to the larger land area needed for phosphorus-based applications and the increased amount of set-up labor needed to satisfy these requirements. Figure 4.5 represents the set-up labor needed for phosphorus and nitrogen-based applications using a center-pivot system. For this study, center-pivot systems were not designed to be stationary units as they are commonly used in clean water irrigation systems. This study assumed that the annual amount of waste for a given operation would be applied using just one mobile center-pivot system. The maximum size of this unit was assumed to be ¼-mile in length. This size unit was capable of applying waste to 126 acres of application land. Operations requiring more than 126 acres of application land required the ¼-mile center-pivot system to be relocated and set-up additional times to cover the required application area. Operations that did not require 126 acres of application land were equipped with pivots of lesser length. The capital cost (purchase price) of these systems was lower than those of the full ¼-mile pivots and costs estimates included the adjusted values.

Center-pivots for all 50-cow operations required the same amount of set-up labor. Application area requirements for these operations only required one set up of the center-pivot system. Also, the 50-cow operations did not require an application area large enough to accommodate a full ¼-mile center-pivot system. Phosphorus-based applications for a 50-cow herd size required a pivot 972 feet long to cover the 68 acres of

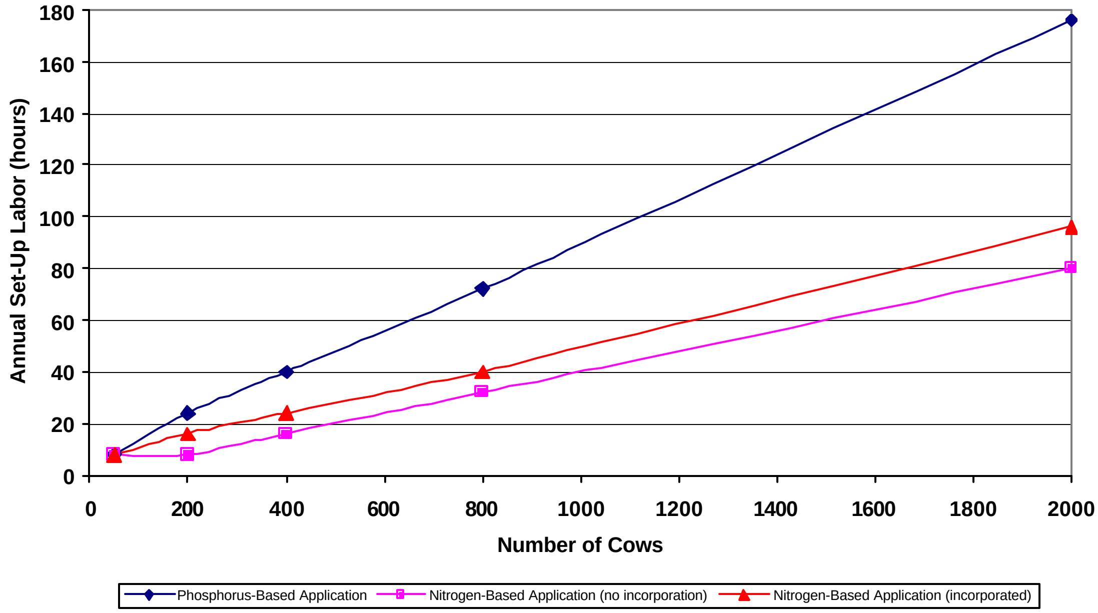

Figure 4.5. Annual set-up labor requirements for center-pivot systems.

application land needed for this application. Nitrogen-based applications for 50-cow herd sizes required pivots of 652 feet to cover the 31 acres of application land needed for a non-incorporated application and a pivot of 729 feet to cover the 38 acres of application land needed for an incorporation application. Manure was assumed to be incorporated using a tractor and incorporation disk within 12 hours of application for center-pivot applications. The length of a pivot determines what discharge rate is required to match adesired application rate. Figure 4.6 presents the total transport and application annual economic costs for a broadcast no incorporation center-pivot system for each herd size and each transport distance.

The cost difference remained approximately constant between phosphorus and nitrogen-based applications for a given herd size and transport distance. One exception

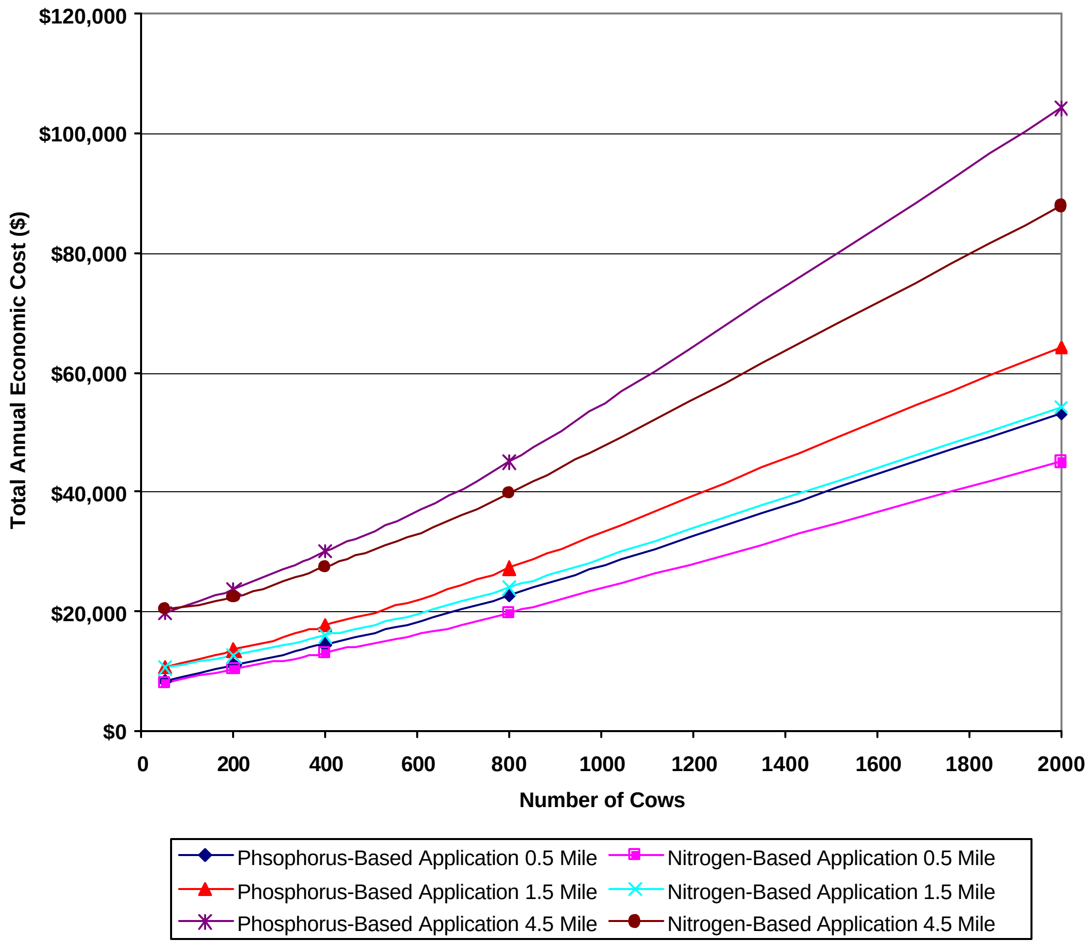

Figure 4.6. Total annual economic cost comparison for a center-pivot system using a no incorporation application.

was for a 50-cow operation with a 4.5-mile transport distance. For this operation, if the liquid waste was broadcast with no incorporation, transport and application costs were annually $460 less to implement a phosphorus-based application. This was the only situation where it showed to be less expensive to implement a phosphorus-based application using a center-pivot system. This is because for this size herd, a phosphorus-based application increased operational hours enough to where it was less expensive annually to operate this system as opposed if the application was based on nitrogen. Phosphorus-based transport and application costs were generally about 6% higher than nitrogen-based applications for a 200-cow operation. The 400-cow operations showed phosphorus-based applications to increase total annual economic costs by 10% over nitrogen-based applications. Phosphorus-based applications resulted in cost increases of 14% and 18% over nitrogen-based applications for 800-cow and 2,000-cow operations respectively when using a center-pivot irrigation system.

***Hypothesis 2:* Phosphorus-based manure applications have higher transport and application net fertilizer values than nitrogen-based applications**

This hypothesis was developed to investigate which application standard (nitrogen or phosphorus) produced the highest returns from land applying dairy slurry. As with any investment opportunity, investments that annually incur higher operating costs may produce higher returns in the end. The same is true for nutrient management. While a nitrogen or phosphorus application standard may incur higher operating costs, the more expensive application standard also may deliver better returns to the operation. Like other industries, the size of the operation and proper management decisions will affect the overall success of the manure transport and application system. If phosphorus-

based manure applications prove to deliver higher net fertilizer values than nitrogen-based applications, operators will have stronger incentives to adopt these application standards, even if higher annual operating costs are incurred.

This hypothesis proved to be true for operations of 200 cows or less. Once herd sizes reached 400 cows, the highest net fertilizer values varied between phosphorus and nitrogen-based applications. There is no clear trend that shows that either phosphorus or nitrogen-based applications produce the highest net fertilizer values for herd sizes of 400 cows and greater across all systems considered. Producers should strive to utilize transport and application systems that produce positive net fertilizer values. When negative net fertilizer values are present, it means that the nutrient value received from those land-applied nutrients was less than the costs that were incurred to transport and apply them. The results show that not all transport and application systems produced positive net fertilizer values. Net fertilizer values expressed significant variability depending on herd size, equipment selection, nitrogen or phosphorus-based application standards, and transport distance. Nitrogen-based applications produced net fertilizer values from $2 up to $300/acre less than the values produced by phosphorus-based applications for herd sizes of 200 cows or less. This results from the fact that transport and application cost on a per acre basis was significantly higher for nitrogen-based applications as compared to phosphorus-based applications for herd sizes of 200 cows or less (refer to Tables C-1 and C-2 located in Appendix C). The land area needed for nitrogen-based applications is generally ½ the land area needed for phosphorus-based applications. The returns from applying nutrients based on nitrogen for this lesser land

area are not as high if nutrients were supplied to a larger land area using a phosphorus-based application for herd sizes up to 200 cows when the transport and application cost per acre is significantly higher than for the phosphorus-based application. For operations of 400 cows and greater, the differences between application costs on a per acre basis were not as significant between nitrogen and phosphorus-based applications (refer to Tables C-3 thru C-5 located in Appendix C). Nitrogen-based applications often produced higher net fertilizer values for operations of 400 cows and greater even though the nutrients were applied to a lesser land area. Some transport and application systems produced very similar net fertilizer values for both phosphorus and nitrogen-based applications while others resulted in differences up to $150/acre.

A transport and application system with a low total annual economic cost does not necessarily produce the highest net fertilizer values. Some of the big gun irrigation systems have lower transport and application economic costs, but higher net fertilizer values for these systems are often produced if these systems use incorporation, even though incorporating the manure increases the total transport and application economic costs. Even though transport and application total economic costs may be higher for phosphorus-based applications for certain systems, the returns received from the fertilizer value of the animal waste from phosphorus-based applications may outweigh their costs. A drag hose system for 400 and 800 cow herds costs more annually than does a center-pivot system, but in some cases delivers higher net fertilizer values (refer to Appendices B and C). In addition, application methods such as no incorporation, incorporation, and injection may significantly influence the net fertilizer values of a given system.

5,000 Gallon Liquid Slurry Tank System (LST 5)

50-Cow Operation 5,000 Gallon LST

The model produced no positive net fertilizers values using the 5,000 gallon liquid slurry tank for a 50-cow operation. The transport and application cost per acre always exceeded the value of the manure for this size operation. Phosphorus-based applications did produce higher net fertilizer values for this system in all situations as compared to nitrogen-based applications because nutrients were applied to a larger land area, producing a significantly lower transport and application cost/acre for the phosphorus-based application. At a transport distance of 0.5 miles, injecting the liquid waste based on phosphorus crop uptake requirements produced the highest net fertilizer value. A broadcast with no incorporation application produced the highest net fertilizer value for a 1.5-mile transport distance. A broadcast with incorporation application produced the highest net fertilizer value for a 4.5-mile transport distance. At a herd size of 50 cows, nitrogen-based application land requirements were not large enough to justify the costs that were incurred to apply the manure nutrients. The costs were the same for phosphorus and nitrogen-based applications, but for this cost twice as much acreage was covered if the application was based on phosphorus. This made nitrogen-based application costs per acre significantly higher than phosphorus-based application costs per acre; therefore nitrogen-based applications did not result in competitive net fertilizer values compared to phosphorus-based applications. Table 4.2 presents a summary of net fertilizer values for the 50-cow operation 5,000 gallon liquid slurry tank system.

Table 4.2. Net fertilizer values for the 50-cow operation LST 5 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$57.40	$52.68	($4.72)	$63.46	$52.68	($10.78)	$82.87	$52.68	($30.19)
N	$127.57	$78.00	($49.57)	$141.02	$78.00	($63.02)	$184.16	$78.00	($106.16)
LST 5 Incorporated P	$60.47	$57.74	($2.73)	$69.29	$57.74	($11.55)	$85.93	$57.74	($28.19)
N	$105.12	$78.00	($27.12)	$120.81	$78.00	($42.81)	$150.39	$78.00	($72.39)
LST 5 Injected P	$65.52	$62.81	($2.71)	$74.91	$62.81	($12.10)	$95.75	$62.81	($32.94)
N	$101.51	$78.00	($23.51)	$110.98	$78.00	($32.98)	$141.86	$78.00	($63.86)

Note: Parentheses indicate negative net fertilizer values

200-Cow Operation 5,000 Gallon LST

As herd size reached 200 cows operational run time and application acreage increased enough that nitrogen-based applications produced competitive net fertilizer values. In addition, transport and application cost/acre values decreased to a point where positive net fertilizer values were produced. At a 0.5-mile transport distance a nitrogen-based injection application produced the highest positive net fertilizer value. An injected phosphorus-based application produced the highest net fertilizer value at a 1.5-mile and 4.5-mile transport distance. Phosphorus-based applications produced the highest net fertilizer values for a 200-cow operation in all situations except the 0.5-mile broadcast with incorporation and injection applications. Table 4.3 presents a summary of net fertilizer values for the 200-cow operation 5,000 gallon liquid slurry tank system.

400-Cow Operation 5,000 Gallon LST

Nitrogen-based applications produced the highest net fertilizer values for all 0.5-mile applications. An injection application produced the highest net fertilizer value at this transport distance for a 400-cow operation. Phosphorus-based applications

Table 4.3. Net fertilizer values for the 200-cow LST 5 system.

		Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
		0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation	P	$23.25	$52.68	$29.43	$30.35	$52.68	$22.33	$56.51	$52.68	($3.83)
	N	$51.68	$78.00	$26.32	$67.44	$78.00	$10.56	$125.57	$78.00	($47.57)
LST 5 Incorporated	P	$26.31	$57.74	$31.43	$33.41	$57.74	$24.33	$59.57	$57.74	($1.83)
	N	$44.40	$78.00	$33.60	$57.02	$78.00	$20.98	$103.52	$78.00	($25.52)
LST 5 Injected	P	$26.42	$62.81	$36.39	$34.12	$62.81	$28.69	$62.75	$62.81	$0.06
	N	$39.14	$78.00	$38.86	$50.55	$78.00	$27.45	$92.97	$78.00	($14.97)

Note: Parentheses indicate negative net fertilizer values

produced the highest net fertilizer values for no incorporation and incorporation application at the 1.5-mile transport distance, but a nitrogen-based injection application produced the highest net fertilizer value of all the application methods at the 1.5-mile transport distance. Phosphorus-based applications produced the highest net fertilizer values for all 4.5-mile situations with an injection application producing the highest overall net fertilizer value. Table 4.4 presents a summary of net fertilizer values for the 400-cow operation 5,000 gallon liquid slurry tank system.

800-Cow Operation 5,000 Gallon LST

For an 800-cow operation, nitrogen-based applications produced the highest net fertilizer values at the 1.5-mile transport distance with an injection application producing the highest overall net fertilizer value. A nitrogen-based injection application produced the highest overall net fertilizer value for the 1.5-mile transport distance. Phosphorus-based applications produced the highest net fertilizer values for no incorporation and incorporated applications at this transport distance. Phosphorus-based applications produced the highest net fertilizer values for all applications at a 4.5-mile transport

Table 4.4. Net fertilizer values for the 400-cow LST 5 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$18.20	$52.68	$34.48	$26.67	$52.68	$26.01	$60.96	$52.68	($8.28)
N	$40.43	$78.00	$37.57	$59.26	$78.00	$18.74	$135.46	$78.00	($57.46)
LST 5 Incorporated P	$21.26	$57.74	$36.48	$29.73	$57.74	$28.01	$64.02	$57.74	($6.28)
N	$35.41	$78.00	$42.59	$50.47	$78.00	$27.53	$111.43	$78.00	($33.43)
LST 5 Injected P	$20.15	$62.81	$42.66	$29.41	$62.81	$33.40	$66.97	$62.81	($4.16)
N	$29.85	$78.00	$48.15	$43.58	$78.00	$34.42	$99.22	$78.00	($21.22)

Note: Parentheses indicate negative net fertilizer values

distance with a phosphorus-based injection application producing the highest overall net fertilizer value. Table 4.5 presents a summary of net fertilizer values for the 800-cow operation 5,000 gallon liquid slurry tank system.

2,000-Cow Operation 5,000 Gallon LST

Nitrogen-based applications produced the highest net fertilizer values for all applications at the 0.5-mile transport distance, with a nitrogen-based injection application producing the highest overall net fertilizer value. At the 1.5-mile transport distance phosphorus-based applications produced the highest net fertilizer values with a phosphorus-based injection application producing the highest overall net fertilizer value. All applications at the 4.5-mile transport distance produced negative net fertilizer values. Phosphorus-based applications produced the highest net fertilizer values at this transport distance for all application methods with a phosphorus-based incorporated application producing the overall highest net fertilizer value. Table 4.6 presents a summary of net fertilizer values for the 2,000-cow operation 5,000 gallon liquid slurry tank system.

Table 4.5. Net fertilizer values for the 800-cow LST 5 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$16.72	$52.68	$35.96	$29.94	$52.68	$22.74	$75.90	$52.68	($23.22)
N	$37.15	$78.00	$40.85	$62.08	$78.00	$15.92	$168.68	$78.00	($90.68)
LST 5 Incorporated P	$19.78	$57.74	$37.96	$29.13	$57.74	$28.61	$78.96	$57.74	($21.22)
N	$32.78	$78.00	$45.22	$49.41	$78.00	$28.59	$138.00	$78.00	($60.00)
LST 5 Injected P	$18.18	$62.81	$44.63	$30.45	$62.81	$32.36	$82.73	$62.81	($19.92)
N	$26.93	$78.00	$51.07	$45.12	$78.00	$32.88	$122.56	$78.00	($44.56)

Note: Parentheses indicate negative net fertilizer values

Table 4.6. Net fertilizer values for the 2,000-cow LST 5 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$18.36	$52.68	$34.32	$36.33	$52.68	$16.35	$140.93	$52.68	($88.25)
N	$40.79	$78.00	$37.21	$80.73	$78.00	($2.73)	$313.18	$78.00	($235.18)
LST 5 Incorporated P	$20.94	$57.74	$36.80	$38.64	$57.74	$19.10	$143.24	$57.74	($85.50)
N	$35.61	$78.00	$42.39	$67.38	$78.00	$10.62	$253.34	$78.00	($175.34)
LST 5 Injected P	$19.76	$62.81	$43.05	$39.25	$62.81	$23.56	$150.06	$62.81	($87.25)
N	$29.28	$78.00	$48.72	$58.15	$78.00	$19.85	$222.32	$78.00	($144.32)

Note: Parentheses indicate negative net fertilizer values

10,000 Gallon Liquid Slurry Tank System (LST 10)

50-Cow Operation 10,000 Gallon LST

No positive net fertilizer values were produced by the 10,000 gallon liquid slurry tank for a 50-cow operation, and these values are also much lower (larger losses) than all the values obtained using the 5,000 gallon liquid slurry tank system. Phosphorus-based applications produced the highest net fertilizer values for all applications for this size operation. Broadcast with incorporation applications produced the highest overall net fertilizer values for all application methods at each transport distance. Table 4.7 presents a summary of net fertilizer values for the 50-cow operation 10,000 gallon liquid slurry tank system.

200-Cow Operation 10,000 Gallon LST

Phosphorus-based applications also produced the highest net fertilizer values for all application methods for a 200-cow dairy. For each transport distance, broadcast with incorporation applications produced the overall highest net fertilizer values. Table 4.8 presents a summary of net fertilizer values for the 200-cow operation 10,000 gallon liquid slurry tank system.

400-Cow Operation 10,000 Gallon LST

The highest overall net fertilizer value for a 400-cow operation with a 0.5-mile transport distance was produced by a nitrogen-based injection application. A nitrogen-based application was also best for an incorporated application. For a no incorporation application, a phosphorus-based application produced the highest net fertilizer value. Phosphorus-based applications produced the highest net fertilizer values for all

Table 4.7. Net fertilizer values for the 50-cow LST 10 system.

		Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
		0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation	P	$93.39	$52.68	($40.71)	$98.43	$52.68	($45.75)	$114.07	$52.68	($61.39)
	N	$207.53	$78.00	($129.53)	$218.73	$78.00	($140.73)	$253.20	$78.00	($175.20)
LST 5 Incorporated	P	$96.45	$57.74	($38.71)	$101.49	$57.74	($43.75)	$117.13	$57.74	($59.39)
	N	$169.09	$78.00	($91.09)	$178.05	$78.00	($100.05)	$205.86	$78.00	($127.86)
LST 5 Injected	P	$129.32	$62.81	($66.51)	$134.45	$62.81	($71.64)	$152.27	$62.81	($89.46)
	N	$191.59	$78.00	($113.59)	$199.63	$78.00	($121.63)	$225.59	$78.00	($147.59)

Note: Parentheses indicate negative net fertilizer values

Table 4.8. Net fertilizer values for the 200-cow LST 10 system.

		Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
		0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation	P	$34.03	$52.68	$18.65	$39.78	$52.68	$12.90	$59.52	$52.68	($6.84)
	N	$75.63	$78.00	$2.37	$88.40	$78.00	($10.40)	$132.28	$78.00	($54.28)
LST 5 Incorporated	P	$37.09	$57.74	$20.65	$42.84	$57.74	$14.90	$62.59	$57.74	($4.85)
	N	$63.56	$78.00	$14.44	$73.78	$78.00	$4.22	$108.89	$78.00	($30.89)
LST 5 Injected	P	$43.91	$62.81	$18.90	$50.49	$62.81	$12.32	$73.50	$62.81	($10.69)
	N	$65.05	$78.00	$12.95	$74.81	$78.00	$3.19	$108.90	$78.00	($30.90)

Note: Parentheses indicate negative net fertilizer value

application methods for transport distances of 1.5 and 4.5 miles. A phosphorus-based injection application produced the highest overall net fertilizer value for the 1.5-mile transport distance and an incorporated application was best for the 4.5-mile transport distance. Table 4.9 presents a summary of net fertilizer values for the 400-cow operation 10,000 gallon liquid slurry tank system.

800-Cow Operation 10,000 Gallon LST

The highest overall net fertilizer value for the 0.5-mile transport was produced by nitrogen-based injection application. At the 0.5-mile transport distance, a nitrogen-based application was also best for incorporated applications whereas a phosphorus-based application produced the highest net fertilizer value for no incorporation applications. Phosphorus-based applications produced the highest net fertilizer values for all applications at transport distances of 1.5 and 4.5 miles. The highest overall net fertilizer value for the 1.5-mile transport distance was produced by a phosphorus-based injection application. For the 4.5-mile transport distance the highest overall net fertilizer value was produced by a phosphorus-based incorporated application. Table 4.10 presents a

Table 4.9. Net fertilizer values for the 400-cow LST 10 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$24.90	$52.68	$27.78	$31.65	$52.68	$21.03	$56.85	$52.68	($4.17)
N	$55.34	$78.00	$22.66	$70.33	$78.00	$7.67	$126.33	$78.00	($48.33)
LST 5 Incorporated P	$27.96	$57.74	$29.78	$34.71	$57.74	$23.03	$59.91	$57.74	($2.17)
N	$47.33	$78.00	$30.67	$59.32	$78.00	$18.68	$104.08	$78.00	($26.08)
LST 5 Injected P	$30.52	$62.81	$32.29	$38.57	$62.81	$24.24	$68.08	$62.81	($5.27)
N	$45.21	$78.00	$32.79	$57.14	$78.00	$20.86	$100.86	$78.00	($22.86)

Note: Parentheses indicate negative net fertilizer values

Table 4.10. Net fertilizer values for the 800-cow LST 10 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$21.63	$52.68	$31.05	$30.36	$52.68	$22.32	$64.21	$52.68	($11.53)
N	$48.08	$78.00	$29.92	$67.46	$78.00	$10.54	$142.69	$78.00	($64.69)
LST 5 Incorporated P	$24.70	$57.74	$33.04	$33.42	$57.74	$24.32	$67.27	$57.74	($9.53)
N	$41.52	$78.00	$36.48	$57.03	$78.00	$20.97	$117.22	$78.00	($39.22)
LST 5 Injected P	$25.67	$62.81	$37.14	$35.88	$62.81	$26.93	$75.42	$62.81	($12.61)
N	$38.03	$78.00	$39.97	$53.16	$78.00	$24.84	$111.74	$78.00	($33.74)

Note: Parentheses indicate negative net fertilizer values

summary of net fertilizer values for the 800-cow operation 10,000 gallon liquid slurry tank system.

2,000-Cow Operation 10,000 Gallon LST

A nitrogen-based injection application produced the highest overall net fertilizer value for a 2,000-cow operation with a 0.5-mile transport distance. Phosphorus-based applications produce the highest net fertilizer values for this operation with transport distances of 1.5 and 4.5 miles. A phosphorus-based injection application produced the highest overall net fertilizer value at the 1.5-mile transport distance and a phosphorus-based incorporated application produced the highest overall net fertilizer value at the 4.5-mile transport distance. Table 4.11 presents a summary of net fertilizer values for the 2,000-cow operation 10,000 gallon liquid slurry tank system.

<u>Drag Hose System (DHS)</u>

50-Cow Operation Drag Hose System

The model produced no positive net fertilizer values using the drag hose system for a 50-cow operation. A phosphorus-based application produced the highest net

Table 4.11. Net fertilizer values for the 2,000-cow LST 10 system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
LST 5 No Incorporation P	$23.72	$52.68	$28.96	$36.45	$52.68	$16.23	$100.73	$52.68	($48.05)
N	$52.71	$78.00	$25.29	$80.99	$78.00	($2.99)	$223.85	$78.00	($145.85)
LST 5 Incorporated P	$25.75	$57.74	$31.99	$38.76	$57.74	$18.98	$103.05	$57.74	($45.31)
N	$43.78	$78.00	$34.22	$67.58	$78.00	$10.42	$181.87	$78.00	($103.87)
LST 5 Injected P	$27.25	$62.81	$35.56	$42.12	$62.81	$20.69	$114.61	$62.81	($51.80)
N	$40.36	$78.00	$37.64	$62.40	$78.00	$15.60	$169.80	$78.00	($91.80)

Note: Parentheses indicate negative net fertilizer values

fertilizer value at all transport distances. Table 4.12 presents a summary of net fertilizer values for the 50-cow operation drag hose system.

200-Cow Operation Drag Hose System

Drag hose systems produced positive net fertilizer values for a 200-cow operation for transport distances up to 1.5 miles. At the 0.5-mile transport distance, a phosphorus-based application produced the highest net fertilizer value. For a 200-cow operation with a 1.5-mile transport distance, a phosphorus-based application also produced the highest net fertilizer value. At this distance, a phosphorus-based application produced a positive net fertilizer value whereas the nitrogen-based application produced a negative net fertilizer value. Both phosphorus and nitrogen-based applications produced negative net fertilizer values at the 4.5-mile transport distance, the phosphorus-based application at this distance produced the lesser negative value. Table 4.13 presents a summary of net fertilizer values for the 200-cow operation drag hose system.

Table 4.12. Net fertilizer values for the 50-cow DHS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
DHS Injected P	$137.12	$62.81	($74.31)	$168.82	$62.81	($106.01)	$298.97	$62.81	($236.16)
N	$203.14	$78.00	($125.14)	$250.11	$78.00	($172.11)	$442.93	$78.00	($364.93)

Note: Parentheses indicate negative net fertilizer values

Table 4.13. Net fertilizer values for the 200-cow DHS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
DHS Injected P	$44.69	$62.81	$18.12	$53.40	$62.81	$9.41	$89.39	$62.81	($26.58)
N	$66.21	$78.00	$11.79	$79.11	$78.00	($1.11)	$132.43	$78.00	($54.43)

Note: Parentheses indicate negative net fertilizer values

400-Cow Operation Drag Hose System

Once herd size reached 400 cows, using a nitrogen-based application produced the highest net fertilizer value for a 0.5-mile transport distance. A phosphorus-based application produced the highest net fertilizer values for transport distances of 1.5 and 4.5 miles. For a 400-cow operation, using a drag hose system with a phosphorus-based application produced the only positive net fertilizer value for all the systems evaluated for a 400-cow operation at the 4.5-mile transport distance. Table 4.14 presents a summary of net fertilizer values for the 400-cow operation drag hose system.

800-Cow Operation Drag Hose System

Drag hose systems produced positive net fertilizer values for all transport distances for an 800-cow operation. Nitrogen-based applications produced the highest net fertilizer values for transport distances of 0.5 and 1.5 miles. A phosphorus-based

Table 4.14. Net fertilizer values for the 400-cow DHS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
DHS Injected P	$30.19	$62.81	$32.62	$35.29	$62.81	$27.52	$56.27	$62.81	$6.54
N	$44.73	$78.00	$33.27	$52.28	$78.00	$25.72	$83.37	$78.00	($5.37)

Note: Parentheses indicate negative net fertilizer values

application produced the highest net fertilizer value for an 800-cow operation with a 4.5-mile transport distance. Table 4.15 presents a summary of net fertilizer values for the 800-cow operation drag hose system.

2,000-Cow Operation Drag Hose System

All net fertilizer values for drag hose systems for a 2,000-cow operation were positive. For transport distances of 0.5 and 1.5 miles, nitrogen-based applications produced the highest net fertilizer values. As transport distance increased to 4.5 miles the highest net fertilizer values were produced by phosphorus-based applications. Table 4.16 presents a summary of net fertilizer values for the 2,000-cow operation drag hose system.

<u>Big Gun Hard Hose Traveler System (BGHH)</u>

50-Cow Operation thru 400-Cow Operation Big Gun Hard Hose System

For all transport distances for operations of 50 thru 400 cows, phosphorus-based incorporated applications produced the highest overall net fertilizer values. No net fertilizer values were positive for the 50-cow operation. Phosphorus-based applications produced positive net fertilizer values for a 200-cow operation with a 0.5-mile transport distance. All nitrogen-based applications produced negative net fertilizer values for the

Table 4.15. Net fertilizer values for the 800-cow DHS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
DHS Injected P	$24.02	$62.81	$38.79	$27.42	$62.81	$35.39	$41.64	$62.81	$21.17
N	$35.58	$78.00	$42.42	$40.63	$78.00	$37.37	$61.69	$78.00	$16.31

Note: Parentheses indicate negative net fertilizer values

Table 4.16. Net fertilizer values for the 2,000-cow DHS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
DHS Injected P	$22.00	$62.81	$40.81	$25.06	$62.81	$37.75	$36.71	$62.81	$26.10
N	$32.60	$78.00	$45.40	$37.13	$78.00	$40.87	$54.38	$78.00	$23.62

Note: Parentheses indicate negative net fertilizer values

200-cow operation. As herd size reached 400 cows, all phosphorus and nitrogen-based applications produced positive net fertilizer values for the 0.5-mile transport distance. At the 1.5-mile transport distance, both phosphorus-based applications produced positive net fertilizer values. At this transport distance a nitrogen-based application produced a positive net fertilizer value if the liquid manure was incorporated. All applications at the 4.5-mile transport distance produced negative net fertilizer values for the 400-cow operation. Tables 4.17 thru 4.19 present a summary of net fertilizer values for the big gun hard hose system for operations of 50 thru 400 cows.

800-Cow Operation thru 2,000-Cow Operation Big Gun Hard Hose System

All applications produced positive net fertilizer values for transport distances of 0.5 and 1.5 miles for the 800-cow operation. A nitrogen-based incorporated application produced the highest overall net fertilizer value for the 0.5-mile transport distance. The

Table 4.17. Net fertilizer values for the 50-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGHH No Incorporation P	$138.36	$52.68	($85.68)	$171.01	$52.68	($118.33)	$303.76	$52.68	($251.08)
N	$299.46	$78.00	($221.46)	$372.21	$78.00	($294.21)	$662.83	$78.00	($584.83)
BGHH Incorporated P	$141.42	$57.74	($83.68)	$174.07	$57.74	($116.33)	$306.82	$57.74	($249.08)
N	$248.90	$78.00	($170.90)	$307.80	$78.00	($229.80)	$547.20	$78.00	($469.20)

Note: Parentheses indicate negative net fertilizer values

Table 4.18. Net fertilizer values for the 200-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGHH No Incorporation P	$51.67	$52.68	$1.01	$61.92	$52.68	($9.24)	$103.20	$52.68	($50.52)
N	$105.44	$78.00	($27.44)	$126.95	$78.00	($48.95)	$213.93	$78.00	($135.93)
BGHH Incorporated P	$54.73	$57.74	$3.01	$64.98	$57.74	($7.24)	$106.26	$57.74	($48.52)
N	$89.62	$78.00	($11.62)	$107.28	$78.00	($29.28)	$178.68	$78.00	($100.68)

Note: Parentheses indicate negative net fertilizer values

Table 4.19. Net fertilizer values for the 400-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGHH No Incorporation P	$39.23	$52.68	$13.45	$46.35	$52.68	$6.33	$74.25	$52.68	($21.57)
N	$76.40	$78.00	$1.60	$90.57	$78.00	($12.57)	$146.56	$78.00	($68.56)
BGHH Incorporated P	$42.29	$57.74	$15.45	$49.41	$57.74	$8.33	$77.31	$57.74	($19.57)
N	$65.78	$78.00	$12.22	$77.42	$78.00	$0.58	$123.38	$78.00	($45.38)

Note: Parentheses indicate negative net fertilizer values

highest overall net fertilizer value for the 1.5-mile transport distance was produced by a phosphorus-based incorporated application. No positive net fertilizer values were produced for an 800-cow operation with a 4.5-mile transport distance. A phosphorus-based incorporated application produced the highest overall net fertilizer value for this transport distance. Both phosphorus and nitrogen-based applications produced positive net fertilizer values for a 2,000-cow operation at the 0.5-mile transport distance. The highest overall net fertilizer for this distance was produced by nitrogen-based incorporated application. A phosphorus-based incorporated application produced the highest overall net fertilizer value for transport distances of 1.5 and 4.5 miles for the 2000-cow operation. No positive net fertilizer values were produced for a 2,000-cow operation with a 4.5-mile transport distance using a big gun hard hose system. Tables 4.20 and 4.21 presents a summary of net fertilizer values for the big gun hard hose system for operations of 800 and 2,000 cows.

Big Gun Soft Hose System (BGSH)

50-Cow Operation thru 200-Cow Operation Big Gun Soft Hose System

For all transport distances for operations of 50 thru 200 cows, phosphorus-based incorporated applications produced the highest overall net fertilizer values. No positive net fertilizer values were produced for the 50-cow operation using a big gun soft hose system. Both phosphorus-based applications produced positive net fertilizer values for the 200-cow operation with a transport distance of 0.5 miles. The nitrogen-based incorporated application also produced a positive net fertilizer value at this transport distance. For transport distances of 1.5 and 4.5 miles, no applications produced positive

Table 4.20. Net fertilizer values for the 800-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGHH No Incorporation P	$35.38	$52.68	$17.30	$41.59	$52.68	$11.09	$64.79	$52.68	($12.11)
N	$65.82	$78.00	$12.18	$77.39	$78.00	$0.61	$121.29	$78.00	($43.29)
BGHH Incorporated P	$38.44	$57.74	$19.30	$44.65	$57.74	$13.09	$67.85	$57.74	($10.11)
N	$57.09	$78.00	$20.91	$66.60	$78.00	$11.40	$102.63	$78.00	($24.63)

Note: Parentheses indicate negative net fertilizer values

Table 4.21. Net fertilizer values for the 2,000-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGHH No Incorporation P	$37.11	$52.68	$15.57	$44.03	$52.68	$8.65	$68.48	$52.68	($15.80)
N	$66.29	$78.00	$11.71	$78.47	$78.00	($0.47)	$121.96	$78.00	($43.96)
BGHH Incorporated P	$39.54	$57.74	$18.20	$46.46	$57.74	$11.28	$70.91	$57.74	($13.17)
N	$57.22	$78.00	$20.78	$67.22	$78.00	$10.78	$102.92	$78.00	($24.92)

Note: Parentheses indicate negative net fertilizer values

net fertilizer values. Tables 4.22 and 4.23 presents a summary of net fertilizer values for the big gun soft hose system for operations of 50 and 200 cows.

400-Cow Operation Big Gun Soft Hose System

All applications produced positive net fertilizer values for transport distances of 0.5 and 1.5 miles. Nitrogen-based incorporated applications produced the highest overall net fertilizer values for these transport distances. No applications produced positive net fertilizer values for a 400-cow operation with a 4.5-mile transport distance. At this transport distance the highest overall net fertilizer value was produced by a phosphorus-based incorporated application. Table 4.24 presents a summary of net fertilizer values for the big gun soft hose system for a 400-cow operation.

800-Cow Operation thru 2,000-Cow Operation Big Gun Soft Hose System

Nitrogen-based incorporated applications produced the highest overall net fertilizer values for all transport distances for 800 and 2,000-cow operations using a big gun hard hose system. All applications produced positive net fertilizer values for these operations with 0.5 and 1.5-mile transport distances. No positive net fertilizer values were produced when transport distance reached 4.5 miles for these operations. Tables 4.25 and 4.26 presents a summary of net fertilizer values for the big gun soft hose system for operations of 800 and 2,000 cows.

Center-Pivot System (CPS)

50-Cow Operation thru 200-Cow Operation Center-Pivot System

Phosphorus-based incorporated applications produce the highest overall net fertilizer values for all transport distances for 50 thru 200-cow operations using a center-

Table 4.22. Net fertilizer values for the 50-cow BGSH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGSH No Incorporation P	$111.36	$52.68	($58.68)	$144.13	$52.68	($91.45)	$277.43	$52.68	($224.75)
N	$225.03	$78.00	($147.03)	$296.24	$78.00	($218.24)	$585.49	$78.00	($507.49)
BGSH Incorporated P	$114.42	$57.74	($56.68)	$147.19	$57.74	($89.45)	$280.49	$57.74	($222.75)
N	$190.83	$78.00	($112.83)	$250.25	$78.00	($172.25)	$491.60	$78.00	($413.60)

Note: Parentheses indicate negative net fertilizer values

Table 4.23. Net fertilizer values for the 200-cow BGSH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGSH No Incorporation P	$49.85	$52.68	$2.83	$60.33	$52.68	($7.65)	$102.42	$52.68	($49.74)
N	$86.03	$78.00	($8.03)	$106.49	$78.00	($28.49)	$189.46	$78.00	($111.46)
BGSH Incorporated P	$52.91	$57.74	$4.83	$63.39	$57.74	($5.65)	$105.48	$57.74	($47.74)
N	$74.84	$78.00	$3.16	$91.91	$78.00	($13.91)	$161.15	$78.00	($83.15)

Note: Parentheses indicate negative net fertilizer values

Table 4.24. Net fertilizer values for the 400-cow BGSH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGSH No Incorporation P	$41.08	$52.68	$11.60	$48.50	$52.68	$4.18	$77.44	$52.68	($24.76)
N	$64.44	$78.00	$13.56	$77.21	$78.00	$0.79	$128.15	$78.00	($50.15)
BGSH Incorporated P	$44.14	$57.74	$13.60	$51.56	$57.74	$6.18	$80.50	$57.74	($22.76)
N	$56.83	$78.00	$21.17	$67.48	$78.00	$10.52	$109.99	$78.00	($31.99)

Note: Parentheses indicate negative net fertilizer values

Table 4.25. Net fertilizer values for the 800-cow BGSH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGSH No Incorporation P	$38.52	$52.68	$14.16	$45.11	$52.68	$7.57	$69.65	$52.68	($16.97)
N	$55.57	$78.00	$22.43	$65.31	$78.00	$12.69	$102.75	$78.00	($24.75)
BGSH Incorporated P	$41.58	$57.74	$16.16	$48.17	$57.74	$9.57	$72.71	$57.74	($14.97)
N	$49.43	$78.00	$28.57	$57.56	$78.00	$20.44	$88.80	$78.00	($10.80)

Note: Parentheses indicate negative net fertilizer values

Table 4.26. Net fertilizer values for the 2,000-cow BGHH system.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
BGSH No Incorporation P	$38.80	$52.68	$13.88	$46.27	$52.68	$6.41	$72.62	$52.68	($19.94)
N	$53.00	$78.00	$25.00	$62.23	$78.00	$15.77	$96.66	$78.00	($18.66)
BGSH Incorporated P	$41.23	$57.74	$16.51	$48.70	$57.74	$9.04	$75.05	$57.74	($17.31)
N	$47.11	$78.00	$30.89	$54.82	$78.00	$23.18	$83.54	$78.00	($5.54)

Note: Parentheses indicate negative net fertilizer values

pivot system. No positive net fertilizer values were produced for the 50-cow operation. All phosphorus-based applications produced positive net fertilizer values for the 200-cow operation with a 0.5-mile transport distance. A nitrogen-based incorporated application also produced a positive net fertilizer value for this operation at the 0.5-mile transport distance. Both phosphorus-based applications produced positive net fertilizer values for a 200-cow operation with a 1.5-mile transport distance. No positive net fertilizer values were produced for a 200-cow operation with a transport distance of 4.5 miles while using a center-pivot system. Tables 4.27 and 4.28 presents a summary of net fertilizer values for the center-pivot system for operations of 50 and 200 cows.

400-Cow Operation Center-Pivot System

All applications produced positive net fertilizer values for transport distances of 0.5 and 1.5 miles for a 400-cow operation. The highest overall net fertilizer value for the 0.5-mile transport distance was produced by a nitrogen-based incorporated application. A phosphorus-based incorporated application produced the highest overall net fertilizer value for the 1.5-mile transport distance. No positive net fertilizer values were produced for this operation with a 4.5-mile transport distance. At this distance a phosphorus-based incorporated application produced the highest overall net fertilizer value. Table 4.29 presents a summary of net fertilizer values for the center-pivot system for a 400-cow operation.

Table 4.27. Net fertilizer values for the 50-cow CPS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
CPS No Incorporation P	$122.02	$52.68	($69.34)	$155.11	$52.68	($102.43)	$289.67	$52.68	($236.99)
N	$262.50	$78.00	($184.50)	$340.75	$78.00	($262.75)	$658.77	$78.00	($580.77)
CPS Incorporated P	$125.09	$57.74	($67.35)	$158.17	$57.74	($100.43)	$292.73	$57.74	($234.99)
N	$209.30	$78.00	($131.30)	$270.34	$78.00	($192.34)	$518.61	$78.00	($440.61)

Note: Parentheses indicate negative net fertilizer values

Table 4.28. Net fertilizer values for the 200-cow CPS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
CPS No Incorporation P	$40.23	$52.68	$12.45	$49.53	$52.68	$3.15	$87.22	$52.68	($34.54)
N	$82.61	$78.00	($4.61)	$102.26	$78.00	($24.26)	$182.07	$78.00	($104.07)
CPS Incorporated P	$43.29	$57.74	$14.45	$52.59	$57.74	$5.15	$90.28	$57.74	($32.54)
N	$71.84	$78.00	$6.16	$87.95	$78.00	($9.95)	$153.35	$78.00	($75.35)

Note: Parentheses indicate negative net fertilizer values

Table 4.29. Net fertilizer values for the 400-cow CPS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
CPS No Incorporation P	$26.50	$52.68	$26.18	$32.22	$52.68	$20.46	$55.02	$52.68	($2.34)
N	$53.08	$78.00	$24.92	$64.78	$78.00	$13.22	$111.77	$78.00	($33.77)
CPS Incorporated P	$29.56	$57.74	$28.18	$35.28	$57.74	$22.46	$58.08	$57.74	($0.34)
N	$47.06	$78.00	$30.94	$56.67	$78.00	$21.33	$95.25	$78.00	($17.25)

Note: Parentheses indicate negative net fertilizer values

800-Cow Operation Center-Pivot System

For transport distances of 0.5 and 1.5 miles, a nitrogen-based incorporated application produced the highest overall net fertilizer values for an 800-cow operation. All applications using a center-pivot system produced positive net fertilizer values for 0.5 and 1.5-mile transport distances. For this operation with a 4.5-mile transport distance, a phosphorus-based incorporated application produced the highest overall net fertilizer value. At this transport distance the center-pivot system produced positive net fertilizer values for all applications except for the nitrogen-based no incorporation application. Table 4.30 presents a summary of net fertilizer values for the center-pivot system for an 800-cow operation.

2,000-Cow Operation Center-Pivot System

Nitrogen-based incorporated applications produced the highest overall net fertilizer values for a 2,000-cow operation with transport distances of 0.5 and 1.5 miles. All center-pivot applications produced positive net fertilizer values for 0.5 and 1.5-mile transport distances. When transport distance increased to 4.5 miles for a 2,000-cow operation, a phosphorus-based incorporated application produced the highest overall net fertilizer value. All applications produced positive net fertilizer values for a 2,000-cow operation at the transport distances considered. Table 4.31 presents a summary of net fertilizer values for the center-pivot system for a 2,000-cow operation.

Table 4.30. Net fertilizer values for the 800-cow CPS.

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
CPS No Incorporation P	$20.68	$52.68	$32.00	$24.92	$52.68	$27.76	$41.25	$52.68	$11.43
N	$40.25	$78.00	$37.75	$48.57	$78.00	$29.43	$81.00	$78.00	($3.00)
CPS Incorporated P	$23.74	$57.74	$34.00	$27.98	$57.74	$29.76	$44.31	$57.74	$13.43
N	$36.16	$78.00	$41.84	$42.98	$78.00	$35.02	$69.53	$78.00	$8.47

Note: Parentheses indicate negative net fertilizer values

Table 4.31. Net fertilizer values for the 2,000-cow CPS

	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Transport and Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
CPS No Incorporation P	$19.48	$52.68	$33.20	$23.50	$52.68	$29.18	$38.20	$52.68	$14.48
N	$36.64	$78.00	$41.36	$44.12	$78.00	$33.88	$71.54	$78.00	$6.46
CPS Incorporated P	$21.64	$57.74	$36.10	$26.01	$57.74	$31.73	$40.68	$57.74	$17.06
N	$32.63	$78.00	$45.37	$38.81	$78.00	$39.19	$61.42	$78.00	$16.58

Note: Parentheses indicate negative net fertilizer values

Hypothesis 3: **Regulations proposing the implementation of phosphorus standards for all land applications of animal waste economically favor large dairy operations over small dairy operations**

This hypothesis was designed to investigate what size dairy operations would be more economically viable if regulations were imposed that demanded all manure applications be based on phosphorus crop requirements. In addition, the hypothesis was designed to evaluate which manure transport and application systems would best suit (economically) certain size dairy operations under the implementation of phosphorus-based applications. If larger operations' manure transport and application systems prove more economically viable over smaller operations, then small operations may be presented with an incentive to increase operation herd size. However, if producers are content with current herd size, hypothesis 3 will present values that will aide in making better manure transport and application system decisions for their given herd size.

What some people consider a large dairy operation may not be considered a large operation to others. The classification of large versus small operations for this study was based on personal observation and personal inquires with individuals who specialize in planning, constructing, and managing dairy operations in the Southeastern United States. For this study it was assumed that a large dairy operation consisted of 400 lactating cows or greater. A small dairy operation was assumed to consist of less than 400 lactating cows. Following is an evaluation of how the implementations of phosphorus standards for land application of animal manure economically affect manure transport and application costs for dairy operations. The results were based on an evaluation of operations' annual cost per cow and net fertilizer values per acre using a

phosphorus-based no incorporation application for hauling and irrigation systems. Drag hose system values were obtained from a phosphorus-based injection application.

Hypothesis 3 proved to be true for all pumping systems, but had mixed results for hauling systems (refer to Appendices C and E). Pumping systems resulted in higher net fertilizer values and lower annual costs per cow values as herd size increased. Once herd size reached 800 cows, the net fertilizer and cost per cow values virtually remained constant for a given pumping system as herd size approached 2,000 cows. Once herd size reached 400 cows for hauling systems, there was a noticeable increase in cost per cow values and a noticeable decrease in the net fertilizer values as herd size approached 2,000 cows. The actual range of high and low cost per cow values was large for each size operation. The 50-cow operation cost per cow values ranged from a low of $78/cow to a high of $418/cow. High and low cost per cow values for the 2,000-cow herd ranged from $25/cow to $577/cow. Net fertilizer values also varied greatly across a given herd size. The overall highest net fertilizer value produced for the 50-cow herd size was -$3 and the lowest was -$584. Overall high and low net fertilizer values for the 2,000-cow herd size ranged from $48 to -$550. Although negative net fertilizer values are not desirable, some herd sizes do not produce positive net fertilizers values considering the equipment evaluated in this study, therefore an operator would want to choose a manure transport and application system that produced the least negative value. Figures 4.7 thru 4.10 illustrate the effects herd size has on net fertilizer values and costs per cow for hauling and pumping systems. Pumping systems showed decreasing costs per cow and

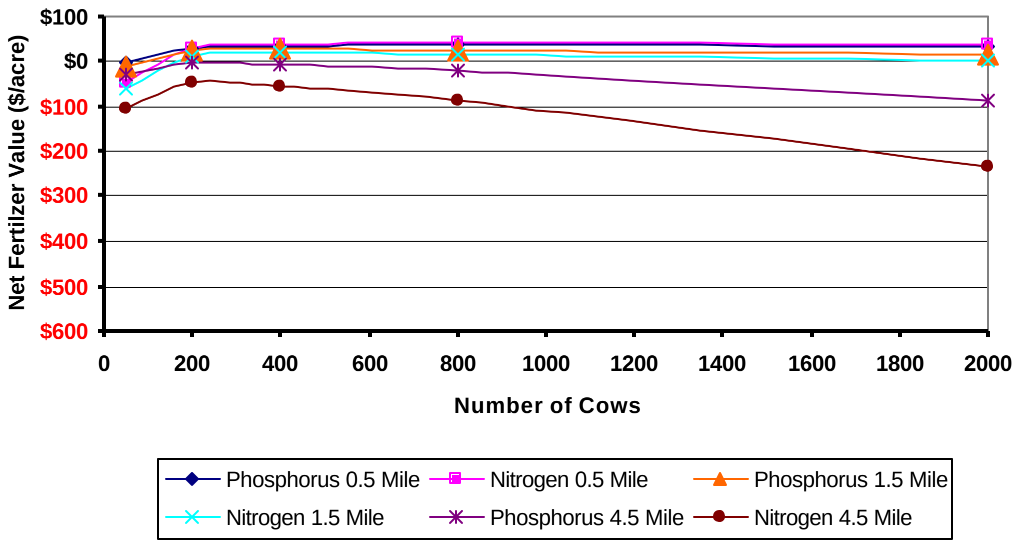

Figure 4.7. 5,000 gallon LST net fertilizer values using a phosphorus-based no incorporation application.

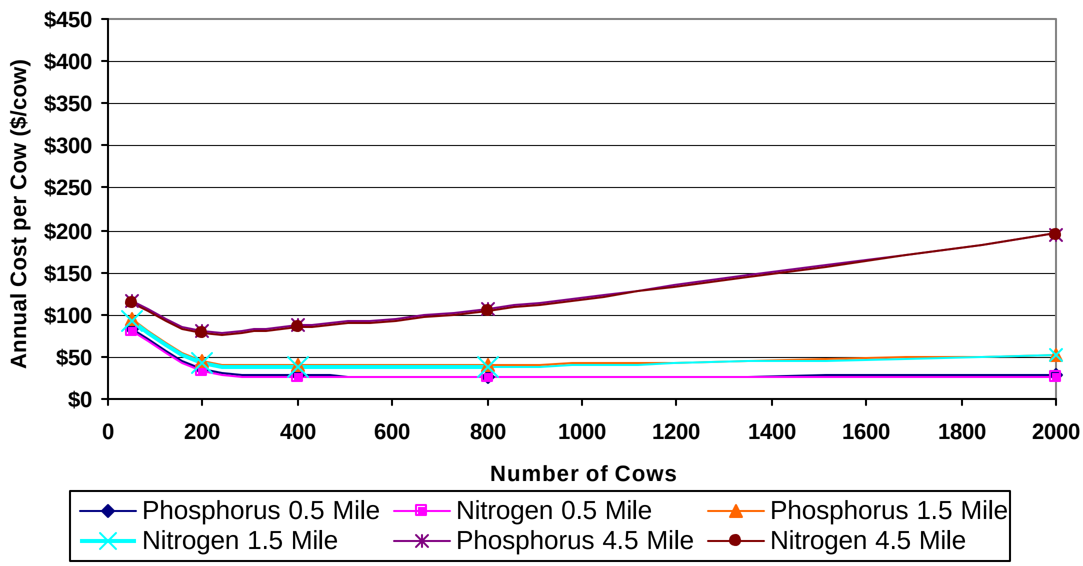

Figure 4.8. 5,000 gallon LST annual cost per cow values using a phosphorus-based no incorporation application.

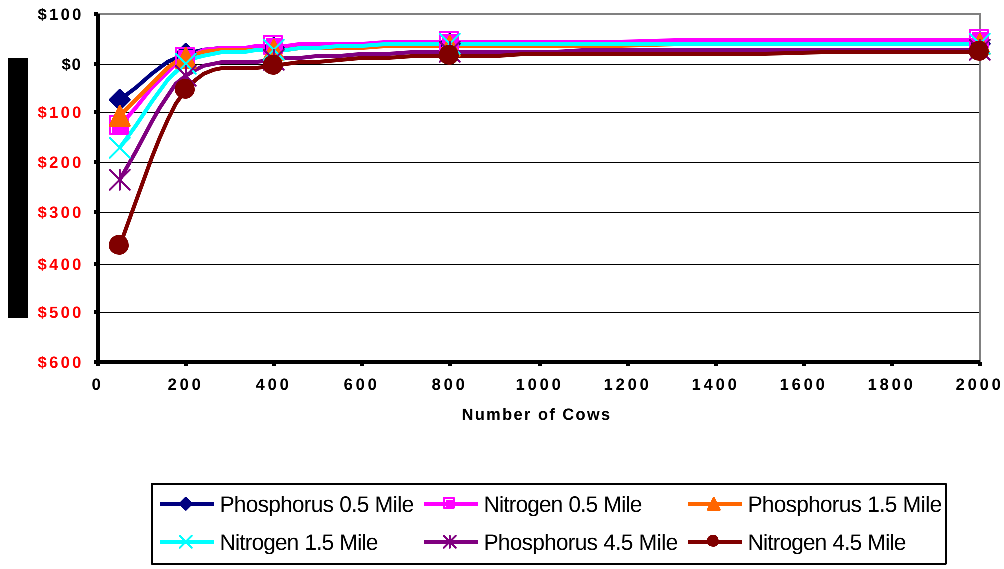

Figure 4.9. DHS net fertilizer values for an injected phosphorus-based application.

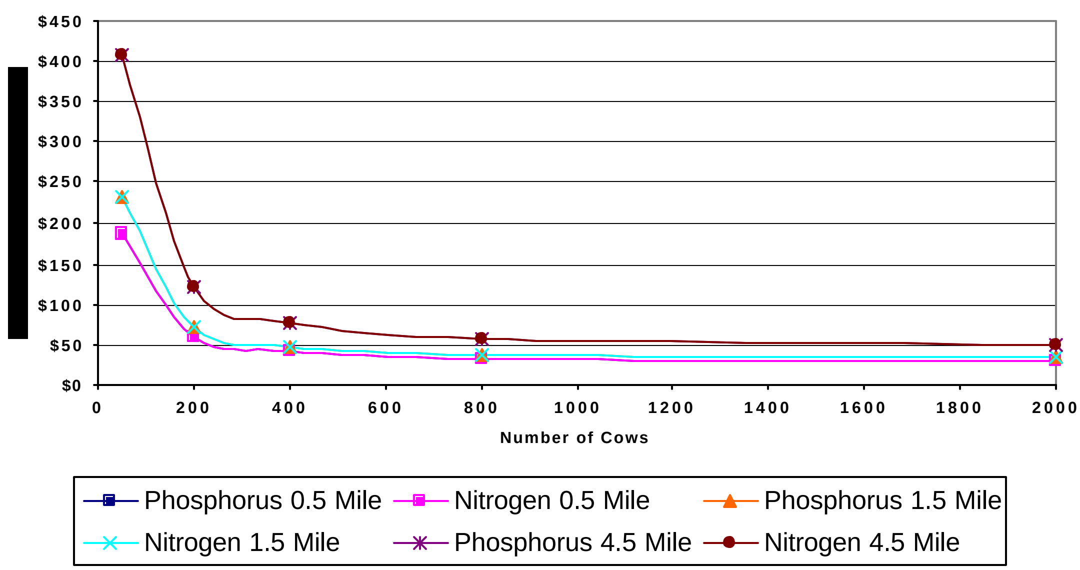

Figure 4.10. DHS annual cost per cow values for an injected phosphorus-based application.

increasing net fertilizer values as herd size increased. The same was true for hauling systems until herd size exceeded 400 cows.

The 50-cow operations proved to not be an economically viable sized operation for any system that was evaluated. When references are made concerning small dairy operations (<400 cows), it must be taken into account that the 50-cow operations did not produce an annual waste volume large enough to justify the costs of most transport and application systems that were analyzed in this study. Table 4.32 summarizes the lowest annual cost per cow value and the highest net fertilizer value produced with a phosphorus-based application for a given herd size. As shown, there was an overall lower cost per cow value and overall higher net fertilizer value produced by some given transport and application system as herd size increased. Table 4.32 does not represent values for just one transport and application system; it is a representation of the best values produced from all systems evaluated over the different herd sizes.

In general, the hauling systems (LST 5, LST 10, LVT 5, and LVT 8) were more feasible and economically favored for small operations. Results showed that at the 0.5 and 1.5-mile transport distances these systems produced competitive cost per cow and net fertilizer values for larger operations (>400 cows). However, the annual operational times for these systems were unfeasible and limited them being used on operations that had greater than 400 cows and a transport distance exceeding 1.5 miles, even though competitive values were produced. Hauling systems were not viable for any large operations with a 4.5-mile transport distance. The pumping systems (DHS, BGHH, BGSH, and CPS) clearly favor increasing herd sizes. The drag hose system

Table 4.32. Lowest cost per cow and highest net fertilizer values produced by phosphorus-based applications.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Lowest Cost per Cow ($/cow)	Highest Net Fertilizer Value ($/acre)	Lowest Cost per Cow ($/cow)	Highest Net Fertilizer Value ($/acre)	Lowest Cost per Cow ($/cow)	Highest Net Fertilizer Value ($acre)
Number of Cows						
50	$78.23	($2.73)	$86.47	($11.55)	$112.93	($28.19)
200	$31.69	$31.43	$41.36	$24.33	$77.00	($1.83)
400	$24.79	$36.48	$36.34	$28.01	$74.97	($6.28)
800	$22.78	$38.79	$33.96	$35.39	$56.21	$21.17
2000	$25.02	$40.81	$32.06	$37.75	$50.03	$26.10

Note: Parentheses indicate negative net fertilizer values

and center-pivot system showed increased benefits as operation size increased to the largest herd size that was evaluated in this study of 2,000 cows. The big gun systems (BGHH and BGSH) showed lower cost per cow values and increased net fertilizer values as herd sized increased to 800 cows. No increased benefits were received if herd size was increased from 800 to 2,000 cows if the operation was using a big gun transport and application system.

<u>5,000 Gallon Liquid Slurry Tank System (LST 5)</u>

Annual cost per cow values for the 5,000 gallon liquid slurry tank system economically favor large operations over small operations at the 0.5-mile transport distance. Once herd size reaches 400 cows, cost per cow values slightly decrease as herd size reaches 800 cows. From 800 cows to 2,000 cows the cost per cow values increase slightly. A 5,000 gallon liquid slurry tank system with a 1.5-mile transport distance is not favored by large operations. At this transport distance, cost per cow values start to increase steadily once operation size exceeds 400 cows. Once herd size reaches 200 cows, cost per cow values start to increase rapidly for a 5,000 gallon liquid slurry tank

system with a transport distance of 4.5 miles. Figure D-1 in Appendix D presents annual cost per cow values for a 5,000 gallon liquid slurry tank system. The 5,000 gallon liquid slurry tank system favored large operations when evaluating the net fertilizer values until transport distance exceeded 1.5 miles. The 5,000 gallon liquid slurry tank produced the best net fertilizer values for operations of 400 and 800 cows with transport distances of 0.5 and 1.5 miles. Net fertilizer values are presented for the 5,000 gallon liquid slurry tank system as Figure D-2 in Appendix D. Table 4.33 presents the actual cost per cow and net fertilizer values for the 5,000 gallon liquid slurry tank system.

<u>10,000 Gallon Liquid Slurry Tank System (LST 10)</u>

The 10,000 gallon liquid slurry tank system favored large operations at transport distances of 0.5 and 1.5 miles. At the 1.5-mile transport distance, cost per cow values started to increase between operations of 800 and 2,000 cows. Cost per cow values remained virtually constant between operations of 800 and 2,000 cows for the 0.5-mile transport distance. Cost per cow values for the 10,000 gallon liquid slurry tank system started to increase rapidly when operation size reached 400 cows with a 4.5-mile transport distance. Cost per cow values are presented as Figure D-3 in Appendix D. The 10,000 gallon liquid slurry tank system's net fertilizer values were favored by large operations for transport distances of 0.5 and 1.5 miles. Net fertilizer values started to decrease once herd size reached 800 cows for the 1.5-mile transport distance. Operations which had a transport distance of 4.5 miles using a 10,000 gallon liquid slurry tank, had a rapid decrease in net fertilizer values once operation herd size reached 400 cows. Net

Table 4.33. LST 5 cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$82.40	($2.73)	$86.47	($11.55)	$112.93	($28.19)
200	$31.69	$31.43	$41.36	$24.33	$77.00	($1.83)
400	$24.79	$36.48	$36.34	$28.01	$83.06	($6.28)
800	$22.78	$37.96	$38.07	$28.61	$103.43	$21.22
2000	$25.02	$36.80	$49.51	$19.10	$192.07	($85.50)

Note: Parentheses indicate negative net fertilizer values

fertilizer values for the 10,000 gallon liquid slurry tank system are presented as Figure D-4 in Appendix D. Both slurry tank systems showed significant decreases in cost per cow values and significant increases in net fertilizer values as herd size increased from 50 cows to 200 cows. Table 4.34 presents the cost per cow and net fertilizer values for the 10,000 gallon liquid slurry tank system.

<u>5,000 Gallon Liquid Vacuum Tank System (LVT 5)</u>

The 5,000 gallon liquid vacuum tank system showed to favor small operations. Once herd size exceed 200 cows, annual cost per cows values started to increase rapidly. Annual cost per cow values for the 5,000 gallon liquid vacuum are presented as Figure D-5 in Appendix D. Net fertilizer values for the 5,000 gallon liquid vacuum tank system also favored small operations. Net fertilizer values for this system started to decrease rapidly as herd size exceeded 200 cows. Net fertilizer values for the 5,000 gallon liquid vacuum tank are presented as Figure D-6 in Appendix D. Table 4.35 presents the actual cost per cow and net fertilizer values for the 5,000 gallon liquid vacuum tank system.

Table 4.34. LST 10 cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$131.43	($38.71)	$138.30	($43.75)	$159.61	($59.39)
200	$50.55	$20.65	$58.38	$14.90	$85.29	($4.85)
400	$38.11	$29.78	$47.29	$23.03	$81.64	($2.17)
800	$33.65	$33.04	$45.54	$24.32	$91.67	($9.53)
2000	$35.10	$31.99	$52.83	$18.98	$140.44	($45.31)

Note: Parentheses indicate negative net fertilizer values

Table 4.35. LVT 5 cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$112.98	($25.17)	$122.24	($33.96)	$152.01	($55.81)
200	$71.65	($48.49)	$85.35	($96.81)	$134.23	($302.34)
400	$74.17	$3.31	$93.15	($10.62)	$159.55	($59.34)
800	$87.17	($6.23)	$116.10	($27.46)	$253.92	($115.38)
2000	$144.77	($48.49)	$210.63	($96.81)	$490.75	($302.34)

Note: Parentheses indicate negative net fertilizer values

8,500 Gallon Liquid Vacuum Tank System (LVT 8)

The 8,500 gallon liquid vacuum tank system favored small operations. Once herd size exceeded 200 cows, annual cost per cow values started to increase rapidly. Net fertilizer values for the 8,500 gallon liquid vacuum tank system began to decrease once herd size exceeded 200 cows. Annual cost per cow values and net fertilizer values are presented as Figures D-7 and D-8 respectively in Appendix D. For both the 5,000 gallon and 8,500 gallon liquid vacuum tank systems there was a significant decrease in annual cost per cow values and a significant increase in net fertilizer values as herd size increased from 50 cows to 200 cows. Table 4.36 presents the actual cost per cow and net fertilizer values for the 8,500 gallon liquid vacuum tank system.

Drag Hose System (DHS)

The drag hose system favored large operations for phosphorus-based applications. Annual cost per cow values decreased at a rapid rate as herd size increased from 50 cows to 800 cows. These values are presented as Figure D-9 in Appendix D. Once herd size reached 800 cows cost per cow values continued to decrease slightly as herd size approached 2,000 cows. The drag hose system produced positive net fertilizer values for all transport distances once herd size reached 400 cows. Net fertilizer values for the drag hose system are presented as Figure D-10 in Appendix D. The drag hose system produced positive net fertilizer values for transport distances of 0.5 and 1.5 miles for the 200-cow operation. Table 4.37 presents the cost per cow and net fertilizer values for the drag hose system.

Table 4.36. LVT 8 cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$173.00	($69.21)	$181.56	($75.49)	$208.76	($95.45)
200	$104.03	($18.60)	$116.91	($28.05)	$160.54	($60.07)
400	$107.76	($21.34)	$126.38	($35.00)	$185.34	($78.27)
800	$128.77	($36.76)	$156.20	($56.89)	$259.44	($132.65)
2000	$223.02	($105.90)	$286.96	($152.82)	$529.67	($330.90)

Note: Parentheses indicate negative net fertilizer values

Table 4.37. DHS cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$186.85	($74.31)	$230.05	($106.01)	$407.40	($236.16)
200	$60.90	$18.12	$72.61	$9.41	$121.81	($26.58)
400	$41.14	$32.62	$48.09	$27.52	$76.68	$6.54
800	$32.73	$38.79	$37.37	$35.39	$56.74	$21.17
2000	$29.99	$40.81	$34.16	$37.75	$50.03	$26.10

Note: Parentheses indicate negative net fertilizer values

Big Gun Hard Hose Traveler System (BGHH)

The big gun hard hose system showed to favor large operations when a phosphorus-based application was implemented. Annual cost per cow values decreased steadily as herd size increased from 50 to 800 cows. As herd size increased from 800 to 2,000 cows there was a slight increase noticed in the annual cost per cow values. Annual cost per cow values for the big gun hard hose system are presented as Figure D-11 in Appendix D. Net fertilizer values for the drag hose system increased steadily as operation size increased from 50 to 800 cows. A slight decrease in net fertilizer values was observed as operation size increased from 800 to 2,000 cows. Net fertilizer values for the big gun hard hose system are presented as Figure D-12 in Appendix D. Table 4.38 presents the cost per cow and net fertilizer values for the big gun hard hose system.

Big Gun Soft Hose System (BGSH)

Large operations implementing a phosphorus-based application were favorable for the big gun soft hose system. Annual cost per cow values decreased as herd size grew from 50 to 800 cows. These values increased slightly when herd size increased from 800 to 2,000 cows. Annual cost per cow values are presented as Figure D-13 in Appendix D. The big gun soft hose system produced positive net fertilizer values for 0.5 and 1.5-mile transport distances once herd size reached 400 cows. Net fertilizer values for the big gun soft hose system are presented as Figure D-14 in Appendix D. Neither of the big gun systems (BGHH or BGSH) produced positive net fertilizer values for operations with a 4.5-mile transport distance. Table 4.39 presents the cost per cow and net fertilizer values for the big gun soft hose system.

Table 4.38. BGHH cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$192.72	($83.68)	$237.20	($116.33)	$418.11	($249.08)
200	$74.58	$3.01	$88.55	($7.24)	$144.80	($48.52)
400	$57.63	$15.45	$67.34	$8.33	$105.35	($19.57)
800	$52.39	$19.30	$60.84	$13.09	$92.40	($10.11)
2000	$53.89	$18.20	$63.32	$11.28	$96.64	($13.17)

Note: Parentheses indicate negative net fertilizer values

Table 4.39. BGSH cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$155.92	($56.68)	$200.58	($89.45)	$382.22	($222.75)
200	$72.11	$4.83	$86.38	($5.65)	$143.74	($47.47)
400	$60.08	$13.60	$70.26	$6.18	$109.70	($22.76)
800	$56.66	$16.16	$65.64	$9.57	$99.09	($14.97)
2000	$56.19	$16.51	$66.38	$9.04	$102.29	($17.31)

Note: Parentheses indicate negative net fertilizer values

Center-Pivot System (CPS)

The center-pivot system showed to favor large operations when a phosphorus-based application was implemented. Annual cost per cow values for the center-pivot system showed to decrease continuously as herd size increased from 50 to 2,000 cows. Annual cost per cow values for the center-pivot system are presented as Figure D-15 in Appendix D. Net fertilizer values showed to increase continuously also as herd size increased from 50 to 2,000 cows. The center pivot system produced positive net fertilizer values for transport distances of 0.5 and 1.5 miles once herd size reached 200 cows. For operations greater than 400 cows, the center-pivot system produced for positive net fertilizer values for a 4.5-mile transport distance. Figure D-16 in Appendix D presents the net fertilizer values for the center-pivot system. Table 4.40 presents the cost per cow and net fertilizer values for the center-pivot system.

Table 4.40. CPS cost per cow and net fertilizer values.

	0.5 Mile		1.5 Mile		4.5 Mile	
	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value	Cost per Cow	Net Fertilizer Value
Number of Cows						
50	$170.45	($67.35)	$215.53	($100.43)	$398.91	($234.99)
200	$58.99	$14.45	$71.67	$5.15	$123.03	($32.54)
400	$40.29	$28.18	$48.07	$22.46	$79.14	($0.34)
800	$32.36	$34.00	$38.13	$29.76	$60.39	$13.43
2000	$29.49	$36.10	$35.44	$31.73	$55.44	($13.80)

Note: Parentheses indicate negative net fertilizer values

***Hypothesis 4:* Hauling system transport and application net fertilizer values are more cost sensitive to increases in transport distances than are pumping system transport and application net fertilizer values**

This hypothesis was designed to evaluate the effects that transport distance have on costs for manure transport and application systems. Instead of making this evaluation based on total annual transport and application economic cost, evaluations were made from net fertilizer values for the systems considered. Net fertilizer values are appropriate for this investigation since the returns received from the land-applied nutrients is the only monetary credits earned by the manure transport and application system. It is well accepted that manure transport and application costs increase with transport distance. However, limited data is available to evaluate the rates at which certain transport and application systems costs are affected by transport distance. In addition, these rates may change for a given system under various herd sizes. If hauling systems' net fertilizer values prove more cost sensitive to increases in transport distance compared to pumping systems, operators would have the incentive to adopt these technologies, especially if increased transport distances to application sites are foreseen in the operation's future.

Hypothesis 3 was false for operations of 50 and 200 cows. Pumping systems were more cost sensitive to increases in transport distance for these operations. This hypothesis proved true for operations of 400 thru 2,000 cows. Hauling systems proved to be more sensitive to increases in transport distances than did pumping systems for these operations. To determine these evaluations, sensitivity to distance was calculated for each system and for each herd size, then by averaging these figures for the hauling systems and the pumping systems. Sensitivity to distance was determined by taking the

difference between net fertilizer values at the 0.5 and 4.5-mile transport distance and dividing this number by the difference in transport distance (i.e. 4 miles). The equation used to calculate sensitivity to distance values follows.

$$\text{Sensitivity to Distance (\$/acre/mile)} =$$
$$\{\text{0.5-Mile Net Fertilizer Value (\$/acre)} - \text{4.5-Mile Net Fertilizer Value (\$/acre)}\} / \text{4 miles}$$

As expected, the net fertilizer values produced from a given transport and application system decreased as transport distance increased. However, the rates at which the net fertilizer values decreased as transport distance increased were significantly different between hauling systems and pumping systems and differed among herd sizes as well. As transport distance increased from 0.5 to 4.5 miles for the 50-cow herd size, hauling system net fertilizer values showed a range of decrease from $0 to -$100 per acre. At this same herd size, pumping system net fertilizer values decreased from -$50 to -$250 per acre as transport distance increased from 0.5 to 4.5 miles. For a herd size of 2,000 cows, hauling systems produced net fertilizer value decreases from -$50 to -$350 as transport distance increased from 0.5 to 4.5 miles, whereas the pumping systems showed net fertilizer value decreases of $50 to $0 as transport distance increased from 0.5 to 4.5 miles. System(s) sensitivity to distance evaluations were determined from phosphorus-based incorporated applications for all systems except the drag hose system. Evaluations for the drag hose system were determined from a phosphorus-based injected application since drag hose systems were only evaluated for injection applications. Figures 4.11 thru

4.15 show the rates at which net fertilizer values decreased as transport distance increased for each transport and application system for each size operation. As transport distance increases for hauling systems, no increase in initial investment is needed. The purchase price for a hauling system will remain constant with varying transport distances. However, this scenario does not hold true for pumping systems. Additional transport pipe and pumping units must be purchased as transport distance increases (refer to Table 3.7). As annual manure volume increases, so do the number of transport trips needed when using hauling systems and as transport distance increases the overall transport time for these systems will increase. Trips to and from the manure storage area are not present for the pumping systems.

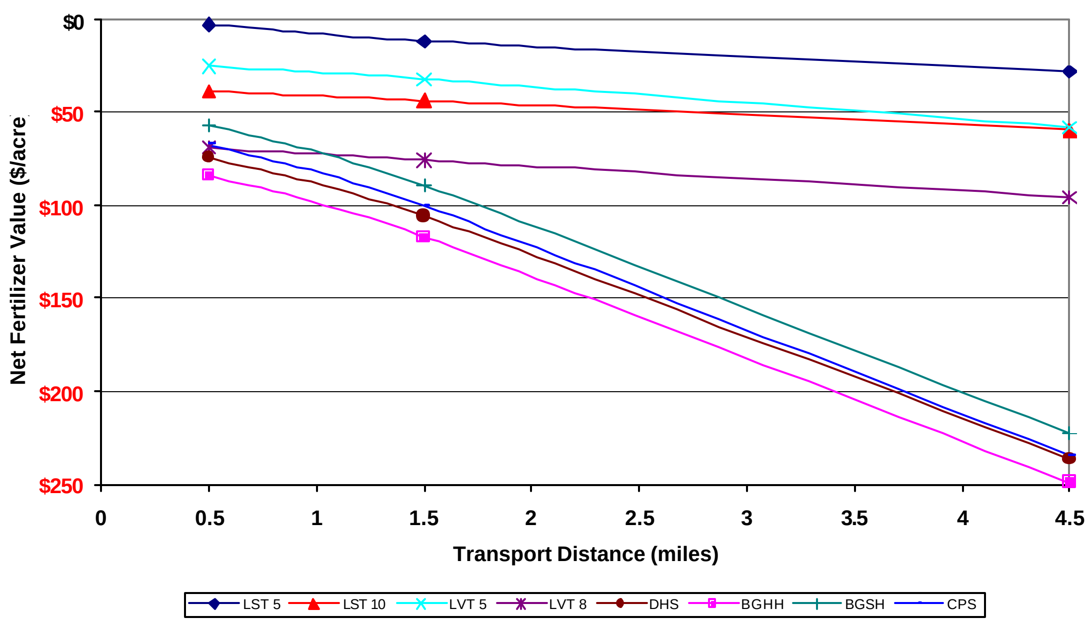

Figure 4.11. Sensitivity to distance net fertilizer value comparison for a 50-cow herd using a phosphorus-based application.

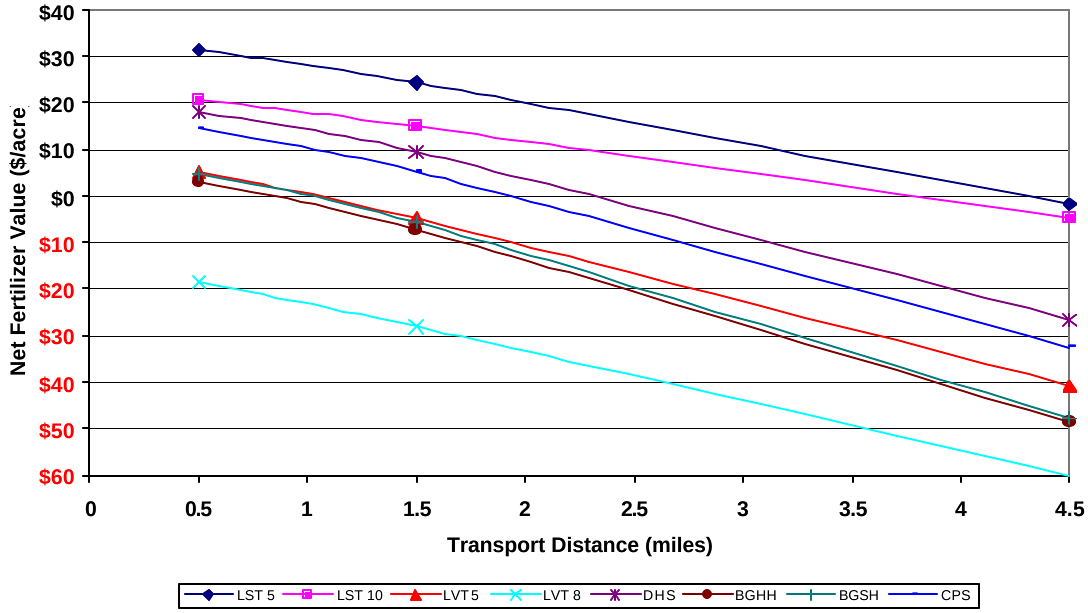

Figure 4.12. Sensitivity to distance net fertilizer value comparison for a 200-cow herd using a phosphorus-based application.

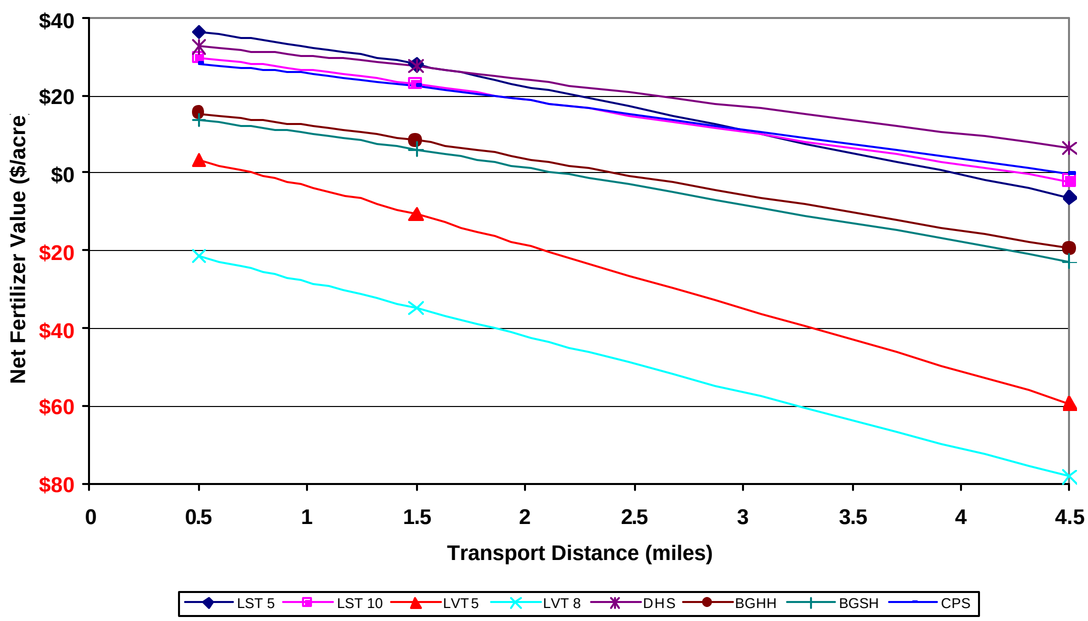

Figure 4.13. Sensitivity to distance net fertilizer value comparison for a 400-cow herd using a phosphorus-based application.

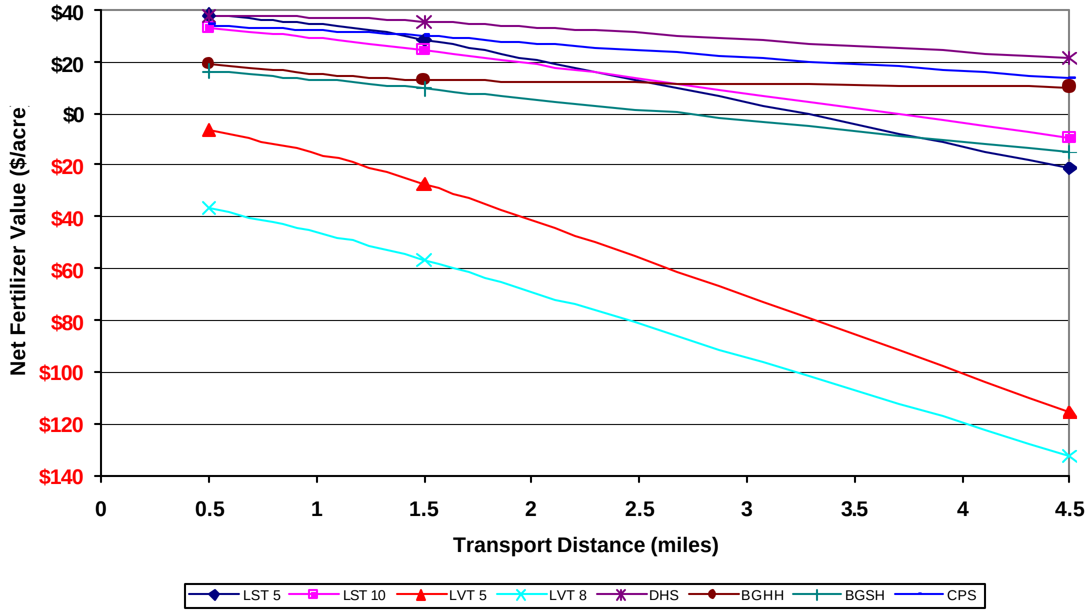

Figure 4.14. Sensitivity to distance net fertilizer value comparison for an 800-cow herd using a phosphorus-based application.

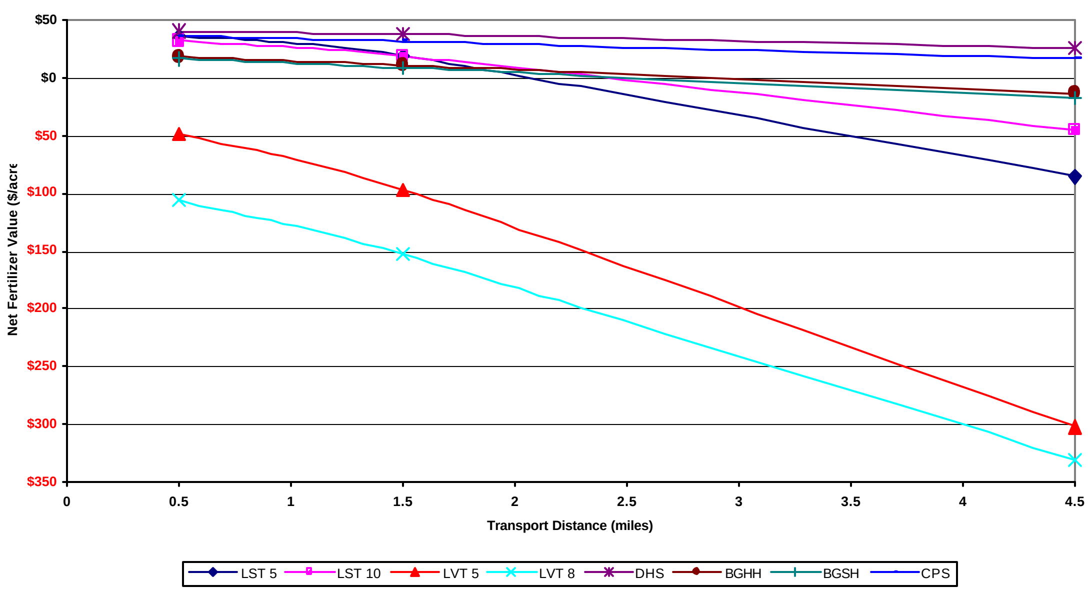

Figure 4.15. Sensitivity to distance net fertilizer value comparison for a 2,000-cow herd using a phosphorus-based application.

Net fertilizer values' sensitivity to increases in transport distance were a function of herd size for a given manure transport and application system. Larger operations could justify owning and operating manure transport and application systems more so than smaller operations. Pumping system net fertilizer values were more cost sensitive to increases in transport distances for operations of 50 and 200 cows than were hauling systems. Operations of 50 and 200 cows did not produce a large enough run (operational) time to justify the costs needed to transport this amount over large transport distances using pumping systems. Operations less than 200 cows did produce an annual waste volume that produced an operational run time that was justifiable for the hauling systems, and in return they proved to be less sensitive to increases in transport distances for operations between 50 and 200 cows than did the pumping systems.

As herd size increased over 200 cows the waste volume produced annually significantly increased the operational hours needed for the hauling systems and their operational costs increased to a point where these systems' net fertilizer values began to decrease rapidly. Once herd size exceeded 200 cows annual operational times were great enough to justify using the more expensive pumping systems and therefore these systems' costs became less sensitive to increases in transport distances. Figure 4.16 presents a summary of net fertilizer value sensitivity to distance values for hauling and pumping systems. Table 4.41 presents sensitivity to distance values for the systems considered using a phosphorus-based application.

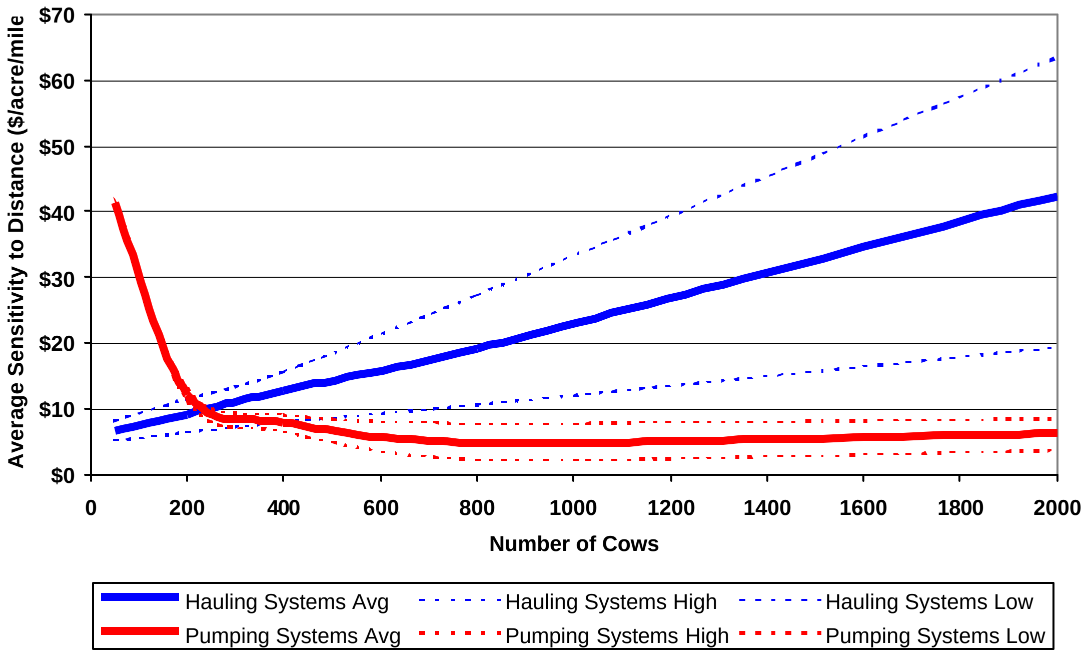

Figure 4.16. Sensitivity to distance comparisons for hauling and pumping systems using a phosphorus-based application.

Table 4.41. Sensitivity to distance values using a phosphorus-based application.

Sensitivity to Distance Values ($/acre/mile) P-Based Application								
	LST 5	LST 10	LVT 5	LVT 8	DHS	BGHH	BGSH	CPS
Number of Cows								
50	$6.37	$5.17	$8.15	$6.56	$40.46	$41.35	$41.52	$41.91
200	$8.33	$6.38	$11.48	$10.37	$11.18	$12.88	$13.14	$11.75
400	$10.69	$7.99	$15.66	$14.23	$6.52	$8.76	$9.09	$7.13
800	$14.80	$10.64	$27.29	$23.97	$4.16	$2.30	$7.78	$5.14
2,000	$30.58	$19.33	$63.46	$56.25	$3.68	$7.84	$8.46	$4.88

Operational Time Evaluation

An evaluation of the systems' operational times and their feasibility was performed. Hauling systems produced costs and net fertilizer values that were competitive with the pumping systems for larger operations even at the longer transport distances. In concentrated feeding and crop producing operations there is a window of opportunity available to apply animal manures. This study was based on nutrient requirements for a 20-ton per acre corn silage crop, which requires 100 to 115 days from planting to harvest. The window of opportunity for operations to apply animal manures is 30 days before the crop is planted. The reasoning behind this window of opportunity is that if animal manure nutrients are applied before 30 days pre-planting, much of the applied nitrogen will be lost. Nitrogen applied to an area without a growing crop will be lost from runoff, leaching, and nutrient fixation. Environmental conditions such as wet soil, frozen soil, and high winds do not allow the transport and application equipment evaluated in this study to be operated. Pulling tanks and drag hose systems over saturated soil will lead to compaction of the soil and in many cases the saturated soil will inhibit traction to the extent that these systems cannot be operated. Injection toolbars cannot be pulled in frozen soil. In addition, saturated soils will increase the likelihood that surface runoff will occur from irrigation systems. High winds make it difficult to achieve accurate application rates for broadcast and irrigation systems and also increase the risks of the liquid waste being carried onto areas such as nearby residences. Considering these environmental possibilities, an operation will be fortunate to operate their transport and application system 25 of the 30 days that are available. If they transport and apply

manure 10 hours a day, their window of opportunity ends up being 250 hours per year to transport and apply their annual manure volume using one transport and application system or 500 hours per year in a double crop situation. Figures 4.17 thru 4.22 present the feasibility of the annual operational times for the individual transport and application systems evaluated in this study. Individual annual operational times for hauling and pumping systems are shown in Tables 4.42 and 4.43.

Hauling systems operational times are very sensitive to transport distances. They must be loaded, transported to the application site, towed through the application site, and be returned to the storage area for another load. During this operational lag time, this equipment is still being operated and operational costs are being incurred even though no animal waste is being applied. In addition, this time becomes more significant once herd size and transport distance increases. The hauling systems evaluated in this study produced unfeasible annual operational times for operations over 400 cows that had one crop rotation. If two crops were grown annually, certain hauling systems could be feasible for operations of 800 cows.

Pumping systems do not possess the operational lag time incurred by the hauling systems to transport the animal waste. Set-up time does present some lag time for these systems, but results show that the set-up lag time for the pumping systems is not as significant as the transport time is for the hauling systems. If operations grew one crop annually, some pumping systems were feasible for operations up to 800 cows. Growing two crops, the drag hose systems produced the only feasible operation time for a 2,000-cow operation.

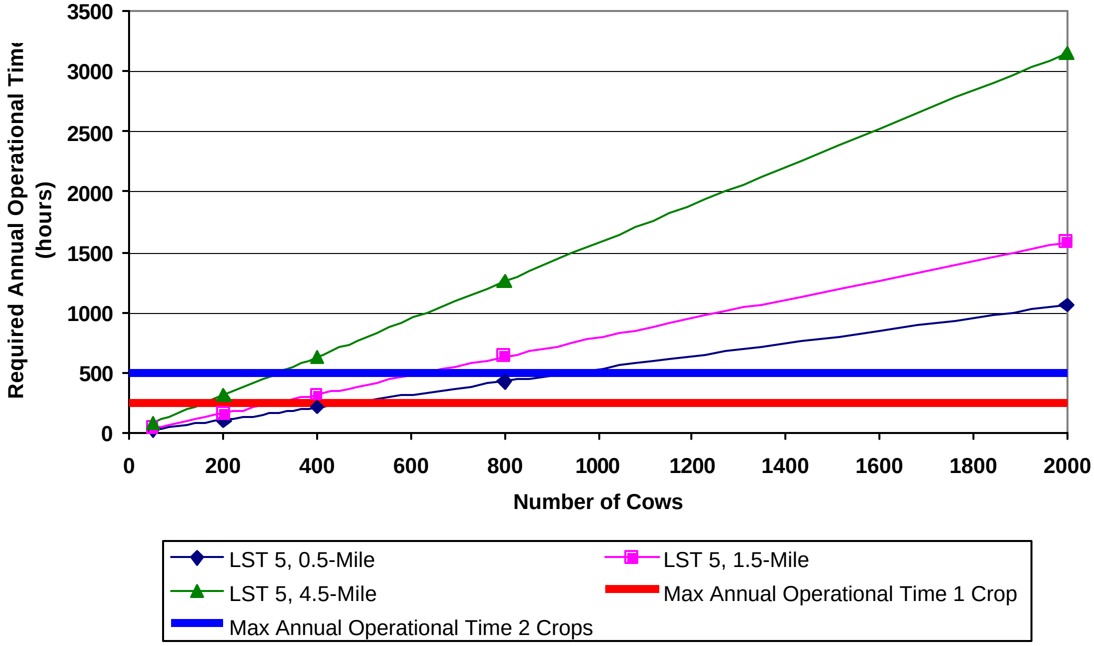

Figure 4.17. Annual operational times for one 5,000 gallon liquid slurry tank system.

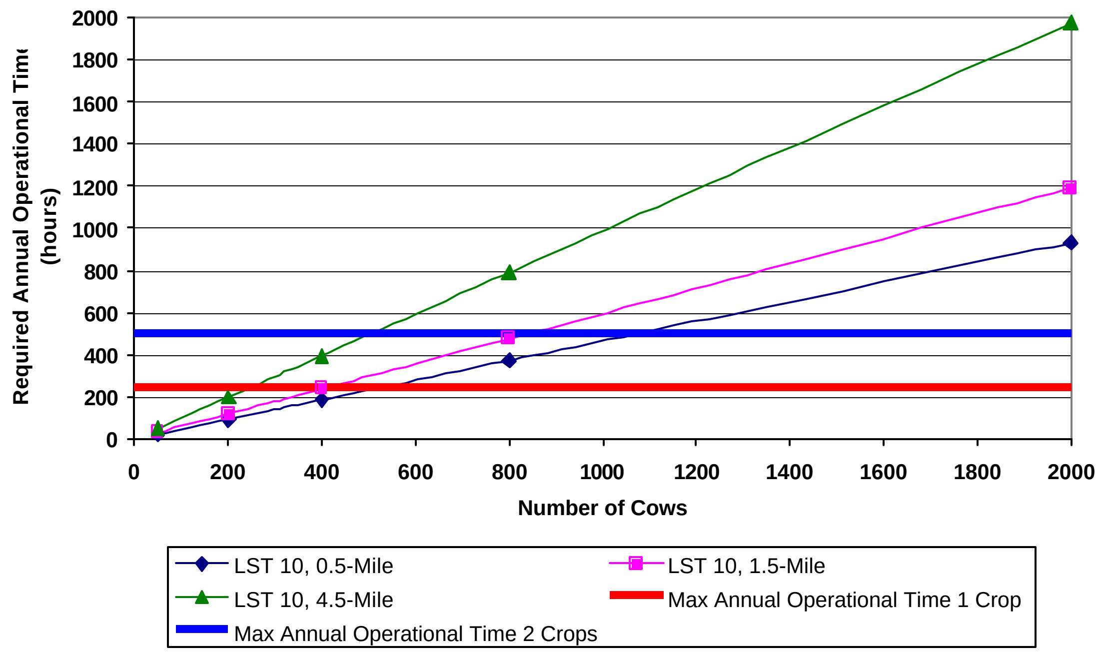

Figure 4.18. Annual operational times for one 10,000 gallon liquid slurry tank system.

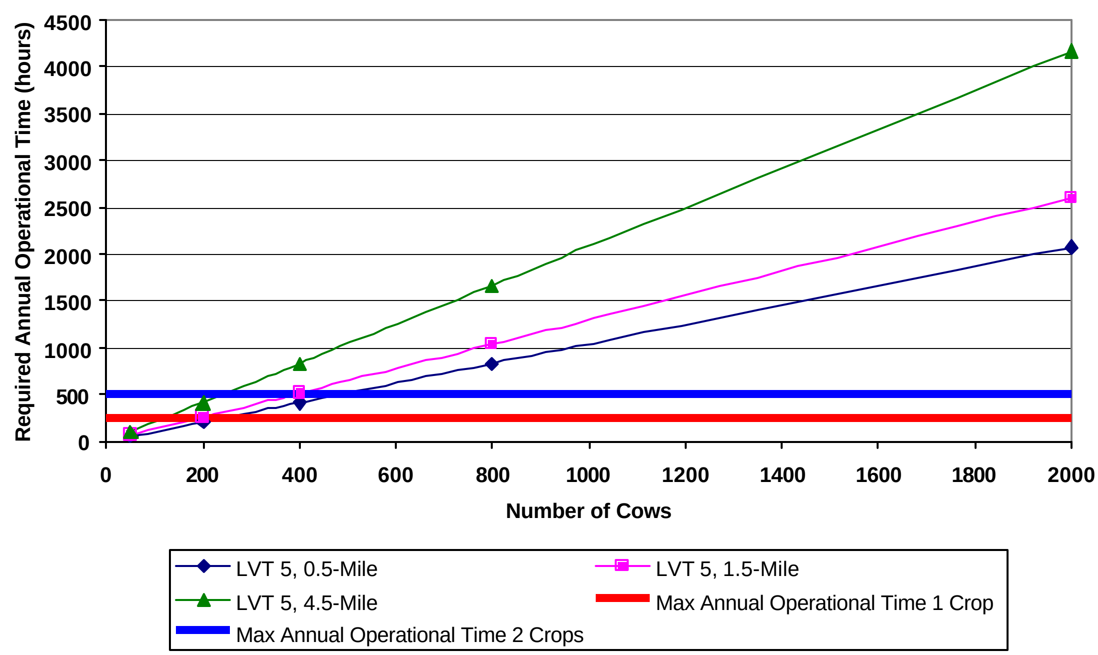

Figure 4.19. Annual operational times for one 5,000 gallon liquid vacuum tank system.

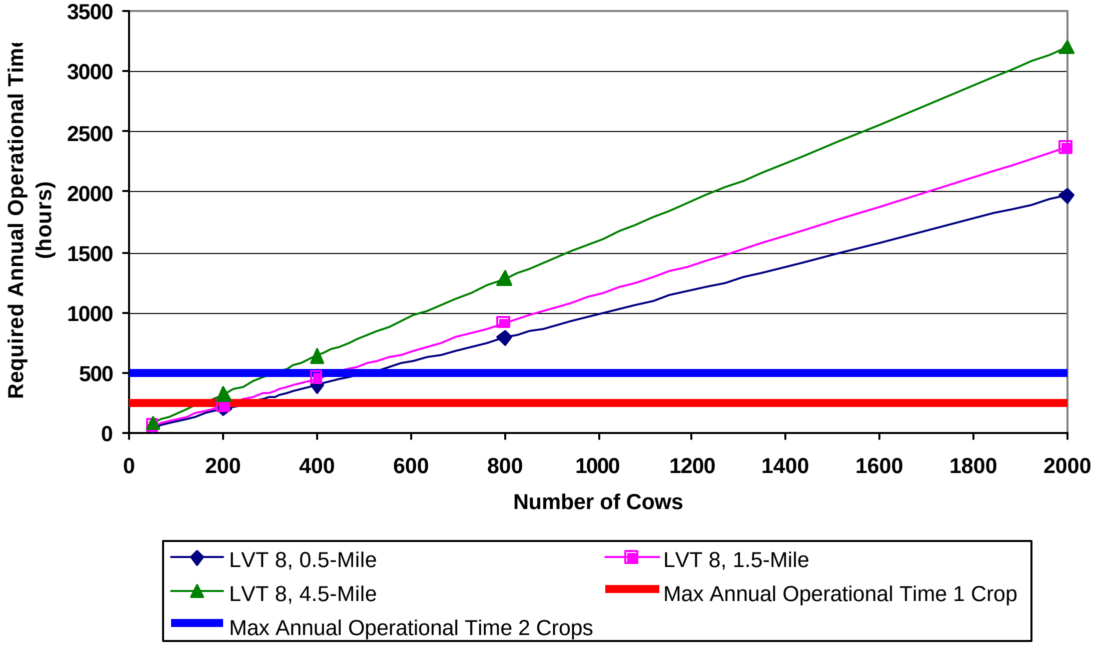

Figure 4.20. Annual operational times for one 8,500 gallon liquid vacuum tank system.

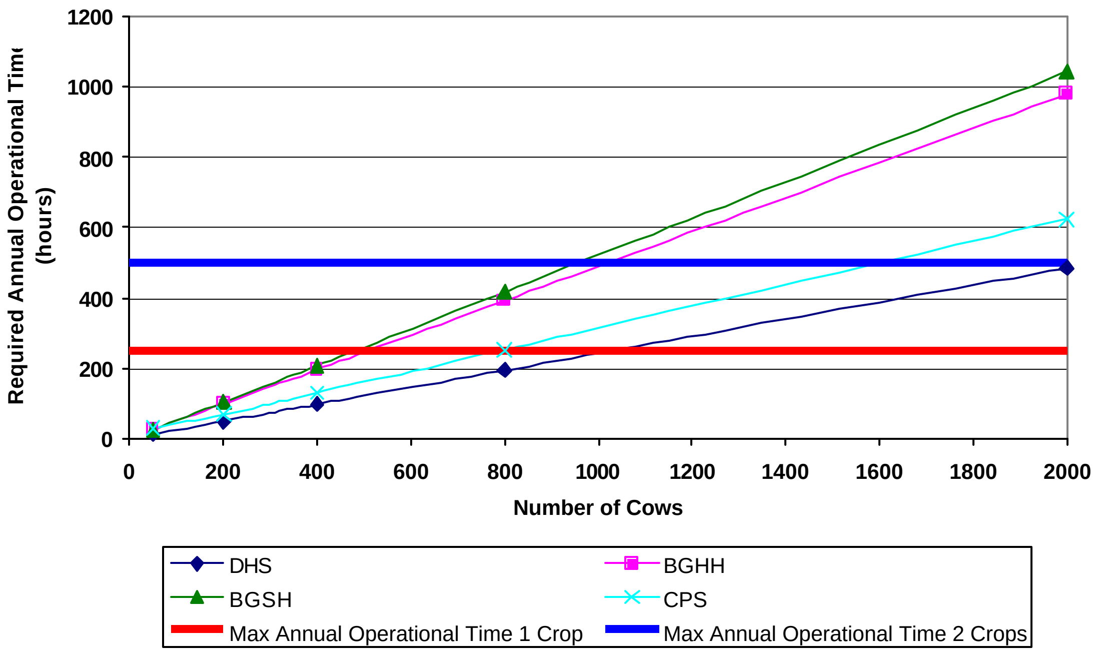

Figure 4.21. Annual operational times for one individual pumping system implementing a phosphorus-based application.

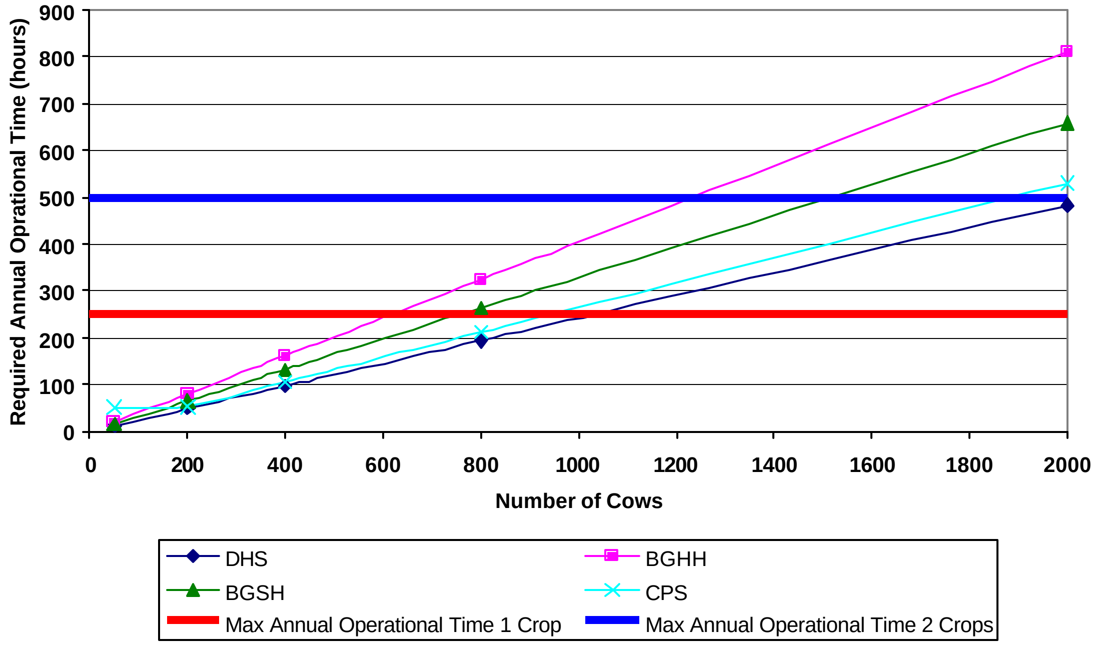

Figure 4.22. Annual operational times for one individual pumping system implementing a nitrogen-based application.

Table 4.42. Annual operational times for single hauling systems.

	5,000 Gallon Liquid Slurry Tank			10,000 Gallon Liquid Slurry Tank		
	* Annual Operation Time in Hours					
Number of Cows	0.5 Mile	1.5 Mile	4.5 Mile	0.5 Mile	1.5 Mile	4.5 Mile
50	27	40	79	23	30	49
200	106	158	315	93	119	197
400	212	317	630	186	238	395
800	424	633	1260	372	476	790
2000	1060	1583	3151	930	1190	1975

Table 4.43. Annual operational times for single pumping systems.

Number of Cows	Drag Hose	Big Gun Hard Hose		Big Gun Soft Hose		Center-Pivot	
	* Operation Time in Hours						
	P & N	P	N	P	N	P	N
50	12	25	20	26	16	30	52
200	49	98	81	104	66	69	53
400	97	196	162	208	132	130	106
800	194	392	324	417	263	252	212
2000	484	980	810	1043	658	625	530

Cost Estimation Model Validation

Hand calculations were performed and compared to the values calculated by the cost estimation model. The cost estimates calculated for each system considered for this study by the cost estimation model were compared to cost estimates that were hand calculated. Overall differences between the two calculation methods were less than 0.001%. These differences were attributed to rounding differences between hand calculations and Microsoft Excel. Table 4.44 presents a comparison of hand and model calculated values for a 400-cow big gun soft hose system using a nitrogen-based no incorporation application.

Custom Manure Applications

Custom manure application operations are increasing in availability across the United States. Geographic regions of densely populated concentrated animal feeding operations have these services readily available. Operations that use custom manure applicators do not incur the costs of owning and operating personal manure transport and application equipment. In addition, hiring custom manure applicators loosens time constraints. However, most operations do not posses the data needed to determine if it is

Table 4.44. Comparison of hand and model calculated values for a 400-cow big gun soft hose system using a nitrogen-based no incorporation application.

Calculation Description	Hand Estimate	Model Estimate
Raw waste + bedding + milking center waste	4,326,307 gal	4,326,307 gal
Runoff volume from loafing lot	279291 gal	279291 gal
Length of other side of holding pond	192.4 ft	192 ft
Holding pond surface area	38,400 square ft	38,477 square ft
Rainfall volume storage	623,716 gal	623,675 gal
Total waste volume	5,229,314 gal	5,229,273 gal
Application rate (gal/acre)	21,307 gal/acre	21,307 gal/acre
Acreage required	245.3 acres	245.4 acres
Tow path spacing	361 ft	361 ft
Length of pull needed to cover 1 acre	121 ft	121 ft
Time to cover 1 acre	26.6 min	26.6 min
Gun tow speed	4.5 ft/min	4.5 ft/min
Application rate (acres/hr)	2.25	2.25
Number of set-ups required	23	22.64
Total set-up time	23 hr	22.64 hr
Total application time	131.50 hr	131.58 hr
System operating cost per hour	$118.23/hr	$118.23/hr
Total annual system cost	$15,547.25	$15,547.40
System cost per acre	$63.38/acre	$63.39/acre
System cost per gallon	$0.002970/gal	$0.002975/gal

more economically viable for them to hire custom manure applicators or own and operate personal manure transport and application equipment. Custom manure applicators generally have a base charge. This charge covers manure agitation, loading, and land application. In addition, a mileage charge is added to the base charge that covers the variable cost of moving a quantity of manure a given distance. For hauling systems, this cost represents the time on the road for the equipment between manure storage area and the entrance to an application site. For pumping systems, this cost represents the added equipment and assembly cost (time and labor) needed to deliver manure a greater distance (Fleming, 1998). A survey of Iowa custom manure applicators showed the

average base charge to be \$0.0079 and \$0.0057/gal for hauling and pumping systems respectively (Lorimor, 1996). It is customary for custom manure applicators to include the cost of transporting manure up to one mile in the base charge. After one mile, an additional charge of \$0.0034/gal/mile and \$0.0028/gal/mile is present for hauling and pumping systems respectively (Fleming, 1998). Custom manure applicators in western Kentucky quote a base charge of \$0.006/gal with an additional transport charge of \$0.001/gal/mile past the first mile (Lyne, 2001).

The cost estimation model was designed to calculate a transport and application system cost per gallon for all systems considered. Appendix F contains the transport and application cost/gal for each herd size, application method, and transport distance for the systems evaluated in this study. These values are designed to determine if a certain operation would be better suited owning manure transport and application equipment or hiring a custom applicator. However, one must be familiar with the assumptions used in this study and with custom manure applicator fees in their locations before making decisions using the presented values. Appendix G presents an overall summary of each transport and application system's total annual economic cost for a given transport distance and application standard.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This study estimated operational costs of transport and application systems used to land apply liquid dairy manure. Comparisons were made for a wide range of dairy herd sizes using numerous combinations of transport and application equipment. Due to increasing concern regarding the non-point pollution potential of land-applied manure, comparisons were made to evaluate how an operation's costs would be affected under a phosphorus-based nutrient management plan. In this study land area was not considered a limiting factor for phosphorus-based applications, and land costs were not considered. Costs for this study were only estimated for the transport and application equipment used to land apply the liquid dairy manure. Cost for confinement housing, milking parlors, and waste storage areas were not evaluated nor included in the cost estimates presented in this study. There are numerous references available if these cost estimates are of interest. Such references as Sustainable Dairy Systems Manual (1997) could be used in combination with the Cost Estimation Model to achieve a realistic total annual waste management operational cost estimate for a given dairy operation.

The results produced from this study show that liquid slurry tank hauling systems are usually best suited for manure transport and application on small dairy operations (<400 cows). Larger operations (>400 cows) usually produce the lowest costs and therefore receive the greatest benefits when pumping systems are used for manure transport and application. Overall transport and application system costs as estimated in

this study are not affected by whether applications are based on phosphorus or nitrogen crop nutrient requirements unless equipment operational parameters do not allow each nutrient to be discharged at the same flow rate (gpm) while adjusting overall application rate (gal/acre) through speed differences. Transport and application systems that require set-up labor produced higher costs if applications were based on phosphorus rather than nitrogen due to the additional number of set ups needed to satisfy application land requirements necessary for phosphorus-based applications. Results show that this increased labor needed for some application systems basing their application on phosphorus can cause cost increases of up to 60% over nitrogen-based applications. Larger operations produced lower costs and better returns than small operations. Cost per cow values generally decreased as herd size increased. Pumping systems proved less sensitive to increases in transport distance than hauling systems once herd size reached 400 cows.

Transport and application hauling systems' (liquid slurry and liquid vacuum tanks) total annual economic costs were not affected by whether applications were based on phosphorus or nitrogen. The model indicated that these systems produced identical cost estimates. These systems were able to operate at different speeds to achieve desired application rates. Even though the phosphorus-based applications required more land to be covered, the lower application rate (gallons/acre) required by the phosphorus-based applications required that the tank systems be towed at faster speeds than for the nitrogen-based applications When equipment is operated at faster rates it is possible that more repair and maintenance costs will be incurred. Therefore, equipment used to apply liquid dairy waste for phosphorus-based applications may need more repair and

maintenance. At the time of this study there were no repair and maintenance values available that adjusted for varying operating speeds. If adjustment values were available, phosphorus-based applications may have shown cost increases over nitrogen-based applications for hauling and drag hose systems and additional cost increases for irrigation systems. Annual operational times (hours of annual use) for hauling systems proved to be the same for a given herd size. Discharge rate for these systems were the same for both phosphorus and nitrogen-based applications. Equipment capabilities allowed this by adjusting tow speeds rather than discharge rates to achieve a desired application rate. If the equipment were not capable of adjusting application rates through speed differences, then adjustment of discharge rate would have been necessary, which would have changed operational time and these systems would have produced different cost estimates for phosphorus and nitrogen-based applications. Phosphorus-based incorporated applications produced slightly higher total annual economic costs than nitrogen-based incorporated applications for all transport and application systems evaluated. This increase was not a reflection of the transport and application equipment, but rather the given that it takes more time to incorporate manure over a larger land area.

Unlike the hauling systems, application rates for the big gun irrigation systems could not be totally adjusted through speed differences. Gun flow rate for these systems had to be decreased for phosphorus-based applications in order to keep gun tow speed within an operational range. Big gun systems had to have lower discharge rates and faster tow speeds for phosphorus-based applications. Nitrogen-based applications using a big gun system could receive the maximum equipment flow rate and speed could be adjusted to produce the desired application rate(s). The largest total annual economic

cost differences between phosphorus and nitrogen-based applications were produced by the big gun systems. The big gun soft hose system produced the largest cost difference because flow rate differences between phosphorus and nitrogen-based applications were greatest for this system and the big gun soft hose system required more set-up labor than any of the other systems evaluated. Annual economic costs for drag hose systems were the same for both phosphorus and nitrogen-based applications. These systems were able to achieve the desired application rates by adjusting speed while maintaining a constant discharge rate.

Phosphorus-based applications produced higher total annual (yearly) economic costs for center-pivot systems than nitrogen-based applications. These cost differences were a direct cause of the additional number of set ups required to cover the larger land area required for phosphorus-based applications. For all herd sizes over 50-cows, enough land area was required to utilize a full ¼-mile pivot and discharge rate could remain the same for phosphorus and nitrogen-based applications and application rate could be achieved by the rotational speed of the pivot.

Net fertilizer values produced by the transport and application systems varied widely between herd sizes and transport distances. Hauling systems produced the best net fertilizer values for small operations with short transport distances. Once herd size reached 400 cows and transport distance exceeded 0.5 miles it was more beneficial to invest in the more expensive pumping systems. Operations between 50 and 200 cows clearly proved to receive higher net fertilizer values from phosphorus-based applications. Once herd size reached 400 cows nitrogen-based applications began to produce net fertilizer values that were competitive and some times exceed those produced by

phosphorus-based applications. Generally speaking, operations up to 200 cows received higher net fertilizer values for phosphorus-based applications than nitrogen-based applications. Once herd size reached 400 cows the highest net fertilizer values were produced by both phosphorus and nitrogen-based applications. Application methods such as no incorporation, incorporation, and injection started to affect whether phosphorus or nitrogen-based applications produced the highest net fertilizer value for a given system. A 5,000 gallon liquid slurry tank system with a no incorporation application had the highest net fertilizer value using a phosphorus-based application for a 400-cow operation with a 0.5-mile transport distance, but if this application was incorporated nitrogen produced the highest net fertilizer value. This scenario was applied to all systems between 400 and 2,000 cows for all systems with transport distances of 0.5 and 1.5-miles. There was a trend that operations with 4.5-mile transport distances almost always received the highest net fertilizer values from phosphorus-based applications. The drag hose and center-pivot system were the only exceptions to this observation where a nitrogen-based application produced the highest net fertilizer values. Results showed that nitrogen-based applications produced higher net fertilizer values for irrigation systems once herd size reached 400 cows. This was the only clearly noticeable trend that showed a breakpoint where once herd size reached a certain number of cows, that it proved to be beneficial to base applications on nitrogen-standards. This breakpoint was to be expected since the results showed that at 400 cows the operational times for the irrigation systems started to drastically favor nitrogen-based applications over phosphorus-based applications. An overall summary of which systems produced the

lowest cost and highest net fertilizer values for each herd size at each transport distance is presented in Tables 5.1 and 5.2.

The center-pivot systems evaluated in this study produced the best annual economic costs and net fertilizer values for several of the operations evaluated. These systems do incur problems when handling animal waste such as getting clogged by the solids that liquid manure contains. The additional costs associated with fixing these problems were not evaluated in this study. In the real world these added costs could make these systems produce significantly higher cost estimates than those that were presented in this study.

Future studies should include evaluations where dairy operations use multiple transport and application systems. This study just used one transport and application system for a given dairy operation. These results showed that one transport and application system might not be capable of transporting and applying the annual waste volume produced by certain sized operations in the available window of opportunity. Future evaluations should be made to investigate if it is economically feasible to operate multiple transport and application systems to accommodate this window of opportunity or is operational downsizing more economically viable. Future studies should also evaluate the feasibility of handling all livestock waste as a liquid, all as a solid, or a combination of the two. The cost estimation model developed for this study is capable of producing the above evaluations.

There are many benefits and costs associated with manure applications that are difficult to assign economic values to. In the US, some states have laws that do not allow animal wastes to be applied by irrigation equipment. The odor from this type of

Table 5.1. Lowest annual economic cost system for each herd size.

Number of Cows	Transport Distance		
	0.5 Mile	1.5 Mile	4.5 Mile
50	5,000 Gallon LST	5,000 Gallon LST	5,000 Gallon LST
200	5,000 Gallon LST	5,000 Gallon LST	5,000 Gallon LST
400	5,000 Gallon LST	5,000 Gallon LST	Center-Pivot
800	5,000 Gallon LST	Center-Pivot	Center-Pivot
2000	Center-Pivot	Center-Pivot	Center-Pivot

Table 5.2. Highest net fertilizer producing system for each herd size.

Number of Cows	Transport Distance		
	0.5 Mile	1.5 Mile	4.5 Mile
50	5,000 Gallon LST	5,000 Gallon LST	5,000 Gallon LST
200	5,000 Gallon LST	5,000 Gallon LST	5,000 Gallon LST
400	5,000 Gallon LST	5,000 Gallon LST	Drag Hose
800	5,000 Gallon LST	Drag Hose	Drag Hose
2000	5,000 Gallon LST	Center-Pivot	Center-Pivot

application can become a nuisance to nearby society. Other areas prohibit land applications using tank systems because of their ability to compact the soil. In order to select the best transport and application system for a given operation, issues such as these must be considered in equipment selection along with an evaluation of the costs. The cost estimates provided in this study did not attempt to evaluate nor credit these values as they pertain to certain transport and application systems. This is a limitation of the cost estimation model developed for this study. Currently a user-friendly software interface to facilitate use of the cost estimation model is under development. After its completion, future studies are planned to further examine the costs for a wider variety of transport and application equipment.

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APPENDICES

APPENDIX A

COST ESTIMATION MODEL EQUIPMENT CAPITAL COST VALUES

Table A-1. Cost estimation model tractor capital cost values.

2WD Tractors		4WD Tractors	
Horsepower	Capital Cost ($)	Horsepower	Capital Cost ($)
40	$18,800	40	$24,700
50	$23,500	50	$28,300
60	$24,600	60	$32,300
70	$30,500	70	$34,500
80	$32,000	80	$39,200
85	$34,500	85	$46,000
90	$41,000	90	$47,600
100	$44,000	100	$54,000
110	$53,000	110	$67,000
125	$63,000	125	$70,000
130	$73,000	130	$85,000
150	$81,000	150	$93,000
175	$94,000	175	$106,500
195	$105,000	195	$116,000
215	$115,000	215	$127,000
225	$130,000	225	$130,000
		250	$140,000
		300	$150,000

Table A-2. Cost estimation model incorporation disk capital cost values.

Disk Width (feet)	Capital Cost ($)
15	$12,000
18	$14,000
20	$15,000
23	$16,000
26	$18,000
30	$26,000
33	$30,000

TableA-3. Cost estimation model tractor mounted front end loader capital cost.

Bucket Capacity (ft3)	Capital Cost ($)
19	$4,000

Table A-4. Cost estimation model skid-steer loader capital cost values.

Loader Horsepower	Capital Cost ($)
25	$16,200
45	$20,000
50	$22,000
65	$24,500
70	$30,000
85	$32,000

Table A-5. Cost estimation model tandem-axle truck capital cost values.

Truck Horsepower	Capital Cost ($)
215	$41,000
275	$47,000
500	$85,000

Table A-6. Cost estimation model box spreader capital cost values.

Spreader Capacity (ft3)	Capital Cost ($)
200	$14,000
300	$18,000
400	$19,500
500	$22,500
700	$29,000

Table A-7. Cost estimation model v-spreader capital cost values.

Spreader Capacity (ft3)	Capital Cost ($)
370	$10,200
500	$17,500
620	$21,000
750	$26,500
1000	$34,000

Table A-8. Cost estimation model truck mounted spreader capital cost values.

Spreader Capacity (ft3)	Capital Cost ($)
200	$11,000
300	$15,000
350	$17,250
500	$19,000
600	$21,800
700	$22,300
850	$28,000

Table A-9. Cost estimation model pull-type litter spreader capital cost values.

Spreader Capacity (ft3)	Capital Cost ($)
230	$8,100
270	$8,400
300	$8,800

Table A-10. Cost estimation model truck mounted litter spreader capital cost values.

Spreader Capacity (ft3)	Capital Cost ($)
260	$6,300
300	$6,700
350	$7,200
400	$7,600
440	$8,000
480	$8,300
525	$8,700

Table A-11. Cost estimation model liquid slurry tank capital cost values.

Tank Capacity (gallons)	Capital Cost ($)
2,300	$12,000
3,000	$16,800
4,000	$17,600
5,000	$23,000
6,000	$29,500
7,500	$38,000
10,000	$47,000
12,000	$63,000

Table A-12. Cost estimation model liquid vacuum tank capital cost values.

Tank Capacity (gallons)	Capital Cost ($)
1,500	$12,000
2,300	$16,500
3,000	$17,000
3,400	$23,000
4,200	$25,000
500	$27,300
6,000	$37,000
7,500	$45,000
8,500	$50,000

Table A-13. Cost estimation model semi-tractor tank capital cost values.

Tank Capacity (gallons)	Capital Cost ($)
6,500	$45,000
7,000	$48,000
9,500	$55,000

Table A-14. Cost estimation model tank injection toolbar capital cost values.

Toolbar Width (feet)	Capital Cost ($)
6	$ 3,700
8	$ 4,900
10	$ 5,700
12	$ 7,000
14	$ 7,700
24	$ 25,000

Table A-15. Cost estimation model drag hose injection toolbar capital cost values.

Toolbar Width (feet)	Capital Cost ($)
10	$ 13,000
14	$ 15,000
18	$ 18,000
23	$ 21,000

Table A-16. Cost estimation model soft hose (drag hose) reel capital cost values.

Number of 660' Hoses	Hose Diameter (inches)	Capital Cost ($)
2	6	$6,000
4	6	$10,800
5	8	$16,500
6	6	$13,000
8	6	$15,000

Table A-17. Cost estimation big gun hard hose traveler capital cost values.

Hose Diameter (inches) and Hose Length (feet)	Capital Cost ($)
3.7 x 1150	$20,450
3.7 x 1250	$27,450
3.7 x 1310	$37,000
4.0 x 1250	$31,000
4.0 x 1215	$37,000
4.5 x 1215	$37,250
4.5 x 1310	$41,000

Table A-18. Cost estimation model big gun soft hose capital cost value.

Hose Diameter (inches) and Hose Length (feet)	Capital Cost ($)
4.0 x 1310	$16,250

Table A-19. Cost estimation model center-pivot capital cost values.

Individual Span Length (feet)	Pipe Inner Diameter (inches)	Sprinkler Head Spacing (inches)	Individual Span Capital Cost ($)
151.1	6 5/8	30	$4,215
135.2	6 5/8	30	$4,415
140.0	6 5/8	30	$4,580
160.0	6 5/8	30	$4,915
180.0	6 5/8	30	$5,165
184.8	6 5/8	30	$5,400
186.7	6 5/8	30	$5,445
204.9	6 5/8	30	$5,845
151.1	6 5/8	108	$4,480
135.2	6 5/8	108	$4,325
140.0	6 5/8	108	$4,480
160.0	6 5/8	108	$4,850
180.0	6 5/8	108	$5,075
184.8	6 5/8	108	$5,325
186.7	6 5/8	108	$5,400
204.9	6 5/8	108	$5,750
115.1	8 5/8	30	$4,620
135.2	8 5/8	30	$4,910
140.0	8 5/8	30	$5,150
160.0	8 5/8	30	$5,475
115.1	8 5/8	108	$4,590
135.2	8 5/8	108	$4,865
140.0	8 5/8	108	$5,100
160.0	8 5/8	108	$5,400
109.7	10	30	$4,890
119.9	10	30	$5,120
127.8	10	30	$5,220

Table A-20. Cost estimation model high volume high pressure pump capital cost values.

Pump Type	Capital Cost ($)
Engine Driven Pump	$7,430
PTO Driven Pump	$6,550

Table A-21. Cost estimation model diesel engine capital cost values.

Engine Description	Capital Cost ($)
157 HP @ 2400 RPM	$15,700
124 HP @ 2200 RPM	$12,915

Table A-22. Cost estimation model PTO agitator-loading pump capital cost value.

Length (feet)	Capital Cost ($)
8	$9,795
10	$9,995
12	$10,195
14	$10,395
16	$9,490
32	$9,845
42	$10,845
50	$11,940
Vertical	$8,900

Table A-23. Cost estimation model prop agitator capital cost values.

Length (feet)	Capital Cost ($)
28	$5,350
31	$6,120
32	$6,990
42	$7,490
50	$7,990

Table A-24. Cost estimation model drag hose system capital cost values.

Transport Distance (miles)	Capital Cost ($)
0.5 Mile	$88,955
0.75 Mile	$103,405
1.0 Mile	$122,835

Table A-25. Cost estimation model PVC pipe capital cost values.

Pipe Diameter (inches)	Installation Cost ($/foot)	Capital Cost ($/foot)
4	$2.25	$1.45
6	$2.25	$2.80
8	$2.25	$4.15
10	$2.25	$5.95

Table A-26. Cost estimation model aluminum pipe capital cost values.

Pipe Diameter (inches)	Capital Cost ($/foot)
4	$1.85
6	$2.80
8	$4.00
10	$6.90

Table A-27. Cost estimation model angus armor guard hose capital cost values.

Pipe Diameter (inches)	Capital Cost ($/foot)
4	$8.80
4.5	$8.73
5	$7.80
6	$9.00

APPENDIX B

TOTAL ANNUAL ECONOMIC COST VALUES

Table B-1. Total annual economic costs for a 50-cow herd.

System Type	Transport Distance (miles) 0.5 P	0.5 N	1.5 P	1.5 N	4.5 P	4.5 N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$3,911.27	$3,911.27	$4,323.68	$4,323.68	$5,646.41	$5,646.41
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$4,119.82	$4,028.57	$4,721.24	$4,630.00	$5,854.96	$5,763.71
5,000 Gallon Liquid Slurry Tank Injected	$4,668.30	$4,668.30	$5,104.11	$5,104.11	$6,523.93	$6,523.93
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$6,362.96	$6,362.96	$6,706.24	$6,706.24	$7,772.20	$7,772.20
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$6,571.51	$6,480.26	$6,914.78	$6,823.54	$7,980.74	$7,889.50
10,000 Gallon Liquid Slurry Tank Injected	$8,810.97	$8,810.97	$9,181.11	$9,181.11	$10,374.69	$10,374.69
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$5,440.63	$5,440.63	$5,903.20	$5,903.20	$7,391.98	$7,391.98
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$5,649.17	$5,594.22	$6,111.75	$6,020.50	$7,600.52	$7,509.28
5,000 Gallon Liquid Vacuum Tank Injected	$6,274.63	$6,274.63	$6,772.41	$6,772.41	$8,382.53	$8,382.53
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$8,441.42	$8,441.42	$8,869.25	$8,869.25	$10,229.30	$10,229.30
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$8,649.97	$8,558.72	$9,077.79	$8,986.35	$10,437.84	$10,346.60
8,500 Gallon Liquid Vacuum Tank Injected	$11,127.69	$11,127.69	$11,618.91	$11,618.91	$13,198.63	$13,198.63
Drag Hose System	$9,342.37	$9,342.37	$11,502.25	$11,502.25	$20,370.16	$20,370.16
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$9,427.27	$9,181.43	$11,651.49	$11,381.23	$20,696.90	$20,322.30
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$9,635.81	$9,538.95	$11,860.03	$11,796.30	$20,905.45	$20,971.29
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$7,587.34	$6,899.37	$9,820.61	$9,082.61	$18,902.62	$17,950.88
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$7,795.88	$7,313.42	$10,029.16	$9,590.57	$19,111.17	$18,840.27
Center-Pivot System Broadcast w/ No Incorporation	$8,314.18	$8,048.11	$10,568.18	$10,447.29	$19,736.92	$20,197.60
Center-Pivot System Broadcast w/ Incorporation	$8,522.73	$8,021.49	$10,776.73	$10,360.84	$19,945.47	$19,875.63
	50 Cow Herd Size					

Table B-2. Total annual economic costs for a 200-cow herd.

System Type	Transport Distance (miles) 0.5		1.5		4.5	
	P	N	P	N	P	N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$6,337.70	$6,337.70	$8,271.14	$8,271.14	$15,400.21	$15,400.21
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$7,171.88	$6,806.91	$9,105.32	$8,740.35	$16,234.39	$15,869.42
5,000 Gallon Liquid Slurry Tank Injected	$7,199.76	$7,199.76	$9,299.86	$9,299.86	$17,102.31	$17,102.31
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$9,274.92	$9,274.92	$10,841.65	$10,841.65	$16,223.03	$16,223.03
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$10,109.10	$9,744.13	$11,675.83	$11,310.86	$17,057.21	$16,692.24
10,000 Gallon Liquid Slurry Tank Injected	$11,966.89	$11,966.89	$13,761.53	$13,761.53	$20,033.09	$20,033.09
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$13,495.26	$13,495.26	$16,236.34	$16,236.34	$26,011.57	$26,011.57
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$14,329.44	$13,964.47	$17,070.52	$16,705.55	$26,845.75	$26,531.59
5,000 Gallon Liquid Vacuum Tank Injected	$14,894.44	$14,984.44	$17,881.22	$17,881.22	$28,503.06	$28,503.06
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$19,972.17	$19,972.17	$22,548.41	$22,548.41	$31,274.71	$31,274.71
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$20,806.36	$20,441.38	$23,382.59	$23,017.62	$32,108.89	$31,743.92
8,500 Gallon Liquid Vacuum Tank Injected	$24,363.52	$24,363.52	$27,386.65	$27,386.65	$37,600.36	$37,600.36
Drag Hose System	$12,180.70	$12,180.70	$14,522.78	$14,522.78	$24,362.37	$24,362.37
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$14,082.11	$12,930.48	$16,876.18	$15,569.28	$28,125.01	$26,236.32
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$14,916.29	$13,738.00	$17,710.36	$16,445.83	$28,959.19	$27,391.95
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$13,586.93	$10,550.35	$16,442.23	$13,059.40	$27,914.54	$23,234.97
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$14,421.11	$11,473.35	$17,276.41	$14,090.31	$28,748.72	$24,703.54
Center-Pivot System Broadcast w/ No Incorporation	$10,964.40	$10,434.52	$13,499.15	$12,540.49	$23,771.82	$22,329.23
Center-Pivot System Broadcast w/ Incorporation	$11,798.58	$11,012.45	$14,333.33	$13,483.08	$24,606.00	$23,508.69

200 Cow Herd Size

Table B-3. Total annual economic costs for a 400-cow herd.

System Type	Transport Distance (miles) 0.5 P	0.5 N	1.5 P	1.5 N	4.5 P	4.5 N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$9,917.82	$9,917.82	$14,535.11	$14,535.11	$33,225.68	$33,225.68
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$11,586.18	$10,856.24	$16,203.48	$15,473.53	$34,894.04	$34,164.10
5,000 Gallon Liquid Slurry Tank Injected	$10,981.50	$10,981.50	$16,032.89	$16,032.89	$36,505.00	$36,505.00
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$13,574.41	$13,574.41	$17,249.29	$17,249.29	$30,987.19	$30,987.16
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$15,242.77	$14,512.83	$18,917.66	$18,187.71	$32,655.53	$31,910.20
10,000 Gallon Liquid Slurry Tank Injected	$16,634.59	$16,634.59	$21,022.19	$21,022.19	$37,108.50	$37,108.50
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$27,998.29	$27,998.29	$35,592.61	$35,592.61	$62,152.30	$62,152.30
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$29,666.66	$28,936.71	$37,260.97	$36,531.03	$63,820.67	$63,090.72
5,000 Gallon Liquid Vacuum Tank Injected	$30,481.10	$30,481.10	$38,721.25	$38,721.25	$67,510.25	$67,510.25
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$41,435.44	$41,435.44	$48,883.22	$48,883.22	$72,465.67	$72,465.67
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$43,103.80	$42,373.86	$50,551.58	$49,821.64	$74,134.04	$73,404.10
8,500 Gallon Liquid Vacuum Tank Injected	$49,088.30	$49,088.30	$57,717.67	$57,717.67	$85,232.10	$85,232.10
Drag Hose System	$16,456.43	$16,456.43	$19,234.01	$19,234.01	$30,673.38	$30,673.38
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$21,381.99	$18,739.88	$25,266.23	$22,216.11	$40,471.85	$35,949.18
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$23,050.35	$20,168.59	$26,934.60	$23,735.77	$42,140.22	$37,828.14
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$22,391.72	$15,805.15	$26,435.25	$18,937.51	$42,210.86	$31,431.45
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$24,030.08	$17,423.36	$28,103.61	$20,690.45	$43,879.22	$33,721.77
Center-Pivot System Broadcast w/ No Incorporation	$14,446.26	$13,020.27	$17,561.35	$15,888.39	$29,987.99	$27,414.83
Center-Pivot System Broadcast w/ Incorporation	$16,114.62	$14,427.76	$19,229.72	$17,376.21	$31,656.35	$29,196.16
	400 Cow Herd Size					

Table B-4. Total annual economic costs for an 800-cow herd.

System Type	Transport Distance (miles) 0.5 P	0.5 N	1.5 P	1.5 N	4.5 P	4.5 N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$18,223.85	$18,223.85	$30,455.32	$30,455.32	$82,747.17	$82,747.17
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$21,560.57	$20,100.69	$31,759.84	$30,299.96	$86,083.90	$84,624.02
5,000 Gallon Liquid Slurry Tank Injected	$19,819.38	$19,819.38	$33,198.56	$33,198.56	$90,185.38	$90,185.38
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$23,585.08	$23,585.08	$33,093.34	$33,093.34	$70,000.00	$70,000.00
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$26,921.80	$25,461.92	$36,430.07	$34,970.18	$73,336.73	$71,876.84
10,000 Gallon Liquid Slurry Tank Injected	$27,983.83	$27,983.83	$39,117.30	$39,177.30	$82,224.22	$82,224.22
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$66,395.90	$66,395.90	$89,546.69	$89,546.69	$185,395.60	$185,395.60
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$69,732.63	$68,272.74	$92,883.42	$91,423.53	$188,732.33	$187,272.44
5,000 Gallon Liquid Vacuum Tank Injected	$71,735.18	$71,735.18	$96,583.53	$96,583.53	$198,328.01	$198,328.01
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$99,682.32	$99,682.32	$121,627.04	$121,627.04	$204,217.31	$204,217.31
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$103,019.05	$101,559.16	$124,963.77	$123,503.88	$207,554.04	$206,094.15
8,500 Gallon Liquid Vacuum Tank Injected	$115,948.60	$115,948.60	$141,106.41	$141,106.41	$233,971.52	$233,971.52
Drag Hose System	$26,182.80	$26,182.80	$29,893.34	$29,893.34	$45,395.52	$45,395.52
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$38,571.89	$32,288.11	$45,336.48	$37,966.17	$70,634.08	$59,501.31
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$41,908.61	$35,009.71	$48,673.20	$40,836.32	$73,920.81	$62,934.88
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$41,991.78	$27,260.23	$49,173.32	$32,038.99	$75,934.06	$50,407.09
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$45,328.51	$30,309.56	$52,510.05	$35,293.86	$79,270.79	$54,452.00
Center-Pivot System Broadcast w/ No Incorporation	$22,547.62	$19,743.59	$27,166.83	$23,827.30	$44,971.95	$39,734.74
Center-Pivot System Broadcast w/ Incorporation	$25,884.34	$22,171.47	$30,503.56	$26,356.88	$48,308.68	$42,635.19
	800 Cow Herd Size					

Table B-5. Total annual economic costs for a 2,000-cow herd.

System Type	Transport Distance (miles) 0.5		1.5		4.5	
	P	N	P	N	P	N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$50,034.00	$50,034.00	$99,020.18	$99,020.18	$384,133.67	$384,133.67
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$57,063.82	$54,596.12	$105,335.67	$103,299.19	$390,449.16	$388,412.67
5,000 Gallon Liquid Slurry Tank Injected	$53,861.00	$53,861.00	$106,991.71	$106,991.71	$409,030.31	$409,030.31
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$64,652.95	$64,652.95	$99,340.32	$99,340.32	$274,566.76	$274,566.76
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$70,197.49	$67,123.72	$105,655.81	$103,619.33	$280,882.25	$278,845.77
10,000 Gallon Liquid Slurry Tank Injected	$74,264.08	$74,264.08	$114,809.78	$114,809.78	$312,395.12	$312,395.12
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$283,579.14	$283,579.14	$415,289.35	$415,289.35	$975,525.23	$975,525.23
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$289,544.63	$287,424.37	$421,254.83	$419,134.57	$981,490.71	$979,370.45
5,000 Gallon Liquid Vacuum Tank Injected	$300,915.28	$300,915.28	$438,757.05	$438,757.05	$1,020,277.59	$1,020,277.59
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$440,082.03	$440,082.03	$567,245.27	$567,245.27	$1,053,381.86	$1,053,381.86
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$446,047.52	$443,927.29	$573,922.17	$571,090.49	$1,059,347.35	$1,057,227.09
8,500 Gallon Liquid Vacuum Tank Injected	$492,485.48	$492,485.48	$630,928.60	$630,928.60	$1,154,451.28	$1,154,451.28
Drag Hose System	$59,977.03	$59,977.03	$68,310.81	$68,310.81	$100,053.68	$100,053.68
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$101,148.07	$81,305.95	$120,003.03	$96,248.80	$186,647.41	$149,590.63
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$107,781.88	$87,728.47	$126,636.83	$103,062.27	$193,281.22	$157,799.68
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$105,754.13	$65,009.18	$126,120.36	$76,332.85	$197,944.69	$118,563.17
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$112,387.94	$72,231.31	$132,754.16	$84,042.02	$204,578.50	$128,088.72
Center-Pivot System Broadcast w/ No Incorporation	$53,096.65	$44,941.45	$64,128.50	$54,120.19	$104,118.18	$87,745.59
Center-Pivot System Broadcast w/ Incorporation	$58,989.08	$50,029.01	$70,889.73	$59,501.70	$110,879.41	$94,160.42

2000 Cow Herd Size

APPENDIX C

NET FERTILIZER VALUES

Table C-1. Net fertilizer values for a 50-cow herd.

	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
System Type	0.5 Mile			1.5 Mile			4.5 Mile		
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$57.40	$52.68	($4.72)	$63.46	$52.68	($10.78)	$82.87	$52.68	($30.19)
	$127.57	$78.00	($49.57)	$141.02	$78.00	($63.02)	$184.16	$78.00	($106.16)
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$60.47	$57.74	($2.73)	$69.29	$57.74	($11.55)	$85.93	$57.74	($28.19)
	$105.12	$78.00	($27.12)	$120.81	$78.00	($42.81)	$150.39	$78.00	($72.39)
5,000 Gallon Liquid Slurry Tank Injected	$65.52	$62.81	($2.71)	$74.91	$62.81	($12.10)	$95.75	$62.81	($32.94)
	$101.51	$78.00	($23.51)	$110.98	$78.00	($32.98)	$141.86	$78.00	($63.86)
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$93.39	$52.68	($40.71)	$98.43	$52.68	($45.75)	$114.07	$52.68	($61.39)
	$207.53	$78.00	($129.53)	$218.73	$78.00	($140.73)	$253.20	$78.00	($175.20)
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$96.45	$57.74	($38.71)	$101.49	$57.74	($43.75)	$117.13	$57.74	($59.39)
	$169.09	$78.00	($91.09)	$178.05	$78.00	($100.05)	$205.86	$78.00	($127.86)
10,000 Gallon Liquid Slurry Tank Injected	$129.32	$62.81	($66.51)	$134.45	$62.81	($71.64)	$152.27	$62.81	($89.46)
	$191.59	$78.00	($113.59)	$199.63	$78.00	($121.63)	$225.59	$78.00	($147.59)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$79.85	$52.68	($27.17)	$86.64	$52.68	($33.96)	$108.49	$52.68	($55.81)
	$117.45	$78.00	($39.45)	$192.45	$78.00	($114.45)	$241.10	$78.00	($163.10)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$82.91	$57.74	($25.17)	$89.70	$57.74	($31.96)	$115.52	$57.74	($57.78)
	$145.97	$78.00	($67.97)	$157.09	$78.00	($79.09)	$195.94	$78.00	($117.94)
5,000 Gallon Liquid Vacuum Tank Injected	$92.09	$62.81	($29.28)	$99.40	$62.81	($36.59)	$123.03	$62.81	($60.22)
	$136.44	$78.00	($58.44)	$147.26	$78.00	($69.26)	$182.27	$78.00	($104.27)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$123.89	$52.68	($71.21)	$130.17	$52.68	($77.49)	$150.13	$52.68	($97.45)
	$275.33	$78.00	($197.33)	$289.28	$78.00	($211.28)	$333.64	$78.00	($255.64)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$126.95	$57.74	($69.21)	$133.23	$57.74	($75.49)	$153.19	$57.74	($95.45)
	$223.32	$78.00	($145.32)	$234.48	$78.00	($156.48)	$269.97	$78.00	($191.97)
8,500 Gallon Liquid Vacuum Tank Injected	$163.32	$62.81	($100.51)	$170.53	$62.81	($107.72)	$193.71	$62.81	($130.90)
	$241.96	$78.00	($163.96)	$252.64	$78.00	($174.64)	$286.99	$78.00	($208.99)
Drag Hose System	$137.12	$62.81	($74.31)	$168.82	$62.81	($106.01)	$298.97	$62.81	($236.16)
	$203.14	$78.00	($125.14)	$250.11	$78.00	($172.11)	$442.93	$78.00	($364.93)
Big Gun Hard Hose Traveller Broadcast w/ No Incorporation	$138.36	$52.68	($85.68)	$171.01	$52.68	($118.33)	$303.76	$52.68	($251.08)
	$299.46	$78.00	($221.46)	$372.21	$78.00	($294.21)	$662.83	$78.00	($584.83)
Big Gun Hard Hose Traveller Broadcast w/ Incorporation	$141.42	$57.74	($83.68)	$174.07	$57.74	($116.33)	$306.82	$57.74	($249.08)
	$248.90	$78.00	($170.90)	$307.80	$78.00	($229.80)	$547.20	$78.00	($469.20)
Big Gun Soft Hose Traveller Broadcast w/ No Incorporation	$111.36	$52.68	($58.68)	$144.13	$52.68	($91.45)	$277.43	$52.68	($224.75)
	$225.03	$78.00	($147.03)	$296.24	$78.00	($218.24)	$585.49	$78.00	($507.49)
Big Gun Soft Hose Traveller Broadcast w/ Incorporation	$114.42	$57.74	($56.68)	$147.19	$57.74	($89.45)	$280.49	$57.74	($222.75)
	$190.83	$78.00	($112.83)	$250.25	$78.00	($172.25)	$491.60	$78.00	($413.60)
Center-Pivot System Broadcast w/ No Incorporation	$122.02	$52.68	($69.34)	$155.11	$52.68	($102.43)	$289.67	$52.68	($236.99)
	$262.50	$78.00	($184.50)	$340.75	$78.00	($262.75)	$658.77	$78.00	($580.77)
Center-Pivot System Broadcast w/ Incorporation	$125.09	$57.74	($67.35)	$158.17	$57.74	($100.43)	$292.73	$57.74	($234.99)
	$209.30	$78.00	($131.30)	$270.34	$78.00	($192.34)	$518.61	$78.00	($440.61)
Note: Phosphorus-based applications are shaded gray	50 Cow Herd Size								

Table C-2. Net fertilizer values for a 200-cow herd.

System Type	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$23.25	$52.68	$29.43	$30.35	$52.68	$22.33	$56.51	$52.68	($3.83)
	$51.68	$78.00	$26.32	$67.44	$78.00	$10.56	$125.57	$78.00	($47.57)
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$26.31	$57.74	$31.43	$33.41	$57.74	$24.33	$59.57	$57.74	($1.83)
	$44.40	$78.00	$33.60	$57.02	$78.00	$20.98	$103.52	$78.00	($25.52)
5,000 Gallon Liquid Slurry Tank Injected	$26.42	$62.81	$36.39	$34.12	$62.81	$28.69	$62.75	$62.81	$0.06
	$39.14	$78.00	$38.86	$50.55	$78.00	$27.45	$92.97	$78.00	($14.97)
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$34.03	$52.68	$18.65	$39.78	$52.68	$12.90	$59.52	$52.68	($6.84)
	$75.63	$78.00	$2.37	$88.40	$78.00	($10.40)	$132.28	$78.00	($54.28)
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$37.09	$57.74	$20.65	$42.84	$57.74	$14.90	$62.59	$57.74	($4.85)
	$63.56	$78.00	$14.44	$73.78	$78.00	$4.22	$108.89	$78.00	($30.89)
10,000 Gallon Liquid Slurry Tank Injected	$43.91	$62.81	$18.90	$50.49	$62.81	$12.32	$73.50	$62.81	($10.69)
	$65.05	$78.00	$12.95	$74.81	$78.00	$3.19	$108.90	$78.00	($30.90)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$49.52	$52.68	$3.16	$59.57	$52.68	($6.89)	$95.44	$52.68	($42.76)
	$110.04	$78.00	($32.04)	$132.39	$78.00	($54.39)	$212.10	$78.00	($134.10)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$52.58	$57.74	$5.16	$62.63	$57.74	($4.89)	$98.50	$57.74	($40.76)
	$91.09	$78.00	($13.09)	$108.97	$78.00	($30.97)	$173.07	$78.00	($95.07)
5,000 Gallon Liquid Vacuum Tank Injected	$54.65	$62.81	$8.16	$65.61	$62.81	($2.80)	$104.58	$62.81	($41.77)
	$80.97	$78.00	($2.97)	$97.20	$78.00	($19.20)	$154.94	$78.00	($76.94)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$73.28	$52.68	($20.60)	$82.73	$52.68	($30.05)	$114.75	$52.68	($62.07)
	$162.85	$78.00	($84.85)	$183.86	$78.00	($105.86)	$255.01	$78.00	($177.01)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$76.34	$57.74	($18.60)	$85.79	$57.74	($28.05)	$117.81	$57.74	($60.07)
	$133.34	$78.00	($55.34)	$150.15	$78.00	($72.15)	$207.07	$78.00	($129.07)
8,500 Gallon Liquid Vacuum Tank Injected	$89.39	$62.81	($26.58)	$100.49	$62.81	($37.68)	$137.96	$62.81	($75.15)
	$132.44	$78.00	($54.44)	$148.87	$78.00	($70.87)	$204.40	$78.00	($126.40)
Drag Hose System	$44.69	$62.81	$18.12	$53.40	$62.81	$9.41	$89.39	$62.81	($26.58)
	$66.21	$78.00	$11.79	$79.11	$78.00	($1.11)	$132.43	$78.00	($54.43)
Big Gun Hard Hose Traveller Broadcast w/ No Incorporation	$51.67	$52.68	$1.01	$61.92	$52.68	($9.24)	$103.20	$52.68	($50.52)
	$105.44	$78.00	($27.44)	$126.95	$78.00	($48.95)	$213.93	$78.00	($135.93)
Big Gun Hard Hose Traveller Broadcast w/ Incorporation	$54.73	$57.74	$3.01	$64.98	$57.74	($7.24)	$106.26	$57.74	($48.52)
	$89.62	$78.00	($11.62)	$107.28	$78.00	($29.28)	$178.68	$78.00	($100.68)
Big Gun Soft Hose Traveller Broadcast w/ No Incorporation	$49.85	$52.68	$2.83	$60.33	$52.68	($7.65)	$102.42	$52.68	($49.74)
	$86.03	$78.00	($8.03)	$106.49	$78.00	($28.49)	$189.46	$78.00	($111.46)
Big Gun Soft Hose Traveller Broadcast w/ Incorporation	$52.91	$57.74	$4.83	$63.39	$57.74	($5.65)	$105.48	$57.74	($47.74)
	$74.84	$78.00	$3.16	$91.91	$78.00	($13.91)	$161.15	$78.00	($83.15)
Center-Pivot System Broadcast w/ No Incorporation	$40.23	$52.68	$12.45	$49.53	$52.68	$3.15	$87.22	$52.68	($34.54)
	$82.61	$78.00	($4.61)	$102.26	$78.00	($24.26)	$182.07	$78.00	($104.07)
Center-Pivot System Broadcast w/ Incorporation	$43.29	$57.74	$14.45	$52.59	$57.74	$5.15	$90.28	$57.74	($32.54)
	$71.84	$78.00	$6.16	$87.95	$78.00	($9.95)	$153.35	$78.00	($75.35)
Note: Phosphorus-based applications are shaded gray	200 Cow Herd Size								

Table C-3. Net fertilizer values for a 400-cow herd.

System Type	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$18.20	$52.68	$34.48	$26.67	$52.68	$26.01	$60.96	$52.68	($8.28)
	$40.43	$78.00	$37.57	$59.26	$78.00	$18.74	$135.46	$78.00	($57.46)
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$21.26	$57.74	$36.48	$29.73	$57.74	$28.01	$64.02	$57.74	($6.28)
	$35.41	$78.00	$42.59	$50.47	$78.00	$27.53	$111.43	$78.00	($33.43)
5,000 Gallon Liquid Slurry Tank Injected	$20.15	$62.81	$42.66	$29.41	$62.81	$33.40	$66.97	$62.81	($4.16)
	$29.85	$78.00	$48.15	$43.58	$78.00	$34.42	$99.22	$78.00	($21.22)
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$24.90	$52.68	$27.78	$31.65	$52.68	$21.03	$56.85	$52.68	($4.17)
	$55.34	$78.00	$22.66	$70.33	$78.00	$7.67	$126.33	$78.00	($48.33)
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$27.96	$57.74	$29.78	$34.71	$57.74	$23.03	$59.91	$57.74	($2.17)
	$47.33	$78.00	$30.67	$59.32	$78.00	$18.68	$104.08	$78.00	($26.08)
10,000 Gallon Liquid Slurry Tank Injected	$30.52	$62.81	$32.29	$38.57	$62.81	$24.24	$68.08	$62.81	($5.27)
	$45.21	$78.00	$32.79	$57.14	$78.00	$20.86	$100.86	$78.00	($22.86)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$51.37	$52.68	$1.31	$65.30	$52.68	($12.62)	$114.02	$52.68	($61.34)
	$114.15	$78.00	($36.15)	$145.11	$78.00	($67.11)	$253.39	$78.00	($175.39)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$54.43	$57.74	$3.31	$68.36	$57.74	($10.62)	$117.08	$57.74	($59.34)
	$94.38	$78.00	($16.38)	$119.15	$78.00	($41.15)	$205.78	$78.00	($127.78)
5,000 Gallon Liquid Vacuum Tank Injected	$55.92	$62.81	$6.89	$71.04	$62.81	($8.23)	$123.85	$62.81	($61.04)
	$82.85	$78.00	($4.85)	$105.24	$78.00	($27.24)	$183.49	$78.00	($105.49)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$76.02	$52.68	($23.34)	$89.68	$52.68	($37.00)	$132.94	$52.68	($80.26)
	$168.93	$78.00	($90.93)	$199.30	$78.00	($121.30)	$295.44	$78.00	($217.44)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$79.08	$57.74	($21.34)	$92.74	$57.74	($35.00)	$136.01	$57.74	($78.27)
	$138.21	$78.00	($60.21)	$162.50	$78.00	($84.50)	$239.41	$78.00	($161.41)
8,500 Gallon Liquid Vacuum Tank Injected	$90.06	$62.81	($27.25)	$105.89	$62.81	($43.08)	$156.37	$62.81	($93.56)
	$133.42	$78.00	($55.42)	$156.88	$78.00	($78.88)	$231.66	$78.00	($153.66)
Drag Hose System	$30.19	$62.81	$32.62	$35.29	$62.81	$27.52	$56.27	$62.81	$6.54
	$44.73	$78.00	$33.27	$52.28	$78.00	$25.72	$83.37	$78.00	($5.37)
Big Gun Hard Hose Traveller Broadcast w/ No Incorporation	$39.23	$52.68	$13.45	$46.35	$52.68	$6.33	$74.25	$52.68	($21.57)
	$76.40	$78.00	$1.60	$90.57	$78.00	($12.57)	$146.56	$78.00	($68.56)
Big Gun Hard Hose Traveller Broadcast w/ Incorporation	$42.29	$57.74	$15.45	$49.41	$57.74	$8.33	$77.31	$57.74	($19.57)
	$65.78	$78.00	$12.22	$77.42	$78.00	$0.58	$123.38	$78.00	($45.38)
Big Gun Soft Hose Traveller Broadcast w/ No Incorporation	$41.08	$52.68	$11.60	$48.50	$52.68	$4.18	$77.44	$52.68	($24.76)
	$64.44	$78.00	$13.56	$77.21	$78.00	$0.79	$128.15	$78.00	($50.15)
Big Gun Soft Hose Traveller Broadcast w/ Incorporation	$44.14	$57.74	$13.60	$51.56	$57.74	$6.18	$80.50	$57.74	($22.76)
	$56.83	$78.00	$21.17	$67.48	$78.00	$10.52	$109.99	$78.00	($31.99)
Center-Pivot System Broadcast w/ No Incorporation	$26.50	$52.68	$26.18	$32.22	$52.68	$20.46	$55.02	$52.68	($2.34)
	$53.08	$78.00	$24.92	$64.78	$78.00	$13.22	$111.77	$78.00	($33.77)
Center-Pivot System Broadcast w/ Incorporation	$29.56	$57.74	$28.18	$35.28	$57.74	$22.46	$58.08	$57.74	($0.34)
	$47.06	$78.00	$30.94	$56.67	$78.00	$21.33	$95.25	$78.00	($17.25)
Note: Phosphorus-based applications are shaded gray	400 Cow Herd Size								

Table C-4. Net fertilizer values for an 800-cow herd.

System Type	0.5 Mile			1.5 Mile			4.5 Mile		
	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$16.72	$52.68	$35.96	$27.94	$52.68	$24.74	$75.90	$52.68	($23.22)
	$37.15	$78.00	$40.85	$62.08	$78.00	$15.92	$168.68	$78.00	($90.68)
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$19.78	$57.74	$37.96	$29.13	$57.74	$28.61	$78.96	$57.74	($21.22)
	$32.78	$78.00	$45.22	$49.41	$78.00	$28.59	$138.00	$78.00	($60.00)
5,000 Gallon Liquid Slurry Tank Injected	$18.18	$62.81	$44.63	$30.45	$62.81	$32.36	$82.73	$62.81	($19.92)
	$26.93	$78.00	$51.07	$45.12	$78.00	$32.88	$122.56	$78.00	($44.56)
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$21.63	$52.68	$31.05	$30.36	$52.68	$22.32	$64.21	$52.68	($11.53)
	$48.08	$78.00	$29.92	$67.46	$78.00	$10.54	$142.69	$78.00	($64.69)
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$24.70	$57.74	$33.04	$33.42	$57.74	$24.32	$67.27	$57.74	($9.53)
	$41.52	$78.00	$36.48	$57.03	$78.00	$20.97	$117.22	$78.00	($39.22)
10,000 Gallon Liquid Slurry Tank Injected	$25.67	$62.81	$37.14	$35.88	$62.81	$26.93	$75.42	$62.81	($12.61)
	$38.03	$78.00	$39.97	$53.16	$78.00	$24.84	$111.74	$78.00	($33.74)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$60.90	$52.68	($8.22)	$82.14	$52.68	($29.46)	$170.06	$52.68	($117.38)
	$135.35	$78.00	($57.35)	$182.54	$78.00	($104.54)	$377.93	$78.00	($299.93)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$63.97	$57.74	($6.23)	$85.20	$57.74	($27.46)	$173.12	$57.74	($115.38)
	$111.34	$78.00	($33.34)	$149.09	$78.00	($71.09)	$305.40	$78.00	($227.40)
5,000 Gallon Liquid Vacuum Tank Injected	$65.80	$62.81	($2.99)	$88.60	$62.81	($25.79)	$181.92	$62.81	($119.11)
	$97.49	$78.00	($19.49)	$131.26	$78.00	($53.26)	$269.53	$78.00	($191.53)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$91.44	$52.68	($38.76)	$111.57	$52.68	($58.89)	$187.33	$52.68	($134.65)
	$203.20	$78.00	($125.20)	$247.94	$78.00	($169.94)	$416.30	$78.00	($338.30)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$94.50	$57.74	($36.76)	$114.63	$57.74	($56.89)	$190.39	$57.74	($132.65)
	$165.62	$78.00	($87.62)	$201.41	$78.00	($123.41)	$336.10	$78.00	($258.10)
8,500 Gallon Liquid Vacuum Tank Injected	$106.36	$62.81	($43.55)	$129.35	$62.81	($66.54)	$214.62	$62.81	($151.81)
	$157.57	$78.00	($79.57)	$191.64	$78.00	($113.64)	$317.97	$78.00	($239.97)
Drag Hose System	$24.02	$62.81	$38.79	$27.42	$62.81	$35.39	$41.64	$62.81	$21.17
	$35.58	$78.00	$42.42	$40.63	$78.00	$37.37	$61.69	$78.00	$16.31
Big Gun Hard Hose Traveller Broadcast w/ No Incorporation	$35.38	$52.68	$17.30	$41.59	$52.68	$11.09	$64.79	$52.68	($12.11)
	$65.82	$78.00	$12.18	$77.39	$78.00	$0.61	$121.29	$78.00	($43.29)
Big Gun Hard Hose Traveller Broadcast w/ Incorporation	$38.44	$57.74	$19.30	$44.65	$57.74	$13.09	$67.85	$57.74	($10.11)
	$57.09	$78.00	$20.91	$66.60	$78.00	$11.40	$102.63	$78.00	($24.63)
Big Gun Soft Hose Traveller Broadcast w/ No Incorporation	$38.52	$52.68	$14.16	$45.11	$52.68	$7.57	$69.65	$52.68	($16.97)
	$55.57	$78.00	$22.43	$65.31	$78.00	$12.69	$102.75	$78.00	($24.75)
Big Gun Soft Hose Traveller Broadcast w/ Incorporation	$41.58	$57.74	$16.16	$48.17	$57.74	$9.57	$72.71	$57.74	($14.97)
	$49.43	$78.00	$28.57	$57.56	$78.00	$20.44	$88.80	$78.00	($10.80)
Center-Pivot System Broadcast w/ No Incorporation	$20.68	$52.68	$32.00	$24.92	$52.68	$27.76	$41.25	$52.68	$11.43
	$40.25	$78.00	$37.75	$48.57	$78.00	$29.43	$81.00	$78.00	($3.00)
Center-Pivot System Broadcast w/ Incorporation	$23.74	$57.74	$34.00	$27.98	$57.74	$29.76	$44.31	$57.74	$13.43
	$36.16	$78.00	$41.84	$42.98	$78.00	$35.02	$69.53	$78.00	$8.47
Note: Phosphorus-based applications are shaded gray	800 Cow Herd Size								

Table C-5. Net fertilizer values for a 2,000-cow herd.

System Type	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)	Application Cost ($/acre)	Manure Value as Fertilizer ($/acre)	Net Fertilizer Value ($/acre)
	0.5 Mile			1.5 Mile			4.5 Mile		
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$18.36	$52.68	$34.32	$36.33	$52.68	$16.35	$140.93	$52.68	($88.25)
	$40.79	$78.00	$37.21	$80.73	$78.00	($2.73)	$313.18	$78.00	($235.18)
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$20.94	$57.74	$36.80	$38.64	$57.74	$19.10	$143.24	$57.74	($85.50)
	$35.61	$78.00	$42.39	$67.38	$78.00	$10.62	$253.34	$78.00	($175.34)
5,000 Gallon Liquid Slurry Tank Injected	$19.76	$62.81	$43.05	$39.25	$62.81	$23.56	$150.06	$62.81	($87.25)
	$29.28	$78.00	$48.72	$58.15	$78.00	$19.85	$222.32	$78.00	($144.32)
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$23.72	$52.68	$28.96	$36.45	$52.68	$16.23	$100.73	$52.68	($48.05)
	$52.71	$78.00	$25.29	$80.99	$78.00	($2.99)	$223.85	$78.00	($145.85)
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$25.75	$57.74	$31.99	$38.76	$57.74	$18.98	$103.05	$57.74	($45.31)
	$43.78	$78.00	$34.22	$67.58	$78.00	$10.42	$181.87	$78.00	($103.87)
10,000 Gallon Liquid Slurry Tank Injected	$27.25	$62.81	$35.56	$42.12	$62.81	$20.69	$114.61	$62.81	($51.80)
	$40.36	$78.00	$37.64	$62.40	$78.00	$15.60	$169.80	$78.00	($91.80)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$101.04	$52.68	($48.36)	$152.36	$52.68	($99.68)	$357.89	$52.68	($305.21)
	$231.20	$78.00	($153.20)	$338.58	$78.00	($260.58)	$795.34	$78.00	($717.34)
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$106.23	$57.74	($48.49)	$154.55	$57.74	($96.81)	$360.08	$57.74	($302.34)
	$187.47	$78.00	($109.47)	$273.38	$78.00	($195.38)	$638.78	$78.00	($560.78)
5,000 Gallon Liquid Vacuum Tank Injected	$110.40	$62.81	($47.59)	$160.97	$62.81	($98.16)	$374.31	$62.81	($311.50)
	$163.56	$78.00	($85.56)	$238.48	$78.00	($160.48)	$554.55	$78.00	($476.55)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$161.45	$52.68	($108.77)	$208.11	$52.68	($155.43)	$386.46	$52.68	($333.78)
	$358.80	$78.00	($280.80)	$462.47	$78.00	($384.47)	$372.49	$78.00	($294.49)
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$163.64	$57.74	($105.90)	$210.56	$57.74	($152.82)	$388.64	$57.74	($330.90)
	$289.55	$78.00	($211.55)	$372.49	$78.00	($294.49)	$689.56	$78.00	($611.56)
8,500 Gallon Liquid Vacuum Tank Injected	$180.68	$62.81	($117.87)	$231.47	$62.81	($168.66)	$423.53	$62.81	($360.72)
	$267.68	$78.00	($189.68)	$342.93	$78.00	($264.93)	$627.48	$78.00	($549.48)
Drag Hose System	$22.00	$62.81	$40.81	$25.06	$62.81	$37.75	$36.71	$62.81	$26.10
	$32.60	$78.00	$45.40	$37.13	$78.00	$40.87	$54.38	$78.00	$23.62
Big Gun Hard Hose Traveller Broadcast w/ No Incorporation	$37.11	$52.68	$15.57	$44.03	$52.68	$8.65	$68.48	$52.68	($15.80)
	$66.29	$78.00	$11.71	$78.47	$78.00	($0.47)	$121.96	$78.00	($43.96)
Big Gun Hard Hose Traveller Broadcast w/ Incorporation	$39.54	$57.74	$18.20	$46.46	$57.74	$11.28	$70.91	$57.74	($13.17)
	$57.22	$78.00	$20.78	$67.22	$78.00	$10.78	$102.92	$78.00	($24.92)
Big Gun Soft Hose Traveller Broadcast w/ No Incorporation	$38.80	$52.68	$13.88	$46.27	$52.68	$6.41	$72.62	$52.68	($19.94)
	$53.00	$78.00	$25.00	$62.23	$78.00	$15.77	$96.66	$78.00	($18.66)
Big Gun Soft Hose Traveller Broadcast w/ Incorporation	$41.23	$57.74	$16.51	$48.70	$57.74	$9.04	$75.05	$57.74	($17.31)
	$47.11	$78.00	$30.89	$54.82	$78.00	$23.18	$83.54	$78.00	($5.54)
Center-Pivot System Broadcast w/ No Incorporation	$19.48	$52.68	$33.20	$23.50	$52.68	$29.18	$38.20	$52.68	$14.48
	$36.64	$78.00	$41.36	$44.12	$78.00	$33.88	$71.54	$78.00	$6.46
Center-Pivot System Broadcast w/ Incorporation	$21.64	$57.74	$36.10	$26.01	$57.74	$31.73	$40.68	$57.74	$17.06
	$32.63	$78.00	$45.37	$38.81	$78.00	$39.19	$61.42	$78.00	$16.58
Note: Phosphorus-based applications are shaded gray	2000 Cow Herd Size								

APPENDIX D

PHOSPHORUS-BASED ANNUAL COST PER COW COMPARISONS

PHOSPHORUS-BASED NET FERTILIZER VALUE COMPARISONS

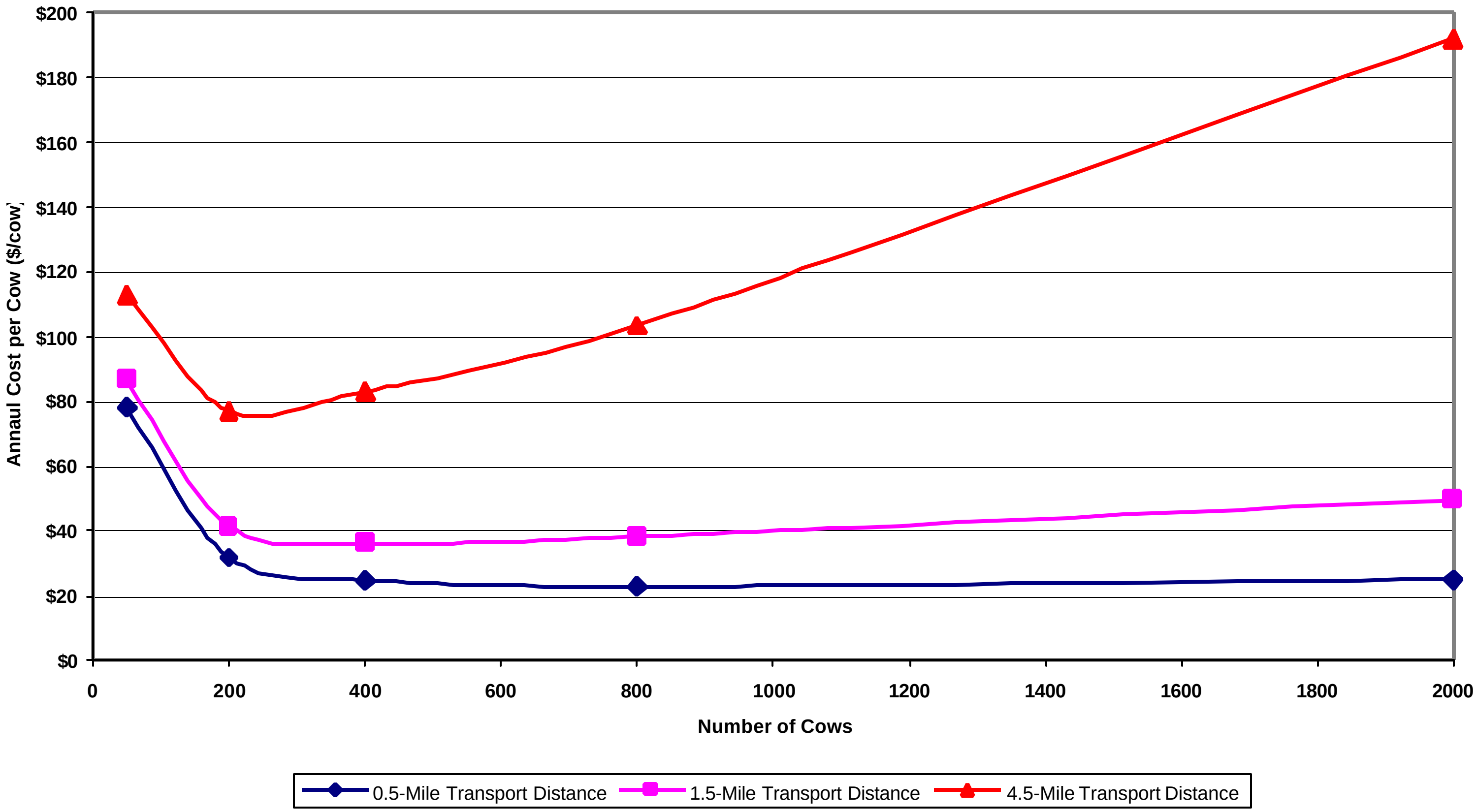

Figure D-1. 5,000 gallon liquid slurry tank system annual cost per cow values.

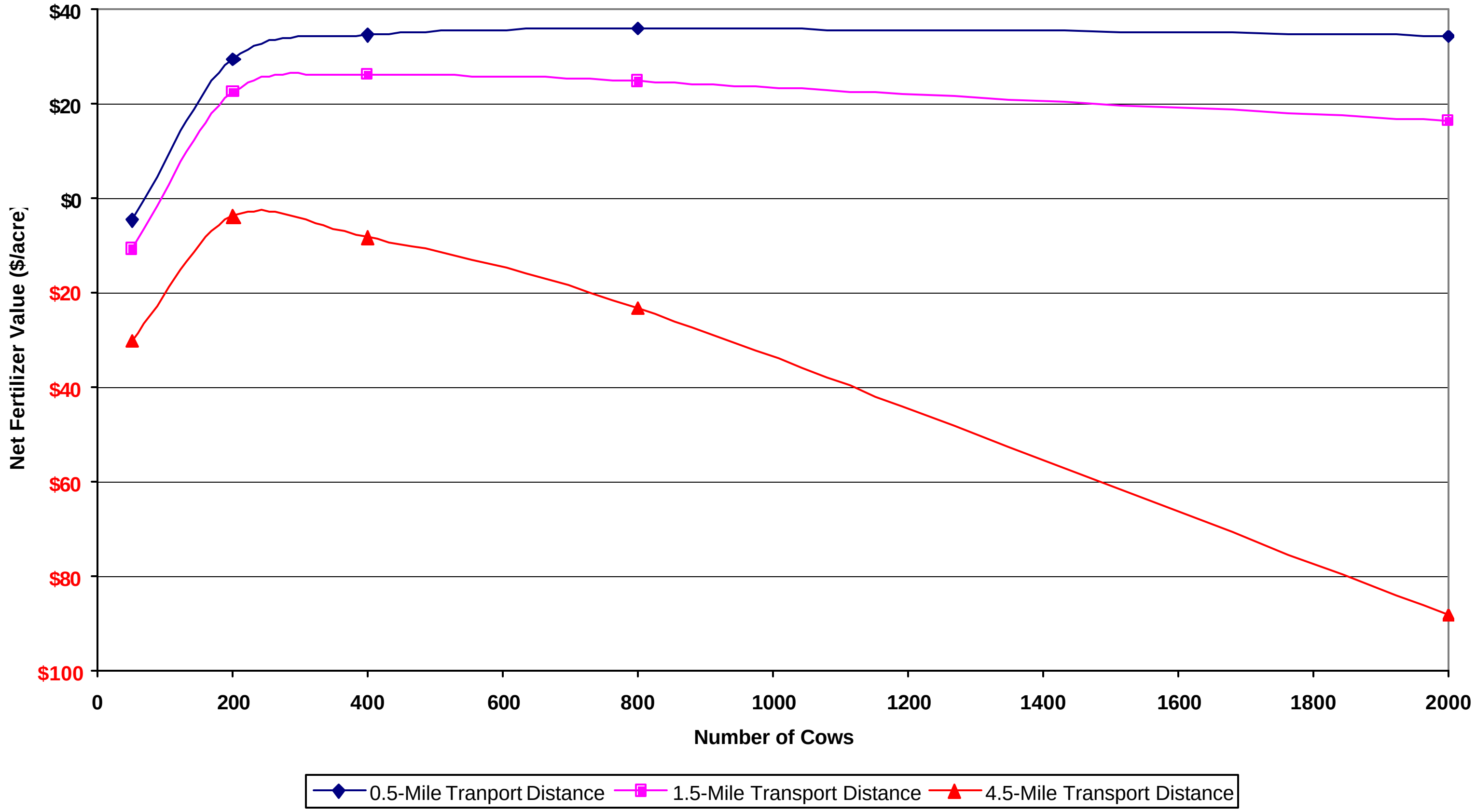

Figure D-2. 5,000 gallon liquid slurry tank net fertilizer values.

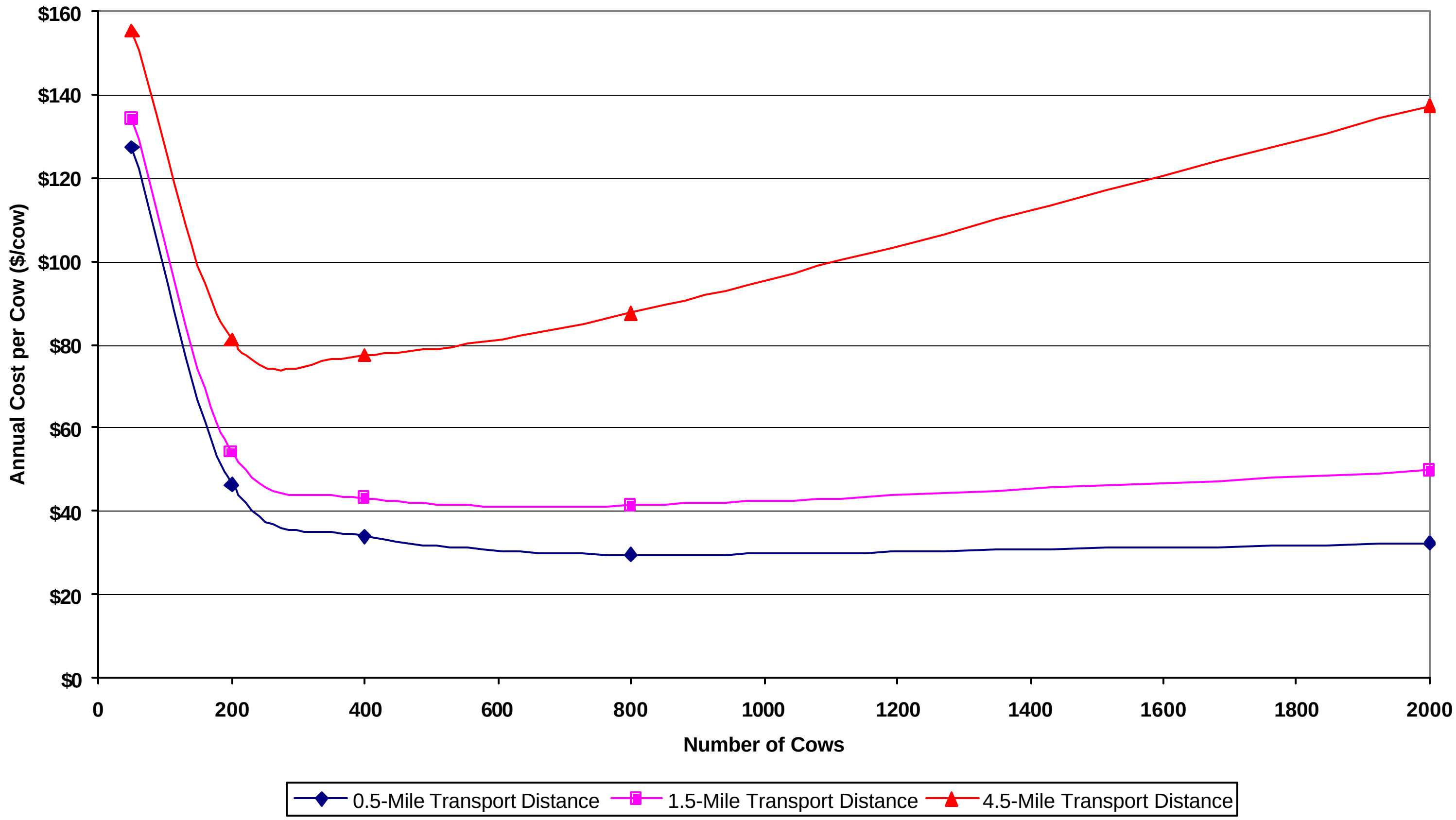

Figure D-3. 10,000 gallon liquid slurry tank system annual cost per cow values.

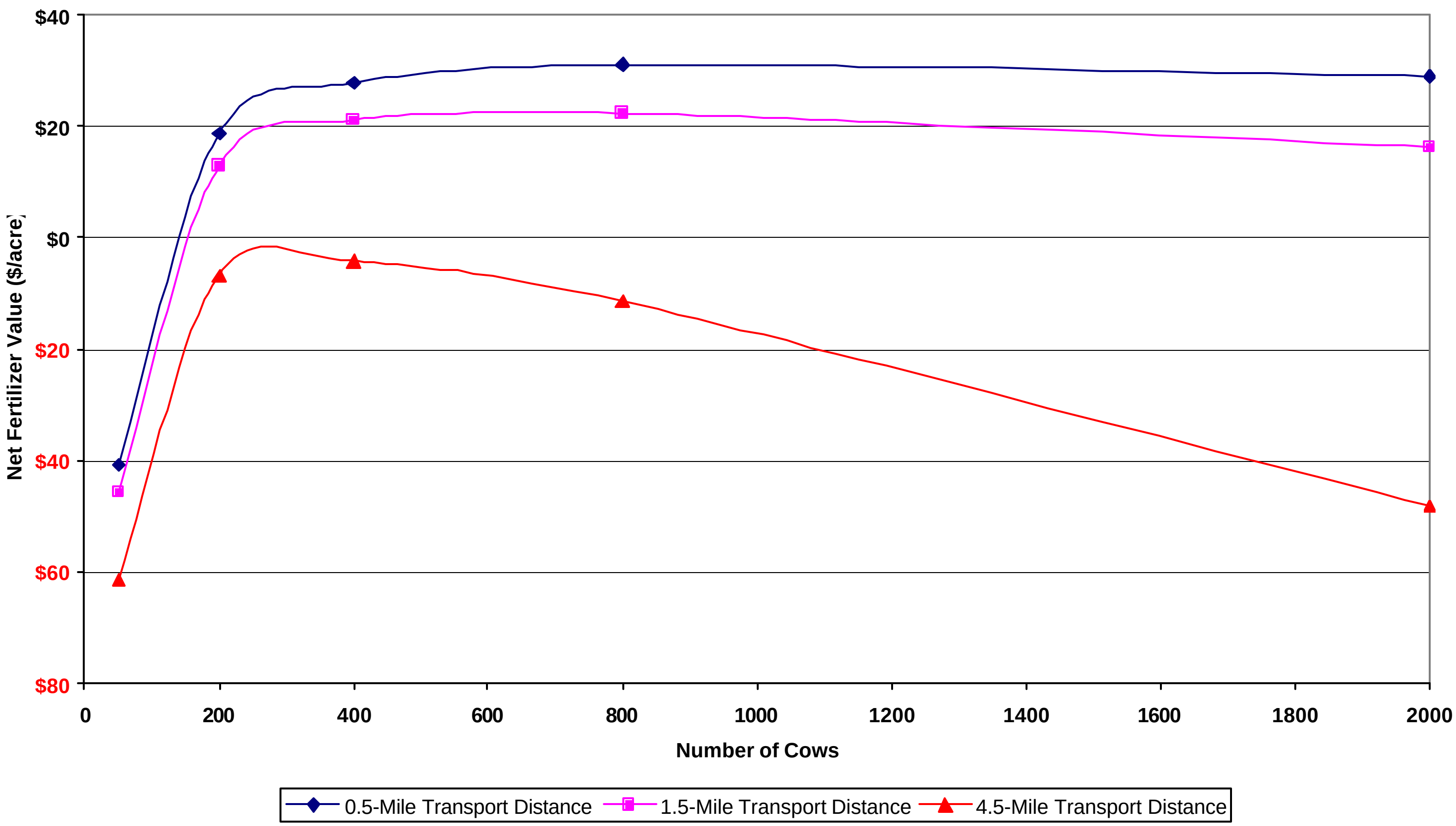

Figure D-4. 10,000 gallon liquid slurry tank system net fertilizer values.

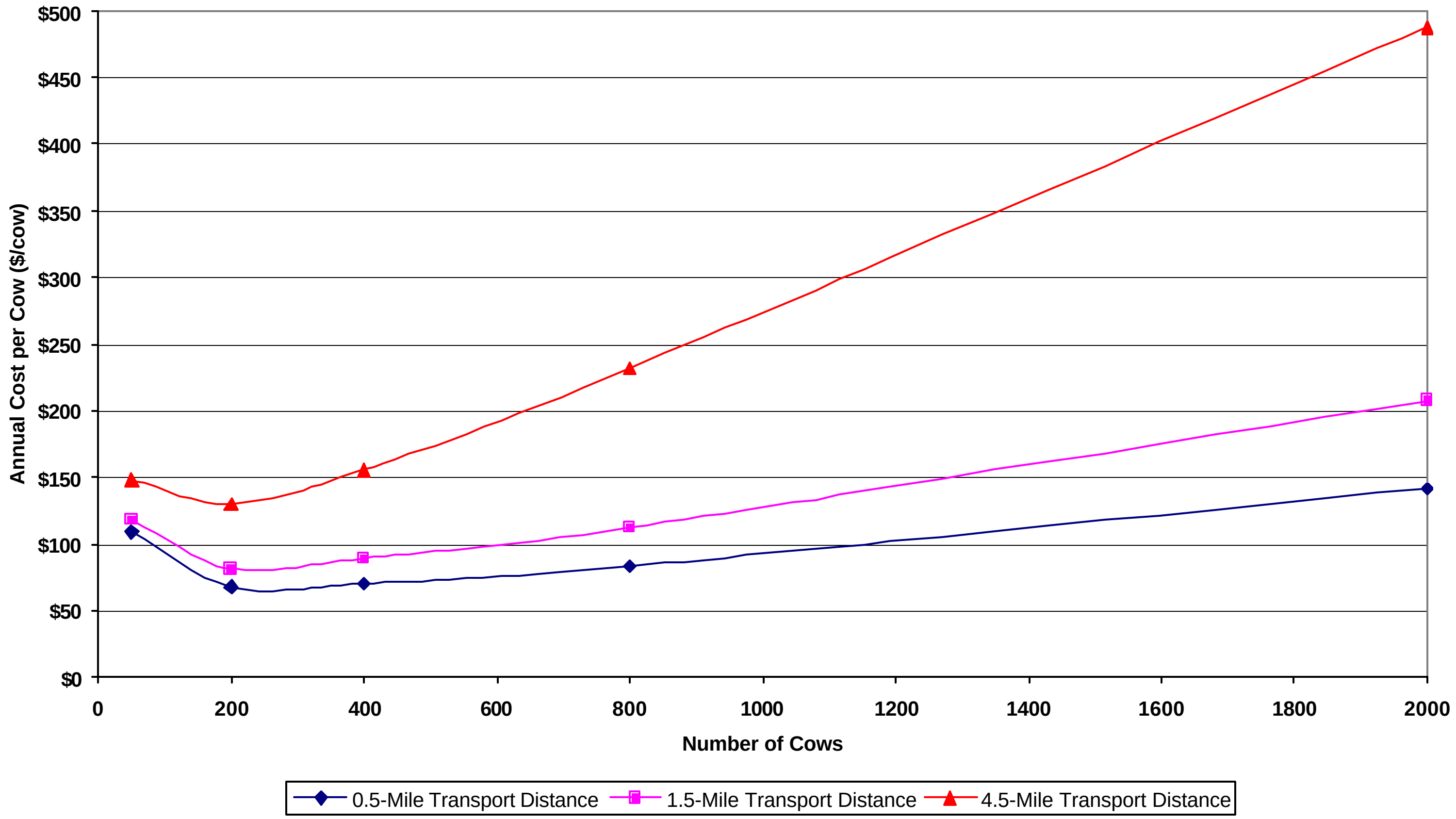

Figure D-5. 5,000 gallon liquid vacuum tank system annual cost per cow values.

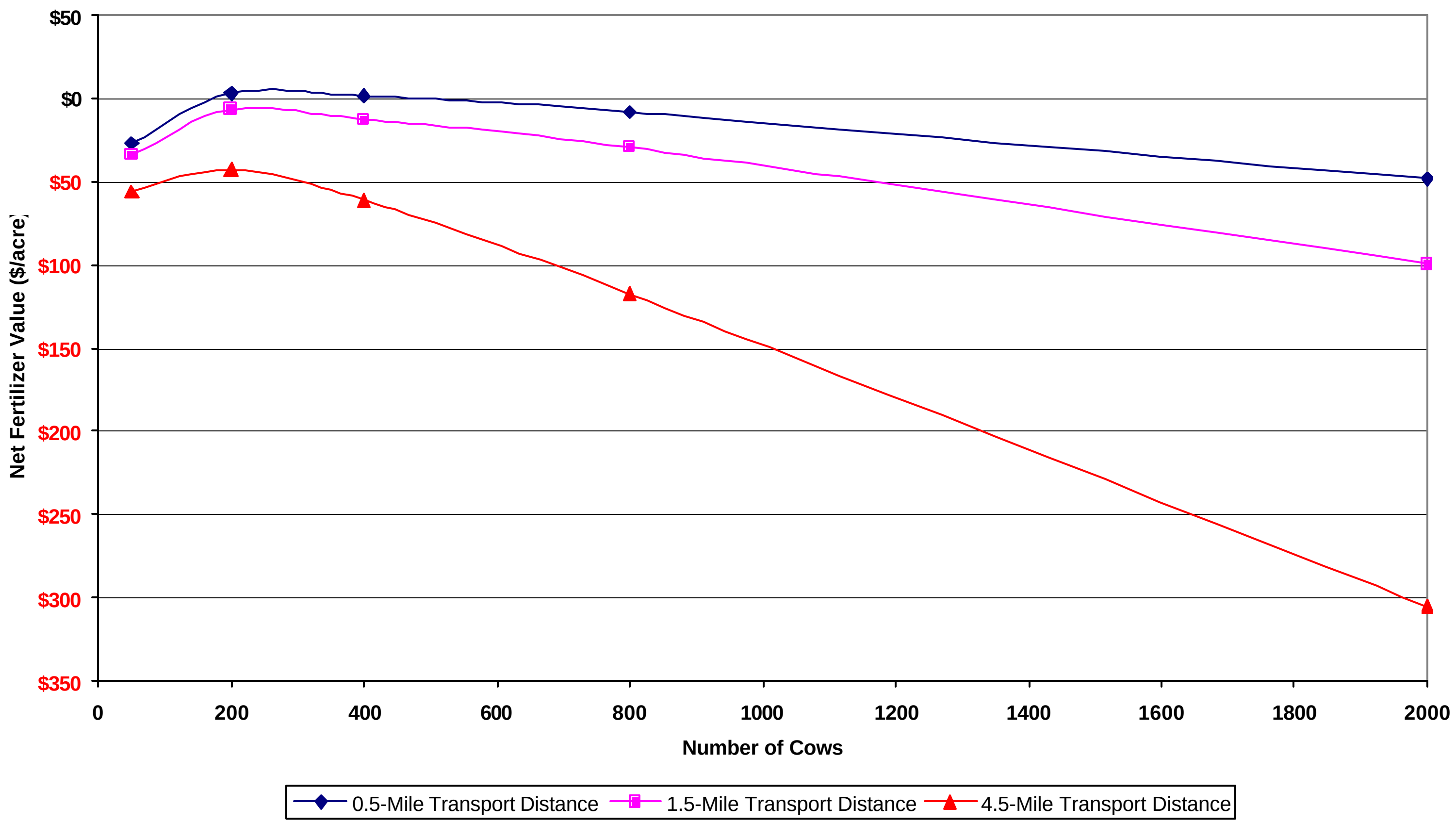

Figure D-6. 5,000 gallon liquid vacuum tank system net fertilizer values.

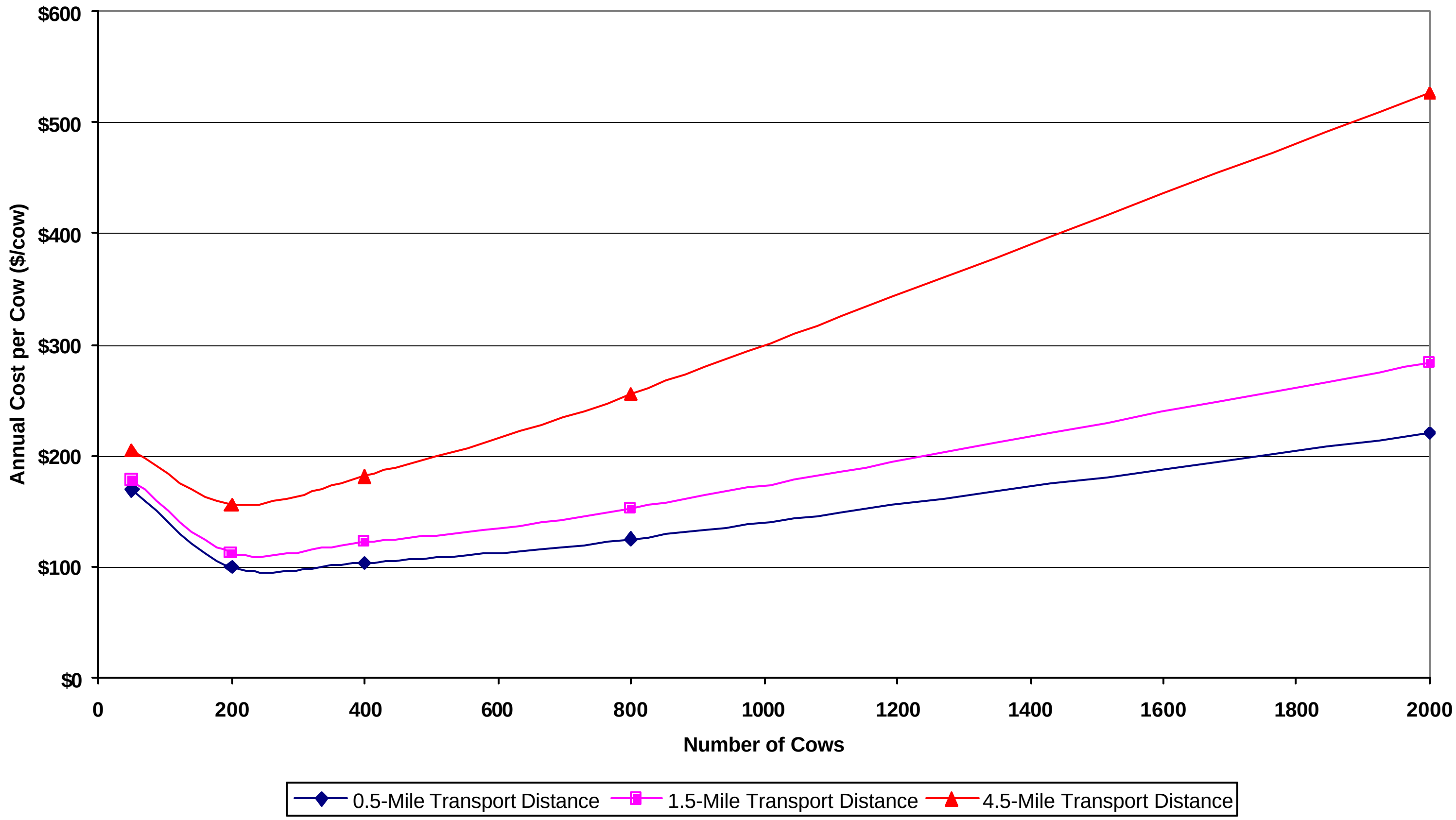

Figure D-7. 8,500 gallon liquid vacuum tank system annual cost per cow values.

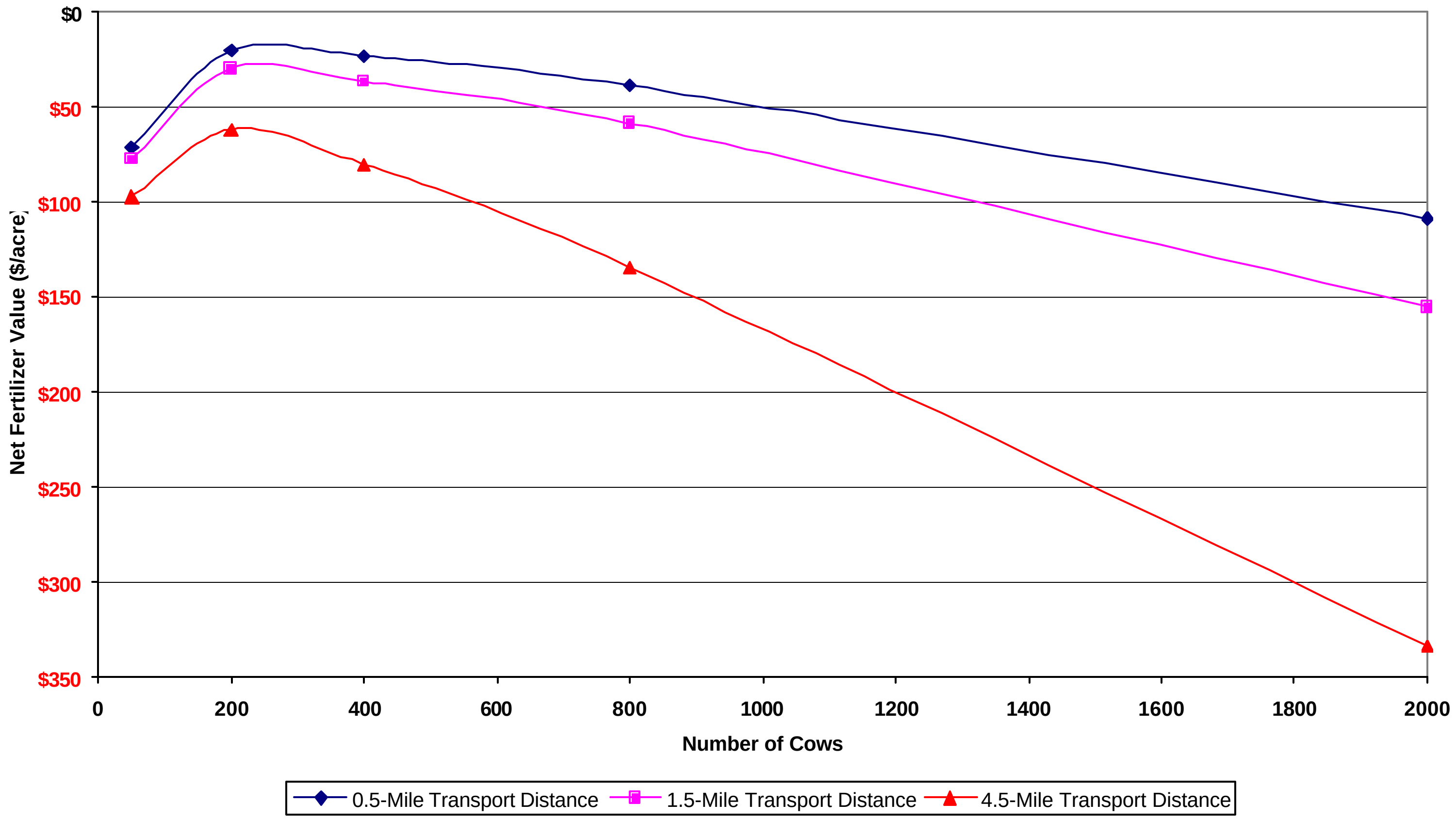

Figure D-8. 8,500 gallon liquid vacuum tank system net fertilizer values.

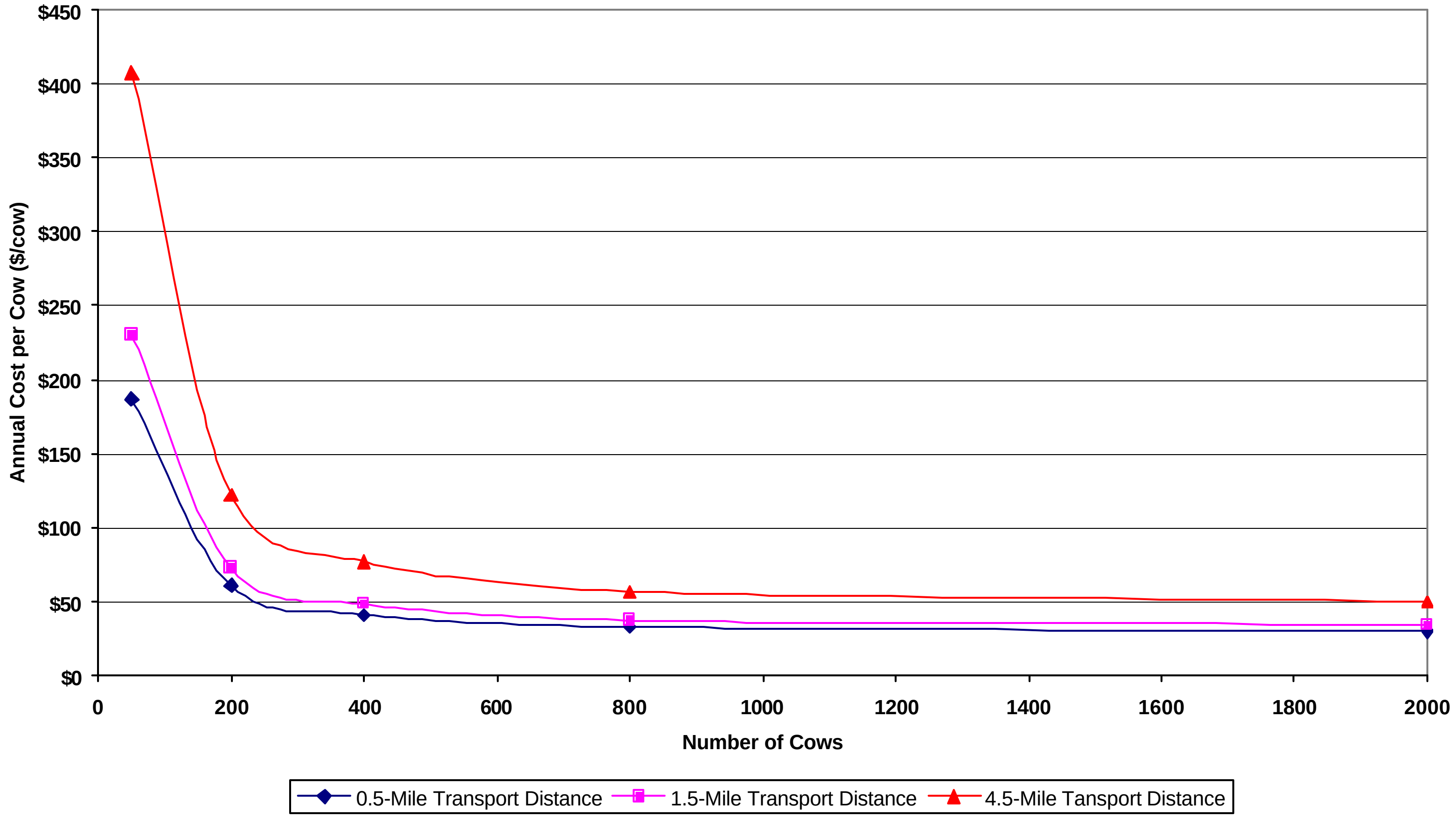

Figure D-9. Drag hose system annual cost per cow values.

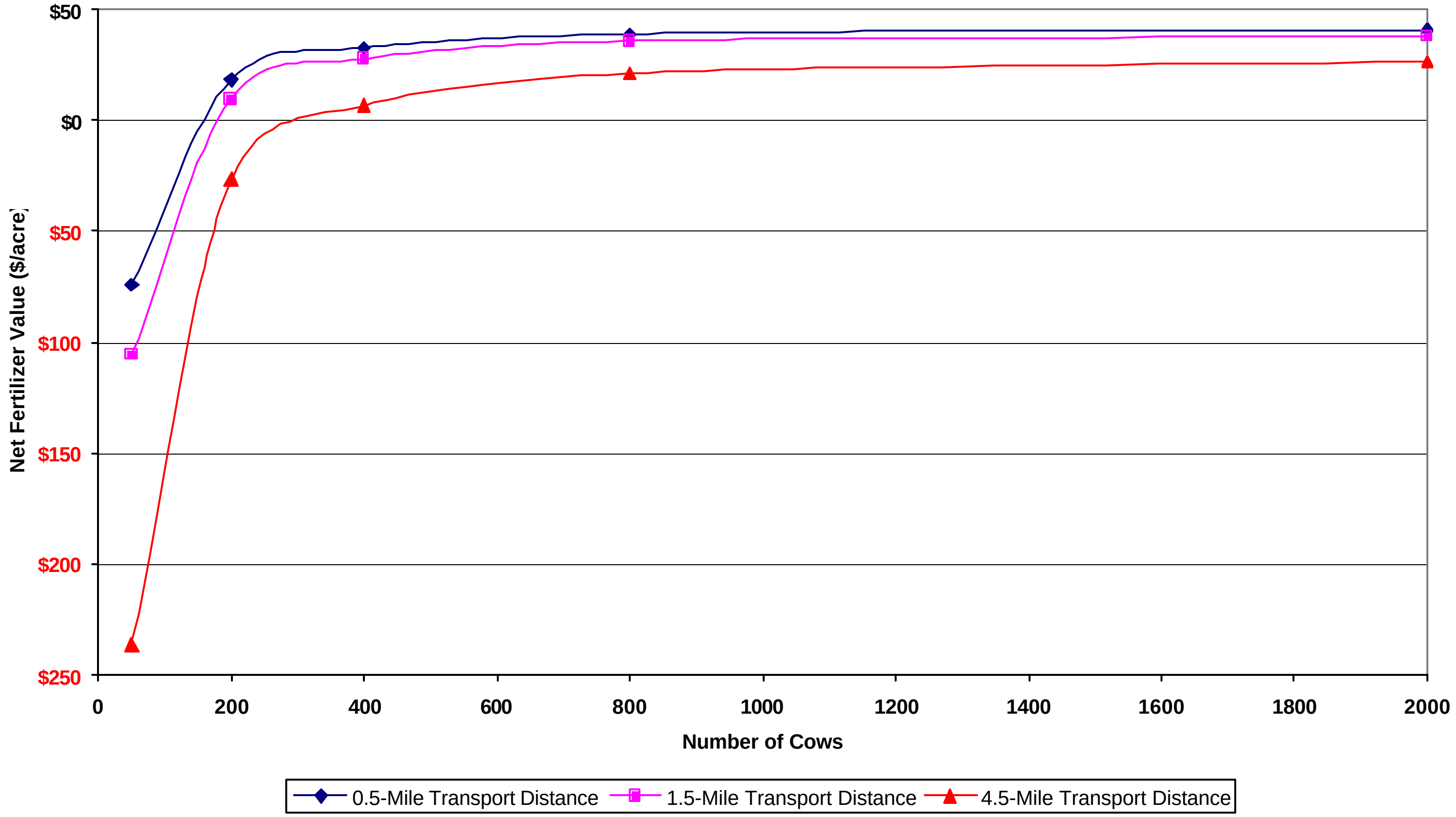

Figure D-10. Drag hose system net fertilizer values.

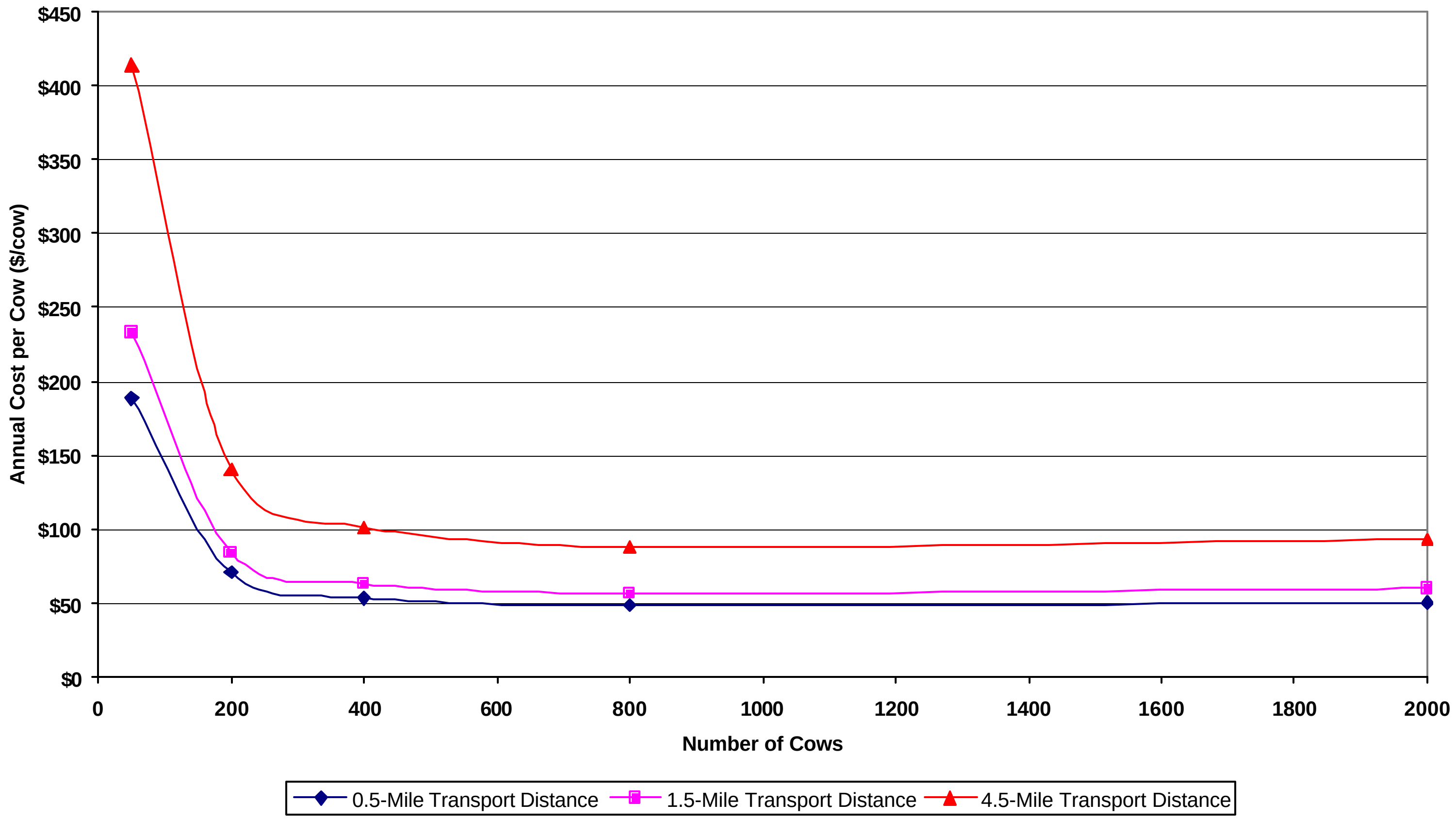

Figure D-11. Big gun hard hose system annual cost per cow values.

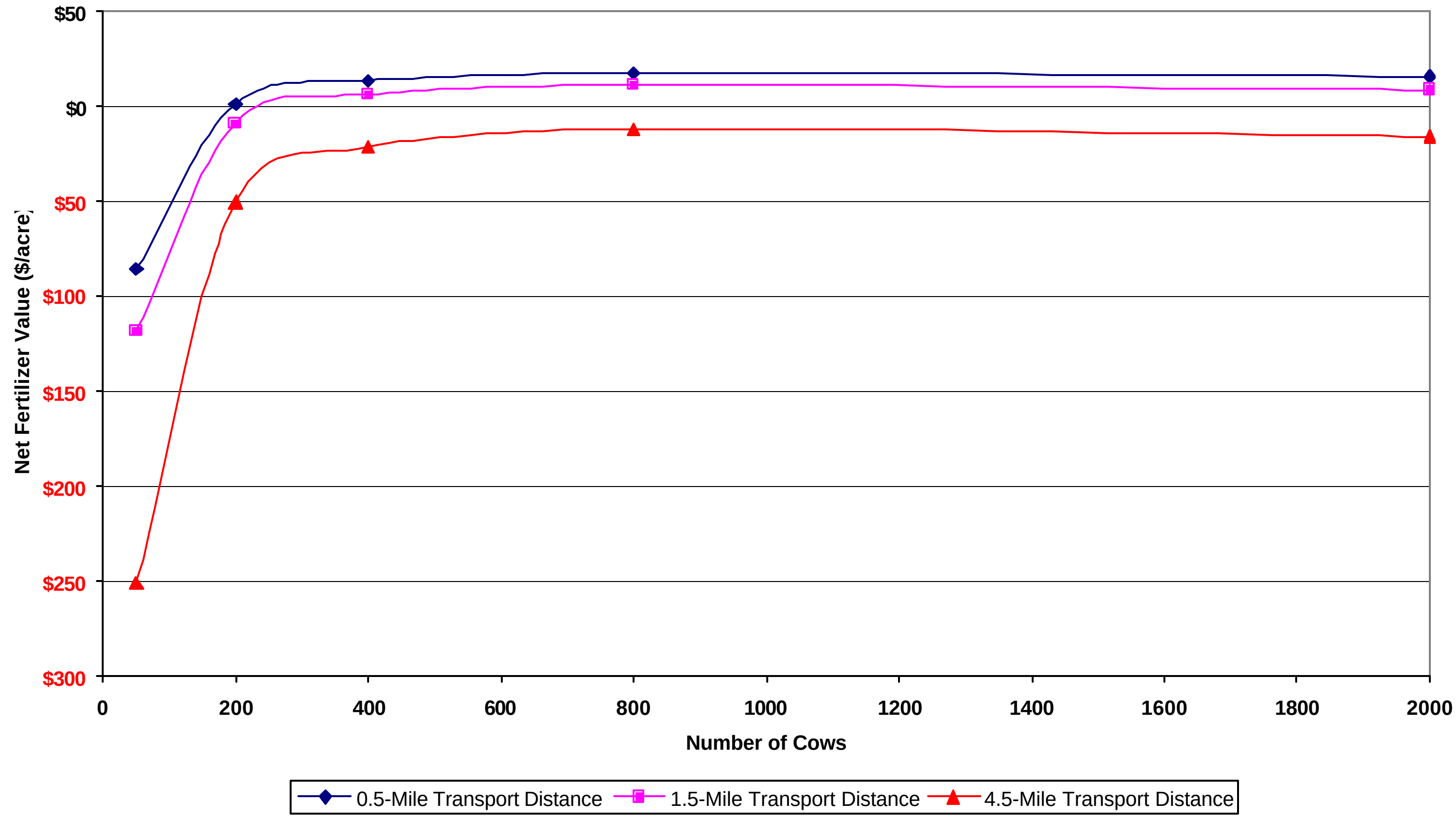

Figure D-12. Big gun hard hose system net fertilizer values.

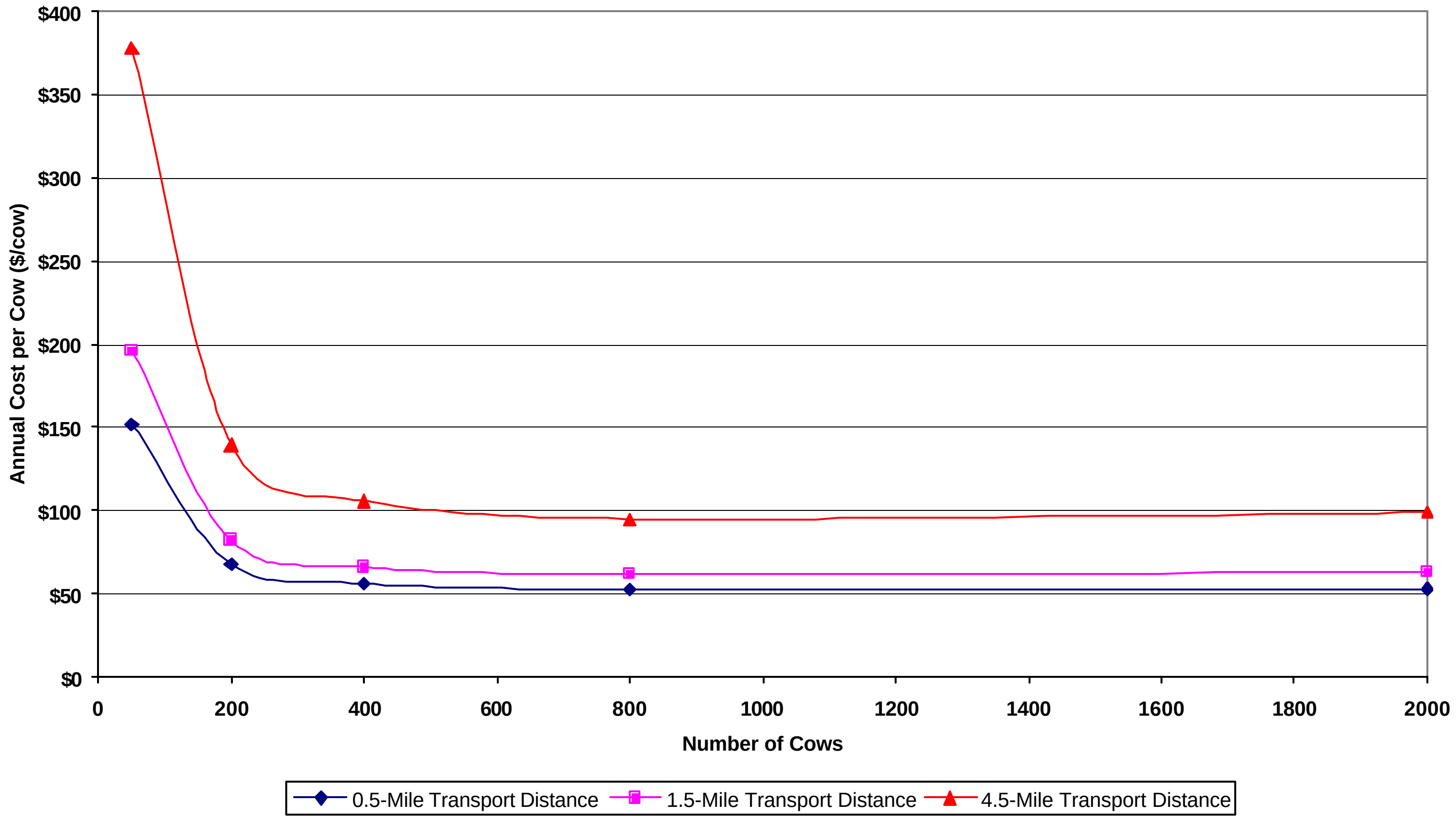

Figure D-13. Big gun soft hose system annual cost per cow values.

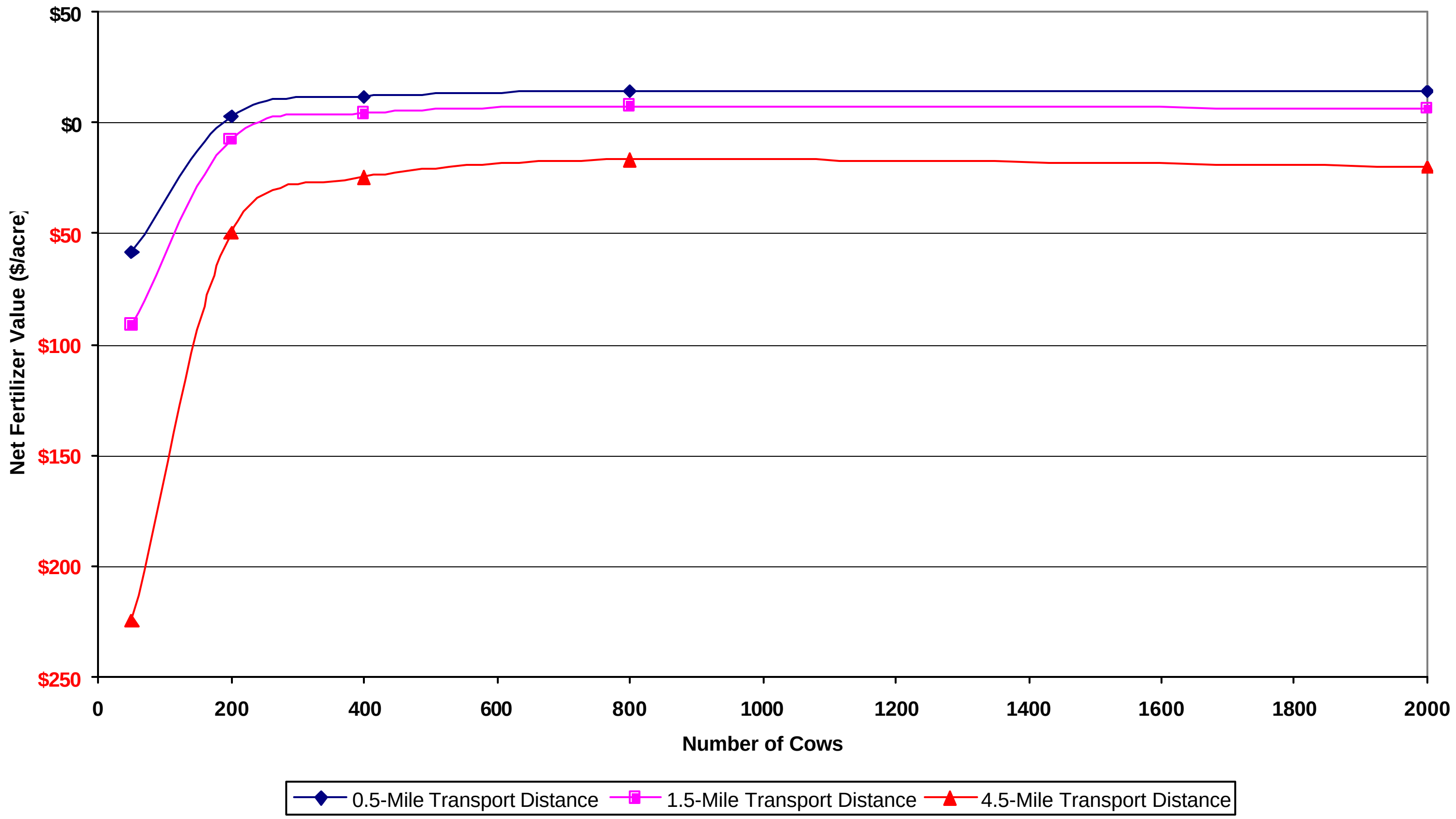

Figure D-14. Big gun soft hose system net fertilizer values.

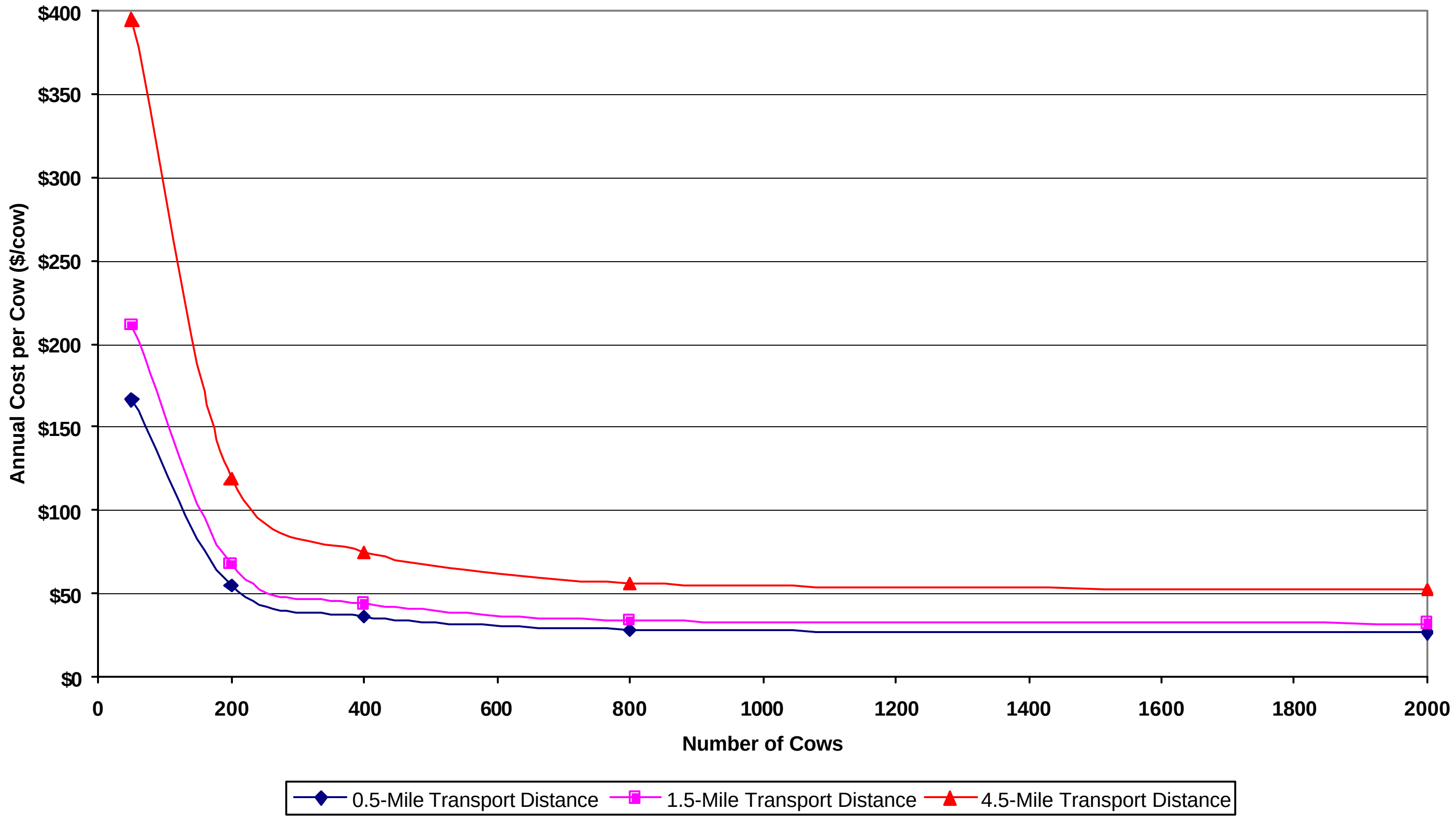

Figure D-15. Center-pivot system annual cost per cow values.

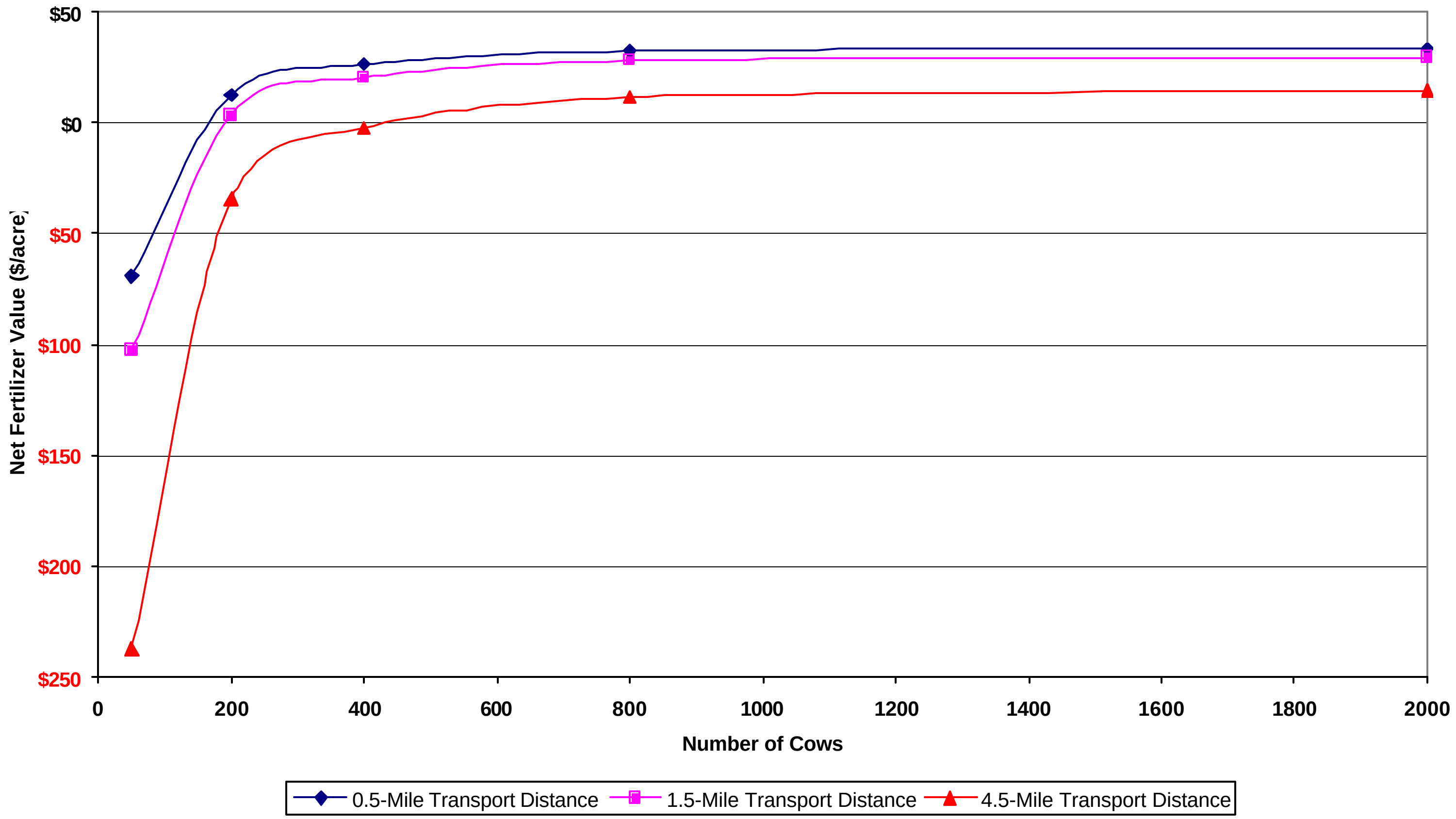

Figure D-16. Center-pivot system net fertilizer values.

APPENDIX E

TOTAL ANNUAL ECONOMIC SYSTEM COST PER COW VALUES

Table E-1. Total annual economic cost per cow values for a 50-cow herd.

System Type	Transport Distance (miles) 0.5 P	0.5 N	1.5 P	1.5 N	4.5 P	4.5 N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$78.23	$78.23	$86.47	$86.47	$112.93	$112.93
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$82.40	$80.57	$94.42	$92.60	$117.10	$115.27
5,000 Gallon Liquid Slurry Tank Injected	$93.37	$93.37	$102.08	$102.08	$130.48	$130.48
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$127.26	$127.26	$134.12	$134.12	$155.44	$155.44
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$131.43	$129.61	$138.30	$136.47	$159.61	$157.79
10,000 Gallon Liquid Slurry Tank Injected	$176.22	$176.22	$183.62	$183.62	$207.49	$207.49
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$108.81	$108.81	$118.06	$118.06	$147.84	$147.84
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$112.98	$111.88	$122.24	$120.41	$152.01	$150.19
5,000 Gallon Liquid Vacuum Tank Injected	$125.49	$125.49	$135.45	$135.45	$167.65	$167.65
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$168.83	$168.83	$177.39	$177.39	$204.59	$204.59
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$173.00	$171.17	$181.56	$179.73	$208.76	$206.93
8,500 Gallon Liquid Vacuum Tank Injected	$222.55	$222.55	$232.38	$232.38	$263.97	$263.97
Drag Hose System	$186.85	$186.85	$230.05	$230.05	$407.40	$407.40
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$188.55	$183.63	$233.03	$227.62	$413.94	$406.45
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$192.72	$190.78	$237.20	$235.93	$418.11	$419.43
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$151.75	$137.99	$196.41	$181.65	$378.05	$359.02
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$155.92	$146.27	$200.58	$191.81	$382.22	$376.81
Center-Pivot System Broadcast w/ No Incorporation	$166.28	$160.96	$211.36	$208.95	$394.74	$403.95
Center-Pivot System Broadcast w/ Incorporation	$170.45	$160.43	$215.53	$207.22	$398.91	$397.51

50 Cow Herd Size

Table E-2. Total annual economic cost per cow values for a 200-cow herd.

System Type	Transport Distance (miles)					
	0.5		1.5		4.5	
	P	N	P	N	P	N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$31.69	$31.69	$41.36	$41.36	$77.00	$77.00
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$35.86	$34.03	$45.53	$43.70	$81.17	$79.35
5,000 Gallon Liquid Slurry Tank Injected	$36.00	$36.00	$46.50	$46.50	$85.51	$85.51
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$46.37	$46.37	$54.21	$54.21	$81.12	$81.12
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$50.55	$48.72	$58.38	$56.55	$85.29	$83.46
10,000 Gallon Liquid Slurry Tank Injected	$59.83	$59.83	$68.81	$68.81	$100.17	$100.17
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$67.48	$67.48	$81.18	$81.18	$130.06	$130.06
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$71.65	$69.82	$85.35	$83.53	$134.23	$132.66
5,000 Gallon Liquid Vacuum Tank Injected	$74.47	$74.92	$89.41	$89.41	$142.52	$142.52
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$99.86	$99.86	$112.74	$112.74	$156.37	$156.37
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$104.03	$102.21	$116.91	$115.09	$160.54	$158.72
8,500 Gallon Liquid Vacuum Tank Injected	$121.82	$121.82	$136.93	$136.93	$188.00	$188.00
Drag Hose System	$60.90	$60.90	$72.61	$72.76	$121.81	$121.81
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$70.41	$64.65	$84.38	$77.85	$140.63	$131.18
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$74.58	$68.69	$88.55	$82.23	$144.80	$136.96
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$67.93	$52.75	$82.21	$65.30	$139.57	$116.17
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$72.11	$57.37	$86.38	$70.45	$143.74	$123.52
Center-Pivot System Broadcast w/ No Incorporation	$54.82	$52.17	$67.50	$62.70	$118.86	$111.65
Center-Pivot System Broadcast w/ Incorporation	$58.99	$55.06	$71.67	$67.42	$123.03	$117.54
	200 Cow Herd Size					

Table E-3. Total annual economic cost per cow values for a 400-cow herd.

System Type	Transport Distance (miles) 0.5		1.5		4.5	
	P	N	P	N	P	N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$24.79	$24.79	$36.34	$36.34	$83.06	$83.06
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$28.97	$27.14	$40.51	$38.68	$87.24	$85.41
5,000 Gallon Liquid Slurry Tank Injected	$27.45	$27.45	$40.08	$40.08	$91.26	$91.26
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$33.94	$33.94	$43.12	$43.12	$77.47	$77.47
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$38.11	$36.28	$47.29	$45.47	$81.64	$79.78
10,000 Gallon Liquid Slurry Tank Injected	$41.59	$41.59	$52.56	$52.56	$92.77	$92.77
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$70.00	$70.00	$88.98	$88.98	$155.38	$155.38
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$74.17	$72.34	$93.15	$91.33	$159.55	$157.73
5,000 Gallon Liquid Vacuum Tank Injected	$76.20	$76.20	$96.80	$96.80	$168.78	$168.78
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$103.59	$103.59	$122.21	$122.21	$181.16	$181.16
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$107.76	$105.93	$126.38	$124.55	$185.34	$183.51
8,500 Gallon Liquid Vacuum Tank Injected	$122.72	$122.72	$144.29	$144.29	$213.08	$213.08
Drag Hose System	$41.14	$41.14	$48.09	$48.09	$76.68	$76.68
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$53.45	$46.85	$63.17	$55.54	$101.18	$89.87
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$57.63	$50.42	$67.34	$59.34	$105.35	$94.57
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$55.98	$39.51	$66.09	$47.34	$105.53	$78.58
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$60.08	$43.56	$70.26	$51.73	$109.70	$84.30
Center-Pivot System Broadcast w/ No Incorporation	$36.12	$32.55	$43.90	$39.72	$74.97	$68.54
Center-Pivot System Broadcast w/ Incorporation	$40.29	$36.07	$48.07	$43.44	$79.14	$72.99
	400 Cow Herd Size					

Table E-4. Total annual economic cost per cow values for an 800-cow herd.

System Type	Transport Distance (miles)					
	0.5		1.5		4.5	
	P	N	P	N	P	N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$22.78	$22.78	$38.07	$38.07	$103.43	$103.43
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$26.95	$25.13	$39.70	$37.87	$107.60	$105.78
5,000 Gallon Liquid Slurry Tank Injected	$24.77	$24.77	$41.50	$41.50	$112.73	$112.73
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$29.48	$29.48	$41.37	$41.37	$87.50	$87.50
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$33.65	$31.83	$45.54	$43.71	$91.67	$89.85
10,000 Gallon Liquid Slurry Tank Injected	$34.98	$34.98	$48.90	$48.97	$102.78	$102.78
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$82.99	$82.99	$111.93	$111.93	$231.74	$231.74
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$87.17	$85.34	$116.10	$114.28	$235.92	$234.09
5,000 Gallon Liquid Vacuum Tank Injected	$89.67	$89.67	$120.73	$120.73	$247.91	$247.91
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$124.60	$124.60	$152.03	$152.03	$255.27	$255.27
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$128.77	$126.95	$156.20	$154.38	$259.44	$257.62
8,500 Gallon Liquid Vacuum Tank Injected	$144.94	$144.94	$176.38	$176.38	$292.46	$292.46
Drag Hose System	$32.73	$32.73	$37.37	$37.37	$56.74	$56.74
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$48.21	$40.36	$56.67	$47.46	$88.29	$74.38
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$52.39	$43.76	$60.84	$51.05	$92.40	$78.67
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$52.49	$34.08	$61.47	$40.05	$94.92	$63.01
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$56.66	$37.89	$65.64	$44.12	$99.09	$68.07
Center-Pivot System Broadcast w/ No Incorporation	$28.18	$24.68	$33.96	$29.78	$56.21	$49.67
Center-Pivot System Broadcast w/ Incorporation	$32.36	$27.71	$38.13	$32.95	$60.39	$53.29
	800 Cow Herd Size					

Table E-5. Total annual economic cost per cow values for a 2,000-cow herd.

System Type	Transport Distance (miles) 0.5 P	0.5 N	1.5 P	1.5 N	4.5 P	4.5 N
5,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$25.02	$25.02	$49.51	$49.51	$192.07	$192.07
5,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$28.53	$27.30	$52.67	$51.65	$195.22	$194.21
5,000 Gallon Liquid Slurry Tank Injected	$26.93	$26.93	$53.50	$53.50	$204.52	$204.52
10,000 Gallon Liquid Slurry Tank Broadcast w/ No Incorporation	$32.33	$32.33	$49.67	$49.67	$137.28	$137.28
10,000 Gallon Liquid Slurry Tank Broadcast w/ Incorporation	$35.10	$33.56	$52.83	$51.81	$140.44	$139.42
10,000 Gallon Liquid Slurry Tank Injected	$37.13	$37.13	$57.40	$57.40	$156.20	$156.20
5,000 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$141.79	$141.79	$207.64	$207.64	$487.76	$487.76
5,000 Gallon Liquid Vacuum Tank Broadcast w/ Incorporation	$144.77	$143.71	$210.63	$209.57	$490.75	$489.69
5,000 Gallon Liquid Vacuum Tank Injected	$150.46	$150.46	$219.38	$219.38	$510.14	$510.14
8,500 Gallon Liquid Vacuum Tank Broadcast w/ No Incorporation	$220.04	$220.04	$283.62	$283.62	$526.69	$526.69
8,500 Gallon Liquid Vacuum Tank Broadcast w/ Incoporation	$223.02	$221.96	$286.96	$285.55	$529.67	$528.61
8,500 Gallon Liquid Vacuum Tank Injected	$246.24	$246.24	$315.46	$315.46	$577.23	$577.23
Drag Hose System	$29.99	$29.99	$34.16	$34.16	$50.03	$50.03
Big Gun Hard Hose Traveler Broadcast w/ No Incorporation	$50.57	$40.65	$60.00	$48.12	$93.32	$74.80
Big Gun Hard Hose Traveler Broadcast w/ Incorporation	$53.89	$43.86	$63.32	$51.53	$96.64	$78.90
Big Gun Soft Hose Traveler Broadcast w/ No Incorporation	$52.88	$32.50	$63.06	$38.17	$98.97	$59.28
Big Gun Soft Hose Traveler Broadcast w/ Incorporation	$56.19	$36.12	$66.38	$42.02	$102.29	$64.04
Center-Pivot System Broadcast w/ No Incorporation	$26.55	$22.47	$32.06	$27.06	$52.06	$43.87
Center-Pivot System Broadcast w/ Incorporation	$29.49	$25.01	$35.44	$29.75	$55.44	$47.08
	2000 Cow Herd Size					

APPENDIX F

COST PER GALLON VALUES

Table F-1. 5,000 LST cost per gallon values.

5,000 Gallon Liquid Slurry Tank ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.005987	$0.005987	$0.006167	$0.006307	$0.007146	$0.007146
200	$0.002425	$0.002425	$0.002605	$0.002745	$0.002745	$0.002745
400	$0.001898	$0.001898	$0.002077	$0.002217	$0.002101	$0.002101
800	$0.001744	$0.001744	$0.001923	$0.002063	$0.001896	$0.001896
2000	$0.001915	$0.001915	$0.002089	$0.002184	$0.020610	$0.020610

5,000 Gallon Liquid Slurry Tank ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.006619	$0.006619	$0.007088	$0.007227	$0.007813	$0.007813
200	$0.003165	$0.003165	$0.003345	$0.003485	$0.003559	$0.003559
400	$0.002781	$0.002781	$0.002961	$0.003100	$0.003068	$0.003068
800	$0.002914	$0.002914	$0.002899	$0.003039	$0.003176	$0.003176
2000	$0.003789	$0.003789	$0.003953	$0.004031	$0.004094	$0.004094

5,000 Gallon Liquid Slurry Tank ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.008643	$0.008643	$0.008823	$0.008963	$0.009987	$0.009987
200	$0.005894	$0.005894	$0.006073	$0.006213	$0.006545	$0.006545
400	$0.006358	$0.006358	$0.006537	$0.006677	$0.006985	$0.006985
800	$0.007917	$0.007917	$0.008096	$0.008236	$0.008628	$0.008628
2000	$0.014699	$0.014699	$0.014862	$0.014940	$0.015651	$0.015651

Table F-2. 10,000 gallon LST cost per gallon values.

10,000 Gallon Liquid Slurry Tank ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.009740	$0.009740	$0.009920	$0.010060	$0.013488	$0.013488
200	$0.003549	$0.003549	$0.003729	$0.003869	$0.004580	$0.004580
400	$0.002597	$0.002597	$0.002777	$0.002917	$0.003183	$0.003183
800	$0.002256	$0.002256	$0.002436	$0.002576	$0.002677	$0.002677
2000	$0.002474	$0.002474	$0.002568	$0.002686	$0.002842	$0.002842

10,000 Gallon Liquid Slurry Tank ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.010266	$0.010266	$0.010445	$0.010585	$0.014054	$0.014054
200	$0.004149	$0.004149	$0.004329	$0.004468	$0.005266	$0.005266
400	$0.003301	$0.003301	$0.003480	$0.003620	$0.004023	$0.004023
800	$0.003166	$0.003166	$0.003346	$0.003485	$0.003742	$0.003742
2000	$0.003801	$0.003801	$0.003965	$0.004043	$0.004393	$0.004393

10,000 Gallon Liquid Slurry Tank ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.011898	$0.011898	$0.012077	$0.012217	$0.015881	$0.015881
200	$0.006208	$0.006208	$0.006588	$0.006528	$0.007667	$0.007667
400	$0.005929	$0.005929	$0.006106	$0.006249	$0.007101	$0.007101
800	$0.006697	$0.006697	$0.006877	$0.007016	$0.007867	$0.007867
2000	$0.010506	$0.010506	$0.010670	$0.010748	$0.011954	$0.011954

Table F-3. 5,000 gallon LVT cost per gallon values.

5,000 Gallon Liquid Vacuum Tank ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.008328	$0.008328	$0.008564	$0.008648	$0.009605	$0.009605
200	$0.005165	$0.005165	$0.005344	$0.005484	$0.005700	$0.005700
400	$0.005357	$0.005357	$0.005537	$0.005677	$0.005832	$0.005832
800	$0.006352	$0.006352	$0.006532	$0.006672	$0.006863	$0.006863
2000	$0.010851	$0.010851	$0.010998	$0.011079	$0.011514	$0.011514

5,000 Gallon Liquid VacuumTank ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.009037	$0.009037	$0.009216	$0.009356	$0.010367	$0.010367
200	$0.006214	$0.006214	$0.006393	$0.006533	$0.006843	$0.006843
400	$0.006811	$0.006811	$0.006990	$0.007130	$0.007409	$0.007409
800	$0.008567	$0.008567	$0.008747	$0.008886	$0.009240	$0.009240
2000	$0.015891	$0.015891	$0.016038	$0.016119	$0.016789	$0.016789

5,000 Gallon Liquid Vacuum Tank ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.011315	$0.011315	$0.011495	$0.011635	$0.012832	$0.012832
200	$0.009954	$0.009954	$0.010153	$0.010274	$0.010908	$0.010908
400	$0.011893	$0.011893	$0.012072	$0.012212	$0.012918	$0.012918
800	$0.017737	$0.017737	$0.017917	$0.018057	$0.018975	$0.018975
2000	$0.037328	$0.037328	$0.037457	$0.037556	$0.039041	$0.039041

Table F-4. 8,500 gallon LVT cost per gallon values.

8,500 Gallon Liquid Vacuum Tank ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.012922	$0.012922	$0.013102	$0.013241	$0.017034	$0.017034
200	$0.007643	$0.007643	$0.007823	$0.007962	$0.009324	$0.009324
400	$0.007929	$0.007929	$0.008108	$0.008248	$0.009393	$0.009393
800	$0.009537	$0.009537	$0.009717	$0.009856	$0.011093	$0.011093
2000	$0.016840	$0.016840	$0.016987	$0.017068	$0.018845	$0.018845

8,500 Gallon Liquid VacuumTank ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.013577	$0.013577	$0.013756	$0.013896	$0.017786	$0.017786
200	$0.008629	$0.008629	$0.008809	$0.008948	$0.010481	$0.010481
400	$0.009354	$0.009354	$0.009533	$0.009673	$0.011044	$0.011044
800	$0.011636	$0.011636	$0.011816	$0.011956	$0.013492	$0.013492
2000	$0.021705	$0.021705	$0.021853	$0.021961	$0.024142	$0.024142

8,500 Gallon Liquid Vacuum Tank ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.015659	$0.015659	$0.015838	$0.015978	$0.020204	$0.020204
200	$0.011969	$0.011969	$0.012148	$0.012288	$0.014389	$0.014389
400	$0.013866	$0.013866	$0.014046	$0.014185	$0.016309	$0.016309
800	$0.019538	$0.019538	$0.019718	$0.019857	$0.022385	$0.022385
2000	$0.040307	$0.040307	$0.040454	$0.040536	$0.044175	$0.044175

Table F-5. Drag hose system cost per gallon values.

Drag Hose System ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	NA	NA	NA	NA	$0.014301	$0.014301
200	NA	NA	NA	NA	$0.004661	$0.004661
400	NA	NA	NA	NA	$0.003149	$0.003149
800	NA	NA	NA	NA	$0.002505	$0.002505
2000	NA	NA	NA	NA	$0.002295	$0.002295

Drag Hose System ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	NA	NA	NA	NA	$0.017607	$0.017607
200	NA	NA	NA	NA	$0.005569	$0.005569
400	NA	NA	NA	NA	$0.003680	$0.003680
800	NA	NA	NA	NA	$0.002860	$0.002860
2000	NA	NA	NA	NA	$0.002614	$0.002614

Drag Hose System ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	NA	NA	NA	NA	$0.631182	$0.631182
200	NA	NA	NA	NA	$0.009323	$0.009323
400	NA	NA	NA	NA	$0.005869	$0.005869
800	NA	NA	NA	NA	$0.004343	$0.004343
2000	NA	NA	NA	NA	$0.003829	$0.003829

Table F-6. BGHH system cost per gallon values.

Big Gun Hard Hose System ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.014055	$0.014431	$0.014602	$0.014750	NA	NA
200	$0.004948	$0.005389	$0.005257	$0.005708	NA	NA
400	$0.003586	$0.004091	$0.003859	$0.004411	NA	NA
800	$0.003089	$0.003690	$0.003350	$0.004010	NA	NA
2000	$0.003111	$0.003870	$0.003357	$0.004124	NA	NA

Big Gun Hard Hose System ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.017422	$0.017836	$0.018058	$0.018155	NA	NA
200	$0.005958	$0.006458	$0.006294	$0.006778	NA	NA
400	$0.004251	$0.004835	$0.004542	$0.005154	NA	NA
800	$0.003632	$0.004337	$0.003907	$0.004657	NA	NA
2000	$0.003683	$0.004592	$0.003944	$0.004846	NA	NA

Big Gun Hard Hose System ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.031109	$0.031682	$0.032102	$0.032002	NA	NA
200	$0.010040	$0.010763	$0.010483	$0.011083	NA	NA
400	$0.006879	$0.007744	$0.007238	$0.008063	NA	NA
800	$0.005693	$0.006758	$0.006021	$0.007077	NA	NA
2000	$0.005724	$0.007142	$0.006038	$0.007396	NA	NA

Table F-7. BGSH system cost per gallon values.

Big Gun Soft Hose System ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.010561	$0.011615	$0.011195	$0.011934	NA	NA
200	$0.004038	$0.005200	$0.004391	$0.005519	NA	NA
400	$0.003024	$0.004285	$0.003334	$0.004604	NA	NA
800	$0.002608	$0.004018	$0.002900	$0.004337	NA	NA
2000	$0.002488	$0.004047	$0.002764	$0.004300	NA	NA

Big Gun Soft Hose System ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.013903	$0.015033	$0.014681	$0.015352	NA	NA
200	$0.004998	$0.006292	$0.005392	$0.006612	NA	NA
400	$0.003624	$0.005058	$0.003959	$0.005378	NA	NA
800	$0.003065	$0.004705	$0.003377	$0.005024	NA	NA
2000	$0.002921	$0.004826	$0.003216	$0.005080	NA	NA

Big Gun Soft Hose System ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.027479	$0.028936	$0.028840	$0.029255	NA	NA
200	$0.008892	$0.010683	$0.009454	$0.011002	NA	NA
400	$0.006014	$0.008077	$0.006453	$0.008396	NA	NA
800	$0.004823	$0.007265	$0.005210	$0.007584	NA	NA
2000	$0.004537	$0.007574	$0.004901	$0.007828	NA	NA

Table F-8. Center-pivot system cost per gallon values.

Center-Pivot System ($/gal) values 0.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.012320	$0.012727	$0.012279	$0.013046	NA	NA
200	$0.003877	$0.004196	$0.004214	$0.004513	NA	NA
400	$0.002491	$0.002764	$0.002761	$0.003683	NA	NA
800	$0.001889	$0.002157	$0.002121	$0.002476	NA	NA
2000	$0.001720	$0.002032	$0.001914	$0.002257	NA	NA

Center-Pivot System ($/gal) values 1.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.015992	$0.016178	$0.015860	$0.016497	NA	NA
200	$0.004799	$0.005166	$0.005160	$0.005485	NA	NA
400	$0.003040	$0.003360	$0.003325	$0.003680	NA	NA
800	$0.002280	$0.002599	$0.002522	$0.002918	NA	NA
2000	$0.002071	$0.002454	$0.002277	$0.002713	NA	NA

Center-Pivot System ($/gal) values 4.5-mile transport distance						
Application Method	No Incorporation		Incorporated		Injected	
Limiting Nutrient	N	P	N	P	N	P
Herd Size						
50	$0.030918	$0.030213	$0.030425	$0.030532	NA	NA
200	$0.008545	$0.009097	$0.008997	$0.009417	NA	NA
400	$0.005246	$0.005738	$0.005587	$0.006057	NA	NA
800	$0.003802	$0.004303	$0.004079	$0.004622	NA	NA
2000	$0.003358	$0.003984	$0.003603	$0.004243	NA	NA

APPENDIX G

TOTAL ANNUAL ECONOMIC SYSTEM COST COMPARISONS

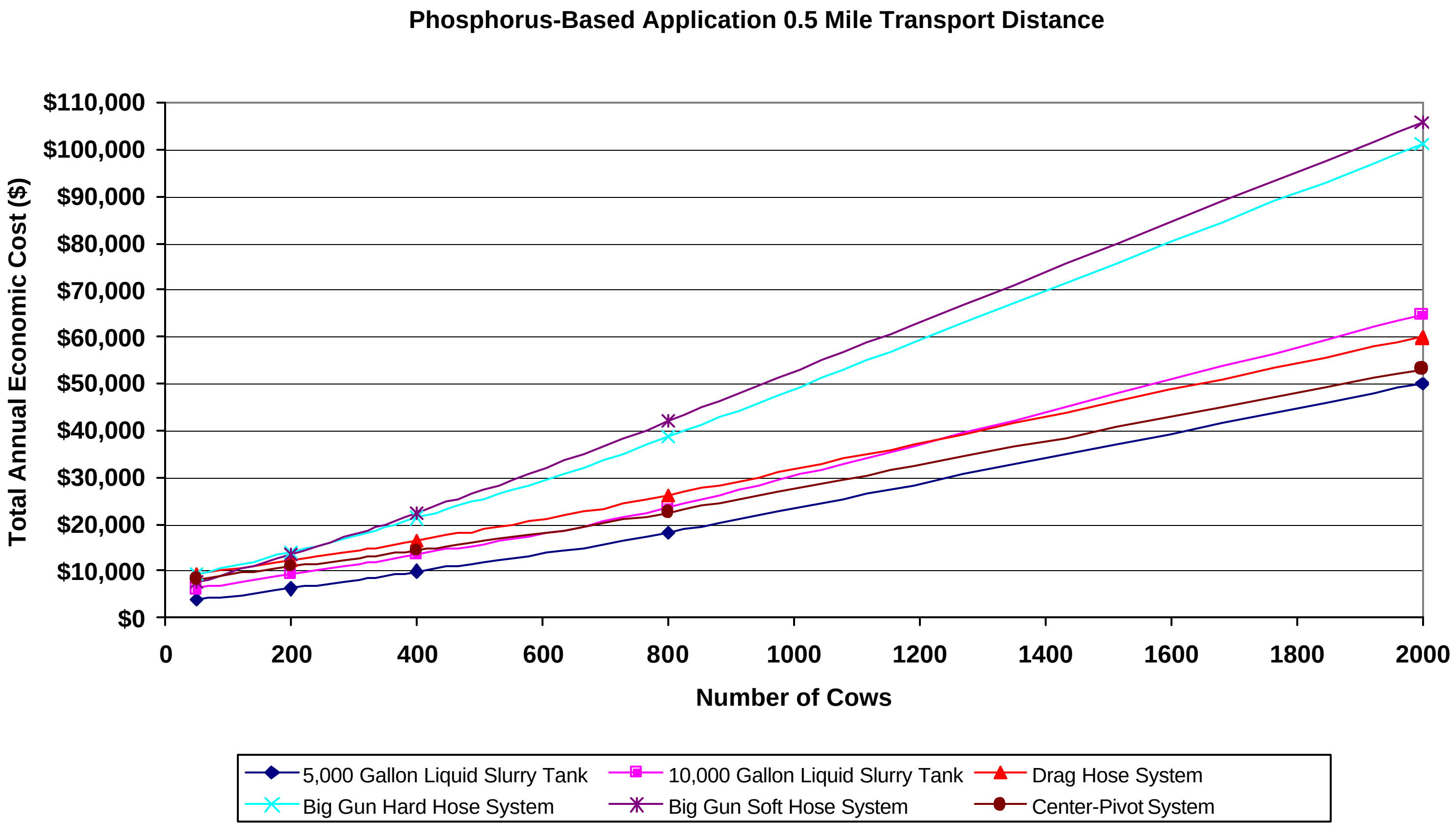

Figure G-1. Total annual economic cost comparison phosphorus-based application, 0.5-mile transport distance.

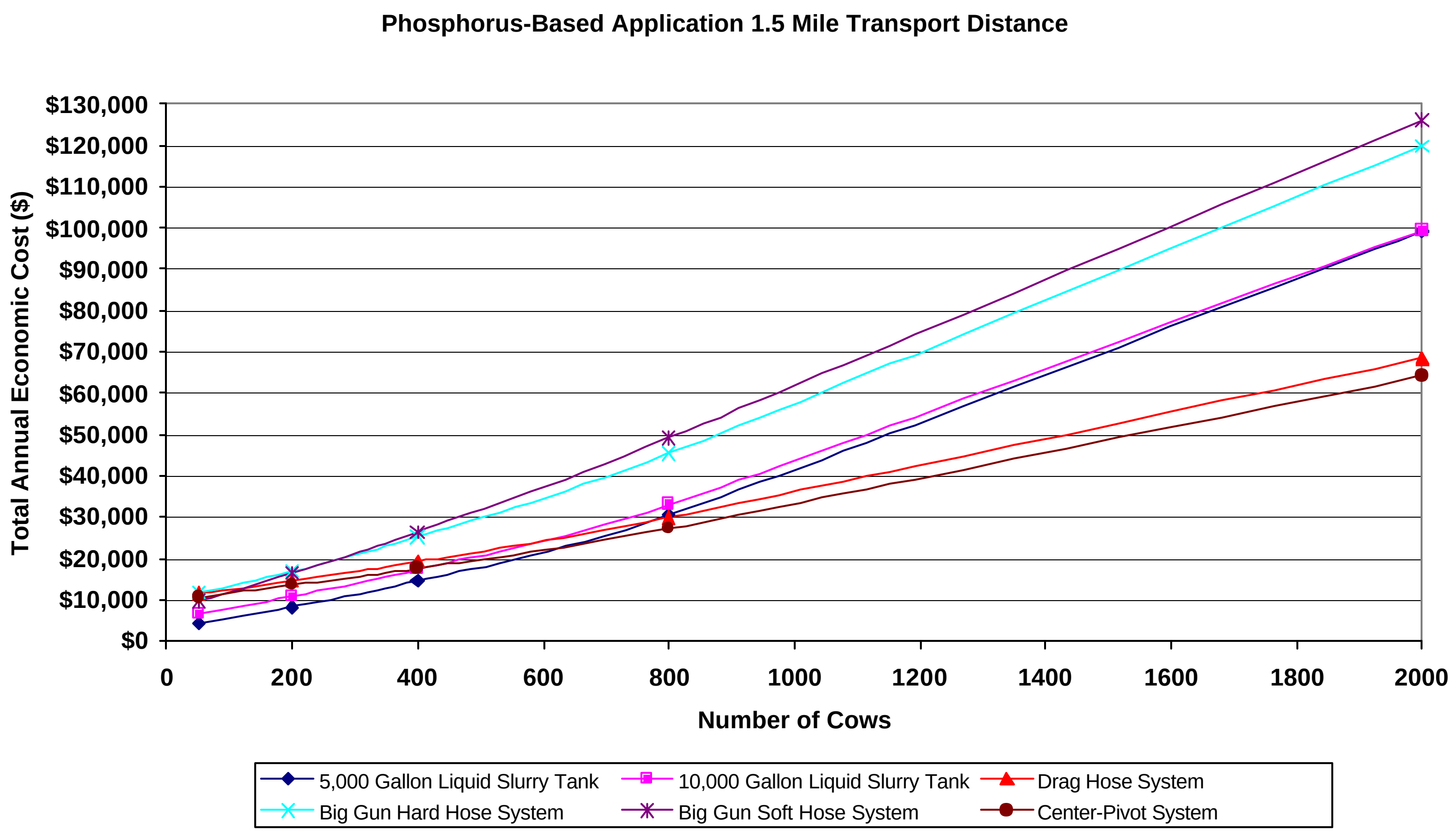

Figure G-2. Total annual economic cost comparison phosphorus-based application, 1.5-mile transport distance.

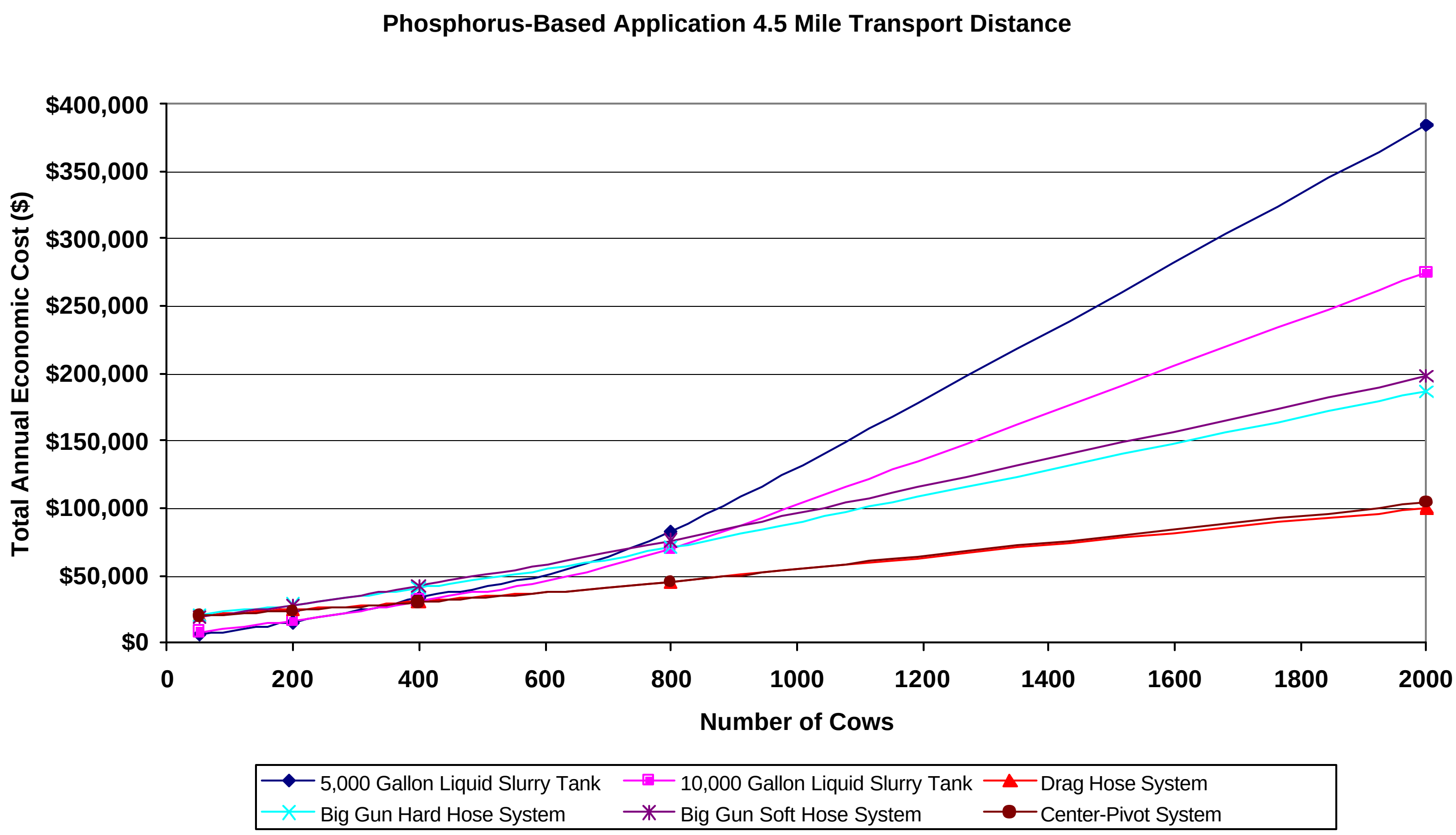

Figure G-3. Total annual economic cost comparison phosphorus-based application, 4.5-mile transport distance.

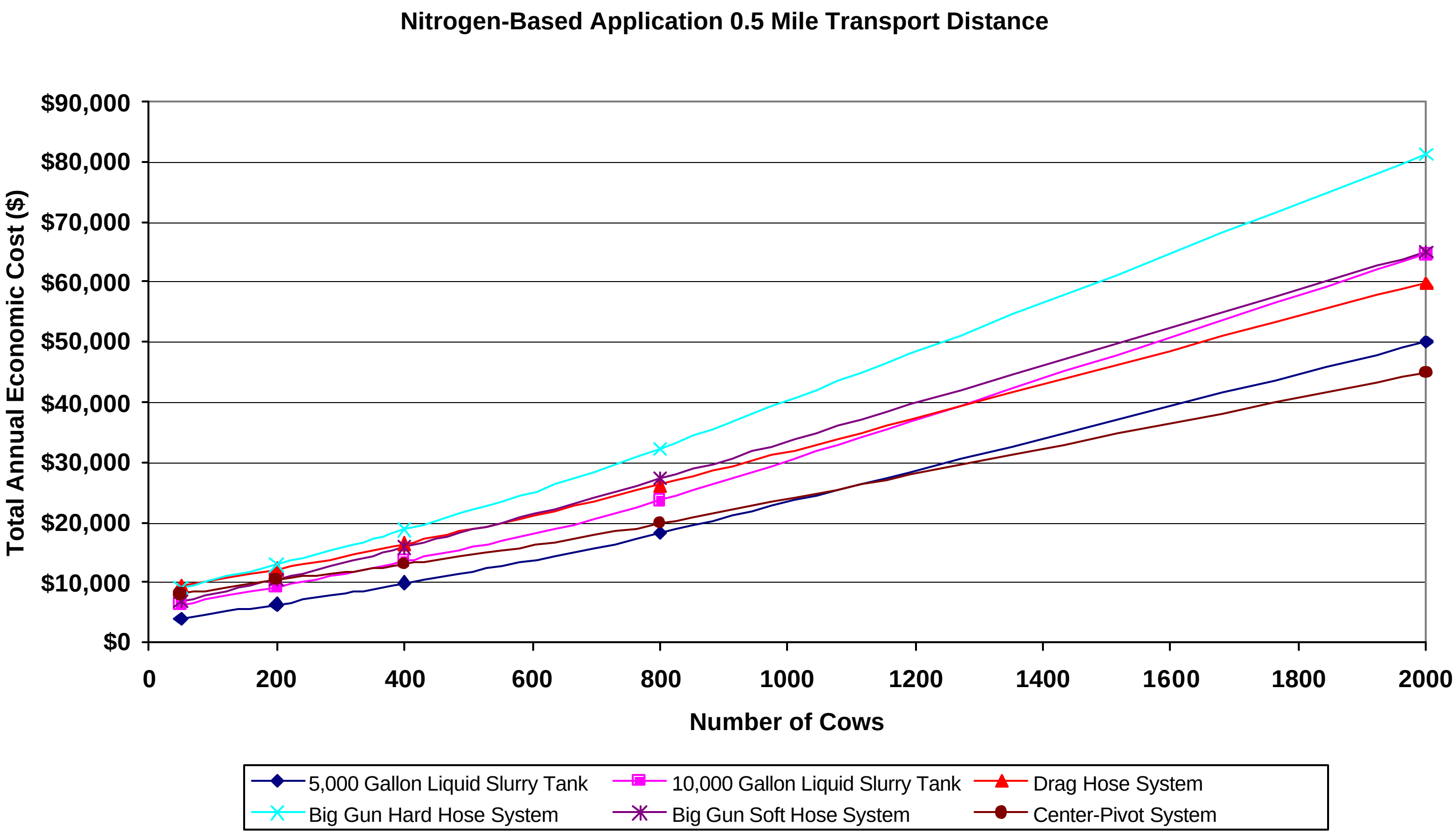

Figure G-4. Total annual economic cost comparison nitrogen-based application, 0.5-mile transport distance.

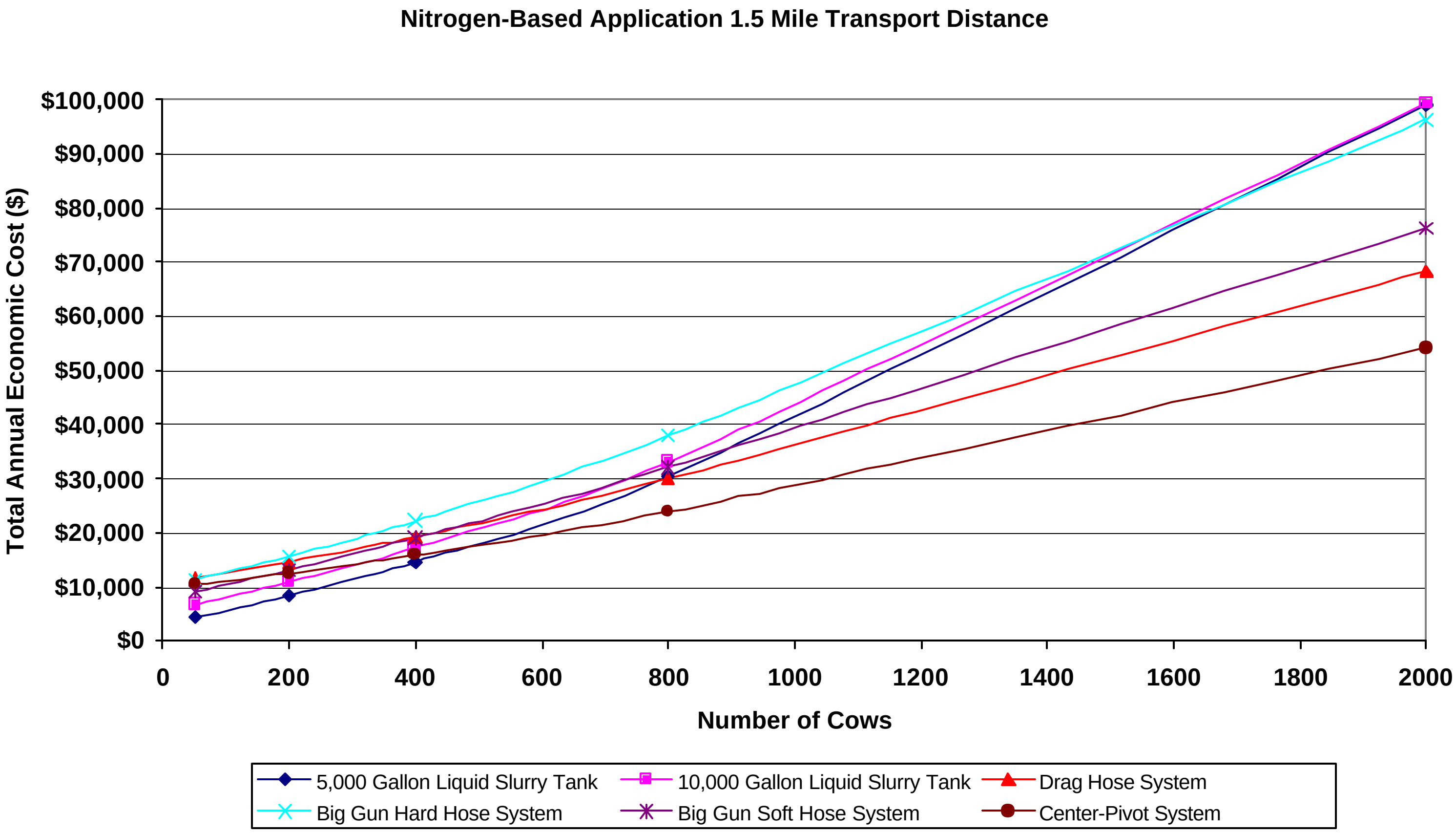

Figure G-5. Total annual economic cost comparison nitrogen-based application, 1.5-mile transport distance.

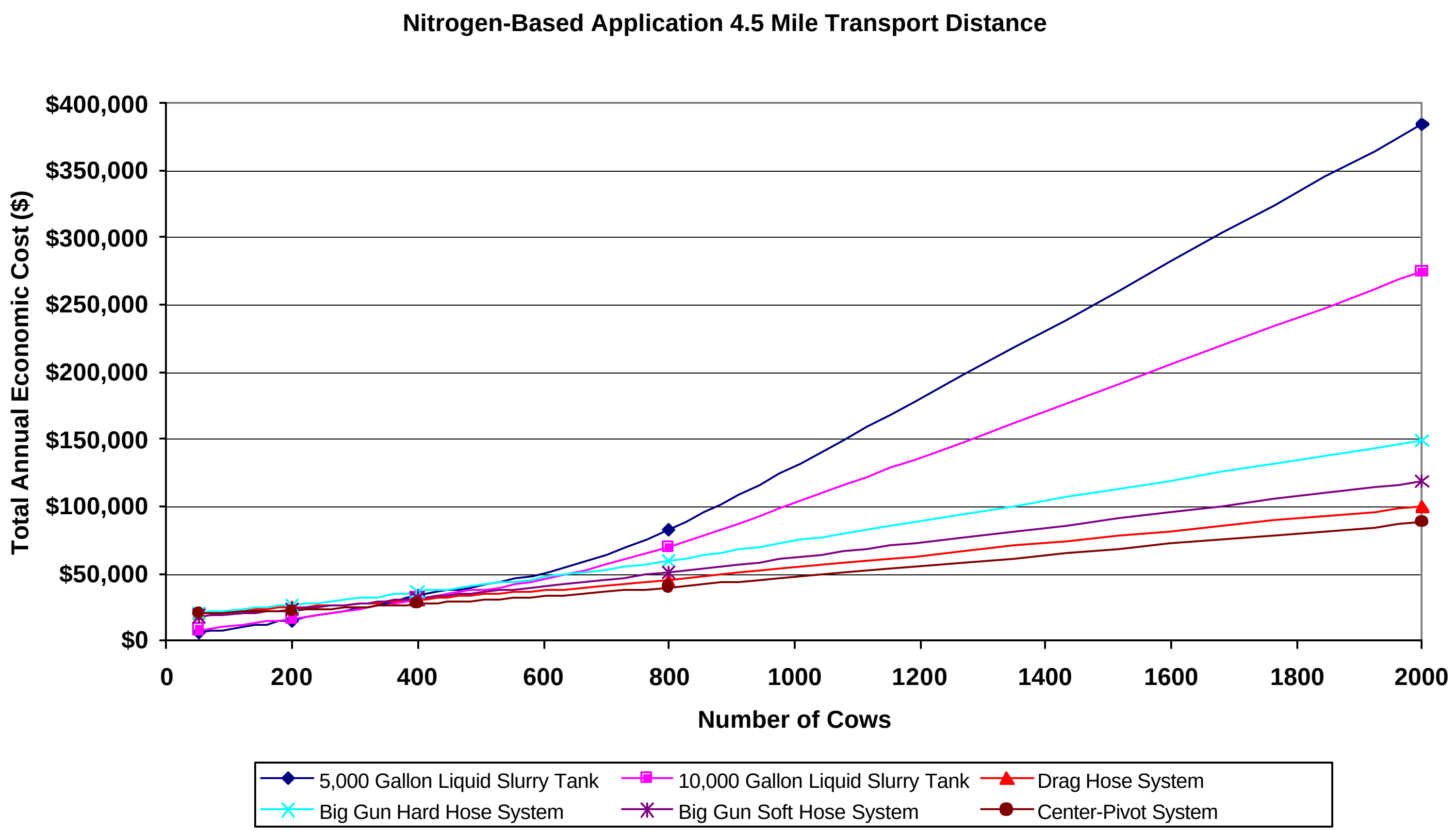

Figure G-6. Total annual economic cost comparison nitrogen-based application, 4.5-mile transport distance.

VITA

Adam Shane Daugherty was born on February 16, 1977 in Crossville, Tennessee. After graduation from Cumberland County High School in Crossville, Tennessee in 1995, he entered Tennessee Technological University in Cookeville, Tennessee and received a B.S. degree in Agriculture with a major in Environmental Agriscience in May, 1999. The following August he entered graduate school at The University of Tennessee, Knoxville. In December 2001, he received a M.S. degree in Biosystems Engineering Technology.