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ECONOMIC AND TECHNICAL EVALUATIONS OF SWINE MANURE MANAGEMENT SYSTEMS WHICH USE LAND APPLICATION

by

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ABSTRACT

The trend towards more and larger confinement swine production operations has meant that larger quantities of localized manure have to be dissipated in cost-efficient and environmentally acceptable ways. Land application of the manure to agricultural crops represents an excellent manure utilization scheme as well as sound environmental management when application rates are based on crop nutrient requirements. Evaluations of which manure management alternatives for storage, treatment, handling and land applications are best for particular situations depend upon several factors, such as ease of management, labor constraints, capital available, land and crops available, and environmental considerations. Collection of waste management technical data and evaluation of the economics of the various feasible alternative manure management systems were the major objectives of this project.

In this study, the major facilities, treatment, and land application options for liquid swine manure were identified and investment and operating costs were estimated. A mathematical integer linear programming model was developed to estimate costs of manure management systems and to determine which of the systems was the optimal or least-cost system. Also, subsidiary models were developed to compute various technical and cost coefficients for use in the main model. Examples include the model for calculating the time and labor requirements for spreading liquid manure with a tank wagon, and the model for determining the nutrients made available by manure applications at various times and rates.

Technical and cost (1978 rates) information are presented in tables and the optimization model (integer linear programming model) is described, but only a small number of analyses using the model is presented.

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SUMMARY AND CONCLUSIONS

Technical and cost data for the major facilities, treatments, and land application options for liquid swine manure were tabulated for use in economic evaluations of the various options. The three types of swine production operations which were considered were: (1) the feeder pig finishing operation, (2) the feeder pig production operation, and (3) the farrow to finish operation. Housing flooring and storage pit costs and manure production were estimated for these major types of operations. Other major factors which were evaluated were liquid manure transport by tank wagon and irrigation systems, lagoon treatment, and manure value for crop nutrients when applied at various times and rates.

Much of the technical data and cost estimates were obtained from straightforward computations, but many assumptions were used in making estimates of some data. Using different assumptions could possibly change some of the results of the analyses, but based upon cost comparisons of specific system components for various sizes of operations, some of the major conclusions for specific components are:

(1) Flooring and in-house pits: Any operation which hauls liquid manure will require some minimum level of storage for convenience, but additional storage would not be worthwhile. The preferred depth of storage pit is three feet, and the preferred floor is totally slatted floor because of lower labor costs for cleaning. For operations using a lagoon, the preferred flooring type is also totally slatted floor with periodic flushing to the lagoon.

(2) Soil injector: Injection of manure to conserve nutrients is economically advantageous for large operations but not for small ones. The break-even sizes are about 30,000 to 60,000 lbs liveweight, depending upon the type of swine operation.

(3) Tank wagons: The optimal size of tank wagon increases as the operation size increases. The changeover points for increasing tank size depend critically on the wash water dilution that occurs in the house.

(4) Lagoons: Mechanically aerated and naturally facultative lagoons are not economically attractive. The optimal size of anaerobic lagoon depends on the crop utilization potential, the irrigation scheme needed and the lagoon construction cost, but a medium-loaded lagoon (100 ft^3/100 lbs liveweight) is probably most economical in the Coastal Plains and the Piedmont.

(5) Irrigation system: The size of the operation, criterion for determining effluent application rates to available land and crops, and the lagoon loading rate influence which type of irrigation system is most economical. In general, a portable system is best if less than 35 ac are needed for effluent application. Although labor-costs tend to shift choices toward a travelling big gun system, the labor involved with irrigation for manure management is small compared to normal irrigation situations because the number of applications made to each acre are so few. Also, the pumping rate

capacity of irrigation equipment used just for lagoon effluent irrigation can be lower than normal irrigation rates because of the relatively small volumes of effluent that have to be irrigated.

(6) Manure value: The amount of manure nitrogen available for crop uptake is often only 40 to 50 percent of the potential value of manure nitrogen because of storage losses, application losses, leaching losses, and unavailability of some portion of organic nitrogen. Also, when application rates are based on nitrogen, excess amounts of phosphorus and potassium are applied relative to normal crop fertilization. If lagoon treatment is used, only 10 to 15 percent of the original potential nutrient value of manure may be recovered. To recover a higher percent, other costs such as storage or land diversion are incurred, and these will usually exceed the value of the additional nutrient recovery.

(7) Manure application rates: For tank wagons, the transportation costs are fairly small. Thus, it will generally pay to apply at rates for normal crop fertilization instead of at excessive rates. The incentives for excessive applications are where land is limited or where land diversion away from the most profitable crop would be required. The economic application rates will often be those meeting any one or two (out of three) nutrient needs, even for operations as large as 400,000 lbs liveweight. For an irrigation system, the economic rates of application are generally those meeting two or all three of the nutrient needs. Diversion costs could tend to encourage excessive applications, but because diversion costs per acre are usually small, and because lagoon storage permits storage for several months, this incentive is small.

The above conclusions apply to specific components of waste management systems, but in order to compare alternative systems for hog operations, the various systems and system components should be evaluated in an optimization model. A mathematical integer linear programming model was developed to determine costs of the various manure management systems and the returns from various cropping and application schedule alternatives, and to choose the optimal or least-cost system. The programming model was used to evaluate only a small number of analyses, but such a model could efficiently evaluate hundreds of alternatives. Based upon the small number of analyses which were conducted, the following conclusions resulted:

(1) The cost-estimates suggest that almost all operations should use a lagoon and irrigation in preference to hauling manure with tank wagons. A large operation greater than 200,000 lbs liveweight with little dilution of the raw manure could have a cost advantage for using tank wagons, but it would be small, about 4 cents/100 lbs liveweight marketed, and would often be considered insignificant to the advantages of lagoons such as added flexibility and less frequent labor needs. As a general recommendation, all totally roofed hog operations in North Carolina should, if given the choice of flooring type and manure disposal facilities, choose a totally slatted floor and a lagoon-irrigation system, the latter most commonly being a portable conventional sprinkler line system.

The costs of manure disposal using this optimal arrangement are only 7 to 28 cents per 100 lbs liveweight marketed.

(2) The important aspect of the manure disposal decision problem is the opportunity costs of making the wrong decision. Although the waste management cost of a good system is a relatively minor cost in terms of the total costs of producing 100 lbs liveweight of hog for market, choosing the wrong system or using a system inappropriately could cause costs to increase to 70 to 80 cents per 100 lbs liveweight marketed.

RECOMMENDATIONS

1. Efforts should continue to improve technical and cost information for swine manure management systems. More research data is needed on nutrient losses for various lagoon types and management schemes and on nutrient losses during storage and land application. Also, the organic nitrogen availability rate and nitrogen leaching losses should be better identified. Better information on the amounts of nutrient losses are needed not only for the economics, but also to evaluate possible environmental impact on water quality.

2. More cost comparisons for alternative systems should be made. The type of optimization model developed in this project has much potential but only a few analyses were conducted in this study. Further sensitivity analysis of the model to various factors should also be conducted.

3. The environmental costs of some decisions must be included to fully evaluate the alternatives. For example, with inadequate land for applying manure nutrients at normal crop fertilization rates, the choice is to buy more land or to apply nutrients at excessive rates, the environmental cost of which is difficult to assess.

4. Technical and costs data should be obtained and economic comparisons of manure management systems for other livestock and poultry systems should be conducted in order that livestock and poultry producers can adequately evaluate the alternatives available for manure management, and also to realize the opportunity costs of choosing a poor system or using a system inappropriately. The opportunity costs of wasting nutrients particularly needs further evaluation.

1. The Economic Problem of Swine Manure Management

1.1 General Perspectives

Since the advent of readily available, easily applied, cheap commercial fertilizer, animal manure has generally been considered to be a waste product to be disposed of as cheaply as possible. Often, disposal has been synonymous with direct discharge into a stream. Three trends have necessitated a reappraisal of the manure disposal question. First, the trend towards more and larger confinement animal production operations, including swine, has meant that larger quantities of more localized manure have to be dissipated. Extensive research indicates that hogs produce manure at a rate of 1 U.S. gal./100 lbs liveweight/day, approximately, so that a hog operation carrying 100,000 lbs liveweight on the average will produce about 365,000 gal. of raw liquid manure per year. Practical experience as reported by George (1975) suggests this volume may be increased from 2 to 8 fold through leaky waterers and shed cleaning operations. The operation carrying 100,000 lbs liveweight may have to dissipate as much as 1,470 tons of liquid manure per year, or 4 tons per day.

The second significant trend is the public's growing environmental awareness, and concern. The developing, and changing, preferences of society have been towards a cleaner environment. Consequently, the social costs of stream disposal, and other uncontrolled forms of disposal, have risen significantly compared to the private costs incurred by the producer to the point where governmental regulations have been introduced to control manure disposal.

A third trend has been the move towards conservation of energy, born largely of the rapid rise in oil prices in 1973. The repercussions of the oil price rise included rises in prices of other energy sources. Commercial fertilizer prices were not exempt, and although they have declined from a peak in 1975, they remain higher than they had been for many years. The higher prices, and an awareness of the possibility of energy shortages have contributed to a reassessment of the manure disposal question.

Manure can no longer be cursorily dismissed as waste. Its economic potential as an energy and biological food source must be considered. In this volume, the writer reports on an attempt to analyze one aspect of the economics of manure utilization, namely choosing economical, socially acceptable methods of land application of manure produced in confinement hog operations.

1.2 General Objectives of the Analysis

An obvious means of dissipating manure is to recycle it by application to land as was the practice prior to the widespread usage of commercial fertilizer. Manure supplies substantial amounts of the primary plant nutrients nitrogen (N), phosphorus (P), and potassium (K), and significant quantities of trace minerals. Additionally, it provides soil organic matter which contributes to improved tilth, structure, water holding capacity, and general soil condition. The disadvantages of dissipating manure by land

application lie in the potential for build-up of soil salt, pathogen, and metal concentrations, the potential for pollution of streams through runoff and leaching, the potential for malodors, and high labor and operating costs.

Alternatives to land application include recycling the manure as a nutrient source in various biological systems. Manure can be refed to hogs, or to other mammals, to fish, to algae, or to more advanced aquatic plants. Prior to disposal, the manure can be treated in a variety of ways, either to deliberately extract some useful product, e.g., methane gas, or to aid in dissipating potentially troublesome elements, e.g., N.

Despite the numerous alternatives, and combinations of alternatives, decisions at the swine producer level have to be made between alternatives which are currently feasible and practical. For most confinement hog production operations, the only option is to install facilities for land application of manure. Lack of knowledge, at the scientific and engineering levels as well as at the production level, precludes the widespread adoption of more novel technology at this time. There are still many decisions to be made by the producer even when the only option is to apply the manure to land. Decisions have to be made about storage, handling, treatment, and methods, rates and times of applications. It is towards these decisions that this study is oriented, with the overall aim being to provide meaningful economic information to assist the hog producer in making decisions about land application based manure handling facilities and practices. Basic objectives of the study are:

(1) to identify the major facilities, treatments, and application options for liquid manure; and, where relevant, to provide estimates of the investment and operating costs of these items;

(2) to determine the optimal facilities for land application of manure, and the ideal use of those facilities, for important categories of North Carolina confinement hog production operations;

(3) to estimate the costs of dissipating swine manure in a socially acceptable way; and to identify differences in costs between alternative hog production operations and sizes of operation;

(4) to investigate the economic sensitivity of decisions relating to manure dissipation.

In pursuing these objectives, valuable information is generated to aid both hog producers in making decisions about manure dissipation, and researchers engaged in manure disposal studies in deciding on directions for future research.

1.3 Methodology

Manure management is but one component of the management system for a hog production operation. Decisions made in the former necessarily affect those in the latter; and vice versa. To this extent, a whole-farm systems approach is needed in analyzing the manure dissipation problem. Interactions between flooring type, cleaning practices and rate of bodyweight gain, or feeding rations and manure composition could then be studied. However, recognizing the infinite complexity of the real world, and the necessity to curtail the analysis at some point, the present study concentrates on the question of what to do with the manure that is produced by a confinement hog operation. The supply side of the manure question is ignored beyond recognizing that some differences in manure concentration and volume occur with different types of hog operations and differences in shed construction and cleaning practices.

Since the emphasis in this study is on helping and advising hog producers about manure dissipation decisions, a normative decision analysis is constructed and manipulated to yield optimal decisions by synthesis. An alternative, descriptive mode of analysis, based on surveys of existing manure dissipation systems was deemed unsuitable because it would serve only to describe what is done on farms, not what should be done.

The main model used is a mathematical programming model, in which linear equations are used to represent engineering and economic reality. Models of this type enable many alternative facilities, and their modes of usage, to be efficiently examined and compared to yield an optimal system of manure dissipation. Unnecessary isolation of the manure management system and excessive predetermination of decisions can thus be avoided.

In addition to the main model, several smaller subsidiary models are used to compute various cost and technical coefficients for use in the main model. Examples include the model for calculating the time and labor requirements for spreading liquid manure with a tank wagon, and the model for determining the nutrients made available by a manure application.

The relationships incorporated in the model are mainly technical ones, defining the restrictions on the hog producer in the pursuit of his goals. It is assumed that the hog producer is profit motivated, desiring to minimize the net cost of manure dissipation, or equivalently, to maximize the net returns to manure and his management of it. The producer is assumed to be a price taker for his inputs and outputs. That is, the supply and demand curves that the individual producer faces are assumed to be perfectly elastic. For many goods, e.g., corn seed, this assumption is very reasonable. For others, e.g., an hour of corn planter operation, it may be questioned. For machinery, there is often a fixed cost component (e.g., depreciation) independent of annual hours of use. Machinery costs would be independent of the total annual usage of the machine in manure dissipation activities if the producer only hired the services of the machine in a perfectly competitive market, rather than owning his own

machine, and would be approximately independent if the producer engaged in a large commercial farming operation in addition to his manure dissipation program. Details of prices and cost calculations are given later.

A major problem in an economic analysis of waste management is the divergence of the social costs and private costs of waste management practices. For the policy maker, the problem seems more complex than many other externality problems, because the externalities associated with manure dissipation are multi-dimensional stream pollution, ground water pollution, potential destruction of a land resource, odors, and health effects. Some of these effects are difficult to quantify. Moreover, the extent of the externalities is highly variable, depending on the weather - rainfall, wind direction, atmospheric conditions. With the multiple dimensions, the variability and the difficulty of measuring the effects, how is a policy making body to impose taxes or subsidies to control pollution or to sell rights to pollute, or to define acceptable practices? Although economists would generally prefer to impose taxes to induce the polluter to switch to more socially acceptable practices or to create a market for pollution rights, the complexity of the manure dissipation problem would seem to necessitate the use of broad regulations instead, with individual cases of pollution being treated separately in greater detail on their own demerits.

Current regulations emanate from the Agricultural and Consumers Protection Act (1973), and from Public Law 92-500. Provisions for feedlot operations in the latter are implemented by the Environmental Protection Agency through its regulations for the National Pollutent Discharge Elimination System as published in the Federal Register (1976). In essence, these regulations require that a hog producer obtain a permit if they both (a) operate a concentrated animal feeding operation in which animals are confined at such densities for 45 days or more in any 12 months so as to prevent normal plant growth, and (b) have either 2500 hogs capacity and discharge pollutants, or 750 hogs capacity and discharge pollutants directly to streams, provided that these discharges occur in cases other than in a 25-year, 24-hour storm or greater storm event. Permits may also be required for smaller operations if on-site field inspection by appropriate officers suggests the need for a permit.

Acceptable practices are loosely identified in the present study. By forcing all manure to be dissipated (ultimately) through land application, direct stream discharge is prevented. With regard to land application, different options considered provide differing amounts of odor control. Similarly, different pretreatments affect odor levels. Although these odor effects are not quantified, or explicitly considered in the analysis, estimates are made of the costs of various practices, and these could be interpreted as some guide in the costs of odor control. The benefits of that control are not assessed. Finally, there are many possible rates and times at which manure could be applied to land. Not all of these would be

environmentally acceptable, although what is acceptable has not yet been defined by environmental scientists. In the analysis, rates which are obviously so high as to cause pollutant discharge to streams are not considered as feasible rates. Other than this, no serious attempt is made to define environmentally acceptable rates. Instead, the economic analysis is allowed to reveal the economically preferred rates and times of application. These preferred practices are then assessed in terms of their environmental acceptability, and compliance with the current regulations.

1.4 North Carolina's Confinement Hog Operations and Manure Dissipation Alternatives

Confinement hog facilities range from fenced pastures, to open lots (dirt or concrete base), to full housing (concrete or slatted floors). The most common systems are pastures and lots. Overcash and Humenik (1976), in an analysis of a 1974 Extension Swine Survey of North Carolina hog producers, estimated that 57% of operating units were open lots, 23% were pastures, 13% were solid concrete floors, and 7% involved slatted floors. On a hog basis, the corresponding percentages were 41% (pasture and lots combined), 28% (solid concrete floor) and 31% (slatted floors). Clearly, the more numerous pasture and open lot operations tend to be smaller in capacity than the housed hog operations. Further, since housing operations use higher live-weight/area densities than the pasture and open lot operations, the potential waste management problems are greatest in housed hog operations.

The major hog production operations in use in North Carolina are idenfified in Table 1. Operations differ in their locale (Coastal Plain, Piedmont, and Mountains), in their type (feeder pig finishing (FPF), feeder pig production (FPP), and farrow to finish (FTF)), and in their facilities and practices. Differences occur in flooring (pasture, dirt, concrete, partial slats, and total slats), in roof cover (none, a third, and total), in ventilation (forced or not), in the use of summer foggers (yes or no), and in floor cleaning (none, scrape, and wash). On the basis of facilities and practices, there are 16 alternative production systems. Each of these can be adopted in any of the three locales, with any of the three types of operation, giving a total of 144 systems. In practice, some of these systems may be rare or non-existent. In the first place, hog production in North Carolina occurs mainly in the Coastal Plain, and to a lesser extent in the Piedmont. The Mountain area has relatively few hogs. Estimates reported in N. C. Agricultural Statistics (1978) for total hogs on farms at December 1, 1976, are 1,525,000 for the Coastal Plain, 365,700 for the Piedmont, and 49,600 for the Mountain. Second, most of North Carolina's hog operations are farrow-to-finish or finishing operations. Feeder pig production is less significant. Third, an item such as summer foggers will be less common in the cooler mountain area than in the warmer coastal regions. On the other hand, there are other systems in addition to those already identified. The farrow-to-finish operation, for example, usually involves several houses, in some of which a slatted floor is used, and in others a solid concrete floor. There are obviously many such combinations. For the purposes of this study, each type of operation is represented by only one typical set-up.

Table 1. A Classification of Major Confinement Swine Production Operations in North Carolina[a].

Production Operation Identification No.	Flooring Type					Roof Cover			Forced Ventilation		Summer Foggers		Floor Cleaning			Type of Operation[b]									Waste Type	
																FPF Location[c]			FPP Location			FTF Location				
	Pasture	Dirt	Concrete	Partial Slats	Total Slats	None	1/3	Total	Yes	No	Yes	No	None	Wash	Scrape	CP	P	M	CP	P	M	CP	P	M	Solid	Liquid
1	X					X				X		X	X			1	2	3	4	5	6	7	8	9		X
2		X				X				X		X	X			10	11	12	13	14	15	16	17	18		X
3			X				X			X	X				X	19	20	21	22	23	24	25	26	27	X	X
4			X				X			X		X			X	19	20	21	22	23	24	25	26	27	X	X
5			X					X		X	X			X		28	28	28	29	29	29	30	30	30		X
6			X					X		X		X		X		28	28	28	29	29	29	30	30	30		X
7			X					X		X	X				X	31	31	31	32	32	32	33	33	33	X	X
8			X					X		X		X			X	31	31	31	32	32	32	33	33	33	X	X
9			X					X		X		X			X	31	31	31	32	32	32	33	33	33	X	X
10				X				X	X		X			X		28	28	28	29	29	29	30	30	30		X
11				X				X	X		X		X			28	28	28	29	29	29	30	30	30		X
12				X				X		X	X			X		28	28	28	29	29	29	30	30	30		X
13				X				X		X	X		X			28	28	28	29	29	29	30	30	30		X
14				X				X		X		X		X		28	28	28	29	29	29	30	30	30		X
15				X				X		X		X	X			28	28	28	29	29	29	30	30	30		X
16					X			X	X		X		X			28	28	28	29	29	29	30	30	30		X

[a]Numbers in body of table are manure type numbers. See Table 2.

[b]FPF (Feeder Pig Finishing), FPP (Feeder Pig Production), and FTF (Farrow to Finish).

[c]Locations: CP (Coastal Plains), P (Piedmont), M (Mountains); main three regions of North Carolina.

Finally, for each of the systems already identified there is a whole range of size of operation (capacity), and a range of manure volumes produced. The latter depends on the extent of floor washing, fogger use and the condition of waterers.

Despite the many production operations, there are only a few types of manure produced. At a very crude level, the manure produced by a hog operation is in one of three forms: liquid, solid, and both. For manure management, the critical specifications of manure are its form, the total volume or amount produced, the time pattern of production and the amounts of nutrients and other elements in the manure. Ignoring volume and dilution effects, there are only 33 manure types produced by North Carolina's hog operations. These are listed in Table 2. The manure type relevant for any particular hog operation is reported in Table 1. A producer with a given manure type has a set of broad alternative ways of dissipating the manure. The alternatives comprising this dissipation practices opportunity set include storage, pretreatment, transport, application, and cropping alternatives. For storage of liquid manure, there are six in-house pit arrangements, namely partial slats and total slats pits for each of the three types of hog production. These are distinguished from each other because their construction differs, so that costs and amounts of storage differ. A lagoon can also be used for storage. A lagoon also performs a pretreatment function. When a lagoon is feasible, several specifications are possible. These are defined later. Lagoons are differentiated by region since their construction and costs can vary with topography. Transport of liquids can be by tank wagon (of which several sizes are available), or by an irrigation system (several types can be used), the latter being used for lagoon effluents, and the former for liquid manure proper. Tank wagon use is accompanied by the use of a pumping pit and the possible use of an injector. Where the solid form of manure is produced, a scraper and spreader are required. Finally, the manure can be applied to crops. Three opportunity sets of crop exists, one for each region. Within each region, the choice between crops will be determined by economic factors.

For any manure type defined in Table 2, there is generally only one disposal practices opportunity set. For example, a producer with manure type 1 has to dissipate the manure through a Coastal Plain lagoon, an irrigation system and a Coastal Plain cropping plan. For some manure types, however, there are several corresponding opportunity sets. Manure type 30, for example, is associated with three opportunity sets depending on which region the manure is produced in. In all, 24 disposal practices opportunity sets can be identified for North Carolina. These are defined in Table 3, while the opportunity sets corresponding to each manure type are listed in Table 2.

In all there are 63 manure type - dissipation opportunity sets combinations. These combinations do not include volume and dilution effects on the manure type side, and land area restrictions and other restrictions on the dissipation opportunity sets side. In reality, there are any number of operations when these effects are considered. However, by selecting a representative finite set of sizes of operations (4 say), dilutions (3 say), and land area constraints (3 say), a reasonably complete analysis of the hog

Table 2. Basic Manure Types Produced by Hog Operations in North Carolina.

Manure type identification No.	Manure physical form			Amount of nutrients produced (Operation tpye)			Level of nutrients (Effluent type)			Geographical variation in manure production				Disposal practices opportunity sets
	Solid	Liquid	Both	FPF	FPP	FTF	Full	Pasture runoff	Lot runoff	None	CP	P	M	
1		X		X				X			X			1
2		X		X				X				X		2
3		X		X				X					X	3
4		X			X			X			X			1
5		X			X			X				X		2
6		X			X			X					X	3
7		X				X		X			X			1
8		X				X		X				X		2
9		X				X		X					X	3
10		X		X					X		X			1
11		X		X					X			X		2
12		X		X					X				X	3
13		X			X				X		X			1
14		X			X				X			X		2
15		X			X				X				X	3
16		X				X			X		X			1
17		X				X			X			X		2
18		X				X			X				X	3
19			X	X			X				X			4
20			X	X			X					X		5
21			X	X			X						X	6
22			X		X		X				X			4
23			X		X		X					X		5
24			X		X		X						X	6
25			X			X	X				X			4
26			X			X	X					X		5
27			X			X	X						X	6
28		X		X			X			X				1,2,3,7,8,9 16,17,18
29		X			X		X			X				1,2,3,10,11, 12,19,20,21
30		X				X	X			X				1,2.3,13,14, 15,22,23,24
31			X	X			X			X				4,5,6
32			X		X		X			X				4,5,6
33			X			X	X			X				4,5,6

Table 3. Major Opportunity Sets of Manure Dissipation Practices.

Opportunity set number	In-house pits by enterprise Type and amount of slats						Pumping pit	Lagoon by region			Irrigation system	Tank wagon	Solid scraper and spread	Crops by region			Injector
	FPF		FPP		FTF												
	Partial	Total	Partial	Total	Partial	Total		CP	P	M				CP	P	M	
1								X			X			X			
2									X		X				X		
3										X	X					X	
4								X			X		X	X			
5									X		X		X		X		
6										X	X		X			X	
7	X						X	X			X	X		X			X
8	X						X		X		X	X			X		X
9	X						X			X	X	X				X	X
10			X				X	X			X	X		X			X
11			X				X		X		X	X			X		X
12			X				X			X	X	X				X	X
13					X		X	X			X	X		X			X
14					X		X		X		X	X			X		X
15					X		X			X	X	X				X	X
16		X					X	X			X	X		X			X
17		X					X		X		X	X			X		X
18		X					X			X	X	X				X	X
19				X			X	X			X	X		X			X
20				X			X		X		X	X			X		X
21				X			X			X	X	X				X	X
22						X	X	X			X	X		X			X
23						X	X		X		X	X			X		X
24						X	X			X	X	X				X	X

manure dissipation problem on North Carolina's hog farms could be accomplished.

1.5 Scope of the Analysis

Not all the various manure type - dissipation opportunity set combinations could be examined in this study. Those that were examined are listed later. However, despite the many combinations, there is a relatively small set of cost and technical data that is required for the analysis of all the combinations. Most of this data is presented in this report. Table 4 identifies the various data categories, and the figures and tables with the corresponding information. No data is presented on items relating to solid manure production and dissipation. Also, only limited data is presented on cropping alternatives for the Piedmont and Mountains, and regional variation in nutrient availability is not presented. The emphasis on the Coastal Plains region and the liquid form of manure reflects the greater manure dissipation problems encountered in the numerous, large, fully housed hog operation in this region.

In addition to the basic data, a programming model is presented. This model can be used to determine the optimal means of dissipating manure for all those North Carolina hog operations which produce manure in the liquid form.

2. Basic Cost and Technical Data for Manure Management Analysis

2.1 Climatic Data

Climatic variables impinge on manure management in several direct ways. The chief effect is the net addition that precipitation can make to the total volume of manure. Any hog operation that is not fully roofed will be affected by rainfall. Also any outside pretreatment process, such as a lagoon, will be associated with net changes in manure volume as a result of rainfall. Rainfall can also affect lagoon pretreatment through alteration of manure detention times, and may limit opportunities for land application. In addition to rainfall, temperatures can affect lagoon performance, biological degradation being reduced as temperatures drop. Humidity and wind patterns may operate to cause unacceptable odors from land application or lagoons, and can thus serve to limit feasible options.

Most of these effects are ignored in this study. Only the rainfall effect on total volume is accounted for in those instances where relevant. Table 5 reports typical monthly precipitation and net precipitation figures for each of the three regions.

2.2 Three Types of Hog Production Operations

2.2.1 The feeder-pig-finishing (FPF) operation

The FPF operation involves a monthly intake of feeder pigs with subsequent resale 114 days later. The feeder pigs are bought at 50 lbs. (about 72 days old) and sold at 220 lbs. A 3% death rate is assumed. At any one

Table 4. Basic Categories of Data for Hog Manure Management Analysis in North Carolina.

Item	Tables and Figures[a]
Rainfall data for three regions	T5
Amounts of nutrients produced in FPF, FPP, FTF	T7, T10, T13, F14
Proportions and amounts of nutrients under different floor types	T7 - T15
Flooring requirements for FPF, FPP, FTF	T21 - T28
Pit construction for FPF, FPP, FTF	T21 - T28, T32, T56
Tank wagons - 5 sizes	T29-T31, F1-F4
Injector	T54
External pumping pit	T32, F5
Irrigation systems - 2 types, several sizes	T41-T48, F7-F13
Aeration equipment	T17
Lagoon details - 5 lagoon types	T33-T40, T45-T47, T50, T51, F6, F11-F13
Basic price data	T16
Commercial crops in 3 regions - labor and fertilizer needs	T19, T20, T57
Nutrient availabilities	T49-T53, T55
Crops with manure applied	T58, T59
Equipment details	T16-T18
Cost calculations	116-T18

[a] T = table, F = figure

Table 5. Precipitation Data for North Carolina by Region and Month (inches)[a,b]

Month	Region		
	Coastal Plains	Piedmont	Mountains
January	3.45 (1.99)	3.39 (2.38)	3.99 (3.51)
February	3.71 (1.90)	3.72 (1.94)	4.42 (3.24)
March	3.85 (1.02)	4.10 (1.26)	5.22 (3.08)
April	3.03 (-0.76)	3.48 (-0.12)	4.26 (1.54)
May	3.71 (-1.24)	3.49 (-0.99)	3.97 (1.10)
June	4.85 (-0.68)	4.01 (-0.77)	4.66 (1.26)
July	6.72 (1.56)	5.30 (0.87)	5.51 (2.36)
August	5.91 (1.53)	4.72 (0.32)	5.17 (2.31)
September	4.89 (1.58)	3.92 (0.29)	4.24 (1.46)
October	3.11 (0.58)	2.99 (0.29)	3.66 (1.57)
November	2.86 (1.54)	2.89 (1.14)	3.57 (2.16)
December	3.30 (2.15)	3.35 (2.37)	4.13 (3.43)
Annual Total	49.40 (11.17)	45.36 (8.98)	52.81 (27.02)
25 year, 24 hour storm[c]	7.5	6.0	7.0

[a]Net precipitation figures are in brackets.

[b]Estimates based on historical observation as reported in Climatology Data, U.S. Department of Commerce, various issues.

[c]Source: U.S. Department of Commerce Technical Paper No. 40, Rainfall Frequency Atlas of the United States (Washington, D.C., 1961).

time, there will be at least 3 batches of hogs in the operation, and usually 4. Over any month, the inventory (see Table 6) will total 14,764 day lbs approximately for each unit (1 pig purchased/month) of the cycle, or about 123 lbs/marketed hog/day. Each 100 lbs liveweight carried is equivalent to 0.204 hogs marketed each month. Raw manure production and composition details are reported in Table 7.

2.2.2 The feeder-pig production (FPP) operation

The FPP operation is based on 5 equal sized groups of sows, one group farrowing each month, each group farrowing in every fifth month. In addition to the litters and the sows that farrow, the operation carries boars, replacement gilts and sows that fail to conceive. For each sow to be mated in a month, there are 0.333 boars. The farrowing rate is 90%. On the average 1 gilt is retained from every fifth litter, providing (after allowing for deaths) about 0.135 replacements/mated sow. Sows potentially farrow 2.4 times per year, producing 8.7 pigs/litter, or 20.9 pigs/year/sow. Because of non-conception, actual pig production is about 19 pigs/year/sow. Feeder pigs are marketed at 72 days of age at about 50 lbs liveweight.

In contrast to the FPF operation which requires only one type of building, namely a finishing house, the FPP operation needs four buildings: a farrowing building, a nursery, a breeding house, and a gestation building. Boars are housed in the breeding house, and gilts in the gestation building until they reach 8.2 months of age when they are introduced to a breeding group. The gestation building also houses sows which fail to conceive first time. Table 8 outlines the basic operation schedule and the basic housing arrangements. The inventory carried in each house, and in the operation as a whole is reported in Table 9.

Details of raw manure production by houses, and in total, are reported in Table 10. Manure production by a hog is assumed to be directly related to the level of rations it receives. Boars are assumed to be on 42% rations, and sows without litters on 25% rations. Amounts of constituents produced by these hogs is then 42% and 25% respectively of that produced by feeder pigs on full rations. The daily volume of manure is assumed constant since water intake is constant over all hogs as a whole. The level of manure constituents in a FPP operation on a per 100 lbs liveweight basis is only 0.5157 that for the FPF operation. Most of the manure, and in its lowest concentration, is produced in the gestation house.

2.2.3 The farrow-to-finish (FTF) operation

The FTF operation is identical to the FPP operation with the addition of a finishing house. Instead of marketing feeder pigs at 72 days of age, they are transferred to the finishing house and finished in the same way as in the FPF operation. Details of the basic operating schedule, inventory, and manure production are reported in Tables 11, 12 and 13. On a total manure production basis, the FTF operation is closer to the FPF operation than was the FPP operation. The level of nutrient production is 80.36% of that in the FTF operation.

Table 6. Inventory Details and Conversion Factors for the Feeder-Pig-Finishing Operation.

Inventory in one month, comprised of purchases of 1 pig in each of 4 months

Pig weight (lbs)[a]	No. of pigs[b]	No. of days	Total weight (day lbs)
70	.995	31	2089.5
115	.985	31	3511.5
165	.975	31	4987.1
205	.97	21	4175.85
		TOTAL	14764.0 day lbs

Average daily inventory when 1 pig purchased each month = 476.26 lb/day

Average daily inventory/purchased pig/day = 119.06/day

Average daily inventory/marketed hog/day = 122.75 lbs/day

No. of pigs purchased each month/100 lbs liveweight inventory = 0.21 pigs

No. of hogs marketed each month/100 lbs liveweight inventory = 0.204 hogs

No of hogs marketed each year/100 lbs liveweight inventory = 2.448 hogs

[a] Estimated average weight of a pig during 1st, 2nd, etc. month after purchase.

[b] Deaths are assumed to occur approximately linearly over the fattening period.

Table 7. Raw Manure Production in Feeder-Pig-Finishing Operations.

Item	Unit	Amount per 100 lbs liveweight/day[a]	Amount per day/pig purchased monthly
Volume	U.S. gal.	1.0	4.7626
Weight	lbs	8.3	39.53
N	lbs	0.04	0.19
P	lbs	0.013	0.062
K	lbs	0.018	0.086
Ca	lbs	0.02	0.095
Cl^-	lbs	0.03	0.143
Cu[b]	lbs	5×10^{-5}	24×10^{-5}
Cu[c]	lbs	4×10^{-4}	19×10^{-4}
Mg	lbs	0.005	0.024
Mn	lbs	1.2×10^{-4}	5.3×10^{-4}
Na	lbs	0.005	0.024
Zn	lbs	3×10^{-4}	14×10^{-4}
COD	lbs	0.661	3.150
BOD_5	lbs	0.265	1.265

[a]Source: Overcash and Humenik (1976).

[b]No copper supplement in feed.

[c]150-350 ppm Cu supplement in feed.

Table 8. Operating Schedule and Basic Housing Needs for the Feeder-Pig-Production Operation.

Day	Operating Schedule				
	Age of litter (days)	Action for sows		Action for litter	
		Enters	Length of stay (days)	Enters	Length of stay (days)
0	-4	Farrowing	25		
4	0				
25	21	Nursery	16	Farrowing	21
41	37	Breeding	10[a]	Nursery	51
51	47	Gestation	104[a]		
76	72			Market	
155 (=0)[b]	151	Farrowing	25		

[a]Breeding building stay may be extended to 24 days in summer, gestation stay being reduced to 90 days.

[b]New cycle starts at day 155.

Basic housing needs (per sow mated each month)

House	Capacity needed
Farrowing	1 sow
Nursery[c]	1.8 sows, 1.8 litters
Breeding	0.333 boars, 1 sow
Gestation[d]	3.6 bred sows, 0.1 unbred sow, 1.225 gilts

[c]Based on 90% farrowing rate

[d]Comprised of 4 batches of sows in pig, 1 batch sows that failed to conceive, and 7 batches of gilts.

Table 9. Inventory Details and Conversion Factors for the Feeder-Pig-Production Operation.

House	Inventory in one month when 1 sow is mated each month				
	Pig Weight (lbs)	Type of Pigs	No. of Pigs	No. of Days	Total Weight (day lbs)
Farrowing	400	sow	0.9	25	9,000
	6.8 x 10.25	litter x 10.25	0.9 x 10.25	21	1,349.5
Nursery	400	sow	0.9	16	5,760
	23 x 8.7	litter x 8.7	0.9 x 8.7	31	5,582.8
	43.4 x 8.5	litter x 8.5	0.9 x 8.5	20	6,640.2
Breeding	400	sow	1.0	10	4,000
	450	boar	0.333	31	4,603
Gestation	400	sow	2.7	31	33,480
	400	sow	0.9	11	3,960
	400	sow	0.1	21	840
	220	gilt	0.175	200	7,700

Summary of inventory details

Item	Farrowing	Nursery	Breeding	Gestation	Total
Average daily inventory (lbs)/sow in breeding building	333.85	580.10	277.52	1,483.20	2,674.67
Average daily inventory (lbs)/owned sow[a]	71.03	123.43	59.05	315.57	569.08
Proportion of total inventory in each house	0.1248	0.2169	0.1038	0.5545	1.0

[a] Conversion factors: 100 lbs liveweight inventory = 0.1757 owned sows = 0.0374 sows in breeding house = 0.3179 feeder pigs produced each month = 3.81 hogs marketed each year. 1 sow in breeding building = 4.7 owned sows.

Table 10. Raw Manure Production in Feeder-Pig-Production Operations (per 100 lbs liveweight inventory in operation).

Item	Breeding	Gestation	Farrowing	Nursery	Total
Liveweight (lbs)	10.38	55.45	12.48	21.69	100
Volume (gal)	0.1038	0.5545	0.1248	0.2169	1.0
Weight (lbs)	0.8615	4.6024	1.0358	1.8003	8.3
Proportion of full nutrients	0.341[a]	0.25[b]	1.0[c]	1.0[c]	0.5157
Proportion of total daily nutrients	0.0686	0.2688	0.2420	0.4206	1.0
N (lbs)	0.00142	0.00554	0.00499	0.00868	0.0206
P (lbs)	0.00046	0.00180	0.00162	0.00282	0.0067
K (lbs)	0.00064	0.00250	0.00225	0.00390	0.0093
Ca (lbs)	0.00071	0.00277	0.00250	0.00434	0.0103
Cl^- (lbs)	0.00106	0.00416	0.00374	0.00651	0.0155
[d]Cu x 10^6[f] (lbs)	1.769	6.931	6.240	10.845	25.78
[e]Cu x 10^6 (lbs)	14.151	55.448	49.920	86.761	206.28
Mg x 10^6 (lbs)	176.88	693.10	624.00	1,084.5	2,578.5
Mn x 10^6 (lbs)	4.245	16.634	14.976	26.028	61.884
Na x 10^6 (lbs)	176.88	693.10	624.00	1,084.5	2,578.5
Zn x 10^6 (lbs)	10.613	41.586	37.440	65.071	134.71
COD (lbs)	0.02340	0.09170	0.08256	0.14348	0.3411
BOD_5 (lbs)	0.00937	0.03673	0.03307	0.05748	0.1367

[a]Sow weight % = 46.4953, Boar weight % = 53.5047; Sow on 25% ration, boar 42%; Proportion of nutrients = 0.341 full.

[b]Sow weight % = 83.2535, Gilt weight % = 16.7465; Sow and gilts on 25% ration; Proportion of nutrients = 0.25 full.

[c]Sow and litter on full ration; Proportion of nutrients = 1.0 full.

[d]No copper supplement in feed.

[e]150 - 350 ppm Cu supplement in feed.

[f]The values for nutrients with 10^6 factor should be divided by 10^6 to get actual value.

Table 11. Operating Schedule and Basic Housing Needs for the Farrow-To-Finish Operation.

Day	Age of Litter (days)	Operating Schedule: Action for Sows — Enters	Action for Sows — Length of Stay (days)	Action for Litter — Enters	Action for Litter — Length of Stay (days)
0	-4	Farrowing	25		
4	0			Farrowing	21
25	21	Nursery	16	Nursery	51
41	37	Breeding	10[a]		
51	47	Gestation	104[a]		
76	72			Finishing	114
155 (=0)[b]	151	Farrowing	25		
190 (=35)	186			Market	

[a]Breeding building stay may be extended to 24 days in summer, gestation stay being reduced to 90 days.

[b]New cycle starts at day 155.

Basic Housing Needs (per sow mated each month)

House	Capacity needed
Farrowing	1 sow
Nursery[a]	1.8 sows, 1.8 litters
Finishing[a]	3.6 litters
Breeding	0.333 boars, 1 sow
Gestation	3.6 bred sows, 0.1 unbred sows, 0.48 gilts

[a]Based on 90% farrowing rate.

[b]Comprised of 4 batches of sows in pigs, 1 batch sows not in pig, and 3 batches of gilts.

Table 12. Inventory Details and Conversion Factors for the Farrow-To-Finish Operation.

House	Inventory in one month when 1 sow is mated each month Pig Weight (lbs)	Type of Pigs	No. of Pigs	No. of Days	Total Weight (day lbs)
Farrowing	400	sows	0.9	25	9,000
	6.8 x 10.25	litter x 10.25	0.9 x 10.25	21	1,349.5
Nursery	400	sows	0.9	16	5,760
	23 x 8.7	litter x 8.7	0.9 x 8.7	31	5,582.8
	43.4 x 8.5	litter x 8.5	0.9 x 8.5	20	6,640.2
Finishing	72 x 8.4	litter x 8.4	0.9 x 8.4	31	16,873.9
	114.5 x 8.3	litter x 8.3	0.9 x 8.3	31	26,514.7
	162 x 8.2	litter x 8.2	0.9 x 8.2	31	37,062.4
	203 x 8.2	litter x 8.2	0.9 x 8.2	21	31,460.9
Breeding	400	sow	1.0	10	4,000
	450	boar	0.333	31	4,603
Gestation	400	sows	2.7	31	33,480
	400	sows	0.9	11	3,960
	400	sows	0.1	21	840
	300	gilts	0.16	84	4,032

Item	Summary of inventory details Farrowing	Nursery	Finishing	Breeding	Gestation	Total
Average daily inventory (lbs)/sow in breeding house	333.85	580.10	3610.06	277.52	1364.9	6166.43
Average daily inventory (lbs)/owned sow	71.03	123.42	768.10	59.05	290.4	1312.00
Average daily inventory (lbs)/pig marketed each month	40.71	70.74	440.3	33.84	166.5	752.00
Proportion of total inventory in each house	.054	.094	.585	.045	.221	1.000

[a]Conversion factors: 100 lbs liveweight inventory = 0.0762 owned sows = 0.0162 sows in breeding building = 0.1328 hogs marketed each month = 1.594 hogs marketed each year. 1 sow in breeding building = 4.7 owned sows.

Table 13. Raw Manure Production in Farrow-To-Finish Operation (per 100 lbs liveweight inventory in operation).

Item	Breeding	Gestation	Farrowing	Nursery	Finishing	Total
Liveweight (lbs)	4.5	22.1	5.4	9.4	58.5	100
Volume (gal.)	0.045	0.221	0.054	0.094	0.585	1.0
Weight (lbs)	0.3735	1.8343	0.4482	0.7802	4.8555	8.3
Proportion of full nutrients	0.341[a]	0.25[b]	1.0[c]	1.0[d]	1.0[e]	0.803
Proportion of total daily nutrients	0.019	0.069	0.067	0.117	0.728	1.0
N (lbs)	0.00061	0.0022	0.002	0.0037	0.023	0.032
P (lbs)	0.00019	0.00069	0.00067	0.0012	0.0073	0.010
K (lbs)	0.00027	0.00097	0.00094	0.0016	0.0102	0.014
Ca (lbs)	0.00030	0.0011	0.0011	0.0019	0.0116	0.016
[f]Cu x 10^6 (lbs)	0.76	2.76	2.68	4.68	29.12	40
[g]Cu x 10^6 (lbs)	6.08	22.08	21.44	37.44	232.96	320
Mg x 10^6 (lbs)	76	276	268	468	2,912	4,000
Mn x 10^6 (lbs)	1.9	6.9	6.7	11.7	72.8	100
Na x 10^6 (lbs)	76	276	268	468	2,912	4,000
Zn x 10^6 (lbs)	4.56	16.56	16.08	28.08	174.72	240
COD (lbs)	0.0101	0.0367	0.0356	0.0622	0.387	0.531
BOD_5 (lbs)	0.0040	0.0147	0.0143	0.0249	0.1551	0.213

[a]Sow weight % = 46.4953, Boar weight % = 53.5047; Sow on 25% ration, Boar 42%; Proportion of nutrients = 0.341 full.

[b]Sow weight % = 90.471, Gilt weight % = 9.529; Sow and gilts on 25% ration; Proportion of nutrients = 0.25 full.

[c]Sow weight % = 86.96, Litter weight % = 13.04; Sow and litter on 100% ration; Proportion of nutrients = 1.0 full.

[d]Sow weight % = 32.03, Litter weight % = 67.97; Sow and litter on 100% ration; Proportion of nutrients = 1.0 full.

[e]Litter weight % = 100; On full ration.

[f]No copper supplement in feed.

[g]150-350 ppm Cu supplement in feed.

2.3 Flooring Type Effects on Manure Production

Although differences are to be expected between the quantities of manure constituents produced on concrete and slatted floors because of different air exposure, etc., these differences turn out empirically to be small, and are not significant in terms of the overall variation that occurs in quantities produced. A more significant source of differences lies in floor cleaning practices. Concrete floors generally require washing and hence extra water is added to the manure. Concrete floors may be associated with 8-10 gal. of water added/gal. of raw waste while total slatted floors may have only 1-2 gal. of water added. Differences can also occur indirectly in the volume of manure produced, for, in contrast to slatted buildings, concrete slabs may only have a one-third roof cover, and the manure volume then depends upon the rainfall. Table 14 reports estimates of the volumes of manure produced each month in each of the three geo-climatic regions for the three different types of operations. The volumes depend on the assumption made about stocking density. These are outlined later, but in effect amount to exposed areas of 6.720 ft^2, 9.985 ft^2, and 7.056 ft^2 per 100 lbs liveweight for the FPF, FPP and FTF operation respectively. The rainfall collected on these exposed areas represent daily average manure volume increases ranging from 51% to 82%.

Rainfall has its greatest effect when dirt and pasture lots are used. Very few empirical observations on the volume of runoff and amounts of constituents in the runoff have been made for swine operations. Overcash and Humenik (1976) have overviewed the associated literature. Volume of runoff is assumed to be proportioned to rainfall, 30% being a typical value. Constituent runoff is proportional to the amount defecated and to the volume of runoff, but differs for dirt lots and pastures. They estimate that for a dirt lot (using a typical stocking rate of 300 ft^2/100 lbs liveweight), 0.71% of the defecated swine manure will be transported in each inch of runoff. For pasture (stocked at 1800 ft^2/100 lbs liveweight), the estimated constituent runoff is only 30% as much, or 0.21% of defecated manure per inch of runoff. Because rainfall varies over the year, the volume of runoff, and amounts of constituents in the runoff will vary over the year. The latter variation is ignored here, however, because of the imprecision in the estimates of actual runoff amounts. Monthly constituent runoff is set to 1/12 the total annual runoff. Runoff details are reported in Table 15. For dirt lots, the actual volume of runoff leaving the hog operation is about 8 times the volume of the raw manure produced by the hogs. For pastures, the factor is about 45. These calculations assume that runoff emanating from land above a hog operation is diverted away by diversion terraces.

2.4 Prices and Costs

The hog producer is assumed to be a price taker in all factors and product markets. A listing of most of the prices assumed in the study is provided in Table 16. For land price, instead of using a typical rental value ($60.00/acre, say), the opportunity cost of transferring land from

Table 14. Volumes of Manure Produced by One-Third Roof Cover, Concrete Floor Hog Operations by Region and Type (gal./day/100 lbs liveweight)[a,b,c]

Month	CP			P			M		
	FPF	FPP	FTF	FPF	FPP	FTF	FPF	FPP	FTF
January	1.47	1.70	1.50	1.46	1.68	1.48	1.54	1.80	1.57
February	1.50	1.74	1.53	1.50	1.75	1.53	1.60	1.89	1.63
March	1.52	1.77	1.55	1.55	1.82	1.58	1.71	1.05	1.74
April	1.41	1.61	1.43	1.47	1.70	1.49	1.58	1.86	1.60
May	1.50	1.74	1.53	1.47	1.70	1.50	1.54	1.80	1.56
June	1.66	1.97	1.69	1.54	1.81	1.57	1.63	1.94	1.66
July	1.91	2.35	1.95	1.72	1.06	1.75	1.74	2.11	1.78
August	1.80	2.19	1.84	1.64	1.95	1.67	1.70	2.04	1.73
September	1.66	1.98	1.69	1.53	1.79	1.56	1.57	1.85	1.60
October	1.42	1.62	1.44	1.40	1.60	1.42	1.49	1.73	1.52
November	1.39	1.57	1.41	1.39	1.58	1.41	1.48	1.72	1.51
December	1.45	1.66	1.47	1.45	1.67	1.48	1.56	1.83	1.59
AVERAGE	1.56	1.82	1.59	1.51	1.68	1.54	1.60	1.80	1.62

[a]Volume includes the 1 gal. actually produced by the hogs.

[b]Conversion factor for altering units to per hog marketed, etc., are given in Tables 6, 9, and 12.

[c]Based on actual precipitation figures as reported in Table 5. Converted at 1 sq ft in = 0.623379 gal.

Table 15. Manure Production Levels from Swine Dirt Lot and Pasture Operations[a].

Item		Dirt Lot			Pasture		
		CP	P	M	CP	P	M
January	volume/day[b,c]	6.54	6.44	7.52	37.76	37.11	43.62
February	volume/day	7.01	7.03	8.30	40.59	40.69	48.30
March	volume/day	7.27	7.72	9.75	42.11	44.82	56.98
April	volume/day	5.78	6.60	8.01	33.20	38.09	46.56
May	volume/day	7.01	6.62	7.48	40.59	38.20	43.41
June	volume/day	9.27	7.56	8.73	52.97	43.84	50.90
July	volume/day	14.46	9.89	10.27	73.27	57.85	60.13
August	volume/day	11.00	8.84	9.66	64.48	51.55	56.44
September	volume/day	9.15	7.39	7.97	53.40	42.87	40.34
October	volume/day	5.93	5.71	6.92	34.07	32.77	40.04
November	volume/day	5.48	5.53	6.76	31.36	31.68	39.07
December	volume/day	6.27	6.36	7.77	35.83	36.68	45.15
Average	volume/day	7.93	7.14	8.26	44.97	41.35	48.08
N[d]	x 10^6 (lb/day)	4,209	3,865	4,499	1,263	1,160	1,350
P	x 10^6 (lb/day)	1,368	1,256	1,462	410.4	376.8	438.6
K	x 10^6 (lb/day)	1,894	1,739	2,025	568.2	521.7	607.5
Ca	x 10^6 (lb/day)	2,104	1,932	2,250	631.2	579.6	675.0
Cu[e]	x 10^6 (lb/day)	5.26	4.83	5.62	1.58	1.45	1.69
Cu[f]	x 10^6 (lb/day)	42.1	38.6	45.0	12.6	11.6	13.5
Mg	x 10^6 (lb/day)	526	483	562	158	145	169
Mn	x 10^6 (lb/day	12.6	11.6	13.5	3.78	3.48	4.05
Na	x 10^6 (lb/day)	526	483	562	158	145	169
Zn	x 10^6 (lb/day)	31.6	29.0	33.7	9.48	8.70	10.1
COD	x 10^6 (lb/day)	69,550	63,360	74,350	20,865	19,158	22,305
BOD_5	x 10^6 (lb/day)	27,880	25,600	29,810	8,364	7,680	8,943
Cl^-	x 10^6 (lb/day)	3,157	2,898	3,375	947	869	1,012

[a]Volumes apply specifically to FPF operations, but approximately to rare FPP and FTF operations.

[b]Based on 30% of actual precipitation figures as given in Table 5.

[c]Units: gal./100 lbs liveweight/day.

[d]Constituent levels apply to the FPF operation. For FPP and FTF operations, amounts would be 0.5157 and 0.8036 times reported figures. Values in table should be divided by 10^6 to get actual value.

[e]No copper supplement in feed.

[f]150-350 ppm Cu supplement in feed.

Table 16. Price Information.

Item	Unit	Price ($)	Item	Unit	Price ($)
Gas	US gal	.43	Rye seed	lb	.165
Diesel	US gal	.43	Rye pasture	ton HE	-
Electricity	kwh	.04	Fescue seed	lb	0.34
Interest rate		.09	Fescue hay	ton	60.00
Insurance rate		.005	Fescue pasture	ton HE	25.00
Tax rate		.01	Soybean seed treat.	acre	1.25
Corn grain	bin	2.40	Custom fertilizing	acre	2.50
Corn silage	ton	-	Lime (applied)	ton	16.50
Corn seed	lb	0.84	N	lb	0.15
Sorghum grain	bin	1.80	P	lb	0.40
Sorghum silage	ton	5.81	K	lb	0.11
Sorghum seed	lb	.366	Concrete mix	ft^3	1.18
CBG[a] hay	ton	60.00	Concrete paving	ft^3	2.04
CBG pasture	ton HE[b]	30.00	Excavation	ft^3	0.03
CBG custom sprigging	acre	48.00	Concrete block, 8"	block	0.53
Barley grain	bin	1.85	Concrete block, 12"	block	0.72
Barley seed	lb	.1046	Block laying	block	0.55
Wheat grain	bin	2.50	Laid concrete slats	ft[c]	2.20
Wheat seed	lb	.1166	Labor	hr	3.00
Oats grain	bin	1.45	Land[c]	acre	111.31
Oats seed	lb	.125	Injector	unit	1,160.00
Small grain seed	lb	.07	Honey wagon, 800 gal	unit	3,525.00
Small grain pasture	ton HE	-	Honey wagon, 1100 gal	unit	4,400.00
Soybeans	bin	5.25	Honey wagon, 1500 gal	unit	5,100.00
Soybean seed	lb	.1333	Honey wagon, 2100 gal	unit	8,325.00
Baling twine	lb	0.34	PVC pipe, 3"	ft	0.80
Tank wagon, 3200 gal	unit	6,900.00	PVC pipe, 4"	ft	1.00
Pump/agitator	unit	3,300.00	PVC pipe, 6"	ft	2.00
Fence (4 strand, barbed)	ft	0.33	PVC pipe, 8"	ft	3.50
PVC pipe, 5"	ft	1.50	PVC pipe, 10"	ft	4.75
PVC pipe, 7"	ft	2.75	Trenching, 4"	ft	0.68
PVC pipe, 9"	ft	-	Trenching, 6"	ft	0.93
Trenching, 3"	ft	0.68	Trenching, 8"	ft	1.43
Trenching, 5"	ft	0.93	Trenching, 10"	ft	1.68
Trenching, 7"	ft	1.18	PVC pipe fittings preparation		00.25
Trenching, 9"	ft	1.68	Aluminum pipe, 3"	ft	1.20
PVC pipe installation	ft	0.07	Aluminum pipe, 5"	ft	2.10
Hydrants	unit	125.00	Aluminum pipe, 7"	ft	3.40
Aluminum pipe, 2"	ft	0.90	Aluminum pipe fittings preparation		0.15
Aluminum pipe, 4"	ft	1.55	Pump/motor, 3 HP		500.00
Aluminum pipe, 6"	ft	2.60	Pump/motor, 15 HP		1,500.00
Aluminum pipe, 8"	ft	4.30	Pump/motor, 60 HP		3,750.00
Aerator for lagoon	unit	800.00			
Pump/motor, 1-2 HP		100.00			
Pump/motor, 7-10 HP		1,000.00			
Pump/motor, 25 HP		2,500.00			

[a] CBG is Coastal Bermudagrass.

[b] HE is Hay Equivalent

[c] Land price represents the best net return to land, risk and management achieveable without manure. The reported figure is for the Coastal Plains, and is the net return for corn/grain.

its optimal use in 'manure-free' agriculture to a manure associated use was used. The hog producer was assumed to be a price taker, where the annual cost of land is set at the returns to land, management, and risk in the best non-manure alternative.

Many of the items needed for manure management practices have a life greater than one production period. Farming equipment, storage devices, irrigation equipment and lagoons are examples. Other items, e.g. corn seed and electricity costs, are expended within a single production period. The annual economic cost calculations for the two categories of items differ. For one-period items, the cost is computed as the sum of the purchase price plus the interest foregone over the period from the purchase of the input until the purchase price is recovered. For the multiple-period items, annual costs include ownership and operation components. The ownership costs of equipment are comprised of annual depreciation (depreciation over lifetime/length of life), property taxes (percentage of purchase price), insurance (percentage of average value), interest (percentage of average value), and repairs and maintenance (percentage of purchase price). Estimates (computed from various sundry reports, Agricultural Experiment Station Reports, and from discussions with members of the Department of Biological and Agricultural Engineering at NCSU) are reported in Table 17 for items specifically concerned with manure dissipation. For farming equipment, overhead costs are allocated on a per acre basis by assuming typical annual usage. For this to be valid, the hog producer must either hire the equipment at the market price or farm the typical area. Details of cost components for farming equipment are given in Table 18, and follow those in the Operations Manual for the Oklahoma State University Budget Generator, and in the North Carolina Agricultural Extension Services' Planning for Profit series.

Budgets for individual cropping alternatives were constructed using the procedures outlined in the sources just mentioned. Details are provided in Tables 19 and 20 for the major crops relevant to manure disposal in the Coastal Plain area. Table 19 presents a summary of monthly labor needs, total fertilizer requirements, and estimates of net returns to land, labor, management and risks. Details of each budget are reported in Table 20. The budgets are essentially the same as those reported in the NCSU Planning for Profit series. Individual prices can be obtained from Table 16, except for herbicides and insecticides for which prices are given in Table 20. All expenses are associated with an interest cost calculated from the month the cost is incurred to the month the expense is recovered, assumed throughout to be the harvest month. Not all possible crops are reported: corn silage, soybean silage, fescue hay, and rye pasture are some examples of omitted crops. The budgeted crops include those which have the greatest returns, those which have high fertilizer requirements, some which have a need for fertilizer over a short period of time and some with needs over a long period of time. Sufficient crops are included to create a potential demand for manure throughout the year.

Table 17. Percentages Used in Computing Annual Overhead Costs for Manure Handling Facilities.

Item	Years of life	Annual overhead cost as a % of investment					
		Depreciation	Insurance	Repairs & maintenance	Taxes	Interest	Total
Concrete floor	20	5	0.5	1	1	4.5	12
Concrete pit	20	5	0.5	1	1	4.5	12
Concrete slats	10	10	0.5	1	1	4.5	17
Floor wash system	20	5	0.5	2	1	4.5	13
Recycling system	7	14.29	0.5	4	1	4.5	24.29
PVC pipe to lagoon	15	6.67	0.5	1	1	4.5	13.17
Earthen holding pit	20	5	0.5	2	1	4.5	13
Concrete holding pit	20	5	0.5	1	1	4.5	12
Anaerabic lagoon	20	5	0.5	2	1	4.5	13
Facultative lagoon	20	5	0.5	2	1	4.5	13
Aerator	6	16.67	0.5	5	1	4.5	27.67
Oxidation ditch rotor	4	25	0.5	5	1	4.5	36
Fencing	20	5	0.5	1	1	4.5	12
Tank wagon[a]	7	13.57	0.525	5	1	4.725	24.82
Impeller pump[a] agitator	7	13.57	0.525	5	1	4.725	24.82
Soil injector[a]	7	13.57	0.525	5	1	4.725	24.82
Irrigation pump/motor	12	8.33	0.5	4	1	4.5	18.33
Irrigation mains + buried laterals	20	5.0	0.5	0.5	1	4.5	11.5
Irrigation laterals + fittings	12	8.33	0.5	3.0	1	4.5	17.33
Travelling big gun sprinkler	7	14.29	0.5	4	1	4.5	24.29

[a]Tank wagon, agitators, and soil injection equipment are assumed to have a salvage value of 0.05 their purchase price. Other equipment is assumed to have a zero salvage value.

Table 18. Farming Equipment Performance and Cost Data.

No.	Item	Width of pass (ft)	Speed (mph)	Field efficiency	RC1[a]	RC2	RC3	Annual usage (hrs)	Length of life (hrs)	Years to obsolescence	RFV1[a]	RFV2
1	Tractor 35 HP, Gas	0.0	4.5	0.88	1.20	0.000631	1.60	600.	12000.	10.0	0.680	0.920
2	Tractor 65 HP, Diesel	0.0	4.5	0.88	1.20	0.000631	1.60	600.	12000.	10.0	0.680	0.920
3	Tractor 85 HP, Diesel	0.0	4.5	0.88	1.20	0.000631	1.60	600.	12000.	10.0	0.680	0.920
4	Pickup, 0.5 ton	-1.0	30.0	0.88	0.60	0.000631	1.40	500.	4000.	8.0	0.600	0.885
5	Truck, 2 ton	-1.0	30.0	0.88	0.80	0.000631	1.40	500.	4000.	8.0	0.670	0.860
6	Combine harv., 12' SP, 60 HP	12.0	3.0	0.68	0.33	0.000251	1.80	167.	2000.	8.0	0.635	0.895
7	Combine harv., 16',SP, 60 HP	16.0	3.0	0.68	0.33	0.000251	1.80	167.	2000.	8.0	0.635	0.895
8	"Dummy sprigger"	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.0	0.0	0.0
9	Vacant	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.0	0.0	0.0
10	Cultivator, 12'	12.0	4.0	0.80	1.00	0.000251	1.80	167.	2500.	10.0	0.600	0.885
11	Tandem disk, 12'	12.0	4.8	0.85	0.65	0.000251	1.80	167.	2500.	10.0	0.600	0.885
12	Chisel plow, 9'	9.0	6.0	0.82	1.00	0.000251	1.80	167.	2500.	10.0	0.600	0.885
13	Harrows, sectional, 13.5'	13.5	5.0	0.85	0.65	0.000251	1.80	167.	2500.	10.0	0.600	0.885
14	Grain drill, 12'	12.0	4.5	0.70	0.65	0.000251	1.80	80.	1500.	15.0	0.600	0.885
15	Corn planter, 4 row	12.0	4.5	0.65	0.80	0.000631	1.60	120.	1500.	10.0	0.600	0.885
16	Cultipack seeder, 8'	8.0	4.5	0.70	0.65	0.000251	1.80	80.	1500.	15.0	0.600	0.885
17	Mower, 7', PTO, conditioner	7.0	4.5	0.80	1.00	0.002510	1.30	133.	2000.	10.0	0.560	0.885
18	Rake, side del, PTO, 9'	9.0	4.0	0.80	1.00	0.002510	1.30	125.	2500.	10.0	0.600	0.885
19	Baler, PTO, 7'	7.0	3.0	0.67	0.85	0.002510	1.30	156.	2500.	8.0	0.560	0.885
20	Bale kicker, loader	7.0	3.0	0.67	1.00	0.002510	1.30	156.	2000.	8.0	0.600	0.885
21	Bale wagon (3 ton)	7.0	3.0	0.40	1.00	0.002510	1.40	100.	1500.	10.0	0.560	0.885
22	Forage harv., PTO, 6'	6.0	3.2	0.60	1.20	0.002510	1.30	167.	2000.	8.0	0.560	0.885
23	Forage harv., PTO, 2 row	6.0	3.2	0.60	1.20	0.002510	1.30	167.	2000.	8.0	0.560	0.885
24	Silage wagon (5 ton)	6.0	3.2	0.60	1.00	0.002510	1.60	200.	2000.	8.0	0.600	0.880
25	Stalk cutter, rot. 6'	6.0	5.0	0.85	0.65	0.002510	1.30	133.	2000.	10.0	0.560	0.885
26	Bush and bog	7.0	4.5	0.85	0.85	0.002510	1.30	167.	2500.	10.0	0.560	0.885
27	Crop sprayer, TM, 100 gals	18.0	4.0	0.60	0.65	0.000251	1.80	60.	1200.	10.0	0.600	0.885
28	Pasture sprayer, PT, 300 gals	24.0	4.0	0.60	0.65	0.000251	1.80	60.	1200.	10.0	0.600	0.885
29	Sod corn planter	12.0	2.5	0.65	1.00	0.000631	1.60	120.	1200.	6.0	0.600	0.885
30	Corn head attach.	12.0	3.0	0.68	0.33	0.000251	1.80	167.	2000.	8.0	0.635	0.895

[a]The RC coefficients are used in computing repairs and maintenance costs, while RFV coefficients serve in computing salvage values. See the Operations Manual for the Oklahoma State University Budget Generator for details.

Table 18. (Continued)

No.	Item	Fuel[b] type	Horse power	Machine to labor hrs factor	Time for pass over 1 acre (hrs)	List price ($)	Purchase price ($)	Interest charge ($/hr)	Ownership[c] costs ($/hr)	Variable costs of repair, fuel lube ($/hr)
1	Tractor, 35 HP, gas	1.0	35.0	0.0	0.0	7500.	6750.	0.67	0.91	1.67
2	Tractor, 65 HP, diesel	2.0	65.0	0.0	0.0	14167.	12750.	1.27	1.71	2.48
3	Tractor, 85 HP, diesel	2.0	85.0	0.0	0.0	16944.	15250.	1.52	2.05	3.14
4	Pickup, half ton	1.0	1.0	1.10	1.000	5800.	5220.	0.59	1.11	1.58
5	Truck, 2 ton	1.0	1.0	1.10	1.000	11667	10500.	1.16	2.31	2.91
6	Combine harv, 12', SP, 60 HP	1.0	1.0	1.20	0.337	38769.	30890.	12.13	21.29	7.16
7	Combine harv, 16', SP, 60 HP	1.0	1.0	1.20	0.253	42222.	38000.	13.21	23.19	7.93
8	"Dummy sprigger"	0.0	0.0	0.0	0.0	0.	0.	0.0	0.0	0.0
9	Vacant	0.0	0.0	0.0	0.0	0.	0.	0.0	0.0	0.0
10	Cultivator, 12'	0.0	0.0	1.21	0.215	1725.	1550.	0.50	0.87	0.50
11	Tandem disk, 12'	0.0	0.0	1.21	0.169	1555.	1400.	0.45	0.78	0.29
12	Chisel plow, 9'	0.0	0.0	1.21	0.186	1083.	975.	0.31	0.54	0.31
13	Harrows, sect, 13.5'	0.0	0.0	1.21	0.144	500.	450.	0.15	0.25	0.09
14	Grain drill, 12'	0.0	0.0	1.50	0.218	3000.	2700.	1.68	2.44	1.09
15	Corn planter, 4 row	0.0	0.0	1.50	0.235	2222.	2000.	0.90	1.56	1.04
16	Cultipack seeder, 8'	0.0	0.0	1.50	0.327	1667.	1500.	0.93	1.36	0.60
17	Mower, 7', PTO, conditioner	0.0	0.0	1.21	0.327	1811.	1630.	0.65	1.16	0.80
18	Rake, side del., PTO, 9'	0.0	0.0	1.21	0.286	1390.	1250.	0.54	0.93	0.45
19	Baler, PTO, 7'	0.0	0.0	1.21	0.586	5555.	5000.	1.78	3.49	1.53
20	Bale picker, loader	0.0	0.0	1.21	0.586	1110.	1000.	0.36	0.68	0.48
21	Bale wagon (3 ton)	0.0	0.0	1.21	0.982	1110.	1000.	0.53	0.95	1.00
22	Forage harv. PTO, 6'	0.0	0.0	1.21	0.216	7220.	6500.	2.16	4.24	3.84
23	Forage harv, PTO, 2 row	0.0	0.0	1.21	0.216	7780.	7000.	2.33	4.56	4.13
24	Silage wagon (5 ton)	0.0	0.0	1.21	0.716	2220.	2000.	0.56	1.08	1.61
25	Stalk cutter, rot., 6'	0.0	0.0	1.21	0.324	890.	800.	0.32	0.57	0.26
26	Bush and hog	0.0	0.0	1.21	2.308	750.	675.	0.22	0.38	0.23
27	Crop sprayer, TM, 100 gals	0.0	0.0	2.00	0.191	670.	600.	0.54	0.93	0.21
28	Pasture sprayer, PT, 300 gals	0.0	0.0	2.00	0.143	1083.	875.	0.87	1.52	0.34
29	Sod corn planter	0.0	0.0	1.50	0.423	4780.	4300.	2.02	3.83	3.48
30	Corn head attach	0.0	0.0	1.20	0.337	7780.	7000.	2.43	4.27	0.93

[b]Fuel type: 1 = gas, 2 = diesel

[c]Ownership costs do not include interest.

Table 19. Summary of Monthly Labor Needs, Total Fertilizer Requirements, and Gross Margins for Major Coastal Plains Crops.

Item	Crop										
	Corn	Sorghum	Wheat	Oats	Barley	Soybeans	CBG hay[a]	CBG[a] pas-ture	C-S[a]	C-W-S[a]	Fescue pasture
Jan labor (hrs/ac)	0	0	0	0	0	0	0	0	0	0	0
Feb labor (hrs/ac)	0	0	.38	.38	.38	0	0	0	0	.19	0
Mar labor (hrs/ac)	.23	0	0	0	0	0	.13	.15	.11	.11	0
Apr labor (hrs/ac)	.56	0	0	0	0	.20	0	0	.38	.28	0.
May labor (hrs/ac)	0	.56	0	0	0	.56	2.56	0	.28	0	.29
June labor (hrs/ac)	.38	0	1.51	1.51	1.51	.64	2.56	.4	.51	1.15	0
July labor (hrs/ac)	0	0	0	0	0	0	2.82	.4	0	0.31	0
Aug labor (hrs/ac)	0	0	0	0	0	0	2.82	0	0	0	0
Sept. labor (hrs/ac)	1.51	1.51	.41	.41	.41	0	0	0	.75	.75	.12
Oct labor (hrs/ac)	.39	.20	.53	.53	.53	0	0	0	.20	.56	0
Nov labor (hrs/ac)	.20	0	0	0	0	1.51	0	0	.75	.75	0
Dec labor (hrs/ac)	0	.23	0	0	0	.20	0	0	.20	.1	0
Total labor (hrs/ac)	3.27	2.50	2.83	2.83	2.83	3.11	10.89	.95	3.18	4.20	.41
N (lbs/ac)	160.	120.	100.	100.	100.	0.	240.	200.	80.	130.	150.
P (lbs/ac)	17.5	17.5	8.7	8.7	8.7	19.6	26.2	21.8	18.6	22.9	19.6
K (lbs/ac)	66.4	66.4	33.2	33.2	33.2	74.7	99.6	83.3	70.6	87.2	74.7
Net return[b] ($)	121.12										
Net return ignoring fertilizer ($)[b]	163.46	125.58	77.02	70.66	72.75	119.01	160.79	63.65	140.29	150.84	61.21

[a] CBG = Coastal Bermudagrass; C-S = corn-soybean rotation; C-W-S = corn-wheat-soybean rotation.

[b] Net returns do not have labor costs subtracted. Thus they are net returns to land, labor, risk and management.

Table 20. Details of Individual Crop Budgets for the Coastal Plains Region.

CORN

A. Land required from November to October
Fertilizer typically applied in April
Manure availability measured until August.

B. Operations schedule: November-disk; March-chisel plow; April-disk/harrow, and plant/spray herbicide; June-post emergence herbidice spray; September-harvest and haul; October-cut stalks.

C. Purchased inputs[a]: November-0.333 ton applied lime; April-16 lb seed, applied fertilizer; and $12 herbicide; June-$4.00 herbicide and $6.50 applied insecticide.

D. Production: 100 bin/ac

[a]NOTE: Inputs are on a per acre basis.

SORGHUM

A. Land required from October to September
Fertilizer typically applied in May
Manure availability measured until August

B. Operations schedule: October-disk; December-chisel plow; May-disk/harrow, and plant/spray herbicide; September-harvest and haul.

C. Purchased inputs: February 0.333 ton applied lime; May 19 lbs seed, applied fertilizer, and $14.00 herbicide.

D. Production: 65 bin/ac.

WHEAT, OATS, AND BARLEY

A. Land required from September to June
Fertilizer typically applied in October
Manure availability measured until May

B. Operations schedule: September-disk twice; October-disk/harrow, and plant; February-spray herbicide; June-harvest and haul.

C. Purchased inputs: September-0.333 ton applied lime; October 90 lbs seed for wheat, 64 lbs for oats, and 96 lbs for barley, and applied fertilizer; February-$2.50 herbicide.

D. Production: 50 bin/ac for wheat; 80 bin/ac for oats; and 65 bin/ac for barley.

SOYBEANS

A. Land required from December to November.
Fertilizer typically applied in April.
Manure availability measured until October.

B. Operations schedule: December-disk; April-disk; May-disk, and plant/spray herbicide; June-cultivate, and spray herbicide; November-harvest and haul.

C. Purchased inputs: December-0.333 tons applied lime; April-applied fertilizer; May-45 lbs seeds, seed treatment, and $7.75 herbicide; June-$7.25 herbicide; August-$5.25 applied insecticide.

D. Production: 35 bin/ac.

Table 20. (Continued)

COASTAL BERMUDAGRASS HAY

A. Land required from March to February
Stand lasts for 10 years
Fertilizer typically applied in April, June, July and August
Manure availability for the 4 application times is measured to May, June, July and August.

B. Operations schedule: a) Establishment year: March-disk pull sprigger, and spray herbicide; July-mow, rake, bale and haul; August-mow, rake, bale and haul. b) other years: In May, June, July and August - mow, rake, bale and haul.

C. Purchased inputs: a) Establishment year: March-custom sprigging, 1.5 tons applied lime, and $3.27 herbicide; April and June-applied fertilizer; July and August-applied fertilizer, baling time, 4 kwh electricity. b) other years: March-0.25 tons applied lime; April, June, July and August-applied fertilizer, baling twine, and 5.5 kwh electricity.

D. Production: a) Establishment year: 1 ton/ac hay in both July and August. b) Other years: 1.00 ton/ac hog in May and August, and 1.25 tons/ac hay in both June and July.

COASTAL BERMUDAGRASS PASTURE

A. Land required from March to February
Stand lasts for 10 years
Fertilizer typically applied in April, June, July and August
Manure availability for the 4 application times is measured to May, June, July and August.

B. Operations schedule: a) Establishment year: March-disk twice, pull sprigger, and spray herbicide. b) Other years: June and July - mow.

C. Purchased inputs: a) Establishment year: March-custom sprigging, 1.5 tons applied lime, and $3.27 herbicide; April, June, July and August-applied fertilizer. b) Other years: March - 0.25 tons applied lime; April, June, July and August - applied fertilizer.

D. Production: a) Establishment year: June - 1.25 tons hay equivalent; b) other years: May - 1.0 tons hay equivalent; June and July - both 1.1 tons hay equivalent.

CORN-SOYBEANS 2 YEAR ROTATION*

A. Land required for corn from December to October; and for soybeans from December to November.
Fertilizer typically applied in April for both corn and soybeans
Manure availability measured until August for corn and until October for soybeans.

B. Operations schedule: a) Corn: December-disk; March-chisel plow; April-disk/harrow and plant/spray herbicide; June - spray herbicide; September - harvest and haul; October - cut stalks. b) Soybeans: December - disk; April-disk; May - disk, plant/spray herbicide; June-cultivate and spray herbicide; November-harvest and haul.

C. Purchased inputs: a) Corn: December 0.333 ton applied lime; April - 16 lbs seed, $12 herbicide, and applied fertilizer; June - $6.50 applied insecticide and $4.00 herbicide. b) Soybeans: December - 0.333 ton applied lime; April - applied fertilizer; May - 45 lbs seed, seed treatment, and $7.75 herbicide; June - $7.25 herbicide; August - $5.25 applied insecticide.

D. Production: Corn - 100 bin/ac; Soybeans - 35 bin/ac.

*NOTE: In any one year, any 0.5 ac is devoted to each component. All quantities should therefore be divided by 2 to get actual amounts on a per acre of rotation basis.

Table 20. (Continued.

CORN-WHEAT-SOYBEANS 2-YEAR ROTATION[5]

A. Land required for corn from December to September; for wheat from October to June; and for soybeans from July to November.
Fertilizer typically applied to corn in April, to wheat in October, and to soybeans in February.
Manure availability measured until August, May and October for corn, wheat and soybeans, respectively.

B. Operations schedule: a) Corn: December-disk; March-chisel plow; April-disk/harrow, and plant/spray herbicide; June-spray herbicide; September-harvest and haul; October-cut stalks. b) Wheat: October-disk, disk/harrow, and plant; February - spray; June- harvest and haul. c) Soybeans: June-disk/harrow twice; July-plant/spray herbicide and cultivate; November-harvest and haul.

C. Purchased Inputs: a) Corn: December - 0.333 tons applied lime; April-applied fertilizer, 16 lbs seed, and $12 herbicide; June $6.50 applied insecticide, and $4.00 herbicide. b) Wheat: September - 0.333 tons applied lime; October - 90 lbs seed applied fertilizer; c) Soybeans: July - 45 lbs seed, seed treatment and $7.75 herbicide; August $5.25 applied insecticide.

D. Production: Corn - 100 bin/ac; wheat - 40 bin/ac; soybeans - 25 bin/ac.

[5]NOTE: In any one year only 0.5 ac is devoted to each component. All quantities should therefore be divided by 2 to get actual amounts on a per acre of rotation basis.

FESCUE PASTURE

A. Land required from September to August
Stand lasts for 10 years
Fertilizer typically applied in February, April, and August except in establishment year when it is applied in September and February.
Manure availability for the 3 application times is measured to February, May and September.

B. Operations schedule: a) Establishment year: September - bush and hog, disk, harrow and plant. b) Other years: May-mow.

C. Purchased inputs: a) Establishment year: September - 20 lbs seed, 2 tons applied lime, applied fertilizer; February - applied fertilizer. b) Other years: September - 0.333 tons applied lime in years 5 and 10; February, April and August - applied fertilizer.

D. Production: April - 2 tons hay equivalent; October - 1.25 tons hay equivalent.

2.5 Housing Details and Costs

Many of the housing costs are incurred whatever manure disposal system is considered. These costs are properly considered fixed and debited to the hog production operation itself, rather than to manure disposal. On the other hand, some housing costs do vary with the manure disposal system. For example, if an underhouse pit is used, by necessity a slatted floor must be used in place of a solid concrete floor. To the extent that housing costs are varied by changing its disposal system, some portion of the housing costs must be assigned to the manure disposal system. Flooring costs in roofed housing, and labor requirements for floor cleaning are the main potentially variable housing costs. Since in-house pits are closely related to flooring type, details on their construction and costs are also presented in this section.

2.5.1 The feeder pig finishing (FPF) operation

Roofed finishing operations can use solid concrete, partially slatted or totally slatted floors. Stocking rates are assumed to be 10, 6.7 and 6.7 sq ft per 100 lbs liveweight for the three flooring types, based largely on housing plans developed by the North Carolina Agricultural Extension Service (Plan #525 and #528). Partially slatted floors have 1/3 of the floor area constructed of 8' slats. Under the slats is a 7'4' wide pit which can be 1'4", 3' or 5' deep. The latter two depths permit storage, while the former serves only as a drain. The same pit depths can be used under total slats too. Pit storage capacity is generally less than the full volume of the pit. First, in operation some fluid must always be left in the bottom of the pit for odor control (4" say); second, some allowance for overflow has to be made at the top of the pit (4" say); and finally, where in-house forced ventilation is used, an allowance for under-floor ventilation is needed (say 1'). The latter is particularly relevant for totally slatted floors where forced ventilation is always used.

Concrete flooring is assumed to be 4" thick. Slats are assumed to be made of reinforced concrete. Pits have a concrete base, but walls are made of 8" concrete blocks in accordance with the available plans. Estimates were made of material required for 100 lbs liveweight, and with the price data in Table 16 and costing information in Table 17, estimates of investment and annual costs of flooring and pits were made. These are reported in Table 21 along with estimates of storage available in pits.

Totally slatted floors have the highest overhead costs, and solid concrete floors the least. Pit costs naturally increase with depth, but if expressed on a per unit of storage basis, pit costs decrease with depth. For example, with partial slats, a 3' deep pit and keeping 16" available for ventilation, dilution, etc., each day's storage (per 100 lbs LW) costs $0.022 per year; at 5', each day's storage costs only $0.013 per year. For total slats the costs are smaller.

In evaluating floor types, the higher costs of totally slatted floors and deep pits have to be set against the lower costs of storage, the greater storage, and the greater flexibility and opportunities they present for

Table 21. Summary of Basic Housing Information for the Feeder-Pig-Finishing Operation[a].

Item	Partial Slats Pit depth 1'4"	Partial Slats Pit depth 3'	Partial Slats Pit depth 5'	Total Slats Pit depth 1'4"	Total Slats Pit depth 3'	Total Slats Pit depth 5'	Solid concrete
Floor area (sq ft)	6.72	6.72	6.72	6.72	6.72	7.72	10.0
Slats area (sq ft)	2.24	2.24	2.24	6.72	6.72	6.72	0
Concrete area (sq ft)	4.48	4.48	4.48	0.	0.	0.	10.0
Storage capacity 1[b,c] (days)	0.	46.1	76.8	0.	144.5	240.3	0.
Storage capacity 2 (days)	0.	35.8	66.6	0.	112.4	208.8	0.
Storage capacity 3 (days)	0.	25.6	56.3	0.	80.3	176.6	0.
N production (lbs/ month)	1.24	1.24	1.24	1.24	1.24	1.24	1.24
P production (lbs/ month)	.403	.403	.403	.403	.403	.403	.403
K production (lbs/ month)	.558	.558	.558	.558	.558	.558	.558
Flooring investment ($)	9.74	9.74	9.74	14.78	14.78	14.78	9.02
Pit investment ($)	3.46	4.72	6.22	9.12	11.32	13.96	0.
Total investment ($)	13.20	14.46	15.96	23.90	26.10	28.74	9.02
Flooring annual cost($)	1.42	1.42	1.42	2.51	2.51	2.51	1.08
Pit annual cost ($)	0.42	0.57	0.75	1.09	1.36	1.68	0.
Total annual cost ($)	1.84	1.99	2.17	3.60	3.87	4.19	1.08
Labor usage[d] (min/month)	4.39	4.39	4.39	0.17	0.17	0.17	9.88

[a] On a 'per 100 lbs liveweight' basis

[b] Storage 1 applies to whole pit, 2 to 8" less, and 3 to an additional 8" less.

[c] Based on raw manure only.

[d] All labor-for-cleaning estimates based on field experience of NCSU Department of Biological and Agricultural Engineering personnel. Includes 5-hr disinfecting program 3 times a year; and with partial slots, 5 min washing/day/30-150 lb hog pen.

manure disposal (see Section 2.10.3). Also, differences in labor cleaning costs have to be considered. For a partial-slats floor, labor cleaning costs would be $2.63/year/100 lbs liveweight (costing labor at $3.00/hr.); for total slats, $0.10; and for concrete floors, $5.93. Considering both labor, operating and overhead costs, totally slatted floors are the lowest cost floors. In allocating floor costs to manure disposal, only those costs in excess of the total-slats flooring costs should be considered.

2.5.2 The feeder pig production (FPP) operation

Because this operation involves 4 types of houses (farrowing, nursery, breeding and gestation), many combinations of floor types are theoretically possible. In practice, however, not all combinations are found. Partial slats can be used for all buildings, and the partially slatted system costed in this section assumes this is the case. Construction details follow North Carolina Agricultural Extension plan #531 for the breeding building, and #530 for the gestation building. The farrowing and nursery buildings are based on plans in Raising Hogs In North Carolina. Totally slatted floors are not commonly used in either the breeding or the gestation building, and are not considered for these buildings. The totally slatted system therefore has total slats only in the farrowing and nursery buildings (based on plans #527 and #529, respectively), and partial slats in the other buildings. Totally solid concrete systems are also uncommon, or at least are quite small when they are used. They are not considered in detail, but for rough estimates, floor costs could be based on 15 sq ft/100 lbs liveweight in the operation.

Cost estimates and pit storage capacities for each building are reported in Tables 22 and 23. A summary for the total slatted and partially slatted operations is presented in Table 24.

Compared to the FPF operation, total flooring and pit costs are higher in the FPP operation. In general, floor area is utilized more efficiently in a finishing building than in other buildings. Table 24 reports minimum and maximum storage capacity. The former indicates how often the building with the least relative storage capacity has to be emptied; the latter how often the building with the greatest capacity has to be emptied. Some pits can store manure for 6 months or more. Others (in the gestation building, for example) need to be emptied about every month. This is not much longer than for the FPF operation. However, in contrast to the FPF operation, the volume necessarily transported each month is much smaller. Relevant volume estimates can be made knowing the liveweight in each building (see Table 10).

2.5.3 The farrow to finishing (FTF) operation

As with the FPP operation, many possible floor combinations exist. Details of costs are given for partially slatted floors in all buildings, and for totally slatted floors in the finishing, farrowing and nursery buildings (Tables 25, 26 and 27). Estimates of total operation flooring

Table 22. Basic Information for the Farrowing and Nursery Buildings in the Feeder-Pig-Production Operation[a].

Item	House Type: Farrowing, Pit depth 1'4"	Farrowing, Pit depth 3'	Farrowing, Pit depth 5'	Nursery, Pit depth 1'4"	Nursery, Pit depth 3'	Nursery, Pit depth 5'
PARTIAL SLATS						
Slats area (sq ft)	.9347	.9347	.9347	1.6824	1.6824	1.6824
Concrete area (sq ft)	1.4955	1.4955	1.4955	2.6919	2.6919	2.6919
Storage capacity 1[b,c] (days)	-	14507	242.8	-	150.8	251.4
Storage capacity 2 (days)	-	11303	210.4	-	117.2	217.9
Storage capacity 3 (days)	-	80.9	178.1	-	83.8	184.3
Flooring investment (annual cost)($)	3.66 (.54)	3.66 (.54)	3.66 (.54)	6.60 (.98)	6.60 (.98)	6.60 (.98)
Pit investment (annual cost)($)	1.68 (.20)	2.49 (.30)	3.46 (.42)	3.02 (.36)	4.48 (.54)	6.23 (.75)
Total investment (annual cost ($)	5.34 (.74)	6.15 (.84)	7.12 (.96)	9.62 (1.34)	11.08 (1.52)	12.83 (1.73)
Labor usage[d] (min/mth)	2.87	2.87	2.87	1.21	1.31	1.44
TOTAL SLATS						
Slats area (sq ft)	1.5	1.5	1.5	2.6919	2.6919	2.6919
Storage capacity 1[b,c] (days)	-	246.6	411.0	-	259.9	433.1
Storage capacity 2 (days)	-	191.8	356.2	-	202.1	375.5
Storage capacity 3 (days	-	137.0	301.4	-	144.4	317.6
Flooring investment (annual cost)($)	3.29 (.56)	3.29 (.56)	3.29 (.56)	5.92 (1.01)	5.92 (1.01)	5.92 (1.01)
Pit investment (annual cost)($)	2.31 (.28)	3.15 (.38)	4.16 (.50)	4.03 (.48)	5.37 (.64)	6.97 (.84)
Total investment (annual cost)($)	5.60 (.84)	6.44 (.94)	7.45 (1.06)	9.96 (1.49)	11.29 (1.65)	12.89 (1.85)
Labor usage (min/month)	0.35	0.35	0.35	0	0	0
N production (lbs/month)	.1548	.1548	.1548	.2690	.2690	.2690
P production (lbs/month)	.0503	.0503	.0503	.0874	.0874	.0874
K production (lbs/month)	.0696	.0696	.0696	.1210	.1210	.1210

[a] On a 'per 100 lbs. liveweight in the operation' basis.

[b] Storage capacities 1, 2 and 3 apply to whole pit, less 8", and less 16", respectively.

[c] Based on raw manure only.

[d] Farrowing house has a monthly washdown; both houses have daily washing on solid floor.

Table 23. Basic Information for the Breeding and Gestation House in the Feeder-Pig-Production Operation[a].

Item	House Type					
	Breeding			Gestation		
	Pit depth			Pit depth		
	1'4"	3'	5'	1'4"	3'	5'
PARTIAL SLATS						
Slats area (sq ft)	.5816	.5816	.5816	1.823	1.823	1.823
Concrete area (sq ft)	.7755	.7755	.7755	2.431	2.431	2.431
Storage capacity 1[b,c] (days)	-	104.8	174.7	-	61.5	102.5
Storage capacity 2 (days)	-	81.5	151.4	-	47.8	88.8
Storage capacity 3 (days)	-	58.2	128.1	-	34.2	75.1
Flooring investment ($)	2.114	2.114	2.114	6.624	6.624	6.624
Pit investment ($)	1.198	1.876	2.688	3.585	5.537	7.879
Total investment ($)	4.312	3.990	4.802	10.209	12.161	14.503
Flooring annual costs ($)	0.32	0.32	0.32	1.00	1.00	1.00
Pit annual cost ($)	0.14	.22	.32	.43	.66	.95
Total annual cost ($)	.46	.54	.64	1.43	1.66	1.95
Labor usage[d] (min/month)	.75	.75	.75	2.34	2.35	2.35
N production (lbs/month)	.0439	.0439	.0439	.1719	.1719	.1719
P production (lbs/month)	.0143	.0143	.0143	.0559	.0559	.0559
K production (lbs/month)	.0198	.0198	.0198	.0774	.0774	.0774

[a] On a 'pre 100 lbs liveweight in the operations' basis.

[b] Storage capacities 1, 2 and 3 apply to whole pit, less 8", and less 16" respectively.

[c] Based on raw manure only.

[d] Both houses have daily washing of solid floor.

Table 24. Summary of Basic Housing Information for the Feeder-Pig-Production Operation[a].

Item	Partial slats			Total slats[b]		
	Pit depth			Pit depth		
	1'4"	3'	5'	1'4"	3'	5'
Floor area (sq ft)	12.416	12.416	12.416	9.803	9.803	9.803
Slats area (sq ft)	5.022	5.022	5.022	6.596	6.596	6.596
Concrete area (sq ft)	7.394	7.394	7.394	3.206	3.206	3.206
Min. storage capacity 1[c,d] (days)	-	61.5	102.5	-	61.5	102.5
Min. storage capacity 2 (days)	-	47.8	88.8	-	47.8	88.8
Min. storage capacity 3 (days)	-	34.2	75.1	-	34.2	75.1
Max. storage capacity 1[c,d] (days)	-	150.8	251.4	-	259.9	433.1
Max. storage capacity 2 (days)	-	117.2	217.9	-	202.1	315.5
Max. storage capacity 3 (days)	-	83.8	184.3	-	144.4	317.6
N production (lbs/month)	.6369	.6369	.6369	.6369	.6369	.6369
P production (lbs/month)	.2079	.2079	.2079	.2079	.2079	.2079
K production (lbs/month)	.2878	.2879	.2978	.2878	.2878	.2878
Flooring investment ($)	18.999	18.999	18.999	17.949	17.949	17.949
Pit investment ($)	9.489	14.386	20.262	11.129	15.932	21.691
Total investment ($)	28.488	33.385	39.261	29.078	33.881	39.640
Flooring annual cost ($)	2.83	2.83	2.83	2.88	2.88	2.88
Pit annual cost ($)	1.13	1.72	2.44	1.33	1.90	2.61
Total annual cost ($)	3.96	4.55	5.27	4.21	4.78	5.49
Labor usage (min/month)	8.585	8.585	8.585	3.456	3.456	3.456

[a]On a 'per 100 lbs. liveweight' basis.

[b]Totally slatted systems assume total slats where possible, and partial slats in other buildings.

[c]Min. and max. storage 1 (MS1) applies to whole pit, MS2 to 8" less, and MS3 to an additional 8" less. Minimum storage is that in the pit with least storage; maximum is that in the pit with the greatest storage.

[d]Based on raw manure only.

Table 25. Basic Information for the Farrowing and Nursery Buildings in the Farrow-to-Finish Operation[a].

Item	House Type: Farrowing, Pit depth 1'4"	Farrowing, Pit depth 3'	Farrowing, Pit depth 5'	Nursery, Pit depth 1'4"	Nursery, Pit depth 3'	Nursery, Pit depth 5'
PARTIAL SLATS						
Slats area (sq ft)	.4044	.4044	.4044	.7297	.7297	.7297
Concrete area (sq ft)	.6470	.6470	.6470	1.168	1.168	1.168
Storage capacity 1[b,c] (days)	-	145.6	242.7	-	150.9	251.5
Storage capacity 2 (days)	-	113.3	210.3	-	117.4	217.9
Storage capacity 3 (days)	-	80.9	178.0	-	83.8	184.4
Flooring investment (annual cost)($)	1.58 (.23)	1.58 (.23)	1.58 (.23)	2.86 (.42)	2.86 (.42)	2.86 (.42)
Pit investment (annual cost)($)	.73 (.09)	1.08 (.13)	1.50 (.18)	1.31 (.16)	1.94 (.23)	2.70 (.32)
Total investment (annual cost)($)	2.31 (.32)	2.66 (.36)	3.08 (.41)	4.17 (.58)	4.80 (.65)	5.56 (.74)
Labor usage (min/month)	1.24	1.24	1.24	1.13	1.13	1.13
TOTAL SLATS						
Slats area (sq ft)	.647	.647	.647	1.1665	1.1665	1.1665
Storage capacity 1[b,c] (days)	-	246.4	410.7	-	260.0	433.3
Storage capacity 2 (days)	-	191.7	356.0	-	202.2	375.5
Storage capacity 3 (days)	-	136.8	301.1	-	144.4	317.8
Flooring investment (annual cost)($)	1.42 (.24)	1.42 (.24)	1.42 (.24)	2.57 (.44)	2.57 (.44)	2.57 (.44)
Pit investment (annual cost)($)	1.00 (.12)	1.36 (.16)	1.80 (.22)	1.75 (.21)	2.30 (.28)	3.02 (.36)
Total investment (annual cost)($)	2.42 (.36)	2.78 (.40)	3.22 (.46)	4.32 (.65)	4.87 (.72)	5.59 (.80)
Labor usage (min/month)[d]	1.22	1.22	1.22	0	0	0
N production (lbs/month)	.0670	.0670	.0670	.1166	.1166	.1166
P production (lbs/month)	.0218	.0218	.0218	.0379	.0379	.0379
K production (lbs/month)	.0301	.0301	.0301	.0525	.0525	.0525

[a] On a 'per 100 lbs liveweight in the operation' basis.

[b] Storage capacities 1, 2 and 3 apply to the whole pit, less 8", and less 16", respectively

[c] Based on raw manure only.

[d] Farrowing house has monthly washdown; both houses have daily washing on solid floor.

Table 26. Basic Information for the Finishing Building in the Farrow-To-Finish Operation[a].

Item	Pit Depth 1'4"	3'	5'
PARTIAL SLATS			
Slats area (sq ft)	1.310	1.310	1.310
Concrete area (sq ft)	2.621	2.621	2.621
Storage capacity 1[b,c] (days)	-	46.1	76.8
Storage capacity 2 (days)	-	35.8	66.5
Storage capacity 3 (days)	-	25.6	56.3
Flooring investment (annual cost)($)	5.70 (.83)	5.70 (.83)	5.70 (.83)
Pit investment (annual cost)($)	2.03 (.24)	2.76 (.33)	3.64 (.44)
Total investment (annual cost)($)	7.73 (1.07)	8.46 (1.16)	9.34 (1.27)
Labor usage[d] (min/month)	2.54	2.54	2.54
TOTAL SLATS			
Slats area (sq ft)	3.931	3.931	3.931
Storage capacity 1[b,c] (days)	-	144.5	240.8
Storage capacity 2 (days)	-	112.4	208.7
Storage capacity 3 (days)	-	80.3	176.6
Flooring investment (annual cost)($)	8.65 (1.47)	8.65 (1.47)	8.65 (1.47)
Pit investment (annual cost)($)	5.34 (.64)	8.05 (.97)	10.45 (1.25)
Total investment (annual cost)($)	13.99 (2.11)	16.70 (2.44)	19.10 (2.72)
Labor usage (min/month)	0	0	0
N production (lbs/month)	.7254	.7254	.7254
P production (lbs/month)	.2358	.2358	.2358
K production (lbs/month)	.3264	.3264	.3264

[a] On a 'per 100 lbs liveweight less the operation' basis.

[b] Storage capacities 1, 2 and 3 apply to whole pit, less 8", and less 16" respectively.

[c] Based on raw manure only.

[d] Daily washing and disinfecting 3 times a year.

Table 27. Basic Information for the Breeding and Gestation Houses in the Farrow-To-Finish Operation.[a]

Item	House Type					
	Breeding			Gestation		
	Pit depth			Pit depth		
	1'4"	3'	5'	1'4"	3'	5'
PARTIAL SLATS						
Slats area (sq ft)	.2523	.2523	.2523	.7022	.7022	.7022
Concrete area (sq ft)	.3364	.3364	.3364	.9364	.9364	.9364
Storage capacity 1[b,c] (days)	-	104.8	174.7	-	59.3	98.9
Storage capacity 2 (days)	-	81.5	151.4	-	46.1	85.7
Storage capacity 3 (days)	-	58.2	128.1	-	33.0	72.5
Flooring investment ($)	.9164	.9164	.9164	2.547	2.547	2.547
Pit investment ($)	.5196	.8133	1.1656	1.379	2.260	3.030
Total investment ($)	1.4260	1.7297	2.0820	3.926	4.807	5.577
Flooring annual cost ($)	.1377	.1377	.1377	.3828	.3828	.3828
Pit annual cost ($)	.0624	.0976	.1399	.1655	.2712	.3636
Total annual cost ($)	.2001	.2353	.2776	.5483	.6540	.7464
Labor usage[d] (min/month)	.3259	.3259	.3259	.9084	.9084	.9084
N production (lbs/month)	.0190	.0190	.0190	.0685	.0685	.0685
P production (lbs/month)	.0062	.0062	.0062	.0223	.0223	.0223
K production (lbs/month)	.0086	.0086	.0086	.0308	.0308	.0308

[a] On a 'per 100 lbs liveweight in the operation' basis.

[b] Storage capacities 1, 2 and 3 apply to the whole pit, less 8" and less 16", respectively.

[c] Based on raw manure only.

[d] Based on daily washing of solid floor.

Table 28. Summary of Basic Housing Information for the Farrow-To-Finish Operation[a].

Item	Partial Slats			Total Slats[b]		
	Pit depth			Pit depth		
	1'4"	3'	5'	1'4"	3'	5'
Floor area (sq ft)	9.1074	9.1074	9.1074	7.9718	7.9718	7.9718
Slats area (sq ft)	3.3986	3.3986	3.3986	6.6990	6.6990	6.6990
Concrete area (sq ft)	5.7088	5.7088	5.7088	1.2728	1.2728	1.2728
Min. storage capacity 1[c,d] (days)	-	46.1	76.8	-	46.1	76.8
Min. storage capacity 2 (days)	-	35.8	66.5	-	35.8	66.5
Min. storage capacity 3 (days)	-	25.6	56.3	-	25.6	56.3
Max. storage capacity 1[c,d] (days)	-	150.9	251.9	-	260.0	433.3
Max. storage capacity 2 (days)	-	117.4	217.9	-	202.2	375.5
Max. storage capacity 3 (days)	-	83.8	184.4	-	144.4	317.8
N production (lbs/month)	.9965	.9965	.9965	.9965	.9965	.9965
P production (lbs/month)	.3239	.3239	.3239	.3239	.3239	.3239
K production (lbs/month)	.4484	.4484	.4484	.4484	.4484	.4484
Flooring investment ($)	13.607	13.607	13.607	16.101	16.101	16.101
Pit investment ($)	5.962	8.853	12.036	9.990	14.788	19.464
Total investment ($)	19.569	22.460	25.643	26.091	30.889	35.565
Flooring annual cost ($)	2.0066	2.0066	2.0066	2.669	2.669	2.669
Pit annual cost ($)	0.72	1.06	1.44	1.20	1.78	2.33
Total annual cost ($)	2.73	3.07	3.45	3.87	4.45	5.00
Labor usage (min/month)	6.145	6.145	6.145	2.454	2.454	2.454

[a]On a 'per 100 lbs liveweight' basis.

[b]Totally slatted systems assume total slats where possible, and partial slats in other buildings.

[c]Min and max. storage 1 (MS1) applies to whole pit, MS2 to 8" less, and MS3 to an additional 8" less. Minimum storage is that in the pit with least storage; maximum is that in the pit with the greatest storage.

[d]Based on raw manure only.

costs are given in Table 28 for operations using partial slats throughout, and total slats where feasible. Totally concrete floor operations are not detailed, but rough estimates could be based on 10.6 sq ft per 100 lbs liveweight.

Flooring and pit costs for the FTF operation fall between those for the FPF and FPP operations, reflecting the addition of a finishing building to an FPP operation. Maximum storage capacities are identical to those in the FPP operation, but minimum storage are the same as for the FPF operation.

Although summaries are given only for partially slatted and totally slatted operations, estimates of costs for operations using mixed flooring can be made by combining the separate housing components detailed in the tables.

2.6 Liquid Manure Transportation and Application

Manure from in-house pits can be hauled and applied directly to the land without any pretreatment. For hauling purposes, tractor-pulled wagons of various sizes can be employed. Table 16 lists prices of five wagons, including four honey wagons with vacuum pump/agitator included, and a larger tank wagon, for which a separate pump/agitator is needed. At the application site, the liquid manure can be applied on the soil surface (perhaps for subsequent plowdown), or it may be incorporated several inches below the surface using a soil injector. A soil injector unit is also priced in Table 16. Using these prices, and data in Table 17, annual ownership costs can be calculated. These are reported in Table 29. Since fixed ownership costs

Table 29. Annual Ownership Costs of Tank Wagons and Soil Injection Equipment.

Item	Investment cost ($)	Annual ownership cost[a] ($)
800 gal. honey wagon[b]	3,525	874.9
1,100 gal. honey wagon[b]	4,400	1,092.1
1,500 gal. honey wagon[b]	5,100	1,265.9
2,100 gal. honey wagon[b]	8,325	2,066.4
3,200 gal. tank wagon[c]	6,900	1,712.6
	10,200	2,53.18
Pump/agitator[c]	3,300	819.1
Soil injector	1,160	287.9

[a]Computed at 24.82% of investment.

[b]These honey wagons incorporate a 135 CFM vacuum pressure pump and spreading attachment.

[c]This is an 8', 21" impeller type pump with chopper.

are incurred no matter what use is made of the equipment (this is only approximately true since depreciation and repairs depend to some extent on the use), economies of size of operation will exist. To some extent, however, these economics of size are offset by diseconomies of size associated with the operating costs of wagons.

The operating costs, which include labor and tractor costs, are directly related to the time required to transport and apply manure. The time taken to apply N as manure to an acre is assumed to be directly related to the distance of travel and to the amount applied, and inversely related to the wagon capacity and to the concentration of the manure. The specific model adapted is

$$T = (T_T + T_{LUL}) \frac{R}{(C)(CAP)(f)}$$

where,

T = time needed to apply manure at N rate R to 1 acre (hr),
T_T = round-trip travelling time (hr),
T_{LUL} = time to load and unload the wagon (hr),
R = rate at which N is applied (lbs/ac),
C = concentration of the liquid manure (lbs N/gal.),
CAP = capacity of the wagon (gal.), and
f = fraction of the tank which is full on an average trip.

Liquid manure concentrations vary with the house, with the amount of wash water added, and with the pit-bottom wash practices. Concentrations can be calculated using estimates of monthly volume production, and the N production figures reported in Tables 21 to 28. Time to load and unload is estimated to vary from 15 to 20 minutes, while travelling time is directly proportional to the distance to the application site (T_T = twice distance/speed of travel). Assuming a 6 mph speed, the travelling time for distances up to half a mile will vary form 0 to 10 minutes. Travel time for most operations will be under 5 minutes, the smaller part of the time for spreading manure. Thus total time for these distances for one wagon load will vary from 15 to 30 minutes, but most frequently from 15 to 20 minutes, and averaging 17 minutes. These estimates are compatible with an earlier North Carolina study [Wells and Parsons, 1967], with Morris (1966) and with McKenna and Clark (1970). None of these studies explicitly considers the effect of distance travelled. For f, a value of 0.9 was used. This is in general agreement with Kesler and Hinton (1966) and George et al. (1975).

Once T is known, the operating cost (OC) can be calculated as:

OC = (T x (hourly tractor cost)) + (T x (1.1 hourly labor cost)).

Hourly tractor cost is reported in Table 18, and hourly labor cost in Table 16. The larger wagons may require more powerful tractors than the smaller wagons, particularly in sloping areas. Also, a larger tractor may be needed if a soil injector is used. A factor of 1.1 to 1.0 is used in calculating operating costs to allow for some labor set-up time.

As examples of tank wagon costs, estimates for spreading liquid manure have been made for the five wagons on a 'per 100 lbs applied N' basis. Table 30 reports estimated times and costs of applying N from various houses at a zero travel distance. In Table 31 are reported the marginal increases in time and costs of transporting the manure an extra 100 yards to the application site. The calculations all relate to undiluted raw manure.

The tables reveal a range of costs for spreading 100 lbs N. These costs may be compared with the potential fertilizer value of the manure containing 100 lbs N (see Section 2.10). Assuming N:P:K = 1.0 : 0.325 : 0.45, and costs of 15, 40 and 11 cents per lb of N, P and K, respectively, the manure has a potential fertilizer value of $32.95. If all plant nutrient requirements are met by the manure, additional costs of fertilizer spreading ($2.50/acre) will be saved. From Table 30, it is clear that manure value will potentially offset the spreading costs only if sufficient use is made of the spreading equipment, that is, if the hog operation is large enough. Chances of net benefits are greater from those houses where the N concentration is greatest, namely the farrowing, nursery and finishing houses.

Several conclusions seem warranted. (a) Very small operations will not find spreading attractive with the wagon sizes considered (other alternatives may be just as unattractive). (b) Distance will only become a dominating cost factor if the manure has to be transported upward of half-a-mile; moreover, because the costs associated with distance are relatively small, it would pay to transport manure several hundred yards in order to capture potential manure value. (c) Comparisons across wagons appear to suggest that the larger wagons have a cost advantage. This is illusionary, as relevant comparisons across wagons are to be made on a constant total operation basis, not on a constant total annual hours of usage basis. Figures 1 to 3 depict cost functions for spreading the total manure produced from all three types of operation and for various wagon sizes. The cost functions are only approximate and only provide guides to actual costs. Manure is assumed to be applied as undiluted raw manure, at a uniform N rate of 175 lbs/ac in a circle surrounding the point of manure production, and to be transported an average distance of 2/3 the radius of the required land circle. Further, for the FPP and FTF operations, the manure from the various houses is assumed to be mixed into one volume of manure at a single concentration. The graphs indicate that as the operation size increases, the least cost wagon size also increases. Moreover, the graphs suggest that two wagons, namely the 1100 and 2100 gallon wagons are rarely the preferred ones. The range over which a given wagon size is optimal depends on the dilution but for operations up to 300,000 lbs liveweight, a wagon no larger than 1500 gallons appears best. For operations up to about 60,000 lbs liveweight, an 800 gallon wagon is best. These observations

Table 30. Costs and Times for Spreading 100 lbs N as Liquid Manure at the Point of Production.

	Housing Type					
	Breeding		Gestation		Others	
	Pit depth, (ft)		Pit depth (ft)		Pit depth (ft)	
	3	5	3	5	3	5
800 gallon wagon						
Labor (hours)	3.61	3.28	4.92	4.47	1.23	1.12
Tractor costs[a,b] ($)	17.91	16.28	24.43	22.21	6.11	5.55
Total cost with 100 hours use[c] ($)	57.43	52.22	78.33	71.21	19.58	17.80
Total cost with 200 hours use ($)	43.08	39.17	58.76	53.42	14.69	13.35
Total cost with 600 hours use ($)	33.52	30.48	45.71	41.56	11.43	10.39
1100 gallon wagon						
Labor (hours)	2.62	2.39	3.58	3.25	0.89	0.81
Tractor costs ($)	13.02	11.84	17.76	16.15	4.44	4.04
Total cost with 100 hours use ($)	46.95	42.69	64.03	58.21	16.01	14.55
Total cost with 200 hours use ($)	33.92	30.85	46.27	42.06	11.57	10.52
Total cost with 600 hours use ($)	25.24	22.95	34.42	31.29	8.61	7.82
1500 gallon wagon						
Labor (hours)	1.92	1.75	2.62	2.39	0.66	0.60
Tractor costs ($)	9.55	8.68	13.03	11.84	3.26	2.96
Total cost with 100 hours use ($)	37.47	34.07	51.10	46.46	12.78	11.61
Total cost with 200 hours use ($)	26.60	24.00	36.00	32.73	9.00	8.18
Total cost with 600 hours use ($)	19.01	17.29	25.93	23.58	6.48	5.89
2100 gallon wagon						
Labor (hours)	1.37	1.25	1.87	1.70	0.47	0.43
Tractor costs ($)	6.82	6.20	9.31	8.46	2.33	2.11
Total cost with 100 hours use ($)	36.77	33.43	50.15	45.59	12.54	11.40
Total cost with 200 hours use ($)	23.86	21.69	32.54	29.58	8.13	7.39
Total cost with 600 hours use ($)	15.25	13.87	20.80	18.91	5.20	4.73
3200 gallon wagon						
Labor (hours)	9.90	0.82	1.23	1.12	0.31	0.28
Tractor costs ($)	4.48	4.07	6.11	5.55	1.53	1.39
Total cost with 100 hours use ($)	27.94	25.41	38.11	34.65	9.53	8.66
Total cost with 200 hours use ($)	17.56	15.97	23.96	21.78	5.99	5.44
Total cost with 600 hours use ($)	10.64	9.68	14.52	13.20	3.63	3.30

[a]Tractor costs assumed to be $5.46/hour for a 65 HP diesel tractor.

[b]Labor time assumed to be 1.1 times tractor time.

[c]Wagon annual costs are $874.95, $1,092.14, $1,265.89, $2,066.38 and $2,531.77 for the five wagons. Soil injection equipment would add another $287.91/year to these costs. Labor is costed at $3.00/hour.

Table 31. Costs and Times for Transporting 100 lbs N as Liquid Manure for 100 Yards.

	Housing Type					
	Breeding		Gestation		Others	
	Pit depth (ft)		Pit depth (ft)		Pit depth (ft)	
	3	5	3	5	3	5
800 gallon wagon						
Labor (hours)	.241	.219	.329	.299	.082	.075
Tractor costs[a,b] ($)	1.197	1.088	1.633	1.484	.408	.371
Total cost with 100 hours use[c] ($)	3.839	3.491	5.236	4.760	1.309	1.190
Total cost with 200 hours use ($)	2.880	2.619	3.928	3.571	.982	.893
Total cost with 600 hours use ($)	2.240	2.037	3.056	2.778	.764	.694
1100 gallon wagon						
Labor (hours)	.175	.160	0.239	.218	.060	.054
Tractor costs ($)	.871	.792	1.188	1.080	.297	.270
Total cost with 100 hours use ($)	3.138	2.854	4.280	3.891	1.070	.973
Total cost with 200 hours use ($)	2.268	2.062	3.093	2.812	.773	.703
Total cost with 600 hours use ($)	1.687	1.534	2.301	2.092	.575	.523
1500 gallon wagon						
Labor (hours)	.129	.117	.175	.160	.044	.040
Tractor costs ($)	.638	.580	.871	.792	.218	.198
Total cost with 100 hours use ($)	2.505	2.279	3.416	3.106	.854	.776
Total cost with 200 hours use ($)	1.764	1.604	2.407	2.188	.602	.547
Total cost with 600 hours use ($)	1.271	1.156	1.734	1.576	.433	.394
2100 gallon wagon						
Labor (hours)	.092	.084	.125	.114	.031	.028
Tractor costs ($)	.456	.415	.622	.566	.156	.141
Total cost with 100 hours use ($)	2.458	2.235	3.352	3.047	.838	.762
Total cost with 200 hours use ($)	1.595	1.450	2.175	1.977	.544	.494
Total cost with 600 hours use ($)	1.019	.927	1.390	1.264	.345	.316
3200 gallon wagon						
Labor (hours)	.060	.055	.082	.025	.021	.019
Tractor costs ($)	.299	.272	.408	.371	.102	.093
Total cost with 100 hours use ($)	1.868	1.698	2.548	2.316	.637	.579
Total cost with 200 hours use ($)	1.174	1.068	1.601	1.456	1.400	.364
Total cost with 600 hours use ($)	.712	.647	.970	.882	.243	.220

[a]Tractor costs assumed to be $5.46/hours for a 65 HP diesel tractor.

[b]Labor time assumed to be 1.1 times tractor time.

[c]Wagon annual costs are $874.95, $1,092.14, $1,265.89, $2,066.38 and $2,531.77 for the five wagons. Soil injection equipment would add another $287.91/year to these costs. Labor is costed at $3.00/hours.

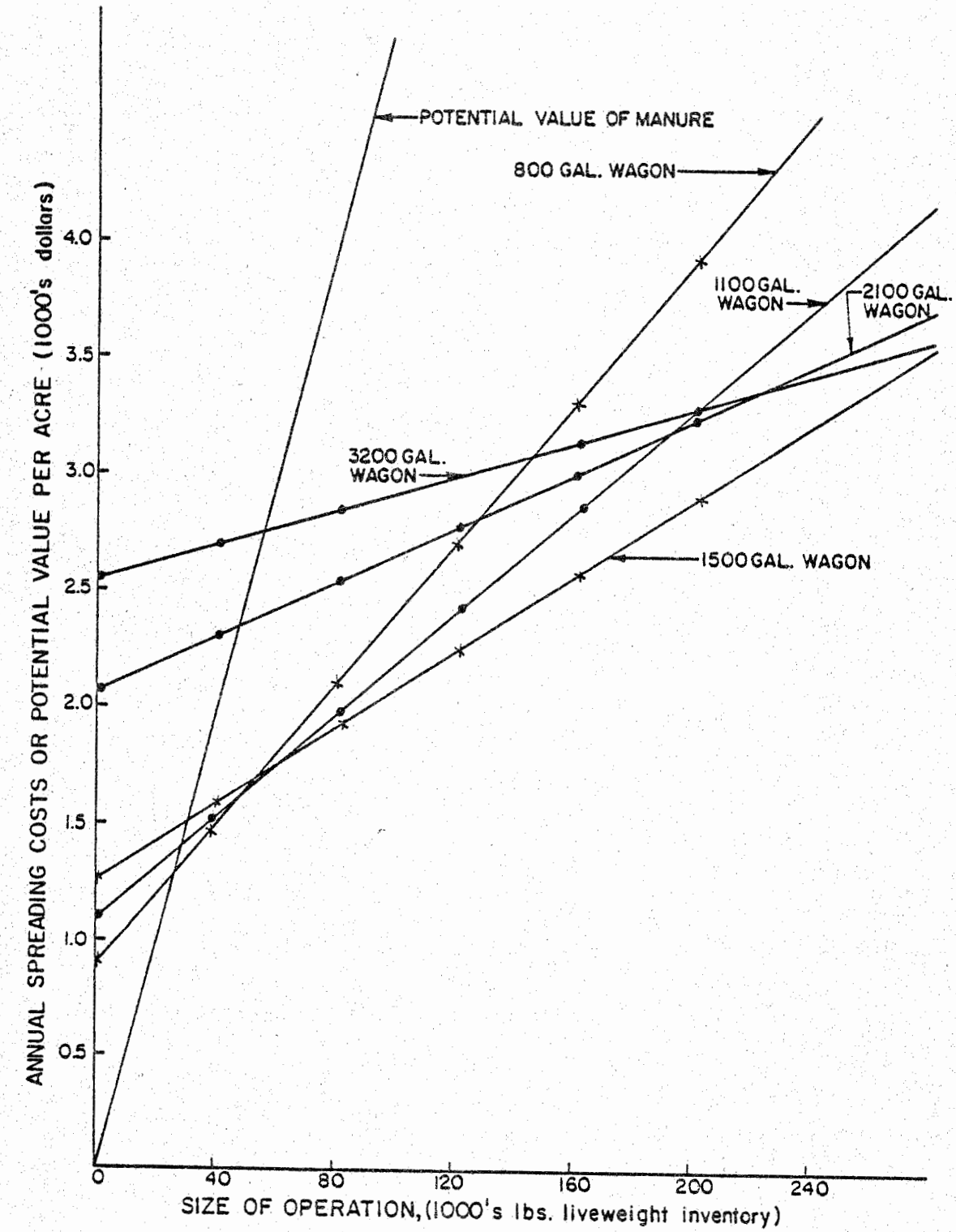


Figure 1. Annual spreading costs for land application of raw manure at N rate of 175 pounds per acre, feeder pig finishing.

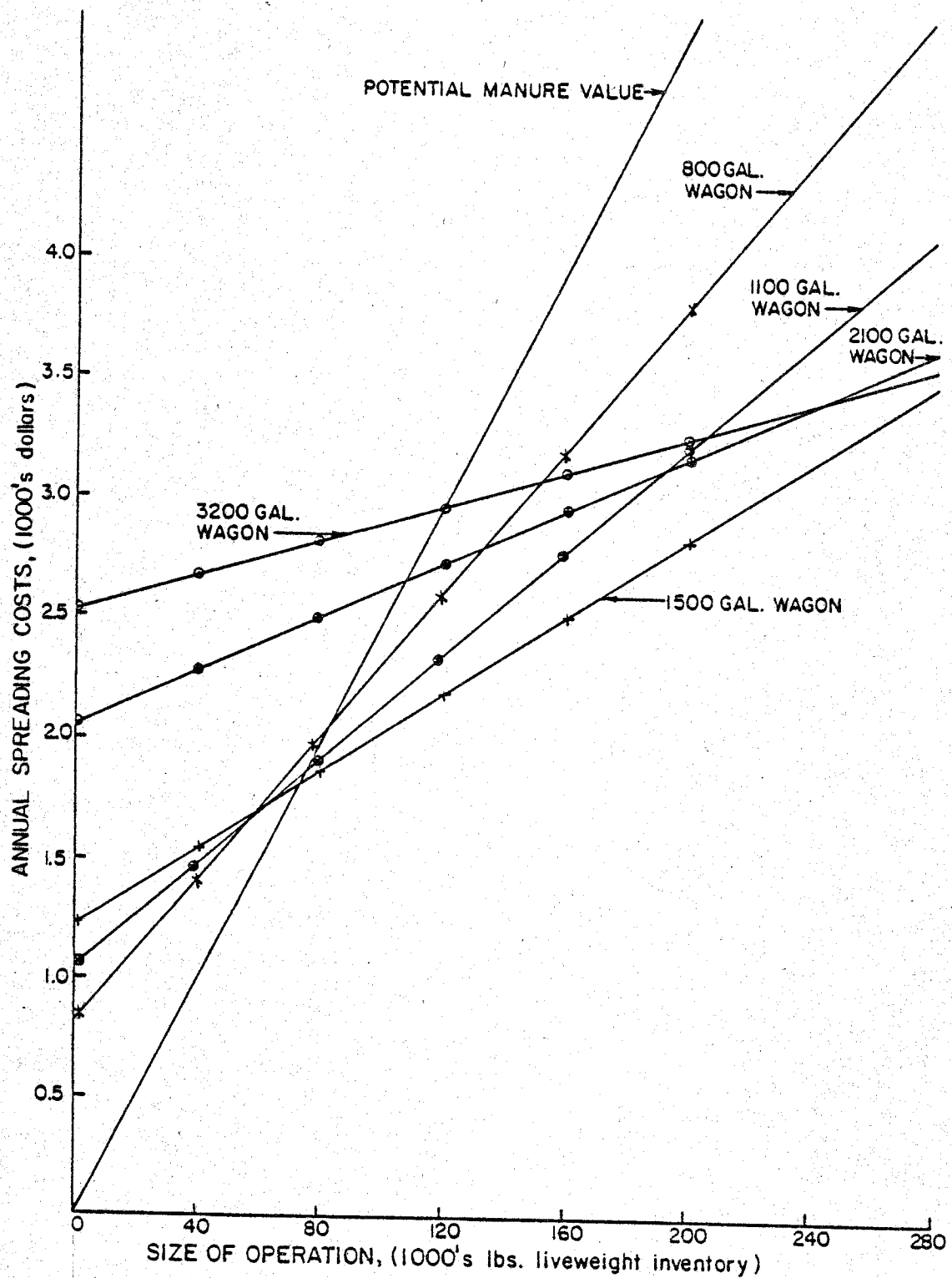


Figure 2. Annual spreading costs for land application of raw manure at N rate of 175 pounds per acre, feeder pig production.

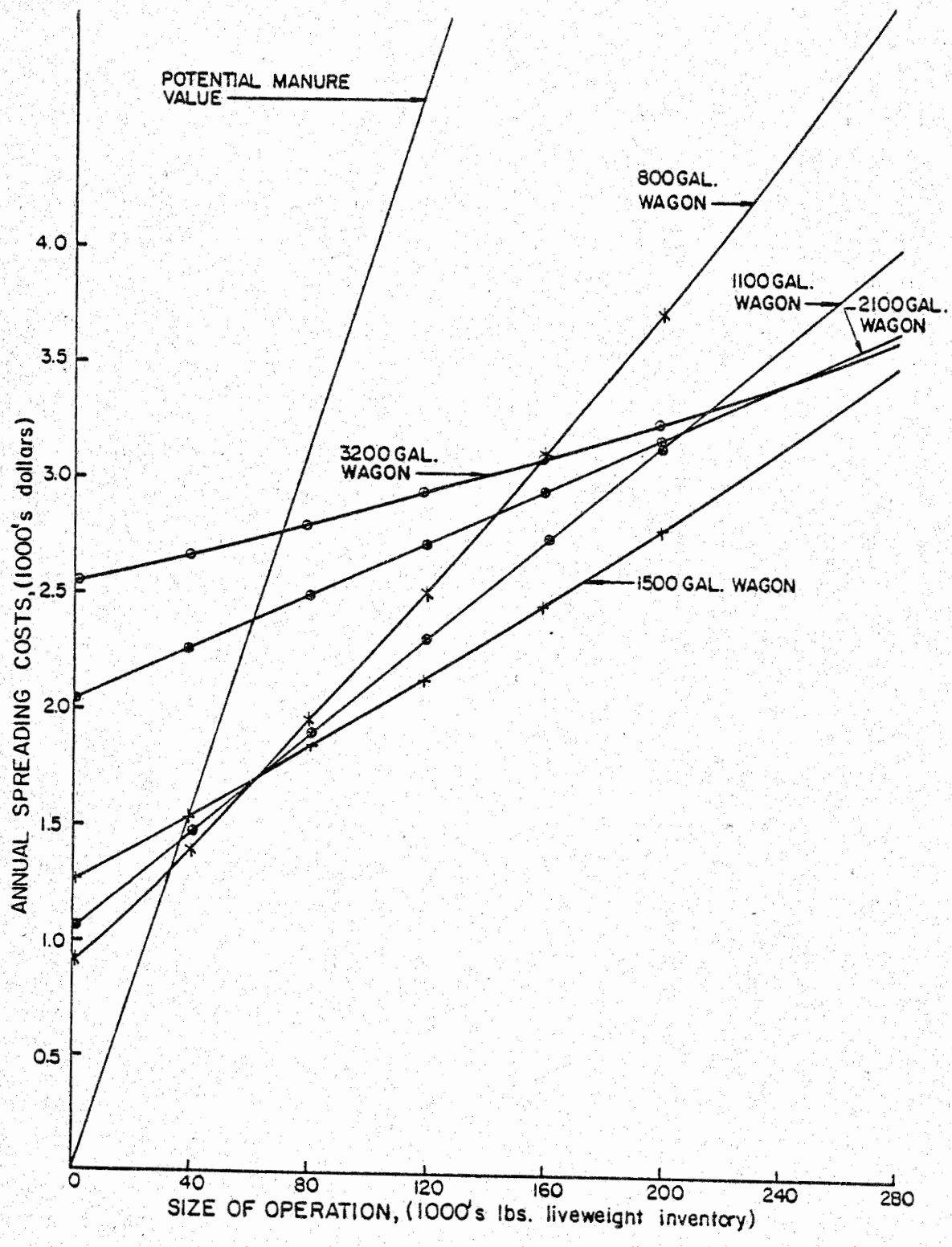


Figure 3. Annual spreading costs for land application of raw manure at N rate of 175 pounds per acre, farrow to finish.

provide some guide to wagon choice. (d) If raw manure were to be diluted through water additions, the cost of manure spreading will rise rapidly. In Figure 4, spreading costs for FPF operations have been depicted assuming that raw manure is diluted by a factor of 6. In comparison to Figure 1, the cost curves are higher and more steeply shaped, reflecting greater operating costs. Although the curves depicted relate specifically to the FPF operation, they apply approximately for FPP and FTF operations, since the costs for the latter differ only because of the relatively small travelling time component of total cost. (e) Finally, the calculations suggest that the profitability of manure spreading will depend closely on the recovery of manure nutrient value. The maximum, or potential value of nutrients function has been graphed in Figures 1 to 4, and for the FPF operation, an approximate actual value of nutrients function (0.7 of potential) has been graphed in Figure 4. While a FPF operation larger than 88,000 lbs liveweight can potentially show net benefits to manure spreading when raw manure is diluted by a factor 6, the operation may actually have to be 400,000 lbs or more in size to achieve net benefits. FPP and FTF operators would have to be even larger because of their lower nutrient content of manure. If, however, less water was added to the manure, the profitability of spreading would be enhanced. In Figures 1 to 3, all slopes of the cost curves would be reduced by a factor 6 compared to those in Figure 4. In this case, if all potential manure value could be recovered, a FPF operator would find spreading attractive at about 28,000 lbs liveweight, a FPP operation at about 70,000 lbs, and a FTF operation at about 35,000 lbs. At actual recovery rates, required sizes may be 2 or more times these. The calculations and graphs reported here are only examples of costs and cost relationships. Estimates under other assumptions can easily be made using the models described.

2.7 External Pumping Pit

While liquid manure can be pumped into hauling wagons directly from the in-house pit, practical experience suggests that pits can be emptied more efficiently if they are first drained to an external pumping pit. The manure can be agitated and stirred much more easily in the latter. This pumping pit is then considered essential in a liquid manure hauling operation.

The pit is assumed to be circular, radius R, with inside depth D feet. Of the latter, H feet are above ground. The pit is assumed to be constructed of reinforced concrete walls and the bottom is T ft thick. A lid, L ft thick ($L \geq 0$), is also included. The volume of such a pit is $V = \pi R^2 D$ ft^3.

The investment cost (PIC) for this pit is comprised of the cost of excavation, and the cost of poured concrete in the base, walls and lid. The following cost-volume relationship is easily established:

$$PIC = \pi T^2[p_c\ (L + D + T) + p_E\ (D - H + T)] + 2T\ (\tfrac{\pi}{D})^{0.5}\ [p_c\ (L + D + T) + p_E\ (D - H + T)]\ V^{0.5} + \frac{1}{D}\ [p_c\ (L + T) + p_E\ (D-H+T)]\ V,$$

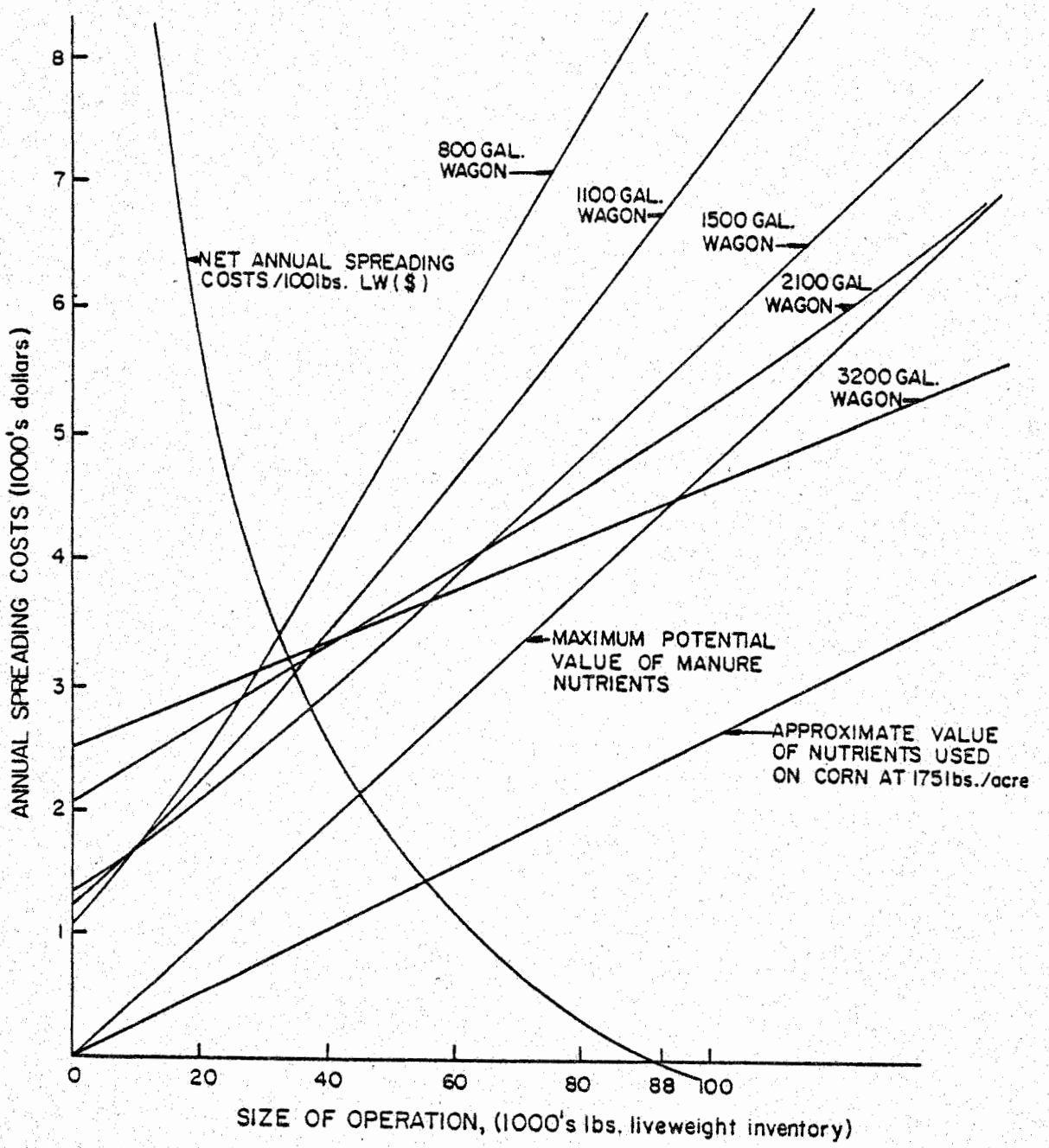


Figure 4. Annual costs for spreading manure from an feeder pig production (FPF) operation when 5 gallons of water are added to each gallon of raw manure (spread at 175 lbs N/acre in circle around point of production).

where p_C and p_E are costs of poured concrete and excavation respectively in $/ft^3$, and where excavation volume is assumed to be equal to the outside dimensions volume of that portion of the pit under ground.

Although there is no single way of choosing the pit size for a given size of hog operation, from a practical standpoint it is convenient to size the pumping pit the same as the largest in-house pit. Each in-house pit in the operation can then be emptied entirely into the external pit for pumping. When this rule is used, pit volume and pit cost will vary from operation to operation depending on the type of operation, type of flooring, and in-house pit details.

Table 32 reports the pit capacity supplied per foot of pit depth for the five types of houses, the three types of operation, and two flooring types. These estimates are based on the pit designs already outlined. Knowing details of the hog operation, housing and flooring, the required total pumping pit volume is easily computed. For example, suppose a 100 sow FPP operation uses partially slatted facilities for the breeding gestation and farrowing houses, and total slats in the nursery building with 3' pits throughout. The required pumping pit volume is then (from Table 9 and 32)

V = operation size (in 100's lbs liveweight) x required volume per 100 lbs liveweight
= 569 x max [1.454, 4.558, 2.43, 7.53]
= 4285 ft^3

Table 32. Pit Volume per 100 lbs Liveweight per Foot of Pit Depth by Operation Type and Flooring Type (cu ft).

	Flooring Type					
	Partial Slats			Total Slats		
	Operation type			Operation type		
Building type	FPF	FPP	FTF	FPF	FPP	FTF
Breeding	nr[a]	0.485	0.210	nr	na[b]	na
Gestation	nr	1.519	0.585	nr	na	na
Farrowing	nr	0.810	0.351	nr	1.37	0.594
Nursery	nr	1.458	0.632	nr	2.51	1.09
Finishing	2.054	nr	1.201	6.438	nr	3.76

[a] nr: not relevant for this type of operation.

[b] na: not available in this flooring type.

The cost can then be computed using the previously outlined model. Sample cost functions for 6', 9', and 12' deep pits are depicted in Figure 5. These costs functions assume 3' pit depth above ground, 6" base and walls, no lid, $0.03/ft^3 excavation costs, and $3.22/ft^3 poured concrete. Where these assumptions hold, the pumping pit investment cost can be read directly. For the example operation, pit construction costs would vary from $2100 to $2300 with the depth of pit.

Annual costs associated with the pumping pit include only overhead costs, since operating costs (pumping and agitation) are included in application costs. Annual costs for a concrete pit (see Table 17) are assessed at 12% of the investment costs, and for the example would be $252 to $276 per year.

Also depicted in Figure 5 for interest are the pumping pit radius and volume relationships for the 6', 9', and 12' deep pits.

2.8 Lagoons

2.8.1 Functions and types

Lagoons offer the hog producer two important opportunities for manure disposal management. First, they serve as storage devices for manure, thus enabling the producer to time his applications to make better use of the nutrients, or to avoid application at inopportune times. Second, when properly designed, lagoons can provide varying amounts of pretreatment of the manure prior to land application. Specifically, levels of N, P and K (and other elements) can be reduced.

The pretreatment performance of a lagoon depends on a number of factors affecting the biological degradation mechanisms. These have been overviewed by Overcash and Humenik (1976), and include ambient temperature, ice formation, rainfall, depth, detention time, loading frequency, loading rate, and micro-climate factors. In the mild North Carolina climate, temperature has a relatively small effect and is ignored in this study.

Given the complexity of the lagoon mechanism, and present lack of understanding, lagoon types are identified quite broadly. Five lagoon types, based on the organic matter loading rate, are considered. Lower loading rates, that is, smaller daily organic matter additions per unit volume of lagoon, are associated with greater reductions in N, P, K, and other constituent concentrations. The loading rates assumed are 62.28, 74.43, 149.3, 447.8, and 1675.0 cu ft of lagoon per lb of daily chemical oxygen demand (COD) added. At these loading rates and with proper design, the first lagoon operates only if mechanically aerated, the next three as anaerobic lagoons, and the last as a naturally facultative lagoon. For facultative lagoons, which must be no deeper than 6', surface area is a critical parameter. At the loading rate considered, and assuming a 6' deep lagoon, 156 lbs COD/day are added per acre of lagoon surface. Surface area is less important for the other lagoons, and they can be deeper. Anaerobic lagoons should be 12' or more, and a mechanically aerated lagoon should be between 5' and 15', deeper lagoons being preferred because of less bottom sludge

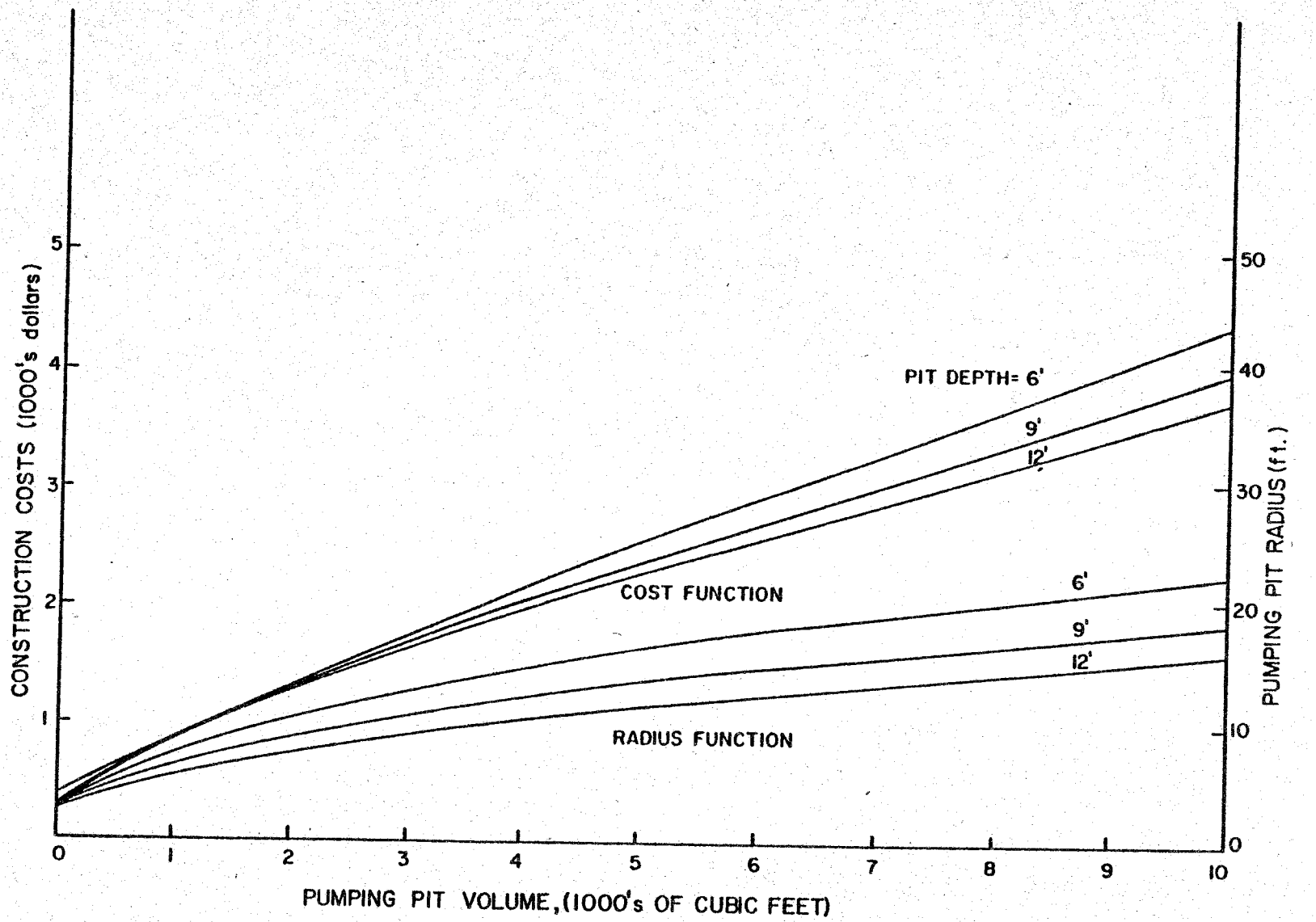


Figure 5. Pumping pit construction costs and radius as functions of pit volume for 6 ft, 9 ft, and 12 ft deep pits.

scour, and the smaller surface area. Since the performance of mechanically aerated lagoons is not well documented yet, a 9' average depth is assumed here.

Lagoon designs must conform to several pollution control and safety guidelines. Thus a lagoon should provide sufficient excess capacity to contain the rainfall from a 25-year, 24 hour storm. Additional freeboard of at least 1' should be provided, the wet-side embankment slope should be no steeper than 2.5:1, the lagoon should be fenced off, and seepage from the lagoon should not occur. Overcash and Humenik (1976) note that several studies have suggested that lagoons tend to be self-sealing, even for soils with a high water table. Seepage is not explicitly considered in this study.

Aside from these considerations, lagoons can be designed to take advantage of the lie of the land, impervious soils, etc. Because construction is a major cost of lagoons, the varying potential to take advantage of nature implies that lagoon costs may vary widely, not only from region to region, but also from farm to farm within a region. As a first approximation to lagoon design, a standard trapezoidal-shaped lagoon is assumed in this study. Depth and slopes used are those already outlined. An additional factor reflecting differences in lagoon volume and necessary excavation is incorporated, and allowed to differ between regions to reflect typical terrain (presented later in Table 34).

Data on lagoon pretreatment performance (that is, constituent losses) are reported in Overcash and Humenik (1976) for all three types of lagoons. By interpolation of their anaerobic lagoon data, and direct use of their data for the other lagoons, % N reductions, amounts of nutrients in the effluent, and constituent ratios were determined. These are reported in Table 33 for the 5 lagoons. The lagoon loading rates are also reported in several different units. The data indicate that lagoons can have a very significant effect on the quality of nutrients to be disposed of.

In addition to affecting the amount of nutrients, lagoons also affect the volume of liquid that has to be applied to land. The latter effect occurs through the net precipitation caught in the lagoon, and will vary from region to region as net rainfall changes (see Table 5). Actual net precipitation caught, and indeed lagoon costs, depend on the details and parameters of the lagoon design. These are outlined below.

2.8.2 Lagoon modelling

Define the following:

H = operating design depth of the lagoon (ft) (6, 9 or 12')
E = extra depth required for freeboard (1') plus that for holding the 25-year, 24-hour storm rainfall (ft)(see Table 5)
L = length of lagoon base (ft)
B = breadth of lagoon base (ft) (0, 150, 300' for naturally facultative lagoons, 0, 50, 150 ft for others)

Table 33. Lagoon Effluent Production and Relative Constituent Proportions by Lagoon Type[a].

Item	Lagoon type[b] 1	2	3	4	5
Loading rate (ft^3/lb daily COD)	62.28	74.43	149.3	447.8	1675.0
Loading rate (ft^3/lb daily N)	1043	1250	2500	7500	28063
Loading rate (ft^3/100 lbs LW in FPF)	42	50	100	300	1122
Loading rate (ft^3/100 lbs LW in FTF)	33.8	40.18	80.36	241.09	901.67
Loading rate (ft^3/100 lbs LW in FPP)	21.7	25.79	51.58	154.74	578.73
% N reduction	66.7	37.85	61.6	83.3	98.
Effluent N (lbs N/day/lb. N influent)	.3333	.6215	.3840	.1670	.0194
Effluent P (lbs P/day/lb. N influent)	.0333	.0299	.020	.0125	.0107
Effluent K (lbs K/day/lb/N influent	.3333	.3333	.3333	.3333	.3333
Approximate effluent nutrient ratios to N (by weight)					
P	.1	.048	.052	.075	.55
K	1.0	.536	.868	1.996	17.18
Ca	.25	.136	.221	.507	4.41
Cl^-	1.667	.852	1.383	3.179	27.63
Cu[c]	.0003	.0002	.0003	.0007	.0005
Cu[d]	.003	.0016	.0026	.0060	.0519
Mg	.0333	.020	.032	.075	.649
Ma	.0008	.00048	.00078	.00179	.016
Na	.25	.152	.247	.567	4.930
Zn	.0017	.0008	.0012	.0030	.025

[a] Source: Overcash and Humenik (1976).

[b] Lagoon 1 is mechanically aerated, 2-4 are anaerobic with different loading rates, and 5 is naturally facultative.

[c] No copper supplement in feed.

[d] 150-350 ppm copper supplement.

S = slope of the lagoon sides (2.5:1)
A = surface area of the lagoon (ft^2)
V = design volume of the lagoon (ft^3)
EV = excavation volume for the lagoon (ft^3) (see Table 34 for EV: V = k)
F = length of fence to fence off the lagoon (ft)
R = distance fence is placed out from bank of lagoon (ft)(20')
I = influent concentration or liquid manure concentration (lbs N/gal)
O = effluent concentration or supernatant concentration (lbs N/gal)
P = net precipitation per year (ft) (see Table 5)
CA = net precipitation collection area (ft^2)
VP = volume of annual net precipitation entering the lagoon (ft^3)
EC = unit construction (excavation) cost for the lagoon ($/$ft^3$)(see Table 16)
FC = unit fencing cost ($/ft) (see Table 16)
C = total lagoon investment cost ($).

When the lagoon has a trapezoidal shape with a fixed breadth and depth, then the equation for the volume (V) of the lagoon is:

$$V = HL\ (B + \frac{H}{S}) + \frac{H^2B}{S} + \frac{4}{3}\ \frac{H^3}{S^2}$$

and the minimum volume for base length (L) equal to zero is:

$$V = \frac{H^2B}{S} + \frac{4}{3}\ \frac{H^2}{S^2}\ .$$

Also, it can be shown that the lagoon surface area, the net precipitation catchment area, the volume of net precipitation, and the length of fence are all linear functions of the lagoon volume. Further, since excavation volume is directly proportioned to lagoon volume and prices are fixed, total lagoon construction costs will be a linear function of volume. These functions are defined below:

$$(1)\quad A = \frac{4\ H^2}{S^2} + \frac{2BH}{S} - \frac{\left(\frac{4H^3}{3S^2} + \frac{H^2B}{S}\right)\left(\frac{2H}{S} + B\right)}{\left(BH + \frac{H^2}{S}\right)} + \frac{\left(B + \frac{2H}{S}\right)}{\left(BH + \frac{H^2}{S}\right)}\ V$$

i.e., $A = K_A + k_A V$, where K_A and k_A have obvious definitions.

$$(2)\quad \underline{CA} = 4\ \frac{(H+E)^2}{S^2} + \frac{2B\ (H+E)}{S} - \frac{\left(\frac{4H^3}{3S^2} + \frac{H^2B}{S}\right)\left(\frac{2(H+E)}{S} + B\right)}{\left(BH + \frac{H^2}{S}\right)} + \frac{\left(B + \frac{2(H+E)}{S}\right)}{\left(BH + \frac{H^2}{S}\right)}\ (V)$$

i.e., $\underline{CA} = K_{\underline{CA}} + k_{\underline{CA}}\ V$

$$(3)\quad VP = \underline{CA}\ P$$

$$= PK_{\underline{CA}} + Pk_{\underline{CA}}\ V$$

i.e., $VP = K_p + k_p V$

$$(4)\quad F = 2B + 8\left(R + \frac{(H+E)}{S}\right) - 2\,\frac{\left(\frac{4H^3}{3S^2} + \frac{H^2B}{S}\right)}{\left(BH + \frac{H^2}{S}\right)} + \frac{2}{\left(BH + \frac{H^2}{S}\right)}\,V$$

i.e. $F = K_F + k_F V$

$$(5)\quad C = \underline{EC}\ \underline{EV} + \underline{FC}\ F$$

$$= \underline{EC}\ kV + \underline{FC}\ (K_F + k_F V)$$

$$= \underline{FC}\ K_F + (EC\ k + \underline{FC}\ k_F)\ V$$

i.e., $C = K_c + k_c V$

For a given operation (type and size), the daily COD production is known, so that by specifying the lagoon type and hence loading rate, the required lagoon volume is easily determined. Figure 6 depicts the size of operation - lagoon volume relationships graphically. Once the volume is known, the linear equations outlined permit easy calculation of total cost, areas, etc.

Annual overhead costs of a lagoon include depreciation, insurance, taxes, interest and repairs and maintenance for the lagoon itself, and for the fence. Table 17 gives the relevant annual costs as percentages of the respective investments, and annual lagoon overhead costs are then:

$$\underline{AC} = 0.12\ \underline{FC}\ k_F + 0.13\ (\underline{EC}\ k + \underline{FC}\ k_F)\ V$$

i.e., $\underline{AC} = K_{\underline{AC}} + k_{\underline{AC}} V$.

With respect to lagoons, it should be noted that their life is limited because of build-up of sludge. In practice this may occur in 12-20 years, at which point the lagoon requires cleaning by dredging. As an approximation to this cost, the lagoon is assumed to last only 20 years, at which time a new lagoon must be constructed.

The linear relationships can be written generally as:

$$Y = K_y + k_y V, \quad Y = A, F, \text{ etc.}$$

This can be rewritten as:

$$Y = K_y + k_y V_{min} + k_y (V - V_{min})$$

or

$$Y = K + k_y (V - V_{min}),$$

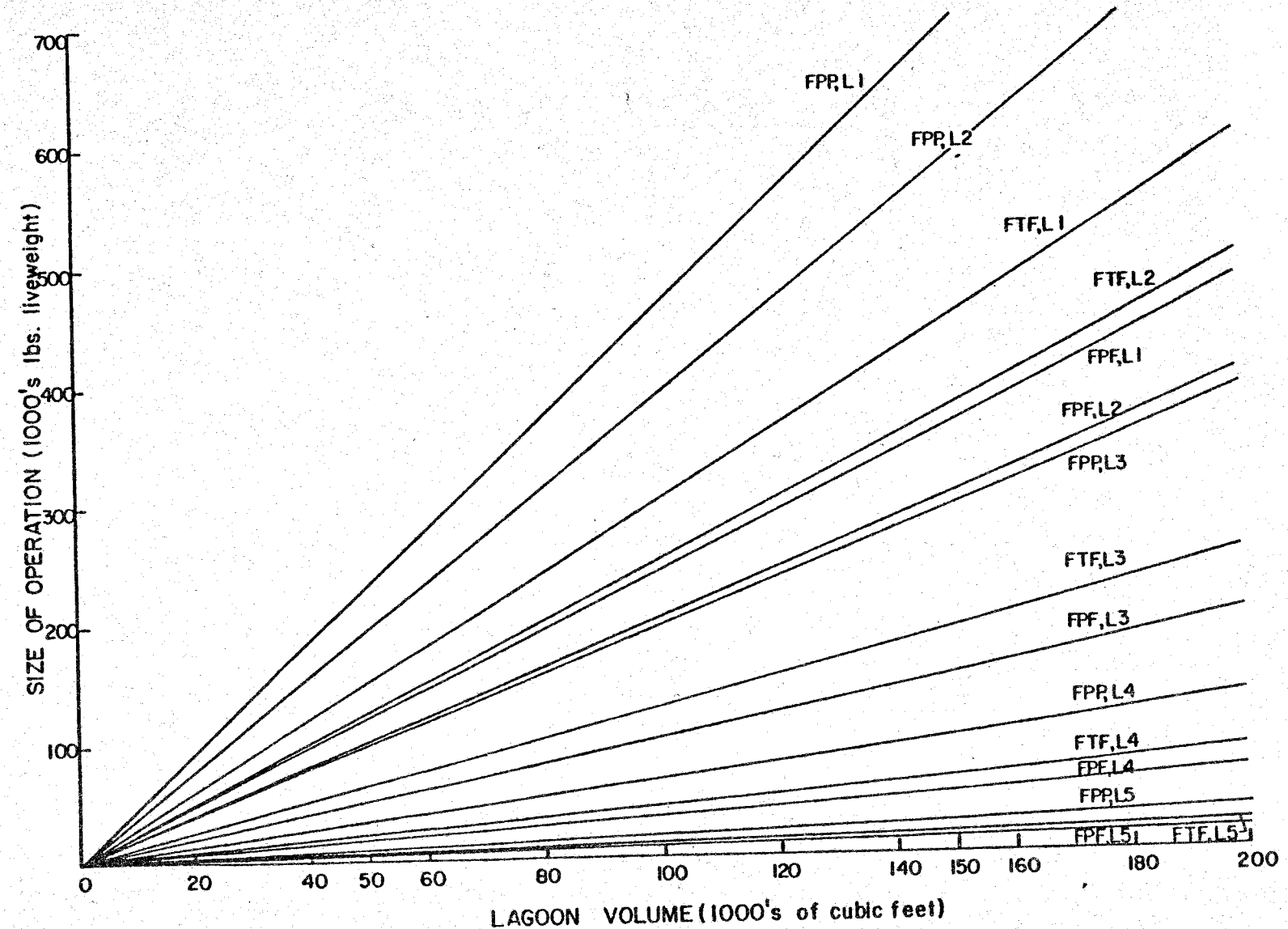


Figure 6. Conversion chart for calculating lagoon sizes needed for a given size of swine operation by type of swine operation and lagoon type (see Table 33).

where V_{min} is the minimum volume obtainable with a specified base breadth, slope, and depth, and K is the functional value for the minimum sized lagoon. The various functions can then be described in terms of K and of k_y, the marginal effect of an increase in lagoon volume. Table 34 reports estimates of K and k_y based on the design parameters outlined.

2.8.3 Lagoon accessories

Several costs in addition to those already mentioned are also incurred with lagoons. Irrigation costs are a prime example, but these are treated separately in Section 2.9. The remaining accessories are the piping to the lagoon from each house, possible recycling equipment for supplying pit flushes, and aeration equipment for mechanically aerated lagoons.

The length and cost of piping to the lagoon will vary with the number of buildings in the operation, and the distance to the lagoon. As a guide, each building is assumed to have a 50-ft long, 6-in diameter polyvinyl chloride (PVC) pipe to the lagoon. As operation size increases, some buildings will need to be duplicated, so total piping costs will vary discontinuously with operation size. Estimates of the operation size at which additional buildings would be needed were made, and on the basis of these, estimates of necessary lengths and costs of piping were made. The investment and annual costs are based on prices in Table 16 and 17, and are reported in Table 35.

In houses which employ shallow pits, lagoon effluent can sometimes be recycled for flushing the manure to the lagoon. In the absence of mechanical aeration devices, effluent from lagoons using lighter loading rates than 100 cu ft lagoon/100 lbs liveweight (LW) should be suitable. Higher loading rates would also be satisfactory with aeration. Recycling has two cost aspects. First, it involves additional equipment (typically 1-2 HP motor and low pressure pump, and 100 ft of 2-in. hose) with overhead and operating costs. This equipment can serve about 400, 100 lb hogs. The investment cost for this equipment will be about $160, with an annual overhead cost of about $0.10/100 lbs LW. Allowing 1.4 gallon/100 lbs LW/flush, and flushing every 4 hours, 3066 gallons of effluent are recycled each year/100 lbs LW. The annual operating cost (electricity) is then about $0.01/100 lbs LW. Hence this portion of recycling costs totals about $0.11/100 lbs LW, a relatively insignificant component of lagoon costs.

The second cost related aspect of recycling is the reduction it brings in the total volume of fluid entering the lagoon. If flushing is necessary, but recycling is not used, the necessary 3066 gallons of flush water/100 lbs LW must be added from an external water source. This additional water must eventually be pumped onto the land (at a cost of $0.25/3066 gallons using a 200 gpm big gun system). More significantly, it affects lagoon storage. Over a year, raw waste/100 lbs LW is only 365 gallons and tap and wash water 400-1000 gallons. Flush water is clearly a major component of manure volume, and can reduce available storage time to 1/3 of what could be obtained.

Table 34: Basic Lagoon Parameters, by Region and Base Width[a].

Item	Lagoon Type[b]	Base Width for Each Region (feet)								
		Coastal Plain			Piedmont			Mountain		
		0[d] 0[e]	50 150	150 300	0 0	50 150	150 300	0 0	50 150	150 300
Excavation volume: Design volume ratio:		1	1	1	1	1	1	.8	.8	.8
Minimum lagoon volume:	AN	14400	32400	68400	14400	32400	68400	14400	32400	68400
	MA	6075	16200	36450	6075	16200	36450	6075	16200	36450
	F	1800	15300	28800	1800	15300	28800	1800	15300	28800
Surface area:	AN, min.	3600	6600	12600	3600	6600	12600	3600	6600	12600
	AN, marg.	.1667	.1146	.0972	.1667	.1146	.0972	.1667	.1146	.0972
	MA, min.	2025	4275	8775	2025	4275	8775	2025	4275	8775
	MA, marg.	.2222	.1456	.1256	.2222	.1456	.1256	.2222	.1456	.1256
	F, min.	900	5400	9900	900	5400	9900	900	5400	9900
	F, marg.	.3333	.1818	.1746	.3333	.1818	.1746	.3333	.1818	.1746
Annual net rainfall:	AN, min.	4320	7491	13830	3410	5935	10990	10370	3801	33290
	AN, marg.	.1761	.1145	.0940	.1403	.0916	.0754	.4243	.2763	.2269
	MA, min.	2627	5100	10040	2063	4027	7956	6298	12250	24150
	MA, marg.	.2442	.1471	.1218	.1940	.1176	.0976	.5877	.3548	.2940
	F, min.	1353	6676	12000	1052	5262	9471	3234	16030	28820
	F, marg.	.3943	.1769	.1665	.3118	.1417	.1336	.9476	.4269	.4021
Land area:	AN, min.	11690	17100	27910	11560	16930	27680	11650	17040	27830
	AN, marg.	.3003	.1647	.1195	.2986	.1641	.1192	.2998	.1645	.1194
	MA, min.	8672	13330	22640	8556	13180	22430	8633	13280	22570
	MA, marg.	.4599	.2193	.1566	.4568	.2184	.1562	.4588	.2190	.1565
	F, min.	6104	17820	29540	6006	17630	29260	6071	17760	29450
	F, marg.	.8681	.2304	.2001	.8611	.2298	.1997	.8657	.2302	.2000
Investment cost:	AN, min.	648.2	1238	2418	647.0	1237	2417	561.4	1043	2007
	AN, marg.	.03278	.03104	.03046	.03278	.03104	.03046	.0268	.0250	.0245
	MA, min.	368.5	722.2	1430	367.2	721.0	1428	331.6	624.6	1211
	MA, marg.	.03494	.03153	.03064	.03494	.03153	.03064	.02894	.02553	.02464
	F, min.	210.2	765.2	1320	209.0	764.0	1319	199.0	673.0	1147
	F, marg.	.04111	.03101	.03053	.04111	.03101	.03053	.03511	.02501	.02453
Annual cost:[c]	AN, min.	84.27	161.0	314.4	84.11	160.8	314.2	72.99	135.6	261.0
	AN, marg.	.00426	.00404	.00396	.00426	.00404	.00396	.00348	.00326	.00318
	MA, min.	47.90	93.89	185.9	47.74	99.73	185.7	43.11	81.20	157.4
	MA, marg.	.00454	.00410	.00398	.00454	.00410	.00398	.00376	.00332	.00320
	F, min.	27.33	99.48	171.6	27.17	99.32	171.5	25.87	87.49	149.1
	F, marg.	.00534	.00403	.00397	.00534	.00403	.00397	.00456	.00325	.00319

[a] Area units are square feet; volume units, cubic feet; and costs in dollars.

[b] AN = anaerobic (12' deep), MA = mechanically aerated (9' deep), F = facultative (6' deep); min. = minimum; marg. = marginal.

[c] Mechanically aerated lagoon costs do not include aeration costs.

[d] Base width (ft) for mechanically aerated and anaerobic lagoons.

[e] Base width (ft) for facultative lagoons.

Table 35: Estimated Lengths and Costs of Piping to a Lagoon by Operation Type and Flooring Type.

Item	Operation Type					
	FPF		FTF		FPP	
	Flooring type		Flooring type		Flooring type	
	Partial slats	Total slats	Partial slats	Total slats	Partial slats	Total slats
Size of operation (1,000's lbs LW)	0 - 1071	0 - 714	0 - 1709	0 - 1219	0 - 658	0 - 658
Length of pipe (ft)	50	50	250	250	200	200
Investment[a] ($)	150.00	150.00	750.00	750.00	600.00	600.00
Annual cost of pipe[b] ($)	19.75	19.75	98.77	98.77	79.02	79.02
Size of operation (1,000's lbs LW)	1071-2142	714-1428	1709-3418	1219-2438	658-1316	658-1316
Length of pipe (ft)	100	100	400	350	300	250
Investment[a] ($)	300.00	300.00	1200.00	1050.00	900.00	750.00
Annual cost of pipe[b] ($)	39.51	39.51	158.04	124.06	118.53	98.77
Size of operation (1000's lbs LW)	2142-3213	1428-2142	3418-5127	2438-3657	1316-1975	1316-1974
Length of pipe (ft)	150	150	650	500	400	350
Investment[a] ($)	450.00	450.00	1950.00	1500.00	1200.00	1050.00
Annual cost of pipe[b] ($)	59.26	59.26	256.81	197.55	158.04	124.06

[a]Pipe (6" PVC) cost of $2.00/ft, trenching and installation at $1.00/ft (see Table 16).

[b]At 13.17% of investment (see Table 17).

The usual design criteria for aeration equipment are the oxygenation capacity and the ratio of power to surface area [Overcash and Humenik, 1976]. Generally each kilowatt of power should serve no more than 4400 ft^2 of surface area, and oxygenation capacity should be 90% or more of daily COD input. Using an aerator rated at 4.63 lbs O_2/kwh, operating at about 80% transfer efficiency in the proposed mechanically aerated lagoon, an aeration system providing about 0.16 kw/1000 ft^3 of lagoon (or 1/6 kw per lb daily N) should prove sufficient.

The investment cost of floating aerators is estimated to be about $800/kw, or about $128/1000 ft^3 lagoon. Assessing annual overhead costs at 27.67% of the investment (see Table 17), and with electricity priced at 4 cents per kwh, annual costs are about $91.36/1000 ft^3 lagoon.

2.8.4 Cost estimates

Using the models for lagoon costs, piping costs, recycling costs, and aeration costs, estimates can be made of the annual cost of any proposed lagoon. Some sample estimates are reported in Table 36 for different types and sizes of operations in the Coastal Plain (estimates for the Piedmont would be slightly lower because of the smaller 25-year, 24-hour storm allowance, while those for the mountains would be lower for this reason as well as the lower excavation : lagoon volume ratio). The cost estimates do not include recycling costs, since recycling is not used for 3' or 5' pits. Recycling cost estimates can easily be made by multiplying the unit cost figure, $0.11/100 lbs LW, by the operation size.

For a given hog operation, there are significant cost differences between lagoons. The naturally facultative lagoon has the highest cost in all cases because of the large volume required. Almost as costly is a mechanically aerated lagoon, the costs in this case being predominantly those of the aeration equipment and its operation. Significantly cheaper than either of these types are the anaerobic lagoons, with the more highly loaded lagoons being the cheapest.

Given the pretreatment performance data in Table 33, it is evident that the marginal cost of obtaining reductions in nutrient levels is quite high, so that unless there is a requirement to dissipate nutrients by pretreatment (e.g. because of inadequate land), highly loaded lagoons will be preferred. Reinforcing this is the opportunity cost of foregone nutrient values in lightly loaded lagoons. There are however, some reasons in favor of the more lightly loaded lagoons. First, they provide better odor control. Where odors are a problem, light loading rates or mechanical aeration may be essential. Second, highly loaded lagoons are more susceptible to fouling, and thus pose greater management problems. Finally, because of their larger capacities, lightly loaded lagoons offer greater flexibility in eventual land application timing.

Table 36: Sample Annual Lagoon Cost Estimates for the Coastal Plains by Lagoon Type, Operation Type, and Size of Operation ($).

Operation Type	Size (1,000's lbs LW)	Lagoon Type[a] 1[b]	2	3	4	5
FPF[c]	5	-[d]	-	-	106.58	283.76
	10	-	-	-	170.48	509.95
	20	840.26	-	127.88	292.25	962.38
	50	2,057.13	149.18	251.85	655.85	2,305.21
	100	4,050.50	251.85	453.85	1,251.29	4,533.41
	200	8,074.11	473.60	875.04	2,459.04	9,009.57
	400	16,138.00	915.50	1,707.50	4,875.50	18,674.60
FPP[c]	5	-	-	-	-	233.49
	10	-	-	-	167.85	350.13
	20	-	-	-	233.76	583.42
	50	1,130.98	-	211.79	421.64	1,283.29
	100	2,199.11	251.30	356.98	773.66	2,473.96
	200	4,293.30	396.49	604.83	1,426.88	4,811.63
	400	8,686.30	822.00	1,230.60	2,864.60	9,617.50
FTF[c]	5	-	-	-	-	318.36
	10	-	-	-	224.40	500.12
	20	762.12	-	190.16	323.67	863.65
	50	1,725.55	207.28	291.20	615.86	1,946.62
	100	3,326.42	291.20	453.53	1,096.98	3,737.20
	200	6,587.44	512.80	837.45	2,110.93	7,377.63
	400	13.187.50	936.80	1,656.40	4,119.20	14,623.00

[a]Lagoon 1 is mechanically aerated, 2-4 are anaerobic with different loading rates, and 5 is naturally facultative.

[b]Mechanically aerated lagoon costs include annual cost of $.09136/cu. ft for aeration.

[c]Flooring type is assumed to be partial slats. Totally slatted operations may have different number of houses and influent piping costs.

[d]-indicates that the minimum volume lagoon exceeded the volume required for this loading area.

2.8.5 Operating practices

Because lagoons involve biological processes, they are apt to foul if subjected to sudden changes, or adverse and extreme conditions. Frequent manure additions to the lagoon are therefore desirable, at least weekly. When pumping down a lagoon, only 1/3 to 1/2 the total supernatant should be pumped at any one time. Following pumping, the lagoon will operate at a higher loading rate than designed until lagoon supernatant volume builds up. In order to achieve proper pretreatment performance, the lagoon should not be pumped down again until it is nearly full, say 90% or more.

When operated in this way, pretreatment performance and effluent concentrations should remain relatively constant throughout the year, although effluent concentration will vary somewhat with the seasonal net precipitation. Available lagoon storage capacity is also fixed once the operating pattern is determined (this again fluctuates a little by season). Table 37 reports estimates of the typical days of storage available in the different types of lagoons by region and by dilution. These are readily computed from the loading rates, daily manure volume and average net rainfall. The estimates assume the lagoon is pumped down to 1/2 its design volume. Less storage than indicated would be available if clean flushing water were used. Table 38 reports estimates of typical lagoon effluent concentrations. These were computed using the effluent concentration (E_c) definition:

$$E_c = \frac{\text{weight of N removed each day on the average}}{\text{volume of liquid removed each day on the average}}$$

$$= \frac{\text{daily N input x (1 - proportion of N lost by treatment)}}{\text{daily volume of influent + average net daily precipitation}}$$

Then,

$$E_c = \frac{(N_D)(1-g)}{\frac{N_D}{I_c} + \frac{7.48055}{365}(K_p + k_p L_N N_D)}$$

where,

E_c = effluent N concentration, lbs N/gal.
N_D = daily N input, lbs N/day
g = proportion of N lost by treatment
I_c = influent concentration, lbs N/gal.
L_N = lagoon loading rate based on N, ft^3/lb N/day

and K_p and k_p were defined earlier.

Because net rainfall addition depends on total lagoon volume ($L_N N_D$), lagoon effluent concentrations vary somewhat from one operation size to another. For estimation purposes, however, net annual rainfall catch was approximated by $\frac{2\ k\ L_N N_D}{(H + E)}$ times annual net precipitation, the factor

Table 37: Estimates of Days of Storage Provided in Lagoons by Lagoon Type, Region and Dilution[a].

Region[b]	Dilution (gal. water/ gal. manure)	Lagoon Type[c]				
		1	2	3	4	5
CP	1	73	87	164	395	552
	2	50	60	114	292	487
	5	26	30	60	164	361
P	1	74	88	168	419	637
	2	51	60	116	305	553
	5	26	31	60	168	396
M	1	66	80	140	278	268
	2	47	56	102	223	252
	5	25	29	56	140	214

[a]Assume lagoon cannot be pumped below one-half design capacity.

[b]CP = Coastal Plains, P = Piedmont and M = Mountain regions of North Carolina.

[c]Lagoon 1 is mechanically aerated, 2-4 are anaerobic with different loading rates, and 5 is naturally facultative.

Table 38. Lagoon Effluent N Concentrations by Lagoon Type, Operation Type, Wash Water Additions, and by Region[a,b].

Region[c]	Lagoon type[d]	Operation Type								
		Feeder Pig Finishing Dilution water (gal.)[e]			Farrow to Finish Dilution water(gal)			Feeder Pig Production Dilution water (gal)		
		1	2	5	1	2	5	1	2	5
CP	1	61.569	42.118	21.624	50.232	34.198	17.470	32.977	22.289	11.301
	2	115.57	78.893	40.416	94.173	64.003	32.637	61.710	41.661	21.098
	3	66.718	46.514	26.372	55.036	38.064	19.773	36.750	25.105	12.870
	4	22.982	17.099	9.672	19.674	14.398	7.978	13.963	9.936	5.327
	5	0.945	0.845	0.642	0.893	0.785	0.574	0.774	0.651	0.442
P	1	62.850	42.713	21.780	51.082	34.590	17.571	33.341	22.454	11.343
	2	117.80	79.925	40.685	95.647	64.681	32.812	62.339	41.947	21.171
	3	69.163	47.689	24.691	56.688	38.848	19.982	37.479	25.443	12.959
	4	25.089	18.239	10.026	21.198	15.197	8.218	14.714	10.311	5.433
	5	1.182	1.030	0.743	1.103	0.941	0.654	0.925	0.756	0.488
M	1	57.430	40.139	21.090	47.442	32.882	17.120	31.752	21.722	11.153
	2	108.40	75.485	39.502	89.357	61.742	32.038	59.605	40.691	20.846
	3	59.379	42.829	23.320	49.943	35.557	19.074	34.407	23.989	12.571
	4	17.764	14.033	8.608	15.721	12.160	7.240	11.849	8.817	4.988
	5	0.548	0.513	0.430	0.531	0.490	0.399	0.486	0.435	0.330

[a]Based on total transfer of manure to the lagoon, and no bottom water in pits.

[b]Units: lbs/gal. x 10^4.

[c]CP = Coastal Plains, P = Piedmont, and M = Mountains regions of North Carolina.

[d]Lagoon 1 is mechanically aerated, 2-4 are anaerobic with different loading rates, and 5 is naturally facultative.

[e]Dilution water = water added per gal. raw manure.

$\frac{2k\ L_N\ N_D}{(H + E)}$ providing an estimate of the lagoon collection area. Then the effluent concentration reduces to

$$E_c = \frac{1-g}{(1/I_c) + \frac{.040989\ PkL_N}{H + E}} \quad \text{lbs/gal.}$$

where P is the annual net precipitation in inches. This same approximation was used in computing the average net rainfall collected for estimating lagoon storages, and also to compute ratios of net precipitation contribution to the total volume of lagoon effluent (Table 39). The approximation is equivalent to assuming an average lagoon depth of (H + E)/2. For large operations this underestimates the actual depth, and leads to overestimates of rainfall catch, and contribution ratios, but an underestimate of storage and concentration. For small operations, the errors are reversed.

Table 39: Estimates of the Contribution of Net Precipitation to Total Effluent Volume by Lagoon Type, Region and Dilution (%).

Region[a]	Dilution (gal. of water/gal. manure)	Lagoon Type[b]				
		1	2	3	4	5
CP	1	7.01	6.54	12.28	29.58	73.72
	2	4.78	4.46	8.54	21.87	65.16
	5	2.45	2.28	4.46	12.28	48.32
P	1	5.77	5.37	10.19	25.41	69.64
	2	3.93	3.65	7.03	18.51	60.46
	5	2.00	1.86	3.65	10.20	43.33
n	1	15.47	14.52	25.35	50.46	87.22
	2	10.88	10.17	18.46	40.45	81.99
	5	5.75	5.36	10.17	25.35	69.47

[a]Regions of North Carolina: CP = Coastal Plains; P = Piedmont; M = Mountains

[b]Lagoon 1 is mechanically aerated, 2-4 are an aerobic with different loading rates, and 5 is naturally facultative.

2.8.6 Retention ponds

Ponds used in conjunction with dirt or pasture lots perform similar functions as lagoons, namely storage and pretreatment. Unfortunately, very little data exists on the pretreatment performance of ponds. Some guides to their performance can probably be derived from lagoon performance but several

differences should be noted. First, the retention pond has a variable loading rate, varying with the rainfall and hence runoff. Second, influent concentrations are far smaller than encountered in sheltered house-lagoon operations. In the latter, even with a dilution factor of 6, influent concentration is 0.0067 lbs N/gallon (0.04/6), while in the retention pond for a dirt lot it averages about 0.00053 lbs N/gallon, and for the pasture lot, 0.000028 lbs N/gallon (see Table 15). Third, because of the aperiodic nature of rainfall events, pond loading frequency is variable, and the pond may be subjected to adverse shocks.

More data is needed on retention pond performance before pretreatment performance can be estimated with confidence. Because the amounts of constituents entering a detention pond are initially small, after pretreatment the levels of nutrients will be so small as to have little fertilizer value. Ponds can then be designed simply as convenient storage devices. Cost estimates of ponds can be made as for lagoons by assuming they are constructed identically. Since ponds would be constructed on slopes, the excavation volume:design volume ratio can be assumed to be about 0.8 throughout North Carolina. Pond volumes can be calculated for a series of lengths of storage (again assuming pumping down only to 1/2 capacity) using the monthly net manure volume figures in Table 15. Costs can then be obtained from applying the formulae in Section 2.8.2.

2.9 Irrigation Systems

An irrigation system provides a time efficient and labor efficient means of transporting and applying liquid materials to land, and thus represents an alternative to hauling-wagons for liquid manure disposal. Of the many variations in irrigation system designing, two are studied here. The first system is a travelling big gun sprinkler connected to underground mains and laterals. This system has very low labor requirements, but involves a high investment even for small systems. The second system is a portable, hand-moved, conventional sprinkler array, and has higher labor requirements, but generally lower investment costs than the big gun system.

Either of the two systems can be used for transportation and application of lagoon effluent. They are particularly relevant for lagoon effluent because the large volumes involved would mean high total operating costs for a hauling operation. Liquid manure from pits can also be pumped by irrigation, but experience to date in North Carolina indicates that the high solids content of liquid manure causes frequent malfunctions of the irrigation equipment, and thus causes management problems. For these reasons, irrigation from pits is not explicitly evaluated in this study. However, the big gun irrigation system outlined can be viewed as a minimum level of equipment for direct-pit pumping, and the associated costs as lower bounds to the costs of a direct-pit irrigation system.

2.9.1 Irrigation system design

The approach to designing an irrigation system for manure disposal differs from that typically used for designing a conventional water irrigation system. For the latter, the first step usually is to determine the necessary system pumping rate, the area to be irrigated, the peak daily

moisture needs of the irrigated crop, and the number of hours per day that the system can be used. Once the pumping rate is determined, layout design, pump size, and other system components can be chosen accordingly.

This approach is inappropriate even for conventional irrigation because it fails to consider economic principles, but in the manure management planning it is also inappropriate on a technical basis. First, the crops to be grown, and their areas are not prespecified, and second, the aim of the irrigation system is not to meet the crop's peak daily water requirement. For manure disposal, the basic criterion for determining pumping rate is the ability of the system to prevent lagoon overflows. The storage capacities reported in Table 37 can be compared with the days of pumping necessary to pump the annual net lagoon effluent reported in Table 40. Estimates are reported only for an FPF operation in the Coastal Plain, and are based on a 24 hr/day pumping, 5 gallons of wash water per gallon of raw manure, a pumping rate of 100 gallons per minute, and the lagoon volume-rainfall collection-operation size relationship described in Section 2.8. Lagoon volume, rainfall volume, and effluent volume are also reported in Table 40. Obviously, even with this very low pumping rate, most operations will need little more than 1 month pumping. Depending on the lagoon storage capacity, this could perhaps be done at one time, in periods of several days at a time. For example, for a 100,000 lbs LW, CP, FPF operation using lagoon type 2, adding 5 gallons of wash water/gallon of raw manure, effluent must be pumped every 30 days. Since 15.7 days of pumping are necessary each year, approximately 1 1/3 days pumping are needed each month.

Low pumping rates will clearly be sufficient for most operations. Only the large operations (400,000 lbs LW) or those using a naturally facultative lagoon might be interested in larger pumping rates. For example, the 400,000 lbs LW operation would reduce its total pumping time to 3-5 weeks by using a 500 gpm pumping rate. Pumping rates are limited on the low side by technical factors. In general, friction losses in pipes and fittings should remain small relative to the total pump head, and this requires a minimum pumping rate.

An irrigation system designed for manure disposal will have some potential value for water irrigation purposes when it is otherwise idle. Ideally, the irrigation system should be designed to serve both water irrigation and manure disposal purposes. Complementarity of the two activities may mean that irrigation is profitable for both, while not for either alone. The complications of a joint purpose design have been avoided in this study, designs being based solely on manure disposal needs. The system chosen based on manure disposal needs could, as a second-best alternative, be assessed in terms of how it could improve crop yields and profits.

2.9.2 Travelling big gun sprinkler system

The system components include the gun sprinkler and hose, pump and motor, mains, laterals, and fittings. Four sizes of systems are budgeted: 35, 50, 100 and 200 acre systems. Approximate costs for other sizes can be obtained by interpolation or extrapolation. Systems were budgeted for

Table 40. Estimates of Lagoon Volume, Rainfall Volume, Effluent Volume and Time to Pump Annual Effluent for FPF Operations in the Coastal Plains by Lagoon Type and Operation Size[a].

Item	Operation size (lbs LW x10^3)	Lagoon Type 1	2	3	4	5
Lagoon Volume[b] (ft^3 x 10^3)	50	21(50)	25 (0)	50 (50)	150(150)	561 (300)
	100	42(150)	50 (50)	100 (150)	300(150)	1122 (300)
	200	84(150)	100 (150)	200 (150)	600(150)	2244 (300)
	400	168(150)	200 (150)	400 (150)	1200(150)	4488 (300)
Rainfall Volume (ft^3 x ft^3)	50	5.806	6.187	9.506	21.5	100.6
	100	10.716	9.506	16.8	35.6	194.0
	200	15.832	16.800	26.2	63.8	380.8
	400	26.063	26.200	45.0	120.2	754.5
Effluent Volume[c,d] (ft^3 x 10^3)	50	152.18	152.84 (357.50)	155.88	167.88	246.99
	100	303.48	302.26 (712.11)	309.56	328.36	486.78
	200	601.35	602.32 (1,422.05)	611.72	649.32	966.35
	400	1,197.1	1,197.2 (2,836.69)	1,216.03	1,291.24	1,925.50
Days of Pumping[d]	50	7.9	7.9	8.1	8.7	12.8
	100	15.8	15.7	16.1	17.1	25.3
	200	31.2	31.3	31.8	33.7	50.2
	400	62.2	62.2	63.2	67.1	100.0

[a]Based on 100 gpm and 24 hours pumping/day. For a pumping rate G, and H hours pumping/day, and tabled value V, the time to pump = $V \cdot \frac{100}{G} \cdot \frac{24}{H}$ days.

[b]Numbers in brackets indicate lagoon base breadth in feet.

[c]Lagoon influent volumes are based on 1 gallon of raw manure and 5 gallons of added water/100 lbs LW/day. They total 1095, 2190, 4380, and 8760 thousands of gallons for the 4 sizes of operation.

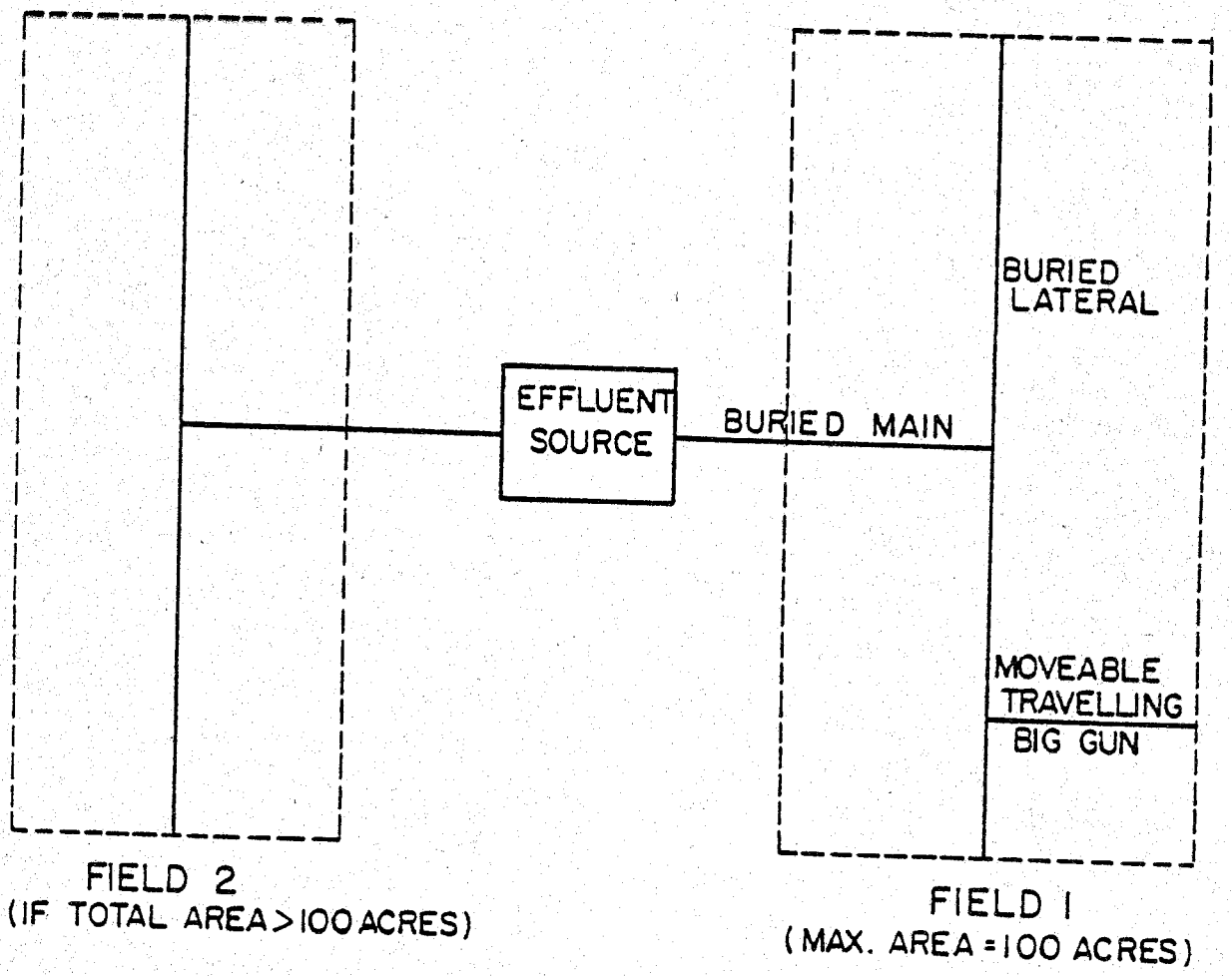
[d]Numbers in brackets apply to case where flushing is used without recycling

three pumping rates: 100 gpm for the 35 and 50 acre systems; 200 gpm for the 50, 100 and 200 acre systems, and 500 gpm for the 50, 100 and 200 acre systems. Designs for areas up to 100 acres are based on one field, while the 200 acre system assumes two fields of 100 acres each. The layout is depicted in Figure 7. Mains and laterals are assumed to be buried PVC pipes (some reduction in investment could be achieved by using portable aluminum laterals, but this option has not been considered). Main lengths to the field differ from one size system to the next, being related to the length of laterals. This dependence is used to reflect the difficulty in practice of expanding the irrigated area simply by extending the length of the lateral. It is for this same reason that the maximum field size is limited to 100 acres. Details of the various systems are reported in Table 41. Estimates of total investment, annual overhead costs, and operating costs are also given in Table 41. A more detailed breakdown of the costs is provided in Table 42.

Investment costs naturally increase as the irrigated acreage increases. The increase reflects both additional piping to service the area and increases in pipe diameter. As pumping distance increases, head loss would also increase unless pipe diameter increased. By increasing the pipe diameter, friction losses are held relatively constant, and pumping rate and pump size are effectively fixed, irrespective of acreage, over a wide range of acreages. Total investment cost, as a function of irrigated acreage, then involves some fixed cost components (pump, motor, big gun sprinkler), and some increasing costs (piping). As a result of the formidable fixed costs, average per acre investment decreases with acreage. This is evident from the total investment functions depicted in Figure 8. In contrast to the declining average investment, the marginal investment remains relatively constant over the 35-200 acre range.

Annual overhead costs for an irrigation system are calculated by applying the appropriate cost percent (see Table 17) for each component of the system with the exception of installation costs which have annual costs of depreciation and interest only. Annual cost, as a function of acreage, behaves similarly to investment.

Irrigation operating costs (ignoring labor) depend on pump size and pumping rate, since head losses and pump size can be held fairly constant over a wide range of acreages. Hence, as a first approximation, operating costs can be assumed constant for all acreages given a particular pump size. Knowing the pump size and the pumping rate, and the cost of electricity (all motors are assumed to be electric), operating cost/unit volume are easily calculated.



LAYOUT FOR TRAVELLING BIG GUN IRRIGATION SYSTEM

Figure 7. Layout for travelling big gun irrigation system.

Table 41: Specifications of Travelling Big Gun Irrigation Systems.

Item	Pumping rate, (gpm)							
	100		200			500		
	Area (ac)		Area, (ac)			Area (ac)		
	35	50	50	100	200	50	100	200
Operating pressure (psi)	50	50	75	75	75	75	75	75
Total mains length (ft)	1,167	1,461	1,458	2,142	4,060	1,430	2,354	4,708
Total laterals length (ft)	830	1,424	1,368	2,736	5,700	1,376	2,772	5,544
Max. pump-sprinkler distance (ft)	1,582	2,173	2,142	3,510	3,455	2,118	3,740	3,610
Sprinkler hose length (ft)	660	660	660	660	660	660	660	660
Mains diameter (in)	3	3	4	5	5	6	6	6
Laterals diameter (in)	3	3	4	4	4	5	6	6
Hose diameter (in)	2.5	2.5	3	3	3	4.5	4.5	4.5
Lift and elevation (ft)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Motor efficiency[a]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Pump efficiency	.65	.65	.65	.65	.65	.65	.65	.65
Motor power (HP)	10	10	25	25	25	60	60	60
Nozzle size (in)								
Spray diameter (ft)	245	245	315	315	315	425	425	425
Area per set (ac)	5.965	5.965	7.846	7.846	7.846	11.043	11.043	11.043
Line spacing (ft)	178	178	228	228	228	308	308	308
Number of fields	1	1	1	1	2	1	1	2
Max . head loss (psi)	38.4	48.8	67.9	71.8	71.8	49.8	62.3	62.3
Labor/ac/irrig (hr)	.333	.333	0.25	0.25	0.25	.181	.181	.181
Time to pump 100,000 gals (hr)	16.67	16.67	8.33	8.33	8.33	3.33	3.33	3.33
Investment ($)	10,018	11,574	16,276	22,255	33,697	27,749	36.729	54,670
Annual overhead cost ($)	1,852	2,018	2,938	3,584	4,817	5,141	6,128	8,088
Operating cost/ 100,000 gals ($)	6.67	6.67	8.33	8.33	8.33	8.00	8.00	8.00

[a]Based on electric motor performance.

[b]Not including labor costs.

Table 42: Components of Investment and Annual Costs for Travelling Big Gun Systems.

Item	Investment ($)								Annual Overhead Cost[b] ($)							
	Pumping rate, (gpm)								Pumping rate, (gpm)							
	100		200			500			100		200			500		
	Area, (ac)		Area, (ac)			Area, (ac)			Area, (ac)		Area, (ac)			Area, (ac)		
	35	50	50	100	200	50	100	200	35	50	50	100	200	50	100	200
Pump/motor[a]																
Equipment	1,000	1,000	2,500	2,500	2,500	3,750	3,750	3,750	183.3	183.3	458.2	458.2	458.2	687.4	687.4	687.4
Fittings	275	275	500	500	500	1,100	1,100	1,100	50.4	50.4	91.6	91.6	91.6	201.6	201.6	201.6
Installation	250	250	625	625	625	938	938	938	32.1	32.1	80.2	80.2	80.2	120.3	120.3	120.3
Mains[c]																
Equipment	934	1,169	1,458	3,213	6,090	2,860	4,708	9,416	107.4	134.4	167.7	369.5	700.3	328.9	541.4	1,082.8
Fittings	233	292	364	803	1,522	715	1,177	2,354	26.8	33.6	41.9	92.4	175.0	82.2	135.4	270.7
Installation	875	1,096	1,093	2,142	4,060	1,430	2,354	4,708	83.1	104.1	103.8	203.5	385.7	135.8	223.6	447.3
Laterals[c]																
Equipment	664	1,139	1,368	2,736	5,700	2,064	5,544	11,088	76.4	130.9	157.3	314.6	656	237.4	637.6	1,275.1
Fittings	166	285	342	684	1,425	516	1,386	2,772	19.1	32.8	39.3	78.7	163.9	59.3	159.4	318.8
Installation	622	1,068	1,026	2,052	4,275	1,376	2,772	5,544	59.1	101.5	97.5	194.9	406.1	130.7	263.3	526.7
Sprinkler/hose																
Equipment	5,000	5,000	7,000	7,000	7,000	13,000	13,000	13,000	1,214.5	1,214.5	1,700.3	1,700.3	1,700.3	3,157.7	3,157.7	3,157.7
Fittings	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Installation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	10,018	11,574	16,276	22,255	33,697	27,749	36,729	54,670	1,852	2,018	2,938	3,584	4,817	5,141	6,128	8,088

[a] Installation investment costed at 25% of equipment cost.

[b] For equipment and fittings, cost include depreciation, insurance, taxes, repairs and maintenance, and interest. Only interest and depreciation occur for installation.

[c] Fittings costed at 25% of equipment cost.

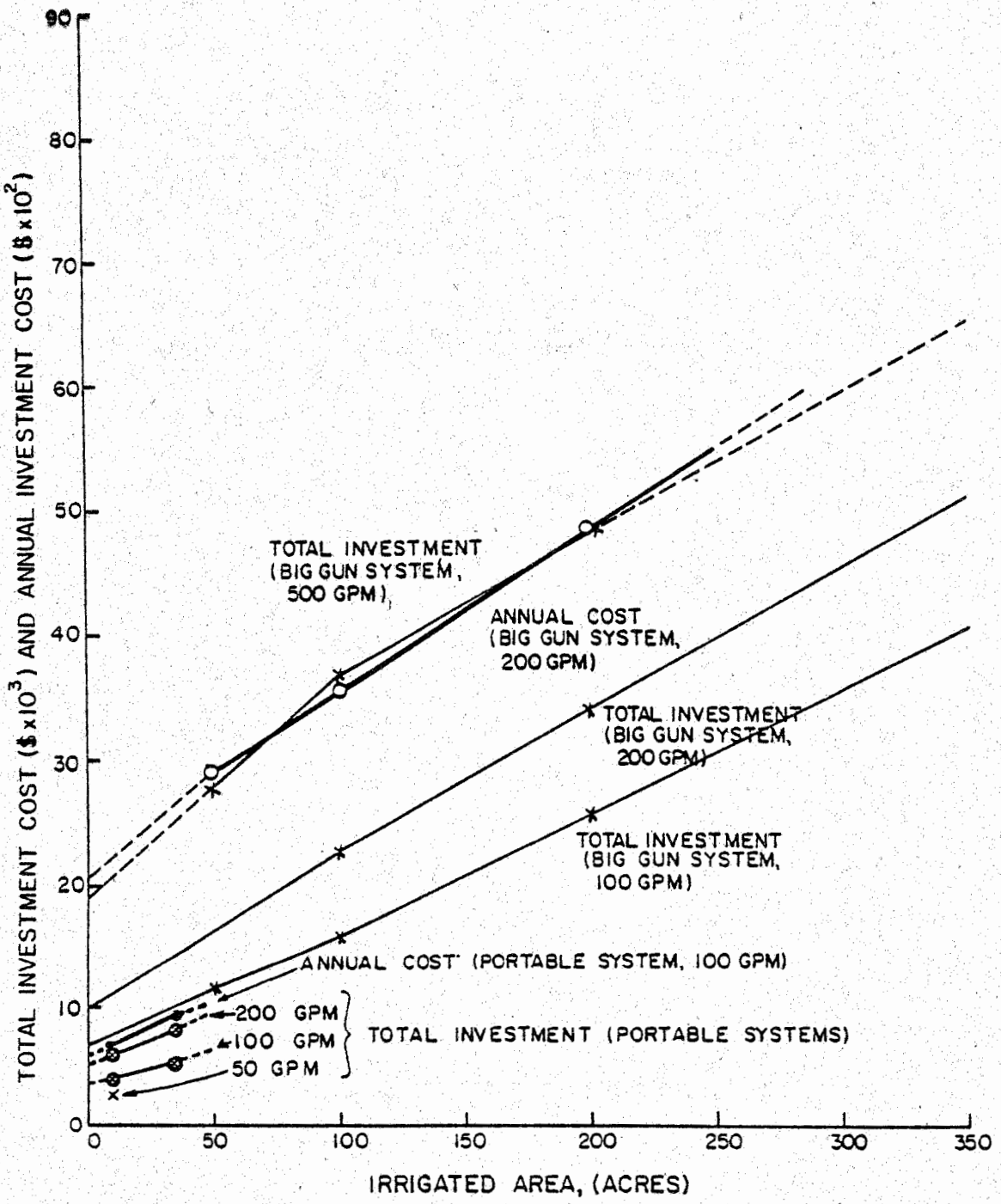


Figure 8. Investment and annual overhead costs for irrigation systems as functions of irrigated area by pumping rate and system type.

Table 41 also reports some crude estimates of the per acre irrigation labor requirements. Point estimates like these are necessarily only guides since labor needs (for routine maintenance and checking and for sprinkler shifting) tend to increase marginally with the total area irrigated, and with the acreage irrigated with each set. These estimates are based on data reported by Sneed (1975).

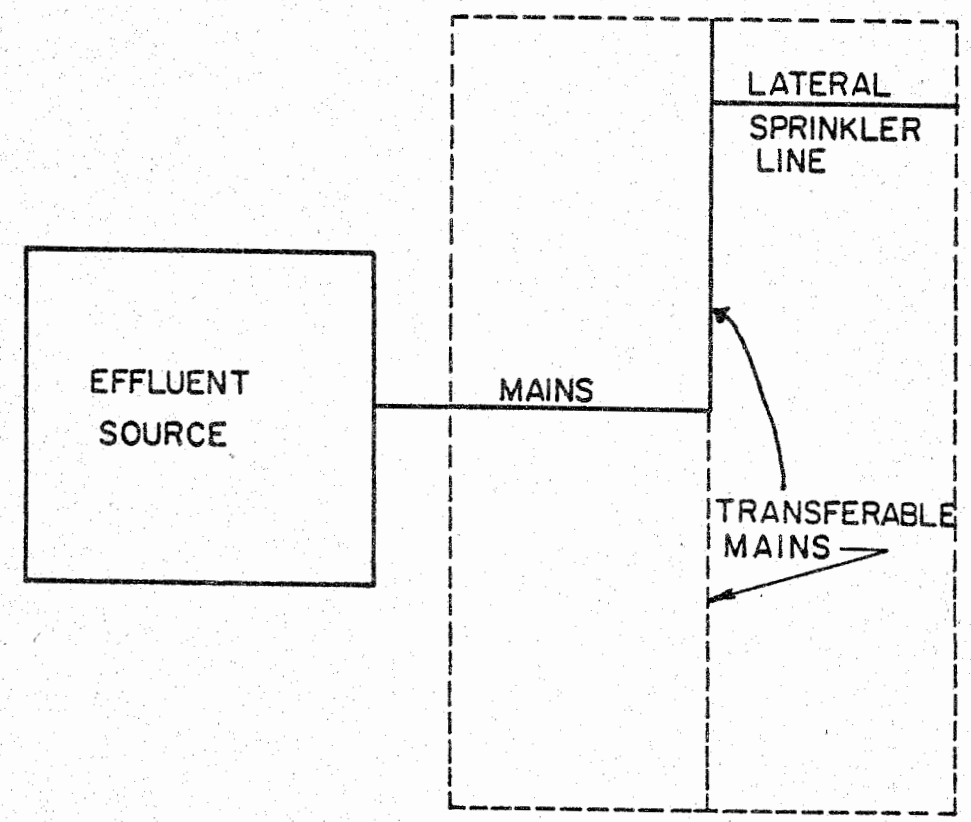
2.9.3 Portable, conventional sprinkler line system

The system components include the pump and motor, main supply line, lateral sprinkler lines, and fittings. In contrast to the big gun system, all lines are aluminum pipe. Two sizes of systems are budgeted, namely 10 and 35 acre systems, each using a single field layout (see Figure 9). Three rates of pumping (50, 100 and 200 gpm) are considered. The 10 gpm is used only for the 10 acre system. Specifications of the systems are given in Table 43, while a more detailed breakdown of costs is reported in Table 44. Comments made in Section 2.9.2 on costs and labor requirements apply equally well here.

2.9.4 Sizing an irrigation scheme

The size of an irrigation system for manure disposal depends on the level of nutrients (N, P and K) to be applied to each acre, and the total supply of nutrients from the lagoon. The former factor is set once the economically optimum mix of cropping activities is determined (Section 3). The latter depends on the operation size, the operation type, flooring type, and the type of lagoon. Knowing the operation size and type, total N, P and K production levels are easily calculated using the unit production levels (Tables 7, 10 and 13), and the lagoon pretreatment performance data (Table 33). As an example of system sizing, estimates were made of the relationship between the area needed to dispose effluent on corn and operation size, assuming the operation was an FPF operation. Estimates were made for each of the five types of lagoon, and for three alternative rate-of-application criteria, namely (a) apply that volume of effluent containing 100 lbs N as needed by corn, (b) apply that volume containing 17.5 lbs P; and (c) apply that volume containing 66.4 lbs K. The fifteen functions are depicted in Figure 10.

This figure also serves as an aid to calculating irrigation areas for other situations: (1) Other types of operation - Since the FPP and FTF operations, respectively, produce only 0.5157 and 0.8036 times the nutrients per 100 lbs live weight produced in the FPF operations, irrigated areas needed for these operations are 0.5157 and 0.8036 times that for the FPF operations; (2) Other crops - If effluent is to be applied to wheat, say, to meet P (or N or K) needs of 8.7 lbs/acre, the required area will be (P needs of corn)/(P needs of crop) X (area needed for corn) = (17.5/8.7) times the area needed for corn; (3) Unavailability of nutrients - A nutrient, N in particular, may not all be available to the crop, but say, only 70% available. To meet N needs, more than the required N must be applied, and required acreage is reduced (in this example) to 70% of the value read from Figure 10; (4) Combination Criteria - Suppose the application criterion is to meet only two of the crop's N, P and K needs, when N



LAYOUT FOR PORTABLE SPRINKLER LINE IRRIGATION SYSTEM

Figure 9: Layout for portable conventional sprinkler line irrigation systems.

Table 43: Specifications of Portable Conventional Sprinkler Line Irrigation Systems.

Item	Pumping rate, (gpm)				
	50	100		200	
	Area, (ac)	Area, (ac)		Area, (ac)	
	10	10	35	10	35
Operating pressure (psi)	50	50	50	50	50
Total mains length (ft)	1,280	1,280	2,320	1,280	2,320
Total laterals length (ft)	280	560	600	1,120	1,200
Separate lateral length (ft)	280	280	600	280	600
Max. pump-sprinkler length (ft)	1,560	1,560	2,920	1,560	2,920
Mains diameter (in.)	3	3	3	4	4
Laterals diameter (in.)	2	2	3	2	3
Lift and elevation (ft)	6.5	6.5	6.5	6.5	6.5
Motor efficiency[a]	1.	1.	1.	1.	1.
Pump efficiency	.65	.65	.65	.65	.65
Motor power (HP)	3	7.5	7.5	15	15
Line spacing (ft)	80	80	80	80	80
Area per set (ac)	.55	1.10	1.17	2.19	2.35
Labor/ac/irrig. (hr)	1.8	1.1	1.1	.8	.8
Time to pump 100,000 gals (hr)	33.33	16.67	16.67	8.33	8.33
Investment ($)	2,712	3,906	5,337	6,063	8,031
Annual overhead cost ($)	471	678	926	1,054	1,395
Operating cost/100,000 gals[b] ($)	4.00	5.00	5.00	5.00	5.00

[a]Based on electric motor performance.

[b]Not including labor costs.

Table 44: Components of Investment and Annual Costs for Portable Conventional Sprinkler Line Irrigation Systems.

Item	Investment ($)					Annual Overhead Cost[a] ($)				
	Pumping rate, (gpm)					Pumping rate, (gpm)				
	50	100		200		50	100		200	
	Area, (ac.)					Area, (ac.)				
	10	10	35	10	35	10	10	35	10	35
Pump/motor[b]										
Equipment	500	1,000	1,000	1,500	1,500	91.6	183.3	183.3	275.0	275.0
Fittings	125	275	275	500	500	22.9	50.4	50.4	91.6	91.6
Installation	125	250	250	375	375	16.0	32.1	32.1	48.1	48.1
Mains										
Equipment	1,536	1,536	2,784	1,984	3,596	266.2	266.2	482.5	343.8	623.2
Laterals										
Equipment	252	504	720	1,008	1,440	43.7	87.3	124.8	174.7	249.6
Sprinklers, tees, etc.	174	341	308	696	620	30.2	59.1	53.4	120.6	107.4
Total	2,712	3,906	5,337	6,063	8,031	471	678	926	1,054	1,395

[a] For equipment and fittings, costs include depreciation, insurance, taxes, repairs and maintenance and interest. Only interest and depreciation occur for installation.

[b] Installation investment cost at 25% of equipment cost.

availability is only 70%. As an example, consider a 200,000 lbs LW-FPF operation using the most highly loaded anaerobic lagoon (i.e., lagoon type 2). From Figure 10, in just meeting K needs, 140 acres would be irrigated. In just meeting P needs, about 48 acres are irrigated. In just meeting N needs, about 110 acres are irrigated; but since N availability is assumed to be only 70%, only 77 acres are irrigated. Clearly by irrigating 77 acres, both N and K needs are met, but not P needs. Hence two nutrient needs are met as required.

2.9.5 Lagoon-irrigation system costs

Annual manure disposal costs using a lagoon and an irrigation system were estimated by combining estimates of the separate system components. The estimates, reported in Tables 45 to 47, include the annual lagoon cost

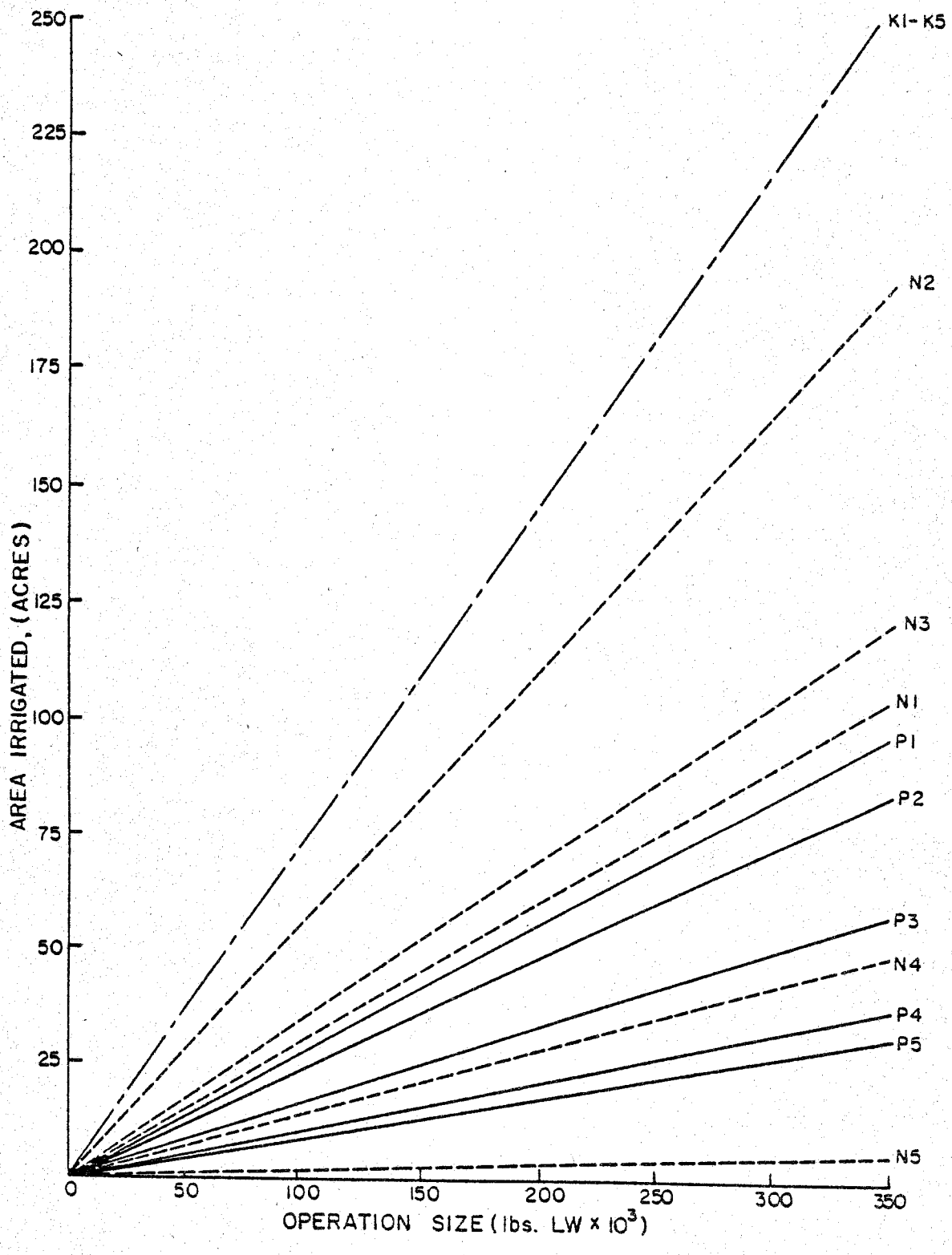


Figure 10. Required land areas to utilize all of either N, P, or K when applied to corn as a function of size of feeder pig finishing (FPF) operation for 5 types of lagoons (See Table 33).

Table 45. Components of Annual Costs for Lagoon-Irrigation Systems for FPF Operations in the Coastal Plains by Lagoon Type.

Item	Operation size (1bLW x 10^3)	Costs, ($) Lagoon type[a] 1	2	3	4	5
Lagoon[b]	50	2,057.1	149.2	251.8	655.9	2,305.2
	100	4,050.5	251.8	453.8	1,251.3	4,533.4
	200	8,074.1	473.6	875.0	2,459.0	9,009.6
	400	16,138.0	915.5	1,707.5	4,875.5	18,674.6
Irrigation system overhead	50	683.0 (P)[c]	769.8 (P)	699.6 (P)	626.9 (P)	623.4 (P)
	100	787.1 (P)	2,793.9 (T)	820.4 (P)	675.0 (P)	668.1 (P)
	200	2,837.8 (T)	3,276.2 (T)	2,921.7 (T)	774.2 (P)	757.4 (P)
	400	3,363.9 (T)	4,240.8 (T)	3,531.8 (T)	2,805.2 (T)	2,762.6 (T)
Irrigation[d] operating costs	50	57.8	57.2	59.7	65.2	94.2
	100	115.2	188.3	118.2	125.2	183.9
	200	377.0	377.3	385.0	245.5	363.1
	400	748.7	748.7	761.8	808.6	1,202.8
Irrigation labor costs	50	69	64	80	52	74
	100	138	29	161	105	148
	200	63	58	73	209	296
	400	126	116	146	118	136
Total costs	50	2,867	1,040	1,091	1,400	3,097
	100	5,091	3,263	1,553	2,156	5,533
	200	11,352	4,185	4,254	3,688	10,426
	400	20,377	6,061	6,147	8,607	22,776

[a] Identification same as in Table 33.

[b] No recycling costs or flushing costs are included.

[c] Bracketed character indicates irrigation system: P = portable; T = travelling big gun. The big gun systems are 200 gpm, the portable system 100 gpm.

[d] Not including labor costs.

Table 46: Components of Annual Costs for Lagoon-Irrigation Systems for FPP Operations in the Coastal Plains by Lagoon Type.

Item	Operation size (1bLW x 10^3)	Costs, ($) Lagoon type[a] 1	2	3	4	5
Lagoon[b]	50	1,131.0	-	211.8	421.6	1,283.3
	100	2,199.1	251.3	357.0	773.7	2,474.0
	200	4,293.3	396.5	604.8	1,426.9	4,811.6
	400	8,686.3	822.0	1,230.6	2,864.6	9,617.5
Irrigation system overhead	50	632.4 (P)	677.3 (P)	641.0 (P)	598.9 (P)	601.9 (P)
	100	685.9 (P)	775.7 (P)	703.3 (P)	628.9 (P)	624.9 (P)
	200	793.1 (P)	2,809.0 (T)	827.8 (P)	679.0 (P)	671.1 (P)
	400	2,852.8 (T)	3,306.3 (T)	2,940.5 (T)	779.2 (P)	763.3 (P)
Irrigation[d,e] operating costs	50	57.8	57.2	59.7	65.2	94.2
	100	115.2	113.1	118.2	125.2	183.9
	200	226.3	377.3	231.1	245.5	363.1
	400	748.7	748.7	761.8	485.3	721.9
Irrigation labor costs	50	53.5	65.5	62	58	77
	100	107	131	124	117	153
	200	214	60	248	233	307
	400	97	120	113	467	614
Total costs	50	1,875	-	974	1,144	2,056
	100	3,107	1,271	1,302	1,645	3,436
	200	5,527	4,068	1,912	2,584	6,153
	400	12,375	4,997	5,045	4,596	11,617

[a] Identification same as in Table 33.

[b] No recycling costs or flushing costs are included.

[c] Bracketed character indicates irrigation system: P = portable; T = travelling big gun.

[d] Not including labor costs.

[e] Only approximate since they are based on the rainfall catch appropriate for an FPF operation of the same size.

Table 47: Components of Annual Costs for Lagoon-Irrigation Systems for FTF Operations in the Coastal Plains by Lagoon Type.

Item	Operation size (1bLW x 10^3)	Costs, ($) Lagoon type[a] 1	2	3	4	5
Lagoon[b]	50	1,725.6	207.3	291.2	615.9	1,946.6
	100	3,326.4	291.2	453.5	1,097.0	3,737.2
	200	6,587.4	512.8	837.5	2,110.9	7,377.6
	400	13,187.5	936.8	1,656.4	4,119.2	14,623.0
Irrigation system overhead	50	662.4 (P)	732.3 (P)	675.8 (P)	618.0 (P)	614.8 (P)
	100	746.0 (P)	885.8 (P)	772.7 (P)	657.2 (P)	650.7 (P)
	200	793.1 (P)	3,087.1 (T)	2,801.5 (T)	735.5 (P)	722.6 (P)
	400	3,156.0 (T)	3,862.5 (T)	3,291.3 (T)	892.3 (P)	866.5 (P)
Irrigation operating costs[d,e]	50	57.8	57.2	59.7	65.2	94.2
	100	115.2	113.1	118.2	125.2	183.9
	200	226.3	377.3	385.0	245.5	363.1
	400	748.7	748.7	761.8	485.3	721.9
Irrigation labor costs	50	56	51	65	52	72
	100	111	101	130	104	144
	200	222	46	59	209	287
	400	101	93	117	417	574
Total costs	50	2,502	1,048	1,092	1,351	2,728
	100	4,299	1,391	1,474	1,983	4,716
	200	7,826	4,023	4,037	3,301	8,750
	400	17,193	5,641	5,826	5,914	16,785

[a] Identification same as in Table 33.

[b] No recycling costs or flushing costs are included.

[c] Bracketed character indicates irrigation system: P = portable; T = travelling big gun.

[d] Not including labor costs.

[e] Only approximate since they are based on the rainfall catch appropriate for an FPF operation of the same size.

estimates in Table 36, and thus apply specifically only to partially slatted operations in the Coastal Plain; but they are approximately correct for totally slatted operations. All assumptions about lagoon construction obviously carry over. For estimating the irrigation system costs, the application rate used was that just meeting two of the N, P and K needs of corn. This criterion was chosen in the belief that corn would be a major component of a manure management cropping plan (because of its high per acre net return, and high nutrient needs), and that the optimal rate of application of manure would often be that just meeting two nutrients (based on experience with optimal cropping mixes, and cost considerations, Sections 2.10.5 and 3.3). On this basis, the irrigated areas necessary for a 200,000 lbs LW operation were calculated for the different types of lagoons and swine operations, and are reported in Table 48. Estimates for other sizes of operations can be made directly proportional to these. When this is done, it is clear that all 50,000 lbs LW operations would use a portable system. All 100,000 lb LW operations except an FPF operation using lagoon type 2 would also do likewise. For the 200,000 lbs LW operation, the systems are mixed, while the 400,000 lbs LW operations using lagoons 4 and 5 usually need only a portable system. Annual costs were read from Figure 8, extrapolating beyond the budgeted systems where necessary. To compute irrigation operating costs, the lagoon effluent volumes reported in Table 40 were used. The costs thus assume that 5 gallons of wash water are added per gallon of raw manure. Further, the volumes given there relate strictly only to the FPF operation. While corresponding estimates could be made for the FPP and FTF operations, the FPF values were used as an approximation. The error introduced is small because, first, rainfall is the only factor that would vary, and this is small relative to total effluent volume; and second, irrigation operating costs are small relative to overheads. To compute labor costs, it was assumed that no more than 3" of water could be applied at any one setting. Total depth of application was determined from the effluent volumes (FPF values), and from the irrigated areas. Total depth of application varies

Table 48: Required Irrigated Areas for 200,000 lbs LW Operations by Lagoon Type and Operation Type (Acres)[a].

		Lagoon Type[b]				
		1	2	3	4	5
Operation Type	FPF	42.0(T)[c]	77.0(T)	48.7(T)	19.7(P)	18.0(P)
	FPP	21.6(P)	39.7(T)	25.1(P)	10.1(P)	9.3(P)
	FTF	33.7(P)	61.9(T)	39.1(T)	15.8(P)	14.5(P)

[a]Based on meeting two of the three (N, P, or K) needs of corn.

[b]Identification same as in Table 33.

[c]Bracketed character P indicates a portable system would be used, T a travelling big gun.

marginally with size of the swine operation, but mainly with lagoon and operation type. The required number of settings varies only with the lagoon and type of swine operation, and were estimated to be 2, 1, 2, 4 and 5 for each lagoon for an FPF operation; 3, 2, 3, 7 and 10 for an FPP operation; and 2, 1, 2, 4 and 6 for an FTF operation. These settings correspond to the following total depths of application: 4.0", 2.1", 3.5", 9.2", 14.9"; 7.7", 4.2", 6.7", 17.7", 28.6"; and 4.8", 2.6", 4.2", 11.1", and 18.0".

Total costs for mechanically aerated and naturally facultative lagoons are much higher than costs for anaerobic lagoons, for all sizes and types of operation. Moreover, because the anaerobic lagoons retain more nutrients, there is added reason to prefer them. Only if odor problems were severe, if there were a need for very long storage, or if there were a need to substantially reduce the level of nutrients, would any hog operation in the Coastal Plain diluting raw manure by a factor of 5 use an aerated or naturally facultative lagoon.

Cost variations between anaerobic lagoons are less pronounced. The most highly loaded one usually has the lowest annual cost, having the advantage of smaller lagoon costs. Offsetting this advantage are higher irrigation costs incurred because the lower pretreatment performance of these lagoons means that a larger disposal area is needed. When the larger area requires a shift from a portable to the more expensive big-gun system, it pays to use the lighter loaded lagoon in order to avoid the big-gun system. Also operating against the highly loaded anaerobic lagoon is the availability of government subsidies of lagoon construction costs for lagoons designed with a loading rate of 100 cu. ft/100 lbs LW, or lighter loading rate. The highly loaded lagoon has greater management and odor problems, and in addition, will prove more costly when flushing is needed since it alone cannot be used with recycling. When flushing is necessary, all total costs in the tables will rise because of the recycling costs (about $0.11/100 lbs LW), but the costs for the highly loaded anaerobic lagoon will increase in addition because the volume of effluent, and hence the operating and labor costs are approximately doubled (see Table 40).

In practice, choice of the optimal lagoon-irrigation system is more complex than suggested because the rates of manure application can be chosen to match the system, and may not be those meeting N needs. In particular, because portable irrigation systems have lower annual costs for a given area than the big gun systems, it may pay to avoid applying to, say, 40 acres using a big gun by applying at higher rates to only 35 acres using a portable system. The cost of achieving a cheaper irrigation system is the value of the foregone nutrients through higher application rates. As the operation size increases, a point will be reached at which the cost of foregone nutrients value exceeds the savings in using the portable 35 acre system. A guide to this break-even point can be found using marginal cost data.

From Tables 41 and 43, the marginal annual overhead cost of providing an extra acre of irrigated land varies from $10 to $12, being about $11.00 in the range of 35-50 acres, and $12 thereafter. Suppose the "normal" application rate is to apply effluent to meet the N needs of corn when only 70% of the N is recovered. From Figure 10, it is clear that P and K are also satisfied if using lagoons 1, 4 and 5; but for lagoons 2 and 3, K needs are fully met, but P needs are only about 50% satisfied. Since corn nutrient needs have values of about $24, $7 and $7.30 for N, P, and K, for any lagoon, each acre that can be covered by irrigation adds about $35 or more to returns. That is, any operation that could shift "excess" effluent from the 35 acres to one more acre would gain $35/acre. The marginal cost of achieving this gain is the cost of supplying the irrigated acre, and the loss of nutrient value from the removal of effluent from the 35 acres. The latter, however, is limited to lagoons 2 and 3, and then only to P. If all the P value were being captured on the 35 acres, it could only be $5 at most, since the N:P ratios for lagoons 2 and 3 show that when meeting N needs for corn when 70% is recovered, only 12 lbs or less P would be involved. Hence each extra acre, beyond 35 acres, irrigated at the assumed rate would be worth $19 or more. To irrigate more than 35 acres, however, involves fixed annual costs of shifting from the portable to the big gun system: approximately $900 if shifting to the 100 gpm big gun, and $1900 if shifting to a 200 gpm big gun for an acre greater than 50 acres. The shift to the big gun also changes irrigation system operating (higher) and labor costs (lower). From Table 47, the difference in operating costs is about $2.00 per acre (by estimating portable and big gun operating costs for the same size hog operation, and expressing on a per acre basis using the corresponding area in Table 45) for lagoon 2, and $3 for lagoon 3. From Tables 41 and 43, labor cost differences are about $0.60 per acre per irrigation and assuming no more than 3 irrigations less than $2.00/acre. As a guide then, the shift from portable to big gun system should have little effect on operating costs.

On the basis of the outlined costs, an additional 100 acres (1900/19) would have to be irrigated with a big gun (200 gpm rate) to make the shift from the portable system worthwhile. With such a large increase, most of the P value applied to the 35 acres would not be recovered. Assuming the P has no value, the net benefit of an entire irrigated acre is about $25. At least an additional 76 acres would be needed, or 110 acres in total. From Table 48, the only operations under 400,000 lbs LW that might need this area are FPF operations larger than 280,000 lbs LW using the highly loaded anaerobic lagoon. The latter has already been deemed an unlikely choice. Hence on economic grounds, hog operations would not use a travelling big gun irrigation system.

In avoiding the big gun system, however, excess manure application rates have to be made to the 35 acres irrigated with the portable system, up to about 3 times the rates needed to satisfy N needs. If this is environmentally unacceptable, large swine operations will have to install the big gun system. However, some excess application is probably acceptable,

and the freedom to do this, and to shift to a more nutrient demanding crop (e.g., Coastal bermudagrass) ensures that there is some range of operation which will prefer to use heavier rates on 35 acres rather than convert to a larger big gun system.

Although the great majority of hog operations would use the medium or lightly loaded anaerobic lagoons (if they use a lagoon), the costs incurred by various operations would differ significantly with operation size and type. The FPF operation has the highest costs, followed by the FTF and FPP operations. This reflects the higher irrigation system and lagoon costs incurred with greater levels of raw manure constituent production. This significant effect of operation type on costs contrasts to the small effect it has on hauling-wagon costs, where volume of manure is the critical factor. With respect to size, there are clearly economies of size, arising chiefly from economies of size in the irrigation system, although there is an incremental diseconomy of size when the irrigation system switches from a portable to a travelling big-gun system. These economies of size are reflected in the average cost functions depicted in Figures 11 to 13 which also show the total lagoon-irrigation system costs.

Although the estimates reported in this section relate specifically to those hog operations in the Coastal Plains which add 5 gallons of wash water per gallon of raw manure, they have implications for other hog operations. First, if different manure dilutions were used, the only effect on costs would be changes in operating and labor costs. These costs are relatively small in relation to total costs, so total costs would not alter dramatically. Moreover, the effect would be essentially identical for all lagoons. Hence, the medium and lightly loaded anaerobic lagoons would remain the generally preferred choices. Second, costs for hog operations would differ for several reasons. The component most affected would be the lagoon costs, since these would be reduced as argued in Section 2.8.4. Cost changes for the Piedmont would be very small. The other regional effect would be on operating and labor costs which, because of differences in net precipitation, would be marginally less in the Piedmont and more in the Mountains. Total costs for the Piedmont will then be marginally less than those for the Coastal Plain, and again the medium and lightly loaded anaerobic lagoons remain cost attractive. In the Mountains, total costs will be some 8-15% smaller, bigger reductions occurring with the more lightly loaded lagoons. Consequently, the preferred lagoon will tend more towards the lightly loaded anaerobic lagoon.

2.10 Manure Valuation and Application Rates

The agronomic value of manure accrues from the value of the macronutrients, N, P, and K, the value of micronutrients, and the value of organic matter. Although in some circumstances, for example in the deep sands of the northern Coastal Plains, the value of micronutrients might dominate the value of N, P, K for several years, in the long term the annual value of N, P and K generally dominates. In keeping with most previous studies (Nordstedt et al., 1971 is an exception) this study focuses solely on the N, P and K value of manure.

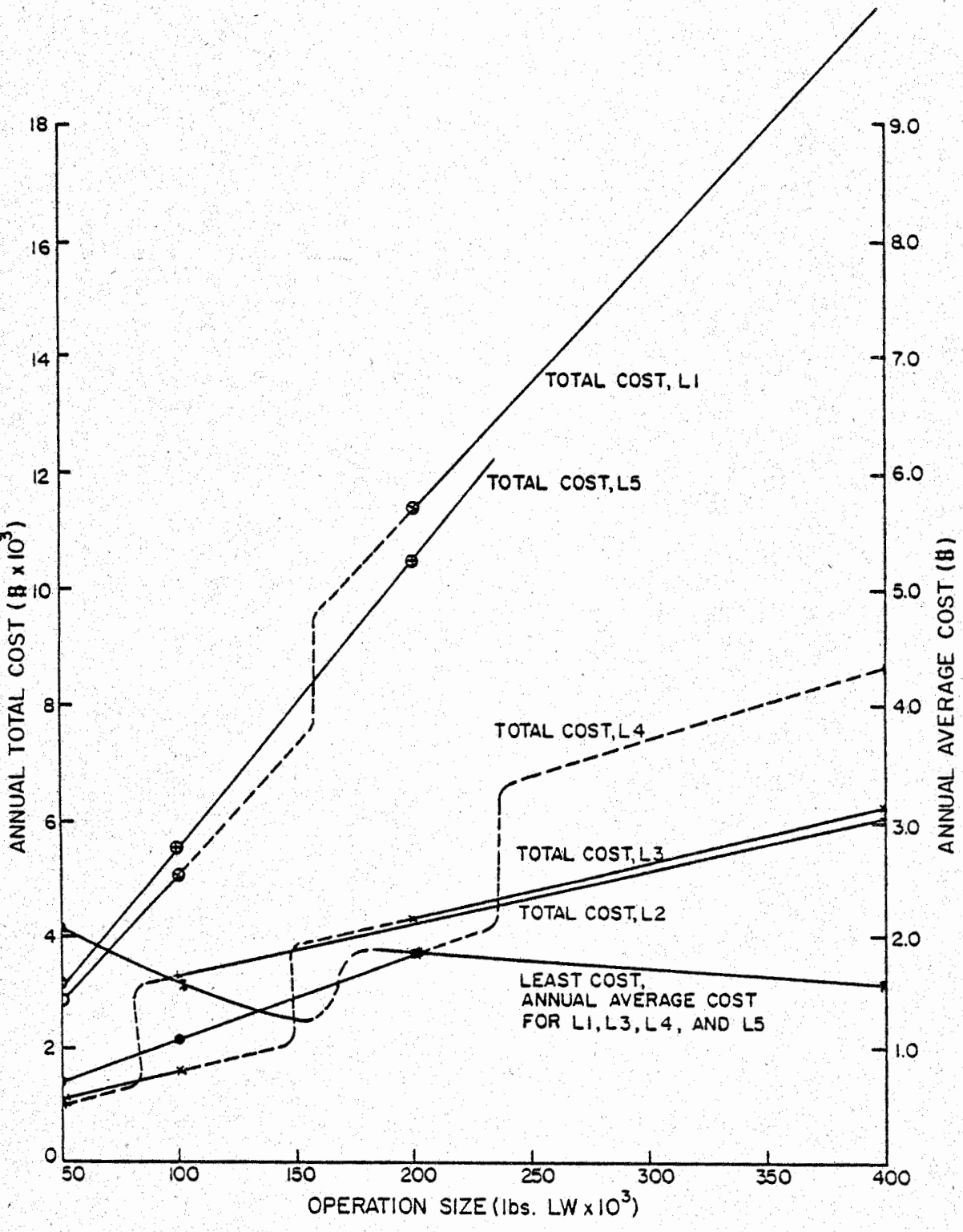


Figure 11. Annual total and average costs for lagoon - irrigation systems in feeder pig finishing (FPF) operations in the Coastal Plains.

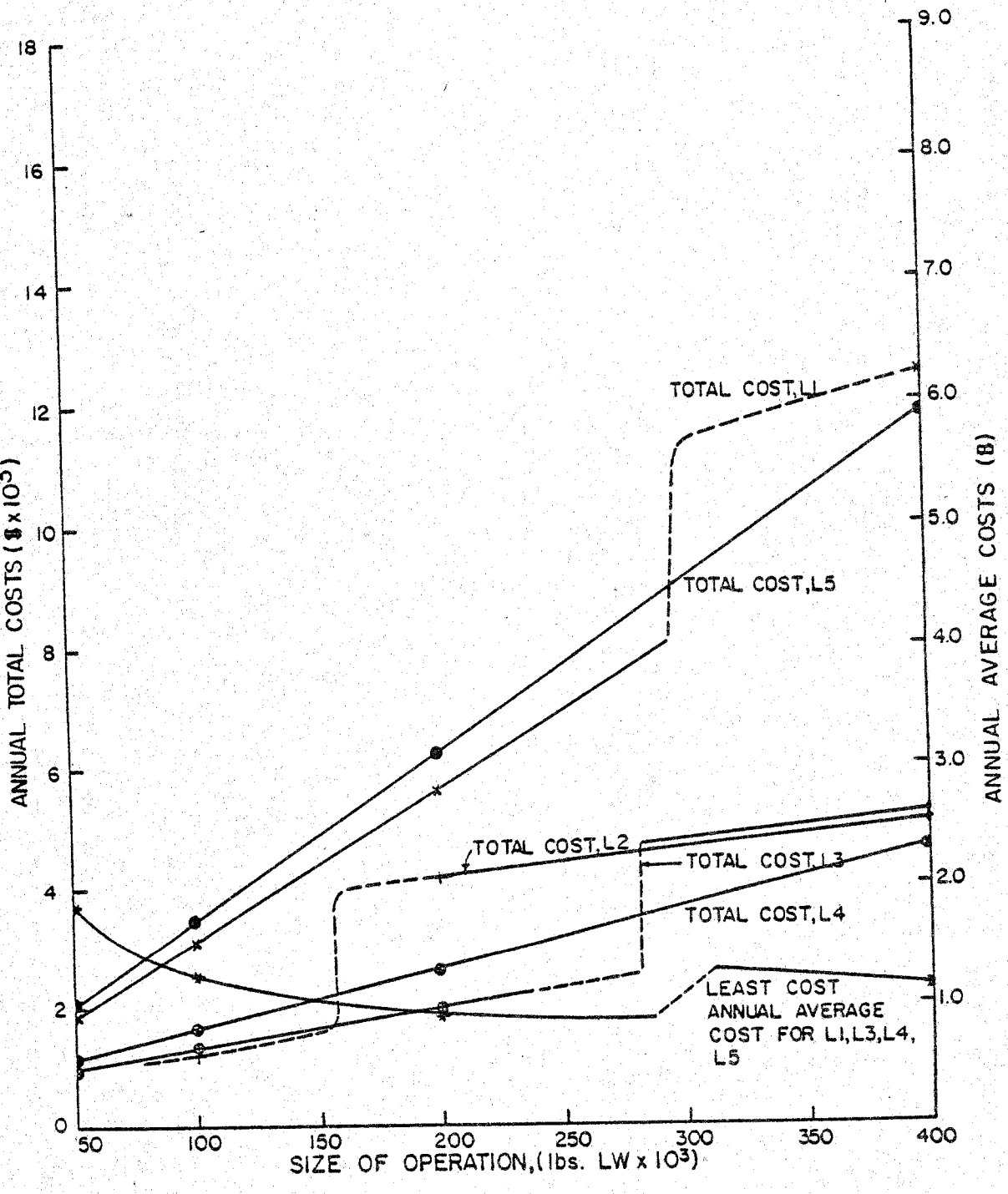


Figure 12. Annual total and average costs for lagoon - irrigation systems in feeder pig production (FPP) operations in the Coastal Plains.

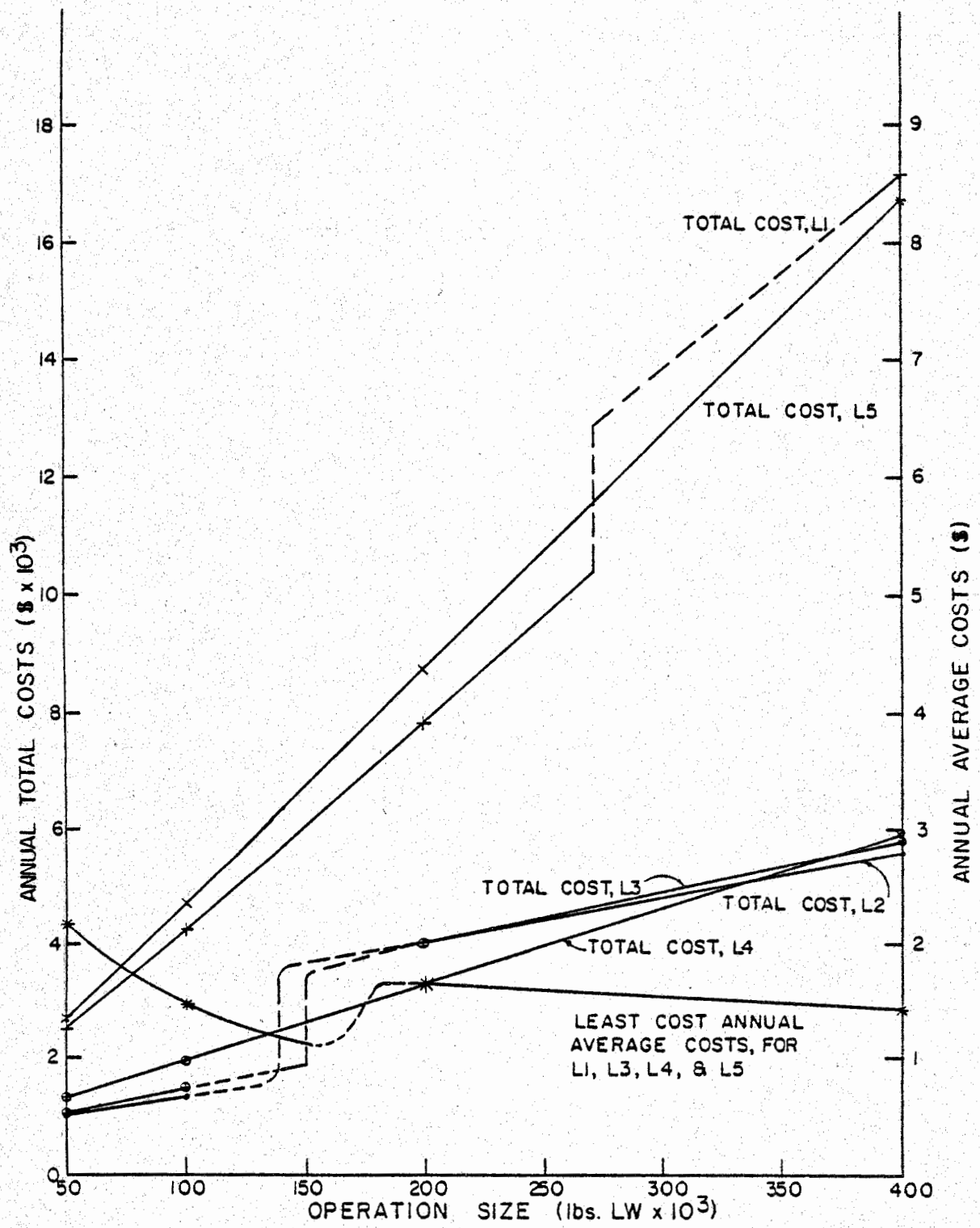


Figure 13. Annual total and average costs for lagoon irrigation systems in farrow to finish (FTF) operations in the Coastal Plains.

Conventionally, the macronutrients in manure are valued at the cost of an equivalent amount of nutrients purchased as commercial fertilizer. This is the approach taken by VanArsdall (1962), Morris (1971) and White and Forster (1977). Individual analyses differ somewhat in how an "equivalent" amount of commercial nutrients is determined. Sometimes a 1:1 conversion is used; in other cases manure nutrients are deflated by availability or effectiveness factors to obtain the equivalent commercial nutrients.

Valuations based on 1:1 conversion ratio provide an estimate of the maximum or potential value of the manure. This potential value may not be realized in practice because it may not always be feasible, or desirable, to use all of the manure nutrients as replacements for commercial nutrients. For example, a producer who has a restricted land acreage, and who has more nutrients than the crops grown on this land can use, must either waste some nutrients by applying more nutrients than required or incur opportunity losses by diverting land to more nutrient-demanding, but less profitable crops. Even with no restrictions on land, it may be preferable to apply nutrients in excess in order to avoid additional transportation costs associated with lighter applications; or because of the cost of manure storage, it may be preferable to apply manure at an excessive rate as it becomes available, allowing natural losses to reduce the available nutrients to the levels the crop needs. Finally, in contrast to commercial nutrients, the nutrient ratios in liquid manure and lagoon effluent are not readily changed by formulation. Consequently, in meeting the N needs of many crops (a common basis for manure use recommendations), excess P and K applications are generally made.

It might be argued that excess nutrients contribute to a nutrient build-up in the soil, that these accumulated excesses or residuals can be used in later years, and that excess nutrients should therefore also be valued as replacement for commercial nutrients. However, most of the excess is usually lost by leaching or other loss mechanisms in the year of application; K also leaches, and while P builds up, it generally does so in relatively unavailable forms. Further, what savings there are from build-up should also be time discounted. Aside from these reasons, it must be recognized that residuals can have no value where it is planned to apply excesses each year. Only if the planned application rates were to alter over time so that the average excesses are zero or less can temporary residuals have positive value. No previous studies have considered the possibility of cycling. This study does in so far that it permits residual carryover in rotations from one component crop to another.

2.10.1 Nutrient availability

Not all the N, P and K in manure applied to soil is available to crops. All three nutrients can be lost by surface runoff and erosion. Significant nitrogen losses can occur through leaching, denitrification and volatilization. Although these losses depend on the weather, soil characteristics and topography, they can be controlled in part by manure application practices - timing, rates, sites, incorporation, etc.

The P and K losses will be fairly small if sensible application sites are chosen. Moreover, the manure P and K forms can be considered almost equivalent to commercial fertilizer P and K for availability. Hence it is assumed that all incorporated P and K is available. When the manure is incorporated by injection or plow down, 100% of the manure P and K is assumed to be available. The P and K in lagoon effluents are assumed to be 100% incorporated because of the greater infiltration of this type of waste. These figures are only estimates, and may not apply in any given situation. Other values have been used in the literature, e.g., Dale and Mentzer (1969) use P and K availabilities of 67% and 75% respectively in their economic analysis of manure disposal. The 88% values were used by White and Forster (1977) in their economic analysis.

Nitrogen availability is more complex than that for P and K, for N is present in manure in convertible organic and inorganic forms. The latter portion is subject to atmospheric losses, and when in nitrate form, to heavy leaching losses. The organic portion is mostly insoluble, and is normally subject only to small runoff losses. As the organic portion is mineralized to inorganic forms, it too becomes available to crops, and subject to leaching.

Nitrogen availability is modelled in this study in a fairly simple way. The two N forms are treated separately. The inorganic form is subject to leaching losses, and ammonia volatilization losses at the time of application. The organic form is slowly converted to the inorganic form and is subject to losses of leaching (when converted) and of maintaining soil microorganisms. The specific model adopted for the proportion of applied N available in month T following application t months earlier is

$$N_{avail}^{t,T} = C_1(1-C_2)(1-C_3^{t,T}) + (1-C_1 - 0.04348\ (\tfrac{C}{N})_o)(1-e^{-31kt}-C_4^{t,T}),$$

for $t = 0,1, \ldots 11$, T = Jan, Feb, ... Dec, and

where C_1 = proportion of total applied nitrogen initially present in inorganic form

C_2 = fraction of the inorganic portion lost at application time. This varies with the delay before incorporation.

$C_3^{t,T}$ = fraction of the incorporated inorganic N which is lost by leaching or other means when measured in month T following application t months earlier. This fraction depends on the soil type, the location, and the measurement month T. The last two effects reflect weather patterns over the preceding t months.

$(C/N)_o$ = the carbon-nitrogen ratio of the applied manure.

k = exponential decay rate constant reflecting the rate at which organic forms are converted to inorganic forms.

$C_4^{t,T}$ = terms reflecting the loss by leaching, etc. of the mineralized organic matter. These values are determined by considering the amounts of inorganic N formed each month, and by applying the loss factor $C_3^{t,T}$ to these amounts:

$$C_4^{t,T} = \sum_{i=o}^{i=t-1} \left(e^{-31\ ki} - e^{-31\ k(i+1)}\right) C_3^{t-i-1,T}$$

for $t = 1, 2 \ldots 11$.

Inclusion of '-1' in $C_3^{t-i-1,T}$ implies that any conversion of organic N to inorganic N in a given month does not suffer leaching losses in the month of conversion. By omitting the '-1', the converted N would be subject to leaching in its month of conversion. The former gives the more conservative estimate of losses. Also, this equation for $N_{avail}^{t,T}$ assumes that all the N required for mineralization of organic matter (in the C/N ratio of 23/1) comes from the organic N portion of the total N in the manure. Thus, the inorganic N is assumed to not be "tied up" by microbial mineralization of organic matter. This assumption has little effect on the amount of N eventually available, but it does affect the short-term rate of availability.

The preceding model applies to manure applications to soil in which no crop is growing. It can be used to determine the available N in the soil at the time of planting following an earlier manure application. Also, manure organic N conversion continues after the crop is planted and thus additional N is made available to the crop. The additional N mineralized over a p month growing period starting t months after application is:

$$N_{min} = (1 - C_1 - 0.04348\ (C/N)_o)(e^{-31\ k\ (t+p)}).$$

If the leaching losses of the N which is mineralized during the p month growing period is neglected, then the total nitrogen made available to a crop (with a p month growing period) planted in month T following a manure application t months earlier is:

$$N_{TAN}^{t,T,p} = C_1(1-C2)(1-C_3^{t,T}) + (1-C_1 - 0.04348\ (\frac{C}{N})_o)(1-e^{-31\ k(t+p)}-C_4^{t,T}).$$

The criteria used to meet crop N requirements by applying manure before the growing season was to set the total available N (calculated by the equation for $N_{TAN}^{t,T,P}$) equal to the normally recommended N fertilization rate for commercial inorganic N.

For manure applications in the growing period following planting, a similar equation holds, except that there are no pre-planting leaching losses. Such past-planting applications must be 'early' in the growing period to avoid detrimental nutrient deficiencies in the early part of the growing period, for the model only determines the nitrogen made available

to the crop, not the time within the growing period that the nitrogen is available. The fraction of application N available to a crop when applied g months after planting a crop with a p month growing period is:

$$N_{TAN}^{p,g} = C_1(1-C_2) + (1-C_1 - 0.04348\ (\frac{C}{N})o)\ (1-e^{-31\ k\ (p-g)}).$$

When several manure applications are made, total nitrogen made available is computed as the sum of the amounts made available from the individual applications.

For those crops for which a distinct, relatively short, growing period can be distinguished, the outlined model should provide an adequate representation of nitrogen availability for the crop. For other crops, such as the pasture crops, the period of nitrogen need may be less clear, longer, and perhaps involve several subperiods. For example, it is generally believed that grass cut for hay needs an application of nutrients following each cutting. Rotations, too, must be treated differently, for an important feature of these is the ability of a following crop to utilize residual nutrients from the preceding crop.

For crops involving several periods of nutrient needs, the model is extended as follows. Each need period is associated with a nutrient 'supply period.' All applications made in the supply period provide available N for the crop in the need period according to the outlined model. Any excess application made for one need period, however, is carried forward to the next need period. The two N forms are again treated separately. For organic N, the carryover is the N that mineralizes between the end of one supply period and the end of the next. For inorganic N, excess available N in one period is depreciated at a rate C_D% per month for each month until the next need period. Some approximations and inconsistencies are involved in this extension. First, the depreciation of available N reflects leaching losses in the main. Ideally these should be computed in the same way as in the basic availability model. Second, leaching losses of the mineralizing organic portion are ignored. Finally, organic N remaining from one need period is only carried over into the next period. Practically, however, these errors are unlikely to be critical.

The extensions to the N availability model also apply to P and K, although more simply. Any excess P and K from one need period is carried forward without depreciation to the next.

For rotations, a similar approach is followed. However, nutrients are not carried over from one cycle of a rotation to the next. Because of this approach, there is necessarily a break in the pattern of carryovers for rotations. In a three-crop rotation, nutrients can be carried over only from two of the crops. Residuals at the end of the third crop are ignored, thus preventing the valuation of potentially perpetually growing residuals.

Then a corn-wheat-soybeans (C-W-S) rotation is different from a S-C-W rotation. In the former case, excess P and K applied to corn and wheat could be used to meet soybeans needs; and perhaps no additional nutrients would have to be applied to soybeans. In the second case, nutrients would have to be applied to soybeans. Excess applied N would then serve to meet the corn's and wheat's needs. To prevent this inconsistency, one could consider more than one rotation cycle.

2.10.2 Estimates of manure value

Parameter values for the nutrient availability model, in particular leaching losses and the decay rate constant, vary with region, and within region by soil type. Sample estimates for sandy soils typical of the northern Coastal Plains are reported in Table 49. Even for this case, however, monthly leaching losses are only approximated as a percent of inorganic N present. Two N leaching loss schedules are reported based on 5% and 10% losses per month, respectively.

Using these estimates, estimates were made of the value of applying 100 lbs N as manure for later use by a crop. Four sets of estimates are reported (Tables 50-53), namely the cases of liquid manure and lagoon effluent under the two alternative leaching schedules. These estimates are based on a 3-month growing period, on full use of the available nutrients, and on the prices listed in Table 16.

The calculations reveal the differences between liquid manure and lagoon effluents, and the effects of alternative leaching schedules, delays in incorporation, and planting date relative to application date. The most important factor in determining the value of liquid manure is the length of delay between application and incorporation. Soil injection can increase the value of manure by $9.28 per 100 lbs applied N. Since soil injection equipment has an annual cost of $287 (see Table 29), 3,102 lbs of N as manure must be applied at planting time and used efficiently (that is so that all available N, P and K are used), to offset the cost of this equipment. With earlier applications, the advantages of rapid incorporation decreases. For example, with an application 4 months before planting, injection is worth only $6.83 under the 10% loss schedule, or $7.95 under the 5% loss schedule. Applications of 4,215 lbs N and 3,621 lbs N respectively, would then need to be efficiently applied to break even with injection equipment. These N requirements can be converted to operation sizes using daily N production rates (Tables 7, 10 and 13). The required operation sizes are reported in Table 54. Also reported are the sizes of operations necessary to break-even with injection equipment when the efficiency of use of available nutrients is less than 1.0. The 0.75 efficiency level is probably the most representative level. These calculations can provide only a guide to the profitability of injection equipment, for first, use of injection equipment may itself alter the efficiency of using available N; and second, the use of injection may necessitate the use of a larger tractor depending on soil conditions.

Table 49: Basic Nutrient Availability Parameters for Sandy Soils of the Coastal Plains.

Item	Parameter value[a]
C_1 = fraction of total N present in inorganic form	0.5 (0.8)
C_2 = fraction of inorganic N lost at application	
(i) immediate incorporation	0.05 (0.25)
(ii) plow down after 1 day	0.5 (-)
(iii) plow down after 4 days	0.9 (-)
(iv) no plow down	1.0 (-)
k = exponential decay rate constant	0.04
$(C/N)_o$ = carbon/nitrogen ratio of manure	5.0 (4.0)
P_A = availability of phosphorus	0.88
K_A = availability of potassium	0.88
$C_3^{t,T}$ = fraction of incorporated N lost by month T after application t months earlier,	
(i) @ 5%/month t = 0, 1, ... 11.	0.0, 0.05, 0.097, 0.143, 0.185, 0.226, 0.265, 0.302, 0.337, 0.370, 0.401, 0.431
(ii) @ 10%/month	0.0, 0.1, 0.190, 0.271, 0.344, 0.409, 0.469, 0.522, 0.569, 0.612, 0.651, 0.686
$C_4^{t,T}$ = fraction of potentially available organic form of N which is lost by leaching	
(i) @ 5%/month	0.0, 0.0, 0.036, 0.080, 0.124, 0.168, 0.209, 0.249, 0.286, 0.322, 0.356, 0.388
(ii) @ 10%/month	0.0, 0.00, 0.071, 0.156, 0.238, 0.313, 0.382, 0.443, 0.499, 0.549, 0.594, 0.635

[a]The first value for each item is for liquid manure from a storage pit. If the lagoon effluent values differ, they are given in brackets, otherwise, not at all. The '-' sign in brackets indicates an irrelevant parameter for lagoon effluent.

Table 50: Value of N, P and K in Lagoon Effluent Containing 100 lbs N When Inorganic N Leaching Losses are 5% per Month.

Item	Months since application											
	0	1	2	3	4	5	6	7	8	9	10	11
N mineralized in next 3 months (lbs)	2.54	0.74	0.21	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Value of N mineralized in next 3 months (lbs)[a]	0.38	0.11	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available N at start (lbs)[b]	60.0	58.85	56.45	53.78	51.14	48.59	46.17	43.86	41.67	39.58	37.60	35.72
N value at start[c]	9.00	8.83	8.47	8.07	7.67	7.29	6.93	6.58	6.25	5.94	5.64	5.36
P value[d], L1[e]	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
K value L1	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
Total N,P,K value, L1	24.38	23.94	23.50	23.08	22.67	22.29	21.93	21.58	21.25	20.94	20.64	20.36
P value, L2	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
K value, L2	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90
Total N,P,K value, L2	17.20	16.75	16.31	15.89	15.49	15.11	14.74	14.39	14.07	13.75	13.46	13.17
P value, L3	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
K value, L3	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55
Total N,P,K value 3	21.01	20.57	20.13	19.70	19.80	18.92	18.55	18.21	17.88	17.56	17.27	16.99
P value, L4	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
K value, L4	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96
Total N,P, K value, L4	34.34	33.89	33.45	33.03	32.63	32.25	31.88	31.53	31.21	30.89	30.60	30.31
P value, L5	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
K value, L5	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98
Total N,P,K value, L5	220.36	219.92	219.45	219.06	218.65	218.27	217.91	217.56	217.23	216.92	216.62	216.34

[a] Values are in dollars ($).

[b] Effluent N is 80% inorganic and 25% of this is lost at application.

[c] N value is that of inorganic forms in the soil at the time.

[d] P and K availabilities assumed to be 100%.

[e] Lagoons (L1-L5) are described in Table 33.

Table 51: Value of N, P and K in Lagoon Effluent Containing 100 lbs N When Inorganic N Leaching Losses are 10% per Month.

Item	Months since application											
	0	1	2	3	4	5	6	7	8	9	10	11
N mineralized in next 3 months (lbs)	2.54	0.74	0.21	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Value of N mineralized in next 3 months[a]	0.38	0.11	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available N at start (lbs)[b]	60.00	55.85	50.80	45.88	41.34	37.22	33.50	30.15	27.14	24.43	21.98	19.78
N value at start[c]	9.0	8.38	7.62	6.88	6.20	5.58	5.03	4.52	4.07	3.66	3.30	2.97
P value[d], L1[e]	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
K value, L1	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
Total N,P, K value, L1	24.38	23.48	27.65	21.89	21.20	20.58	20.02	19.52	19.07	18.66	18.30	17.97
P value, L2	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
K value, L2	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90
Total N,P, K value, L2	17.20	16.30	15.47	14.71	14.02	13.40	12.84	12.34	11.89	11.48	11.11	10.78
P value, L3	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
K value, L3	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55	9.55
Total N,P, K value, L3	21.01	20.12	19.28	18.52	17.83	17.21	16.65	16.15	15.70	15.29	14.93	14.60
P value, L4	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
K value, L4	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96
Total N,P,K value, L4	34.34	33.44	32.61	31.85	31.16	30.54	29.98	29.48	29.03	28.62	28.25	27.92
P value, L5	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
K value, L5	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98	188.98
Total N,P,K value, L5	220.36	219.47	218.63	217.87	217.18	216.56	216.00	215.50	215.05	214.64	214.28	213.95

[a]Values are in dollars ($).

[b]Effluent N is 80% inorganic and 25% of this is lost at application.

[c]N value is that of inorganic forms in the soil at the time.

[d]P and K availabilities assumed to be 100%.

[e]Lagoons (L1-L5) are described in Table 33.

Table 52: Value of N, P, K Nutrients in Liquid Manure Containing 100 lbs N When Inorganic N Leaching Losses are 5% per Month.

Item	Months since application											
	0	1	2	3	4	5	6	7	8	9	10	11
N mineralized in next 3 months (lbs)[a]	27.58	7.98	2.31	0.67	0.19	0.06	0.02	0.01	0.00	0.00	0.00	0.00
Value of N mineralized in next 3 months	4.14	1.20	0.35	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Available N injection[c] (lbs)	47.50	65.20	67.76	66.05	63.24	60.22	57.25	54.39	51.68	49.09	46.64	44.31
N value, injection	7.12	9.78	10.16	9.91	9.49	9.03	8.59	8.16	7.75	7.36	7.00	6.65
P value, injection[b]	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
K value, injection	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
Total value, injection	29.21	28.93	28.46	27.96	27.46	26.99	26.54	26.11	25.70	25.31	24.95	24.60
P value, delayed plow down	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44
K value, delayed plow down	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36
Available N, 1 day plow down	25.00	43.83	47.45	46.76	44.91	42.81	40.71	38.68	36.75	34.91	33.17	31.51
N value, 1 day plow down	3.75	6.57	7.12	7.01	6.74	6.42	6.11	5.80	5.51	5.24	4.98	4.73
Total value, 1 day plow down	23.68	23.57	23.26	22.91	22.56	22.23	21.90	21.60	21.31	21.03	20.77	20.52
Available N, 4 day plow down	5.00	24.83	29.40	29.61	28.62	27.33	26.00	24.72	23.48	22.31	21.19	20.13
N value, 4 day plow down	0.75	3.72	4.41	4.44	4.29	4.10	3.90	3.71	3.52	3.35	3.18	3.02
Total value, 4 day plow down	20.68	20.72	20.55	20.34	20.12	19.90	19.70	19.50	19.32	19.14	18.97	18.82
Available N, 10 day plow down	0.00	20.08	24.89	25.33	24.55	23.46	22.30	21.22	20.16	19.16	18.20	17.29
N value, 10 day plow down	0.00	3.01	3.73	3.80	3.68	3.52	3.35	3.18	3.02	2.87	2.73	2.59
Total value, 10 day plow down	19.93	20.01	19.88	19.70	19.51	19.32	19.15	18.98	18.82	18.67	18.53	18.39

[a]Values are in dollars ($).

[b]P and K values assume 0.88 availability when plow down is delayed, and 1.00 when injected

[c]N values refer to the value of inorganic forms in the soil at the given time.

Table 53: Value of N, P, K Nutrients in Liquid Manure Containing 100 lbs N When Inorganic N Leaching Losses are 10% per Month.

Item	Months since application											
N mineralized in next 3 months (lbs)	27.58	7.98	2.31	0.67	0.19	0.06	0.02	0.01	0.00	0.00	0.00	0.00
Value of N mineralized in next 3 months[a]	4.14	1.20	0.35	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Available N, injection[c]	47.50	62.83	62.36	57.81	52.51	47.40	42.70	38.44	34.60	31.15	28.03	25.23
N value, injection	7.12	9.42	9.35	8.67	7.88	7.11	6.41	5.77	5.19	4.67	4.20	3.78
P value, injection[b]	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
K value, injection	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
Total value, injection	29.21	28.57	27.65	26.72	25.86	25.07	24.36	23.72	23.14	22.62	22.15	21.93
P value, delayed plow down	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44
K value, delayed plow down	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36
Available N, 1 day plow down	25.00	47.58	44.14	41.40	37.75	34.12	30.74	27.68	24.92	22.43	20.19	18.17
N value, 1 day plow down	3.75	6.39	6.62	6.21	5.66	5.12	4.61	4.15	3.74	3.36	3.03	2.73
Total value, 1 day plow down	23.68	23.38	22.76	22.11	21.49	20.92	20.41	19.95	19.53	19.16	18.82	18.52
Available N, 4 day plow down	5.00	24.58	27.94	26.82	24.63	22.31	20.12	18.12	16.31	14.68	13.21	11.89
N value, 4 day plow down	0.75	3.69	4.19	4.02	3.69	3.35	3.02	2.72	2.45	2.20	1.98	1.78
Total value, 4 day plow down	20.68	20.68	20.33	19.92	19.52	19.15	18.82	18.51	18.24	18.00	17.78	17.58
Available N 10^{+} day plow down	0.0	20.08	23.88	23.18	21.35	19.35	17.46	15.72	14.16	12.74	11.47	10.32
N value, 10 day plow down	0.0	3.01	3.58	3.48	3.20	2.90	2.62	2.36	2.12	1.91	1.72	1.55
Total value 10^{+} day plow down	19.93	20.07	19.73	19.37	19.03	18.71	18.42	18.16	17.92	17.71	17.52	17.34

[a]Values are in dollars ($).

[b]P and K values assume 0.88 availability when plow down is delayed, and 1.00 when injected.

[c]N values represent the value of inorganic forms in the soil at the given time.

Table 54: Estimated Minimum Operation Sizes to Break Even on Injection Equipment (1,000's lbs LW).

N leaching loss, (%/month)	Efficiency of use of available nutrients	Operation Type					
		FPF[a]		FPP[b]		FTF[c]	
		Months since application		Months since application		Months since application	
		0	4	0	4	0	4
5%	0.25	84.8	99.2	164.8	192.4	105.6	123.6
	0.5	42.4	49.6	82.4	96.2	52.8	61.8
	0.75	28.3	33.1	54.9	64.1	35.2	41.2
	1.00	21.2	24.8	41.2	48.1	26.4	30.9
10%	0.25	84.8	115.6	164.8	224.0	105.6	143.6
	0.50	42.4	57.8	82.4	112.0	52.8	71.8
	0.75	28.3	33.1	54.9	64.1	35.2	47.9
	1.0	21.2	28.9	41.2	56.0	26.4	35.9

[a]Based on 0.04 lbs N/day/100 lbs LW (Table 7).

[b]Based on 0.02063 lbs N/day/100 lbs LW (Table 10).

[c]Based on 0.03214 lbs N/day/100 lbs LW (Table 13).

It is generally accepted that manure applications should be made as near to planting as possible to gain the full value of the nutrients. The calculations reported in Tables 50-53 suggest, however, that the advantage of applying nearer to planting is relatively small. For injection manure, applying at planting time instead of 4 months earlier increases the manure value by only $1.75/100 lbs applied or $3.35/100 lbs applied N for the 5% and 10% leaching loss schedules respectively. The gains of better timing are only 6% and 11% respectively of the total value obtained by applying at planting time; and only 1/4 to 1/3 the gains of injection. For lagoons, the absolute value of better timing is even less, although relatively more (up to 18% of total value).

To some extent, the small gains from better timing reported here are misleading. These calculations are all based on efficient (full) use of the available nutrients. When more realistic use of the available nutrients is assumed, the timing of a manure application can have a greater economic significance. Table 55 reports estimates of the foregone values of nutrients when manure applications are made to corn to meet its N needs. The values

Table 55: Manure Nutrient Ratios and Opportunity Costs of Inefficient Use of the Nutrients in Liquid Manure.

Time since application (months)	Available nutrient[a] ratio, N:P:K	Available N (lbs N/100 lbs applied N)	Value if used efficiently ($/100 lbs applied N)	Value if used on corn grain ($/100 lbs applied N)	Opportunity cost of inefficient use ($/100 lbs applied N)	Opportunity cost of early application ($/100 lbs applied N)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	1:.43:.60	75.0	29.1	17.9	11.2	-
1	1:.47:.65	69.0	28.3	16.5	11.8	1.4
2	1:.52:.71	62.9	27.4	15.0	12.4	2.9
3	1:.56:.78	57.5	26.4	13.8	12.6	4.1
4	1:.62:.86	52.4	25.8	12.5	13.3	5.4
5	1:.68:.94	47.6	25.0	11.4	13.6	6.5
6	1:.75:1.04	43.1	24.3	10.3	14.0	7.6
7	1:.84:1.17	38.6	23.7	9.2	14.5	8.7
8	1:.96:1.32	34.0	23.1	8.1	15.0	9.8
9	1:1.08:1.49	30.1	22.5	7.2	15.3	10.7
10	1:1.23:1.71	26.3	21.8	6.3	15.5	11.6
11	1:1.40:1.94	23.2	21.4	5.6	15.8	12.3

[a]Available N computed as the inorganic N in soil at the time plus the organic N that would mineralize in the following 3 months. Injection and an approximately 10% N leaching loss/month are assumed.

[b]Corn grain requirements are there for the Coastal Plain: 160, 17.5 and 66.4 lbs N, P and K.

[c]Some of the calculations are irrelevant inasmuch as manure cannot be applied to corn in every month. For example, with planting in April and harvesting in October, manure could not be applied in the September preceding planting if continuous corn is grown.

are expressed in terms of dollars per 100 lbs applied N. Column 6 shows the value of available nutrients which are in the soil, but which are not used by the corn. When applications are made earlier, the losses through failure to use the available nurtients increases. Comparing the planting time application, and the 4 months early application, the latter incurs an additional cost of $2.10/100 lbs applied N. This extra cost of early application must be added to the leaching losses already mentioned. When this is done, the total opportunity costs of earlier application reported in column 7 are obtained. These costs are necessarily also equal to the difference between the value of manure used on corn when applied at different times.

Although the costs of earlier applications are now seen to be greater, they are still small. In relation to the opportunity cost of inefficient use of the available nutrients, losses through early applications are only 1/3 as much or less for applications made within four months of planting. With even earlier application, timing losses become relatively more important, but never exceed the losses of inefficient use.

Tables similar to Table 55 could be derived for different incorporation practices, for the 5% N leaching loss schedule, for lagoon effluent and for different crops or application criterion. With the first three factors, the opportunity cost of early application would be absolutely and relatively less than the costs in Table 55. Changing the crop would have little effect since most crops have similar ratios of N, P and K requirements (soybeans is an exception). Changing the application criterion affects both the absolute and relative losses of early application, but the assumed criterion is the most commonly used one. The reported opportunity costs thus effectively represent estimates and upper bounds on the losses of early application of manure.

Using daily N, P and K rates of production, estimates were made of the annual value of manure produced by different sized FPF operations under different timing of applications, and efficiency of use assumptions. These calculations are reported graphically in Figure 14. Separate functions are reported for liquid manure, and for the effluents from lagoons 3 and 4, the most economical alternative lagoons. For each of these effluents, three functions are depicted: (1) the potential value of the effluent if all N, P and K were recovered; (2) the value of the available N, P and K when effluent is applied at planting time assuming the available nutrients are efficiently utilized; and (3) same as (2) but when the manure is applied 4 months prior to planting. For liquid manure, in addition to these three functions, functions for nutrient utilization consistent with applications meeting corn's N needs are also reported.

Apart from the obvious substantial reductions in value caused by inefficient use, early application, and lagooning, the graphs indicate an important interaction between these factors. In particular, while using a lagoon (L4 say) there is a large drop in potential nutrient value ($15,000

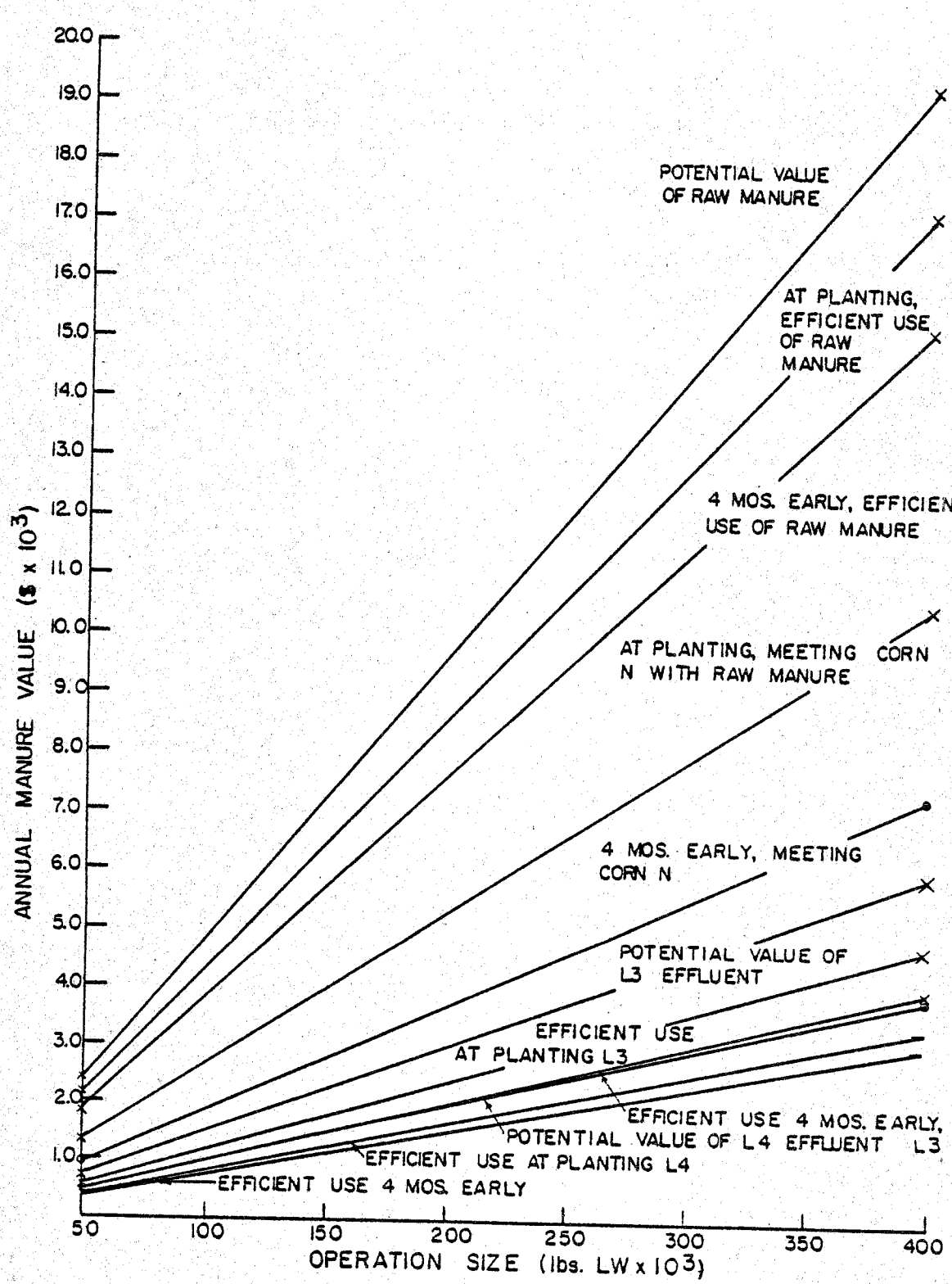


Figure 14. Estimates of annual manure values produced by feeder pig finishing (FPF) operations by application time and use efficiency.

for a 400,000 lb LW operation). When realistic nutrient recoveries are used, lagooning losses will be much smaller (about $6,000 for the 400,000 lbs LW operation). In reality, lagoons are not at quite the disadvantage they appear to be if examined in terms of potential value.

Finally, Figure 14 can be used for FPP and FTF operations by reducing all manure values in that figure by a factor 0.5057 and 0.8036 respectively in accordance with their relative nutrient production levels.

2.10.3 Storage - manure use efficiency tradeoffs

Using the pit storage information and the annual cost information reported for different types of operations and houses in Tables 21-28, the annual marginal cost of providing an additional day's storage for raw manure was calculated. The estimates are reported in Table 56 on a per 100 lbs LW basis. Using daily N production rates (Tables 7, 10 and 13) storage costs were also calculated on the basis of an operation producing 100 lbs N/day, that is for a 250,000 lbs LW FPF operation, a 769,231 lbs LW FPP operation, and a 555,556 lbs LW FTF operation.

Table 56: Estimates of the Annual Marginal Cost of Providing Additional Storage for Raw Manure by Operation Type and Flooring Type[a].

	Floor type[b]	Operation Type[c]			
		FPF	FPP[d]	FTF[d]	Units
A. One day's storage	PS	0.586	0.70 - 1.17	0.36 - 0.79	cents per
	TS	0.332	0.70 - 1.02	0.29 - 0.66	100 lbs LW
B. One month's storage	PS	18.17	21.70 -36.27	11.16 -24.49	cents per
	TS	10.29	21.70 -31.62	8.99 -20.46	100 lbs LW
C. One month's storage	PS	454.25	1,669.2-2,790.0	620.00-1,360.6	$/operation production
	TS	257.25	1,669.2-2,432.3	499.44-1,136.7	100 lbs N/day

[a]Based on undiluted raw manure. 16" of pit unavailable for manure storage because of ventilation, overflow, and pit bottom water.

[b]PS = partial slats; TS = total slats.

[c]FPF = feeder pig finishing; FPP = feeder pig production; FTF = farrow to finish.

[d]The FPP and FTF operations have a cost range. For small operations only one pit will need deepening for added storage. Eventually all pits need deepening, causing increased costs.

These costs can be compared with estimates of the value of improved timing of applications. The latter will depend on the way the manure is used. For estimation purposes, assume that the opportunity costs given in Table 55, Column 7, apply. Further assume that nutrients are needed twice a year in month 6 and 12, that applications following these months contribute to the next need period, and that the operation initially has 1 month storage, and produces 100 lbs N/day.

An additional month's storage results in an improvement in the available nutrients in only 6 months, namely months 1, 3, 5, 7, 9 and 11, all of which have their manure applications delayed one month. For months 1 and 7, the opportunity cost of early application is reduced from that for 5 months to that for 4 months; for months 3 and 9, the corresponding reduction is from 3 to 2 months early; and for months 5 and 11, from 1 to 0 months. Using savings of \$0.9, \$1.2 and \$1.4/100 lbs N applied for the 3 cases, the annual savings for the total operation is \$217. This is well below the marginal cost of the storage. Moreover, since the estimated opportunity costs used are those for where the available nutrients are used inefficiently on corn, the savings from better application timing would be less if the available nutrients were fully used. Finally, since the estimated marginal storage costs are based on the assumption of no dilution, they are conservative, and may often be two to six times higher. Clearly, it does not pay to provide additional storage in an attempt to capture greater nutrient value.

Increased storage can be obtained by changing from partially slatted to totally slatted floors, as well as by using deeper pits. Assuming the proportion of floor that is slatted is continuously variable, the marginal cost of an added day's storage through wider pits is generally greater than the marginal cost through deeper pits (based on pit and flooring costs in Tables 21-28). It follows that it does not pay to change from partial slats to total slats in order to achieve better timing of nutrient applications. However, as discussed in Section 2.5.1, the totally slatted floors are preferred because of lower labor costs for cleaning the floors.

Storage may be desirable for other reasons such as convenience and flexibility. In some regions of the U.S., seasonal weather conditions may prevent application at certain times. Manure normally should not be applied to snow covered, or frozen ground, for example. Such factors are not likely to impinge on hog operations in North Carolina, except possibly in the Mountains. A potentially more significant economic consideration is the need to divert land from the most profitable crop to another crop which can accept manure as it becomes available.

From Table 19, corn is the most profitable crop in the Coastal Plains region (\$153.65/acre after subtracting labor costs, and ignoring fertilizer), followed by the corn-wheat-soybean rotation. If we say that corn land is unavailable to receive manure applications from July through October, the

most profitable crop that could receive manure in these 4 months is Coastal Bermudagrass for hay ($128.12). Each acre diverted to Coastal Bermuda costs $25.53 ($153.65-$128.12)in foregone opportunities. Since 124,000 lbs N would have to be applied if only one month's storage were available, and assuming only 50% N availability, full use of the available N and that these July-October applications are to meet 75% of Coastal Bermuda N needs, then about 34 acres must be diverted from corn, at a cost of $868. This cost exceeds the marginal costs of a month's storage for the FPF operation. However, since four months storage would be required, the total cost of providing storage beyond the minimum needed for convenience would exceed the cost of diversion, and the latter would be preferred.

On the basis of the foregoing, despite the narrowness of the assumptions (emphasis on corn; full use of available N, etc.) it seems reasonable to conclude that storage of liquid manure by the use of deeper pits, or by wider pits, will not be an attractive proposition in the Coastal Plain. For the Mountains and the Piedmont, leaching losses are likely to be less than in the light soils of the Coastal Plain, so the opportunity costs of earlier applications are probably smaller. On the demand side, corn is still potentially the most profitable crop. However, Coastal Bermuda is not a reasonable alternative crop in these regions, and instead, land may have to be diverted to wheat. Using the Coastal Plain net returns for wheat and corn as approximate values for the returns in the other areas, the opportunity cost of land diversion is about $84/acre. Using Coastal Plains wheat needs for N, at 75% recovery and use of applied N, 93 acres would be needed; and the cost of diversion would be about $8000. The cost of diversion for each month's manure is about $2000. This is well in excess of storage costs for a 4 month period for the FPF operation. Only if it used dilution factors of 5 or more might diversion become attractive. Similarly, the FTF operation would find storage attractive unless dilution factors of 4 or more were used. The FPP operation, however, because it produces relatively less N, would find diversion attractive at any dilution factor greater than 2.

There are two further factors favoring minimal pit storage. First, the smaller the pit storage, the smaller the external pump is, and the less its cost. The second disposal opportunity operating against storage is the practice of deliberately applying an excess amount of nutrients to the diverted land, thus reducing the area diverted, and the cost. If N application rates that are 3 or 4 times the required N are permitted, diversion costs can be reduced substantially, and to the point where land diversion is favored over storage.

The storage-timing-diversion analysis has been for liquid manure storage. For lagoons, the matter is complicated since any change in storage is equivalent to a change in lagoon loading rate and pretreatment performance. The advantages of greater storage for better timing will be small. The savings through not having to divert land will also be small because so little land would need to be diverted since nutrient levels are low. These small savings

are surely dominated by the lagoon-irrigation system costs discussed in Section 2.9.5. Their effect would be to push lagoon preference towards the lightest loaded anaerobic lagoon and away from the medium loaded lagoon.

Since the area diverted depends on the N produced, the cost of diversion for a liquid manure hauling operation is greater than that for a lagooning operation, not only because the farmer has more limited storage, but because it produces much more N. For the 100 lbs N/day hog operation, 34 acres have to be diverted with liquid manure, but perhaps only 8 would have to be diverted with an anaerobic lagoon. If the former costs about $868, liquid manure operations have a $650 extra cost over lagooning. The 400,000 lbs FPF operation thus saves about $1,000 by lagooning instead of hauling liquid manure. This saving offsets, to some extent, the aparent losses in manure value ($6,000 for a 400,000 lbs LW FPF operation; Section 2.10.3) when lagooning is used instead of hauling.

2.10.4 Rates and times of applications

For each agronomic crop, a yield level is identified along with N, P and K levels required to attain this yield. For rotations, and some perennial crops, several nutrient need periods are specified and nutrient levels are identified for each. The latter become the basic reference points for manure applications. The nutrient requirements established are those used in the North Carolina Agricultural Extension Service's Planning for Profit series, adapted when necessary to obtain regional levels. To simplify analyses, these nutrient levels are deemed the economic optimal levels irrespective of the cost of nutrients, or of product prices.

With the nutrient requirements established, alternative ways of meeting them can be defined. Five basic ways are considered:

a) commercial fertilizer alone - no excess nutrients

b) satisfy one nutrient need by manure, and use supplementary commercial fertilizer to meet the other two - no excess nutrients

c) satisfy two nutrient needs by manure, and use supplementary commercial fertilizer to meet the third - one excess nutrient

d) satisfy all three nutrient needs by manure - two excess nutrients

e) apply excesses of all nutrients by manure at levels considered safe from environmental and agronomic viewpoints - three excess nutrients.

Additional alternatives are created by alternative timings of applications. Each of these alternatives can be used either with liquid manure or a lagoon effluent; and for liquid manure, variations in soil incorporation practices (from immediate injection, one day plow down, to no plow down) also exist.

Nutrient need periods, and corresponding application periods for the major crops grown in the Coastal Plain region are reported in Table 57 along with the nutrient needs for each period. Separate feasible periods of application are identified for irrigation, surface spreading, and immediate injection because different constraints act to determine the feasibility of any application practice. Surface applications with plow down, for example, are necessarily limited to pre-planting applications.

Only two rotations are included. Agronomically, crop rotations have a number of advantages over repetitive (or continuous) cropping. These include superior disease, insect and weed control; more consistent soil cover; greater use of, and hence a greater potential return from land; and replenishment of soil N by the inclusion of legumes in rotation. To a considerable extent, these advantages have been neutralized over the years by the availability of commercial N, soil conditions, and chemical pest control. Where manure is available for disposal, rotations offer the advantages of increased utilization ratios, and a greater variety of times and rates at which nutrients are required. For example, consider a rotation of corn and soybeans. If a proportion, α, of the years for the rotation are planted to corn, and $(1-\alpha)$ to soybeans, then 160 α, 19.6 - 2.1α, and 74.7 - 8.3α lbs of N, P and K are used on the average each year of the rotation. By varying α, different N:P:K utilization ratios can be obtained, and so matched to the N:P:K ratios in the manure.

Practically, however, the ability to vary utilization ratios is restricted because, for a given location, crops often have similar ratios of nutrient needs. In the Coastal Plains, all the major crops require P and K in the ratio of approximately 1:4. The only scope for variation is in the N:P and N:K ratios by rotating the cereals with soybeans. Greater, but still limited, flexibility probably exists in the Piedmont and Mountain regions. Estimates were made of the economic value of the improved ratios obtained with the corn-soybeans, and corn-wheat-soybean rotations, and are reported in Table 58. The estimates, made for liquid manure and the five types of lagoon effluents, are based on the assumption that manure is applied to meet the N needs of each crop. For corn, the P and K actually used is calculated and valued along with the N used. For the rotation, it is assumed incorrectly that no shortfalls in P and K occur, and that P and K are used relative to N in the ratios required over the rotation cycle. The error associated with this assumption increases the calculated value of manure used on rotations, and thus also leads to an overestimate of the value of diverting manure to rotations. The estimates also assume that the manure is applied at planting time, when the value of rotations should be greatest.

On a per 100 lbs available N basis, the value of diverting manure from corn to rotation is less than $6. Since C-W-S, for example requires 130 lbs N/acre, an acre of C-W-S would save $7.80 through better nutrient recovery. However, since the cost of diverting land form corn would be about $15, it clearly would not be profitable using rotation solely to achieve better

Table 57: Nutrient Need Periods, Feasible Application Periods, and Nutrient Needs for Major Crops in the Coastal Plains.

	Nutrient need periods and feasible application period[a]											
Month	Corn	Sorghum	Wheat, Oats Barley	Soybeans	CBG[b] Hay	CBG[b] Pasture	Fescue[b] Pasture	Corn - soybeans[c] 1	2	Corn - Wheat - soybeans[c] 3	4	5
Jan	IJS	IJS	N I	IJS	IJS	IJS	IJS	IJS	IJS	IJS	I N	
Feb	IJS	IJS	N I	IJS	IJS	IJS	N IJS	IJS	IJS	IJS	I N	
Mar	IJS	IJS	N I	IJS	IJS	IJS	N IJS	IJS	IJS	IJS	I N	
Apr	N IJ	IJS	N	IJS N	IJS N	IJS	N IJS	IJ N	IJS	IJ N	N	
May	N IJ	N IJ	N	N	N	IJS N	IJS N	IJ N	N	IJ N	N	
Jun	N I	N I		N	N	IJS N	IJS N	I N	N	I N		
Jul	N	N	IJS	N	N	IJS N	IJS	N	N	N	J[d]	N
Aug	N	N	IJS	N	N	IJS N	IJS	N	N	N		N
Sep			IJS	N	N	IJS N	IJS N		N			N
Oct	IJS	IJS	N I			IJS	IJS N	IJS		IJS		N
Nov	IJS	IJS	N I			IJS	IJS N	IJS		I N		
Dec	IJS	IJS	N I	IJS		IJS	IJS	IJS	IJS	I N		
	Nutrient needs, lbs/ac											
N1	160	120	100	0	60	50	50	80	Apply only to	80	Apply only to	
P1	17.5	17.5	8.7	19.6	6.55	5.45	6.53	8.75	0.5 acre of	8.75	0.5 acre of	
K1	66.4	66.4	33.2	74.7	24.9	20.82	24.9	33.2	corn	33.2	corn	
N2					60	50	50	0	Apply only to	50	Apply only to	
P2					6.55	5.45	6.53	9.8	0.5 acre of	4.35	0.5 acre of	
K2					24.9	20.82	24.9	37.35	soybeans	16.6	wheat	
N3					60	50	50			0	Apply only to	
P3					6.55	5.45	6.53			9.8	0.5 acre of	
K3					24.9	20.82	24.9			37.35	soybeans	
N4					60	50						
P4					6.55	5.45						
K4					24.9	20.82						
Total N	160	120	100	0	240	200	150	80		130		
Total P	17.5	17.5	8.7	19.6	26.2	21.8	19.6	18.6		22.9		
Total K	66.4	66.4	33.2	74.7	99.6	83.3	74.7	70.6		87.2		

[a]The periods defined for each crop are: N = nutrient need period; feasible periods for application are indicated by I = irrigation, J = injection and S = surface spreading. The surface spread manure could also be plowed under during the same months for all except grass crops.

[b]These grass crops have several times designated within the growing season when the specified nutrient levels should be met. Designated times for Coastal Bermudagrass are: (1) April 1, (2) June 1, (3) July 1 and (4) August 1. Designated times for fescue are (1) Feb. 1, (2) April 1, and (3) August 1. Injection to established grasses is not a common practice, but is feasible with special equipment on short grass.

[c]For rotations, two years' data are given for needs and application periods. The first crop is corn.
(1) Corn following soybeans.
(2) Soybeans following corn.
(3) Corn following soybeans; corn is to be followed with wheat.
(4) Wheat following corn; wheat is to be followed with soybeans.
(5) Soybeans following wheat.

[d]Injection application to soybeans is a questionable practice. More data is needed on this.

Table 58: Estimates of the Economic Value of Applying Manure to Rotation Instead of Corn.

Manure type	Available N/P/K ratio[a]	Value used on corn	Value used on C-S	Value used on C-W-S	Value of diverting manure from corn to[b]: C-S	C-W-S
(1)	(2)	(3)	(4)	(5)	(4)-(3)	(5)-(3)
Liquid manure	1/0.43/0.60	17.9	25.5	24	7.6	6.1
Effluent, L1[c]	1/0.16/1.60	15	19.4	18.1	4.4	3.1
Effluent, L2	1/0.07/0.86	13.7	16.9	15.6	3.2	1.9
Effluent, L3	1/0.08/1.39	14.4	17.5	16.2	3.1	1.8
Effluent, L4	1/0.12/3.19	15	18.1	16.9	3.1	1.9
Effluent, L5	1/0.88/27.5	15	21.2	18.7	6.2	3.7

[a]Based on application at planting time.

[b]To convert values to a "100 lbs available N" basis, the values should be multiplied by the N availabilities, 0.75 and 0.625 for liquid manure and lagoon effluents respectively.

[c]Lagoon types are described in Table 33.

nutrient use. The role of rotations, therefore, would appear to be in adding more times at which manure can be applied to land, thus avoiding added storage costs (Section 2.10.3).

2.10.5 Economic application rates

Although details are not presented here, comparison of the value of manure nutrients and application costs suggests: (1) that the economic rate of application of liquid manure will be that recovering maximum nutrient value; i.e., apply only to meet one nutrient need, because transporation costs

are relatively small for areas up to 600 acres, and (2) that the economic rate of application of lagoon effluent for the practical anaerobic lagoons will often be that meeting two or three nutrient needs. (This conclusion does not hold when there is a possibility of avoiding a big-gun irrigation scheme through heavier applications.)

Thus, generally it is in the economic interest of the producer to apply his manure (liquid manure or lagoon effluent) in an agronomically and environmentally acceptable way.

2.10.6 Example schedules

Within the limitations implied by Table 57, there are an infinite number of methods, times, and rates for applying manure. One method for developing schedules for manure applications is to specify the application criterion, e.g., meet two nutrient needs, and then specify the proportions of the available N that will be applied in each month of the feasible application period. With these specified, actual N application rates in each month are readily determined. Available N, P and K can be computed from the availability models, and necessary fertilizer supplementation levels can then be determined. The procedure for calculating the required N application rates is as follows: Let

A_i = amount of N applied in month i (lbs),

f_i^N = proportion of N applied in month i that is made available,

f^P and f^K = proportions of P and K that are available,

C_N, C_P, C_K = the concentrations of N, P and K in the waste relative to that of N,

p_i^N = proportion of the total available N that is to be applied in month i,

R_t = required application of the critical nutrient, t (lbs), and

AV_N, AV_P, AV_K = total available N, P and K (lbs).

Then, for a given schedule of actual N applications, the available nutrients are:

$$AV_N = \sum_i A_i f_i^N$$

$$AV_P = \sum_i A_i C_p f^P = C_P f^P \sum_i A_i$$

and $$AV_K = C_K f^K \sum_i A_i.$$

Suppose the critical nutrient, i.e., the rate determing one, is N. Then the schedule must satisfy:

(i) $\sum_i A_i f_i^N = R_N$ (total availability)

and (ii) $A_k f_k^N / \sum_i A_i f_i^N = p_k^N$, for all k (distribution of availability). Substituting

(i) into (ii) yields

$$A_k = \frac{R_N p_k^N}{f_k^N}, \text{ for all k.}$$

Hence, knowing the total available N required, the proportion of available N to be applied each month, and N availabilities for each month, the schedule of actual N applications is easily found.

When the critical nutrient is P, conditions (i) and (ii) become:

(i) $C_p f^P \sum_i A_i = R_P$

(ii) $A_k f_k / \sum_i A_i f_i = p_k$, for all k.

Since $\sum_i p_i = 1$, the last 12 equations are not linearly independent. One equation can be dropped. The remaining 11, together with (i) give a set of 12:

$$A_1 + A_2 + \ldots + A_{12} = R_p/(C_p f^P)$$

$$f_1(1-p_1)A_1 - p_1 f_2 A_2 \cdots - p_1 f_{12} A_{12} = 0$$

$$-p_2 f_1 A_1 + f_2(1-p_2) A_2 \cdots - p_2 f_{12} A_{12} = 0$$

$$\vdots$$

$$-p_{11} f_1 A_1 - p_{11} f_2 A_2 \cdots + f_{11}(1-p_{11}) A_{11} - p_{11} f_{12} A_{12} = 0$$

These equations can be solved for the applied N levels. The same procedure can be used when K is the critical nutrient.

Which nutrient is critical is not known initially. A trial and error procedure in which one nutrient (P say) is assumed to be critical must be used. The corresponding applied N schedule and P and K availabilities are calculated. The availabilities are compared with the requirements and the rate determining criterion. If, for example, only one nutrient should be satisfied but two are, the other satisfied nutrient is clearly the critical nutrient. The analysis is then rerun for this nutrient. By using the trial and error method with forethought, only 1 or 2 runs are needed, rarely 3.

Examples of manure application schedules for some of the important crops in the Coastal Plains are reported in Table 59. Schedules are given only for injected liquid manure, and for effluent from lagoon 3. The schedules include some for the three criteria; meet all, 2, or 1 nutrient need. No schedules are given in which excesses of all available nutrients are applied. Information is given for each schedule relating to the efficiency of nutrient recovery. The calculated efficiencies confirm the earlier discussion; earlier applications have a smaller effect on use efficiencies than does the application criterion. For example, for injected corn, a November application meeting any one nutrient need (K), recovers 76% of the potential value of the applied nutrients. An April application recovers 89%. An April application meeting 2 needs (K and P) leads to a nutrient value recovery of only 64%. An April application meeting 3 needs (N, P and K) leads to a nutrient value recovery of only 55%. Differences also exist between crops, and between liquid manure and effluent. These, however, are generally small compared to the effect of the application rate criterion.

3. Optimization of Manure Disposal Facilities

3.1 Conclusions and Implications of Analysis in Section 2

Although the cost estimates reported in the previous section are based on many assumptions, a number of conclusions of a more general nature can be drawn.

(1) FLOORING AND IN HOUSE PITS: Any operation which hauls liquid manure will require some minimum level of storage for convenience, but additional storage would not be worthwhile. The preferred pit depth is 3 ft. Totally slatted floors would not be used to gain storage, but are preferred because lower labor cleaning costs more than offsets its costs of providing totally slatted floors. For an operation using a lagoon, the preferred flooring type is also totally slatted floor with periodic flushing to the lagoon. Concrete floors have lower annual overhead costs but significantly higher labor cleaning costs. The shallow pits under a total slatted floor will also be preferred on health grounds. These conclusions hold for all regions.

(2) SOIL INJECTOR: Small operations will prefer not to use an injector, large ones will. Although dependent on nutrient usage, as a guide, an FPF

Table 59: Example Manure Application Schedules for Major Crops for the Coastal Plains.

Item	Crop, Application Information, and Manure Value																						
	1			2			3			4			5			6			7				
(1) Crop/manure form[a]	CORN/LE3			CORN/LE3			CORN/LE3			CORN/LE3			CORN/LE3			CORN/LE3			CORN/LE3				
(2) Application criterion[b]	1			1			1			2			2			3			3				
(3) Month and proportion of available N applied of each application for each need period[c] 1.	NOV (1)			MAR(1)			FEB(0.5),MAY(0.5)			NOV(1)			MAR(1)			NOV(1)			MAR(1)				
2.																							
3.																							
4.																							
(4) Manure nutrients applied[d] (lbs) 1.	76.6	4.0	66.4	76.6	4.0	66.4	42.2	22.1	36.6	334	17.5	289	283	14.8	245	430	22.5	372	334	17.5	289		
2.							34.4	18.0	29.8														
3.																							
4.																							
(5) Total applied nutrients (lbs)	76.6	4.0	66.4	76.6	4.0	66.4	76.6	4.0	66.4	334	17.5	289	283	14.8	245	430	22.5	372	334	17.5	289		
(6) Value of applied nutrients ($)	11.5	1.6	7.3	11.5	1.6	7.3	11.5	1.6	7.3	50.0	7.0	31.8	42.4	5.9	27.0	64.4	9.0	41.0	50.0	7.0	31.8		
(7) Total value applied ($)	20.4			20.4			20.4			88.8			75.3			114.4			88.8				
(8) Crop nutrient needs (lbs)	160	18	66	160	18	66	160	18	66	160	18	66	160	18	66	160	18	66	160	18	66		
(9) Value of required nutrients ($)	24	7	7.3	24	7	7.3	24	7	7.3	24	7	7.3	24	7	7.3	24	7	7.3	24	7	7.3		
(10) Total value required ($)	38.3			38.3			38.3			38.3			38.3			38.3			38.3				
(11) Commercial nutrients applied (lbs)	131.5	13.5	0	116.7	13.5	0	116.9	13.5	0	35.8	0	0	0	2.67	0	0	0	0	0	0	0		
(12) Value of commercial nutrients ($)	19.7	5.4	0	17.5	5.4	0	17.5	5.4	0	5.4	0	0	0	1.07	0	0	0	0	0	0	0		
(13) Total commercial nutrients value ($)	25.1			22.9			22.9			5.4			1.07			0			0				
(14) Value of used manure nutrients ($)	4.3	1.6	7.3	6.5	1.6	7.3	6.5	1.6	7.3	18.6	7	7.3	22.9	7	7.3	24	7	7.3	24	7	7.3		
(15) Total used manure value ($)	13.5			15.5			15.4			33.9			37.2			38.3			38.3				
(16) % recovery of applied manure value	37	100	100	56	100	100	51	100	100	37	100	22	54	100	27	37	78	18	48	100	23		
(17) % recovery of total applied manure value	66			76			75			38			49			33			43				

[a]Crop: CWS = Corn-wheat-soybeans rotation; CBG = Coastal Bermudagrass. Manure form: LE3 = lagoon 3 effluent; INJ = injected liquid manure.

[b]Code: 0 = meet no needs; 1 = meet 1 need; 2 = meet 2 needs; 3 = meet 3 needs. Criterion is given for each need period.

[c]Crops considered had no more than 4 separate need periods, and no more than 2 applications for each need period.

[d]Where 3 quantities are given, the first is for N, the second for P, and the last for K. For 2 applications, the second is below the first. The inorganic nitrogen leaching rate is 10%/month. P and K are considered 100% available for irrigation and injection with no losses through the next need period.

Table 59 (Cont.)

	8	9	10	11	12	13	14
(1)	CWS/LE3	CWS/LE3	CWS/LE3	CBG/LE3	CBG/LE3	CORN/INJ CBG/LE3	CORN/INJ
(2)	1 1 1	2 2 2	3 3 3	1 1 1 1	2 2 2 2	3 3 3 3	1
(3) 1.	FEB (1)	FEB (1)	FEB (1)	OCT(0.5) APR(0.5)	OCT(0.5), APR(0.5)	OCT(0.5), APR(0.5)	NOV (1)
2.	OCT(0.5) MAR(0.5)	OCT(0.5), MAR(0.5)	OCT(0.5), MAR(0.5)	JUN(1)	JUN (1)	JUN (1)	
3.	JUL 1	JUL (1)	JUL (1)	JUL (1)	JUL (1)	JUL (1)	
4.				AUG (1)	AUG (1)	AUG (1)	
(4) 1.	38.3 2.0 33.2	157 8.2 136	167 8.8 145	18.8 0.98 16.3	81.2 4.26 70.5	89.6 4.70 77.8	53.8 17.5 24.2
				10.1 0.53 8.7	43.6 2.29 37.8	48.1 2.52 41.7	
2.	9.5 0.5 8.3	39.9 2.1 34.6	41.2 2.2 35.7	28.8 1.51 25.0	96.9 5.08 84.1	112 5.87 97.2	
	9.7 0.5 8.4	40.4 2.1 35.0	41.2 2.2 36.2				
3.	0 0 0	0 0 0	187 9.8 162	28.8 1.51 25.0	96.1 5.04 83.4	125 6.55 108	
4.				28.8 1.51 25.0	95.9 5.03 83.3	125 6.55 108	
(5)	57.5 3.0 49.9	237 12.4 206	436 22.9 378	115.3 6.04 100.1	414 21.7 359	499 26.2 433	53.8 17.5 24.2
(6)	8.6 1.2 5.5	35.6 5.0 22.6	65.5 9.2 41.6	17.3 2.4 11.0	62.1 8.7 39.5	74.9 10.5 47.7	8.1 7.0 2.67
(7)	15.3	63.2	116.2	30.7	110.3	133.1	17.8
(8)	130 22.9 87.2	130 22.9 87.2	130 22.9 87.2	240 26.2 99.6	240 26.2 99.6	240 26.2 99.6	160 17.5 66.4
(9)	19.5 9.16 9.59	19.5 9.2 9.6	19.5 9.2 9.6	36 10.5 11.0	36 10.5 11	36 10.5 11	24 7.0 7.3
(10)	38.2	38.2	38.2	57.5	57.5	57.5	38.3
(11)*	98.5 19.9 37.4	0 10.4 0	0 0 0	173.6 20.2 0	5.61 4.5 0	0 0 0	134 0 42.2
(12)	14.8 8.0 6.1	0 4.2 0	0 0 0	26.0 8.06 0	0.84 1.8 0	0 0 0	20.2 0 4.64
(13)	26.8	4.2	0	34.1	2.64	0	24.8
(14)	4.7 1.2 5.5	19.5 5.0 9.6	19.5 9.2 9.6	10.0 2.4 11.0	35.2 8.7 11.0	36 10.5 11	3.8 7.0 2.7
(15)	11.4	34.1	38.3	23.4	54.9	57.5	13.5
(16)	55 100 100	55 100 42	30 100 23	58 100 100	57 100 28	48 100 23	47 100 100
(17)	75	54	33	76	50	43	76

*(11) APR(CORN)

60.5 6.7 0	0	0.52	0	0	0	0	APR	47.4	5.0	0	5.61	0	0
JUL(Soyb.)													
0 9.8 37.4	0	9.8	0	0	0	0	JUN	42.2	5.0	0	0	1.47	0
OCT(Wheat)													
38.0 3.3 0	0	0.13	0	0	0	0	JUL	42.0	5.0	0	0	1.51	0
							AUG	42.0	5.0	0	0	1.52	0

Table 59 (Cont.)

	15			16			17		
(1)	CORN/INJ			CORN/INJ			CORN/INJ		
(2)	1			2			3		
(3) 1.	APR(1)			APR(1)			APR(1)		
2.									
3.									
4.									
(4) 1.	53.8	17.5	24.2	148	48.0	66.4	211	68.7	95.1
2.									
3.									
4.									
(5)	53.8	17.5	24.2	148	48.0	66.4	211	68.7	95.1
(6)	8.1	7.0	2.67	22.1	19.2	7.3	31.7	27.5	10.5
(7)		17.8			48.6			69.6	
(8)	160	17.5	66.4	160	17.5	66.4	160	17.5	66.4
(9)	24	7.0	7.3	24	7.0	7.3	24	7.0	7.3
(10)		38.3			38.3			38.3	
(11)	119	0	42.2	48.3	0	0	0	0	0
(12)	17.9	0	4.64	7.24	0	0	0	0	0
(13)		22.5			7.24			0	
(14)	6.1	7.0	2.7	16.8	7.0	7.3	24	7.0	7.3
(15)		15.8			31.1			38.3	
(16)	75	100	100	76	36	100	76	25	70
(17)		89			64			55	

operation larger than 30,000 lbs LW should use an injector. For FPP and FTF operations, the break-even sizes are about 60,000 lbs LW and 40,000 lbs LW respectively.

(3) TANK WAGONS: The optimal size of tank wagons increases as the operation size increases, changing from 800 gallons to 1500, to 3200 gallon wagons. The changeover points depend critically on the wash water dilution that occurs in the house. For no dilution, the two changeover points are approximately 65,000 lbs LW and 300,000 lbs LW for FPF, FPP, and FTF operations. For a dilution factor of 6, the changeover points are reduced to 15,000 and 90,000 lbs LW. In choosing an optimal wagon size, then, estimates of the average dilution are needed. These conclusions hold for all regions.

(4) LAGOONS: Mechanically aerated and naturally facultative lagoons are not economically attractive. Although the highest loaded anaerobic lagoon has the lowest cost, when considering the irrigation scheme size needed to apply the effluent, the medium loaded lagoon (100 ft^3/100 lbs LW) in an FPF operation is the most attractive, at least for the Coastal Plain when a fixed criterion (meet corn's N needs) for manure application is assumed. Other regions may prefer a lighter loaded lagoon because crop diversion costs are higher and storage is more attractive, and because lagoon construction costs tend to be cheaper, particularly in the mountains. The medium loaded anaerobic lagoon probably is optimal in the Piedmont while in the mountains the lightly loaded anaerobic is preferred. Both lagoons, however, would be reasonable for each region. Under an assumption of no fixed criterion for determining application rates, lighter loaded lagoons would be further favored if they permit the use of a portable irrigation system. Dilution would have no effect on these conclusions.

(5) IRRIGATION SYSTEM: Using a fixed criterion for determining effluent application rates (meet corn's N needs), estimates were made of the required irrigation sizes for different lagoons. For the medium loaded anaerobic lagoon, any FPF operation larger than about 140,000 lbs LW would use a travelling big gun system since the required irrigated area would exceed 35 acres. For the FPP operation, any larger than 280,000 lbs LW would use the traveller; any FTF operation larger than 180,000 lbs LW would use the traveller. All smaller hog operations would choose a portable hand-move system. If the lightly loaded anaerobic lagoon were used, the changeover sizes would increase to about 350,000 lbs LW, 690,000 lbs LW, and 440,000 lbs LW respectively. Thus almost all operations would use a portable system. These conclusions apply only when the fixed rate determining criterion is used. When there is freedom to alter the rates and crops to match the system, many of the operations that would use a big gun irrigation system on the preceding basis would prefer to install a 35 acre portable system (and perhaps a more highly loaded lagoon) and apply manure in excess amounts, and perhaps to a more nutrient demanding crop. On economic grounds, manure could be applied to the 35 acres of corn at rates providing 3 times

the available N needs of corn before it would pay to shift to the travelling big gun system. All the liveweights mentioned above could therefore be increased by a factor of 3. Even if environmental considerations restrict the rates to those providing only 2 times the available N needs of corn, it is obvious that almost all hog operations would use a portable system. For a lagoon-irrigation system, it follows that a lagoon and feasible application rates should be chosen subject to the constraint that a portable conventional sprinkler system no larger than 35 acres be used.

(6) IRRIGATION LABOR COSTS: While labor costs are an important reason to prefer a travelling big gun system to a portable conventional sprinkler line system in normal irrigation situations, for manure management they play a lesser role, since (at least for the economically preferred lagoons) the number of applications made to each acre are so few, and the total labor involved so small.

(7) PUMPING RATE: Because the effluent volumes produced by lagooning are very small, the pumping rate capacity of irrigation equipment does not need to be large. Rates of 100 and 200 gpm are ample.

(8) MANURE VALUE: Although manure contains significant quantities of N, P and K, and thus has a high potential for fertilizer value, this potential cannot be realized in practice. Application losses, and unavailability of organic N are unavoidable. Leaching losses are incurred if manure is applied early, and nutrients are wasted because in meeting N needs, for example, excess amounts of P and K are often applied. Because of these losses, recovered manure value will often be only 40-50% of the value of applied nutrients. If lagoon pretreatment is used, only 10-15% of the original potential value may be recovered. To recover a higher percent, other costs such as storage, or land diversion are incurred, and these will exceed the value of the added manure recovered.

(9) MANURE APPLICATION RATES: Transportation costs for tank wagons are fairly small, and it will generally pay to incur the small transportation costs in order to avoid wasting nutrients. In fact, the economic application rates will often be those meeting any one or two nutrient needs, even for operations as large as 400,000 lbs LW. The major incentive for excessive applications is not transportation costs, but the need to divert land away from the most profitable crop at certain times of the year. In the Coastal Plains, this diversion cost is relatively small, so the incentive to apply manure at excessive rates should not be high. The other situation where excessive rates may be chosen is where land area is limited.

For an irrigation system, the economic rates of application are generally those meeting 2 or all of the nutrient needs. However, because there is a large increase in costs in going from a portable system to a big gun system, operations needing more than 35 acres (recommended maximum size for portable system) to utilize nutrients may tend to apply excess nutrients to avoid the changeover to a big gun system. Since hog operations of all types up to 200,000 lbs LW prefer a portable system without excess applica-

tions (if they can choose their preferred lagoon) it is only the very large operation or the land-limited operation that may tend to apply lagoon effluent in excess of the crop's needs. Diversion costs will also tend to encourage excess application, but because diversion costs/acre are small, and because lagoon storage permits storage for several months, this incentive will also be small.

(10) OPTIMAL SYSTEM FOR MANURE HANDLING: Using the models outlined in Section 2, cost estimates can be made for all parts of a system for manure handling. Although many such estimates were made in Section 2, the assumptions on which those estimates were based varied from case to case, being chosen to reflect most realistically the conditions that would apply for each case. For example, the majority of the cost calculations for tank wagons were based on an assumption of no dilution because it is for low dilution cases that a tank wagon would be most appropriate. Calculations for the lagoons generally assumed dilution by a factor of 6. Because of these differing assumptions, and because some estimates (notably those concerning manure, crop diversion and storage valuation) were made only approximately the preferred system (liquid manure hauling, or lagooning) for any given hog operation is not precisely determined by the cost estimates reported. In order to facilitate comparisons of alternative systems for numerous hog operations, the various models of Section 2 were incorporated into a computer optimization model. This model is outlined in Section 3.2 and Appendix B while cost analyses and comparisons for several important hog operation categories are reported in Section 3.3.

3.2 The Programming Optimization Model

Optimization is accomplished efficiently through the use of an integer linear programming model. The general formulation of a linear programming model is:

$$\max z = \underline{C}' \underline{X}$$

subject to $A\underline{X} \leq \underline{b}$

$$\underline{X} \geq 0,$$

where $\underline{C}$ is a vector of returns associated with units of activities whose levels are represented by $\underline{X}$, A is a matrix of coefficients, and $\underline{b}$ is a vector of constraint levels. The objective function $\underline{C}' \underline{X}$ is to be maximized by choosing a set of activity levels $\underline{X}$ from the set of feasible levels defined by the constraints $A\underline{X} \leq \underline{b}$, $\underline{X} \geq 0$. This formulation has particular relevance to normative economics.

For the manure management decision, the objective function to be maximized is the annual return to fixed resources, where the latter are defined as those physical resources or components of a manure management system which the hog producer considers fixed. They may include the manure produced by the operation, and may also include land, capital, or existing hog

housing and manure disposal facilities already in use in the operation.

Positive contributions to the returns function are made by gainful cropping activities. Receipts from hog sales are not included since these are assumed fixed and not directly attributable to manure disposal operations. Negative contributions to returns include the costs of cropping, the costs of ownership of manure disposal facilities, and the costs of operating these facilities in disposing of the manure. Manure, itself, makes an implicit positive contribution to returns by reducing cropping costs through reduced expenditures on commercial fertilizer.

The major activities included in the programming model can be classified as follows:

(a) hog production, housing, and in-house storage provision alternatives

(b) transfer and storage activities, transferring liquid manure to lagoons for treatment prior to land application, and storing both liquid manure and lagoon contents from one time period to the next, e.g., month to month,

(c) provision of manure handling facilities, such as tank wagons, lagoons, soil injectors, etc.

(d) provision of additional resources where the producer considers this feasible, e.g., hiring extra labor.

(e) gainful activities such as growing crops with specified liquid manure application schedules, or crops with specified lagoon effluent application schedules, or crops without manure.

(f) logic structure variables, e.g., if a lagoon is loaded at a certain rate, then a 0-1 logic variable is triggered (=1) permitting pumping from that lagoon at the associated lagoon concentration.

The effect of constraints on a hog producer is to force a balance or tradeoff between alternative activities. The essential trade-off in the present model is between the extent of recovery of the potential value of the manure as fertilizer, and the opportunity costs of recovering that value. As has been indicated, actual recovery of manure value will depend on how efficiently that manure is used. However, there is no point pursuing greater recovery if this requires very costly storage facilities, or the use of low profitability crops in place of high profitability ones. The optimal solution to the mathematical programming model will be such that any change in the facilities or their use as a means of increasing recovery of manure value will be associated with a more than offsetting rise in the costs of recovery.

The major constraints imposed on the hog producer can be broadly classified as follows:

(a) resource availabilities for land, labor and capital.

(b) operating constraints for lagoons and in-house pits, restricting, for example, the volumes stored from one time period to the next.

(c) definitional equations defining net revenue, volume passed to a lagoon, etc.

(d) logic structure equations to impose logic of the following type: allow crops using liquid manure only if there is a tank wagon, etc.

A complete list of activity and constraint is provided in Appendix A. Many individual members of the classes are identified in part by arguments which are defined in Table A-1. Tables A-2 and A-3 summarize the purpose of each activity class and constraint class respectively, and indicate the number of individual activities or constraints in each class. In all, there are 33 activity classes, and 59 constraint classes which are defined in Appendix A.

The programming model essentially budgets alternative manure disposal facilities, but for each set of facilities it determines the optimal flow of manure from the point of production to the final application to land, with crops, ratio, times etc. being chosen in an optimal manner. The solution obtained is the set of facilities, and associated uses, which maximizes net returns.

3.3 Sample Analyses

Only a small number of analyses are reported. In selecting cases to consider, the following factors were considered: (1) Analyses were performed only for the Coastal Plain region because about 80% of North Carolina's swine is produced in this region, and because explicit data on the cropping options in the Piedmont and Mountain regions were not obtained in this study. (2) Analyses were performed only for operations producing liquid manure (pit or lagoon) because these are the most common operations and because technical performance and cost data on facilities for solid manure handling were not collected. (3) For dirt lot and pasture operations, there is no question of whether a lagoon is preferable to a hauling wagon since a lagoon is necessarily involved. Further, since the nutrient collection for these operations is very small, its value (and cropping pattern) can be ignored. Costs for these operations are then the lagoon and irrigation costs, and these can readily be assessed approximately using data reported in Section 2. These considerations reduce the manure types (Table 2) to only 3, namely 28, 29, and 30; and the disposal practices opportunity sets to 21. (4) Finally, runs were made only for the FPF operation. Although the results do not carry over directly to the other operations, some conclusions can be drawn. For example, for a given sized operation a tank wagon hauling operation has relatively constant costs for all 3 types of operation, but since the amount of nutrients

(and recovered value, surely) increases from FPP to FTF to FPF, the latter will have the lowest net costs (ignoring flooring, etc.) of the three. For lagoons, calculations reported in Section 2 indicate that the costs will increase from FPP to FTF to FPF. Since nutrient value is relatively less important for lagoons, the net cost ranking will probably be the same. Then, if an FPF analysis shows that a lagoon-irrigation system is preferred to hauling, then a fortiori, the former is preferred for the FPP and FTF operations as well. If a tank wagon is preferred for the FPF operation, no conclusions can be drawn about the others.

There are 24 case studies in total, identified in Table 60. Three rates of manure dilution were considered, namely 1, 2 and 5 gallons of water per gallon of raw manure. Dilution was expected to alter substantially the costs of hauling operations, but to have a minor effect on lagoon-irrigation system costs. For each rate of dilution, 4 sizes of operation, namely 50, 100, 200 and 400 thousand lbs liveweight, were considered. These cover the range of sizes found in practice. By comparing costs for different sizes of operation, some idea can be gained of the comparative advantages of larger operations wrought by economies of size in manure disposal.

For each of these 12 situations, a single run of the integer programming model could provide the optimal means of manure disposal. However, in order to gain information not only on the optimal system (hauling or lagooning), but also on the other major alternatives, separate runs were made for liquid manure hauling and for lagooning, thus creating the 24 case studies in Table 60.

A number of decisions about the optimal facilities for any case study were made prior to the computer runs. These decisions were based on the analysis reported in Section 2. First, all operations were assumed to use totally slatted floors, with a 16" pit for lagooning operations, and a 3' pit for hauling (that is, minimum storage). Second, a 100 ft^3/100 lbs LW lagoon (lagoon 3) was assumed for all sizes of operation except the 200,000 lbs LW operation for which a 300 ft^3/100 lbs LW lagoon was assumed. These choices are least cost choices based on the assumptions implicit in Table 45. For the 200,000 lbs LW operation, a cheaper system may be to use a lagoon of type 3, and to apply the manure at times and rates such that a portable irrigation system is compatible with this type of lagoon. Similarly, for the 400,000 lbs LW operation, the use of higher application rates, and more nutrient demanding crops than corn may enable a portable system to be used in place of the costly big gun travelling system. The feasible cropping options used were those presented in Table 61, with detailed examples of schedules given in Table 59. Land requirements for these schedules were such that the large areas required resulted in preventing a portable irrigation system for the 400,000 lbs LW operation. Costs presented for the 200,000 and 400,000 lbs LW operation thus probably exceed the minimum costs that could be achieved. Third, all hauling operations were assumed to use an

Table 60: Case Study Specifications

Specification	Case study identification no.																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PRODUCTION UNIT																								
Location: Coastal Plain	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Piedmont																								
Mountains																								
Type: Feeder pig production (FPP)																								
Farrow to finish (FTF)																								
Feeder pig finishing (FPF)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Water dilution:																								
1 gal. water/gal. raw waste	x			x			x			x			x			x			x			x		
2 gal. water/gal. raw waste		x			x			x			x			x			x			x			x	
5 gal. water/gal. raw waste			x			x			x			x			x			x			x			x
10 gal. water/gal. raw waste																								
Floor type: Solid concrete																								
Partial slats																								
Total slats	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Size of operation:																								
50,000 lbs inventory	x	x	x	x	x	x																		
100,000 lbs. inventory							x	x	x	x	x	x												
200,000 lbs. inventory													x	x	x	x	x	x						
400,000 lbs. inventory																			x	x	x	x	x	x
STORAGE AND PROCESSING OPTIONS																								
In-house pit depth: 16 in.				x	x	x				x	x	x				x	x	x				x	x	x
36 in.	x	x	x				x	x	x				x	x	x				x	x	x			
60 in.																								
External pumping pit:	x	x	x				x	x	x				x	x	x				x	x	x			
Lagoon: aerated																						x	x	x
50 ft^3 lagoon/100 lbs inventory				x	x	x				x	x	x				x	x	x						
100 ft^3 lagoon/100 lbs inventory																								
300 ft^3 lagoon/100 lbs inventory																								

Table 60 (Cont.)

Specification	Case study identification no.																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
TRANSPORT AND APPLICATION OPTIONS																								
Tank wagon: 800 gallons	x																							
1100 gallons		x	x				x	x					x	x					x	x	x			
1500 gallons									x						x									
2100 gallons																								
3200 gallons																								
Application: surface spreading	x	x	x				x	x	x				x	x	x				x	x	x			
injection																								
plow down																								
Irrigation system:																								
big gun traveller (200 gpm)																						x	x	x
conventional portable sprinkler (100 gpm)				x	x	x				x	x	x				x	x	x						
big gun traveller (100 gpm)																								
AGRONOMIC OPTIONS																								
Crops considered: Corn	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
(See Table 59 for details of examples of schedules considered and Table 61 for summary of types and numbers of schedules considered) Sorghum																								
Wheat																								
Soybean																								
Corn-wheat-soybean	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Corn-soybean																								
Coastal bermuda grass hay	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 61: Summary of Types and Numbers of Cropping Schedules Considered for Case Studies (Tables 59).

Crop	Lagoon 3[a] Number of nutrients[c] 1	2	3	Injection[b] Number of nutrients[c] 1	2	3	Total
Corn	8	8	8	7	7	7	45
CWS[d]	3	3	3	3	3	3	18
CBG[e]	8	12	12	8	12	12	64
Total	19	23	23	18	22	22	127

[a]Lagoon 3 is anaerobic lagoon loaded at 100 cu ft/100 lbs LW.

[b]Injection to Coastal Bermudagrass is not a common practice but was included as being feasible.

[c]The number of nutrients whose needs were met with manure nutrients.

[d]Corn-wheat-soybeans rotation. There were 3 application periods with 0 to 2 applications/period.

[e]Coastal Bermudagrass - there were 4 application periods with 0 to 2 application/period.

injector; and finally, set tank wagon sizes were specified for each case study, varying with dilution and operation size (Section 3.1, conclusion 3). The 3,200 gallon wagon was not considered a feasible option.

A summary of the resources utilized, and the net annual costs of manure disposal is presented in Table 62. For smaller operations (up to 100,000 lbs LW), less investment is required for irrigation-lagooning systems than for tank wagon hauling facilities; but for larger operations this is reversed. Investment for hauling facilities increases with size, but less than proportionally, indicating potential economies of size for hauling operations. For lagoon-irrigation systems, the increase in investment with size is more nearly proportional, reflecting lagoon volume increases, and changes to relatively more expensive irrigation equipment. With respect to labor, there is a significant difference between hauling operations and lagooning; and for hauling, between dilutions. Annual labor costs for hauling range from about $700 for 2 gallons dilution in a 50,000 lbs LW operation to about $10,000 for 5 gallons dilution in a 400,000 lbs LW operation.

Table 62. Summary of Manure Disposal Costs and Resource Requirements.

Item	Case study identification no.[a]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Investment[b] ($)	10,484	12,059	12,059	5,798	5,758	5,746	14,532	14,532	17,757	8,133	8,057	7,921	16,742	16,742	19,967	23,338
Labor (hr)	263.1	232.9	463.0	18.6	18.5	26.1	326.4	483.7	744.2	32.2	32.1	46	683.2	1,016.7	1,554	46.6
Land (acres)	94.2	88.9	82.2	10.9	10.2	10.0	188.4	177.8	164.1	21.8	20.4	18.0	376.8	355.5	328.1	20.8
Total annual cost[bc] ($)																
Net value of crops ($)																
Net total annual cost ($)	2,429	2,638	4,576	606	646	757	2,130	3,550	6,612	607	683	897	2,383	5,341	10,801	2,645
Net annual cost/ 100 lbs inventory ($)	4.86	5.28	9.15	1.21	1.29	1.51	2.13	3.55	6.612	.61	.68	.90	1.19	2.67	5.40	1.32
Net annual cost/hog marketed[d] ($)	1.98	2.16	3.73	.49	.52	.62	.87	1.45	2.70	.25	.26	.37	0.49	1.09	2.20	0.54
Net annual cost/100 lbs LW marketed[e] ($)	0.90	0.98	1.70	.22	.24	.28	.39	.66	1.23	.11	.13	.17	0.22	0.50	1.00	0.25

[a] See Table 59 for specifications.

[b] Floor and pit costs are assessed relative to a floor and pit investment of $23.90/100 lbs LW in a totally slatted FPF operation, and $3.60/100 lbs LW annual cost. This is the cheapest when cleaning costs are considered. Investment does not include land.

[c] Labor cleaning costs are assessed relative to the cleaning cost of $0.10/100 lbs LW/year in the minimum cost situation, namely the totally slatted floor.

[d] Based on 2.45 hogs marketed for each 100 lbs LW average inventory.

[e] Based on 220 lbs LW at marketing, i.e. 100 lbs LW = 539 lbs marketed.

Table 62. (Cont.)

17	18	19	20	21	22	23	24
23,338	23,317	24,389	24,389	24,389	33,511	32,860	31,853
45.3	79.5	1,125	1,665	3,285	32.1	32.5	45.7
20.2	19.5	753.6	711.0	655.9	84.3	78.7	69.9
2,699	2,983	1,451	6,341	20,087	2,267	2,540	3,388
1.35	1.49	.36	1.59	5.02	.57	.64	.85
0.55	.60	.15	0.65	2.05	.23	.26	.35
0.25	.28	.07	.29	.93	.11	.12	.16

For lagooning, labor costs vary from about $55 to $240. For land requirements, the major factor is whether hauling or lagooning is used, the latter requiring only 1/10 as much land as the former. Land areas are approximately proportional to operation size (except where the lagoon type changes) and as a guide are about 0.2 acre/100 lbs LW if lagoon type 3 is used, 0.1 acre/100 lbs LW if lagoon type 4 is used, and 2 acres/100 lbs LW if hauling is used. Where land areas available for manure applications is limited, lagooning will be necessary unless excessive rates of liquid manure application are permitted.

Even when land area is not limited, lagooning will usually be the preferred means of manure disposal. Estimates of net annual costs attributable to manure disposal are given in Table 62. For the 50,000 and 100,000 lbs LW operations, hauling is more costly than lagooning, no matter what dilution is used. The investment overheads of a tank wagon, injector and pumping pit, and the labor and tractor operating costs of applying the manure are high, even when partially offset by good nutrient recovery. For larger operations, lagooning remains optimal for the 2 and 5 gallons water/gallon of raw manure dilution cases, but not for the lowest dilution case. In the latter case, use of a large wagon helps to keep operating times and costs low, while the cost of the wagon and other equipment is spread over a large number of animals. Lagoon-irrigation costs are high because of the need to use either a more lightly loaded, more costly lagoon, or a big gun irrigation system. At greater dilution rates, the lagooning approach is preferred because of the rapidly rising hauling costs.

Net annual costs per 100 lbs marketed are depicted in Figure 15. The economies of size with tank wagons are very obvious for operations marketing up to 1,500,000 lbs (=280,000 lbs LW). Beyond this, operating costs begin to dominate, and would eventually lead to diseconomies. The lagooning operation also shows some economies of size with a discontinuity diseconomy when the operation must switch to a lightly loaded lagoon, or big-gun traveller irrigation system. The economies of size are not, however, nearly as substantial as with hauling.

3.4 Conclusions

The cost estimates suggest that almost all operations will choose to use a lagoon in preference to hauling manure with tank wagons. The only operation that would prefer to haul are those 200,000 lbs LW or larger with very little dilution of the raw manure. The cost advantage of tank wagons for these operations, however, is very small, 4 cents/100 lbs LW marketed. Since lagooning has other advantages of flexibility and less frequent labor needs, this cost disadvantage may often be considered insignificant. Moreover, for these operations, the calculated costs are, as already noted, perhaps not the least costs.

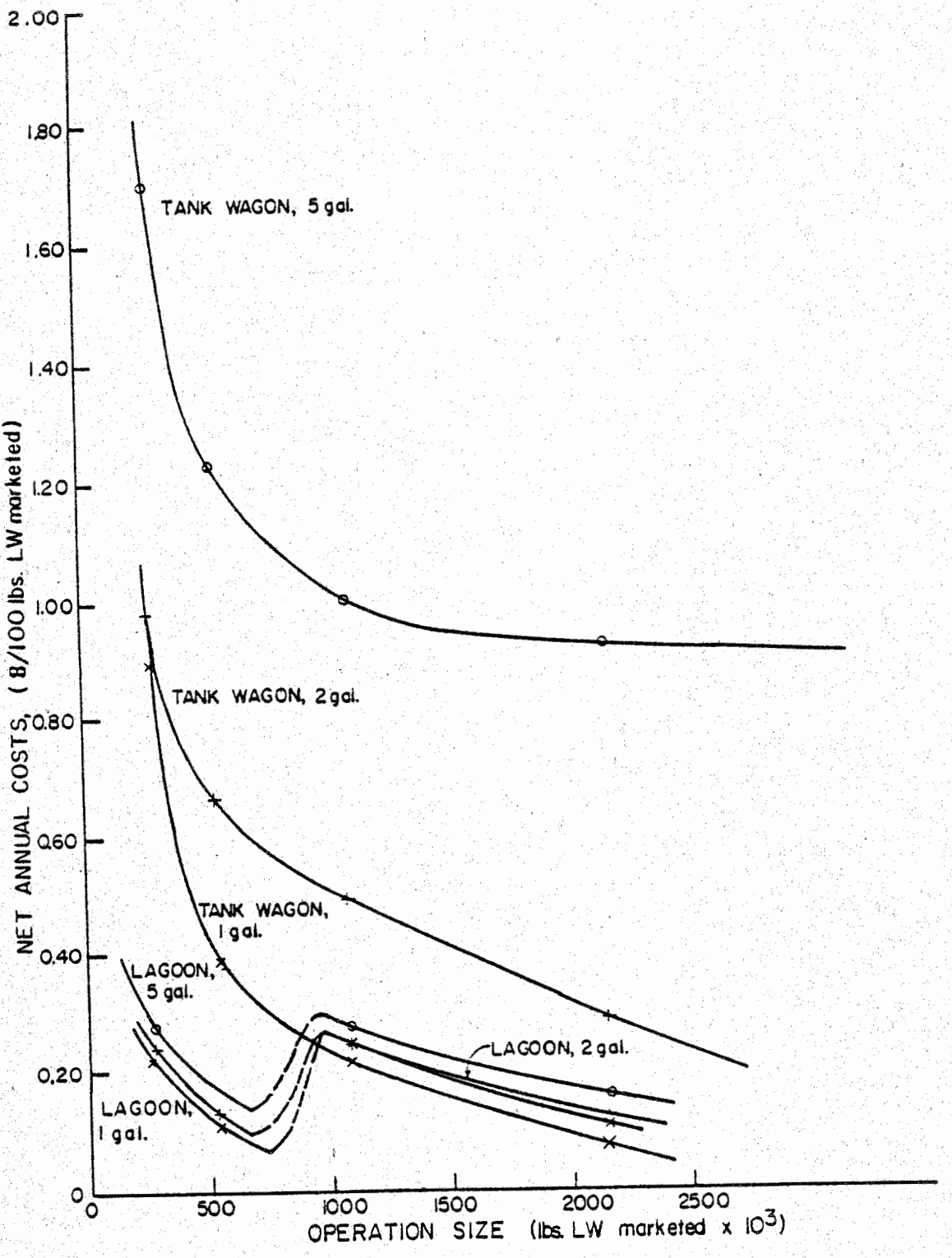


Figure 15. Net annual costs of alternative means of manure disposal for feeder pig finishing (FPF) operations in the Coastal Plain by dilution.

Because the lagooning approach is superior for FPF operations, it follows from previously stated arguments that it will also be preferred for FPP and FTF operations. Hence, as a general recommendation, all totally roofed hog operations in North Carolina should, if given the choice of flooring type and manure disposal facilities, choose a totally slatted floor and a lagoon-irrigation system, the latter most commonly being a portable conventional sprinkler line system. The costs of manure disposal using this optimal arrangement are only 7 to 28 cents per 100 lbs liveweight marketed, a relatively minor cost in terms of the total costs of producing 100 lbs liveweight of hog for market.

The small cost of optimal manure disposal belies the importance of the manure disposal decision problem. For the latter, the opportunity costs of making the wrong decision are the appropriate measures. Thus, for the operation marketing about 2,200,000 lbs LW, and diluting raw manure by a factor of 6, the cost of using a tank wagon system instead of an irrigation system is about 77 cents per 100 lbs LW marketed. Even within a given type of system, the opportunity costs of using that system inappropriately may be quite high. For example, for a 50,000 lbs LW operation using a tank wagon system, the bulk of the costs of manure disposal are incurred whether the manure is applied optimally, or at higher rates to a smaller area. If all the nutrient value (approximately $1,800) is foregone, net costs rise almost by this amount, increasing net costs by 60-70%, and adding 70-80 cents per 100 lbs LW marketed to the costs of manure disposal. Opportunity costs of this order cannot easily be ignored by the hog producer or his extension advisor. Also, the results show that manure management can be conducted in an environmentally acceptable way (no excessive nutrient applications) for relatively minor costs of manure management if the optimal manure management system is chosen.

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APPENDIX A

ACTIVITIES AND CONSTRAINTS

FOR THE

LINEAR PROGRAMMING MODEL

This appendix defines the activities and constraints which were formulated for the linear programming model summarized in Section 3.2. Several individual members of the classes are identified in part by the arguments which are defined in Table A-1. The purpose of each activity class and constraint class, as well as the number of individual activities or constraints in each class, are presented in Tables A-2 and A-3. In all, there are 33 activity classes and 59 constraint classes which are defined more fully below. In the constraint classes, any coefficient other than ± 1 is identified by A_{ij}, where i is the constraint class number, and j is the activity class name. This single identification is used for all elements in the particular constraint class - activity class intersection, even though all the coefficients in this intersection would not normally be the same. Summations in constraints are over all relevant indexing arguments except those used in defining the particular constraint. Infeasible combinations of index values are to be implicitly excluded. Finally, the character "2" is used in the constraint classes to denote a large positive number.

Table A-1: Arguments Used in Identifying Activity and Constraint Class Members.

Description/Item	Identifying argument	Maximum value of argument
Building	I	NHSE
Pit depth in building I	J(I)	NPIT(I)
Hauling wagon	K	NWAG
Time period	L	NPER
Lagoon	M	NLGN
Lagoon concentration	N	NLPS
Crop	O	NCRP
Manure application schedule for crop O	P(O)	NPAT(O)
Land class	Q	a. NDIST for tank wagons b. NIRD for irrigation
Month	R	12
New irrigation scheme	S	NIGR
Pumping pit volume ordinate	T	4
Pumping pit volume range	U	3

Table A-2: Activity Class Identifications[a].

Activity Class No.	Identification	Number of separate activities
1	Crops using liquid manure application without injection	NWAG·NDIST·NPT·NCC
2	Crops using liquid manure application with injection	NWAG·NDIST·NPT·NCI
3	Null class	
4	Null class	
5	Crops grown without any manure application	NOW
6	Area of each pit in each building	NPT
7	Storage in each building for each time period	NBWP·NPER
8	Transfer from each pit (and no pit) to each lagoon each period	NPER·NLGN·(NPT+NHSE)
9	Storage at each concentration, each lagoon, each time period	NPER·NLGN·NLPS
10	Lagoon specifics: supply of new lagoon, size of lagoon; excess volume over minimum, volume of liquid passed to the lagoon, amount of N passed to the lagoon	NLGN·5
11	Crops grown under irrigation of effluent	NLPS·NIRD·NIP
12	Irrigation systems, and new mains	NIGR+min(1,NIGR)
13	Use of existing mains; fraction used	IESI·2
14	Borrow capital	IBRC
15	Rent land	IRNL
16	Hire labor in each time period	NPER·IHRL
17	Cost function points for pumping pit; supply of the pit	IPPP·5
18	Objective function levels: net returns to fixed resources; investment capital in waste facilities; labor spent on waste disposal; land used in waste application	4
19	Rights to pump from each building	NHSE·min(1,NWAG)
20	Use of each pit in each building	NPT

Table A-2: (Continued)

Activity Class No.	Identification	Number of separate activities
21	Purchase of each tank wagon	NWAG
22	Purchase of an injector	min(NCI,1)
23	Rights to use each lagoon	NLGN
24	Use existing lagoon as each type of lagoon	IESL·NLGN
25	Rights to pump each lagoon, each time period	NLGN·NPER
26	Rights to pump each lagoon at each concentration	NLGN·NLPS
27	Rights for a new irrigation system	min(NIGR,1)
28	Rights to use an existing irrigation system	IESI
29	Use a pumping pit in each of 3 size ranges	IPPP·3
30	Liveweight carried on average in the operation	1
31	Constraint type identification; and RHS	2
32	Volume of overflow from each lagoon in each period	NPER·NLGN·IOVL
33	Volume of overflow from each house in each period	NPER·NHSE·IPOVF

[a]The following definitions used have not already been defined:

NPT = total number of possible pits, totalled over all houses
NCC = number of liquid manure cropping activities, without injection, totalled over all crops and schedules
NCI = number of liqiud manure with injection cropping activities
NOW = number of no-waste crops considered
NBWP = number of buildings which have a pit
NIP = number of irrigation with effluent cropping activities, totalled over crops and schedules
IBRC, IRNL, IESL, IESI, IOVL, IPOVF, IHRL, IPPP: 0-1 indicators; 1 when capital can be borrowed, land rented, a lagoon already exists, an irrigation scheme exists, lagoon overflow is permitted, pit overflows are permitted, labor is hired, and an external pumping pit is installed, respectively.

Table A-3: Constraint Class Identifications.

Constraint Class No.	Identification	Number of separate constraints
1	Sets hog operation to specified size	1
2	The area of pit in a house = area required by the type of flooring used	NBWP
3	Manure volume accounting each period, each house	NPER•NHSE
4	Manure volume stored cannot exceed house capacity	NPER•NBWP
5	Null class	
6	Null class	
7	Annual total N passed to each lagoon	NLGN
8	Lagoon size met from new and old lagoon	NLGN
9	Lagoon liquid stored cannot exceed lagoon capacity	NPER•NLGN
10	Minimum lagoon volume transferred from period to next	NPER•NLGN
11	Even lagoon N loading rate over all periods	NPER•NLGN
12	Lagoon size must have fixed relation to added N	NLGN
13	Demand for irrigated land in each month cannot exceed the supply of irrigated land	NIP•12
14	Length of existing mains used cannot exceed availability	IESI
15	Labor demand in each period cannot exceed supply	NPER
16	Pumping pit volume is a convex combination of given sizes	IPPP
17	Land demand cannot exceed supply	12
18	Investment must be less than initial investment and borrowing	1
19	Annual total volume passed to each lagoon	NLGN
20	Investment in manure disposal facilities definition	1

Table A-3: (Continued)

Constraint Class No.	Identification	Number of separate constraints
21	Labor spent on manure disposal definition	1
22	Net return from the manure disposal operation	1
23	Injection acts require the use of an injector	min(NCI,1)
24	Lagoon can only be installed if "permission" given	NLGN
25	Irrigated crops forbidden without "permission"	NPER•NLGN
26	Tank wagon activities forbidden without tank wagon	NWAG
27	Can only stare and pump in a lagoon with "permission"	NLGN•NLPS
28	If tank wagon and irrigation are both used, then mains are needed to bring manure to irrigation area	min(NIGR•IESI,1)
29	Can only pump when lagoon is nearly full	NPER•NLGN
30	Can only pump at given concentration if in that concentration range (L)	NLGN•NLPS
31	Can only pump at given concentration if in that concentration range (U)	NLGN•NLPS
32	Lagoon volume accounting, each period each lagoon	NPER•NLGN
33	Fraction of existing scheme used must be 0 without permission	IESI
34	If new irrigation scheme, must be a convex combination of the sizes specified	min(NIGR, 1)
35	If pumping from a building, pumping pit volume must exceed building pit volume	min(NHSE•(NWAG,1))
36	Lagoon volume = minimum volume + extra volume	NLGN
37	Pumping from a building forbidden without permission	min(NHSE(NWAG,1))
38	Area of a given pit type is zero unless that pit type is used	NPT

Table A-3: (Continued)

Constraint Class No.	Identification	Number of separate constraints
39	Pumping pit volume defined by two end points, weights sum to 1	IPPP
40	Smallest pit volume point weighted 0 unless volume in bottom segment	IPPP
41	Weights on 2nd and 3rd points are 0 unless relevant segments used	IPPP•2
42	Largest pit volume point weighted 0 unless volume in upper segment	IPPP
43	Application of liquid manure from a pit occurs only if pit exists	NPT
44	New and existing irrigation systems are mutually exclusive	min(IESI(NIGR,1))
45	Irrigation system requires a lagoon	min(IESI(NIGR,1))
46	A lagoon requires an irrigation system	min(NLGN,1)
47	There can be only one tank wagon	min(NWAG,1)
48	A lagoon can be operated at only one concentration	NLGN
49	An injector needs a tank wagon	min(NCI,1)
50	Lagoon pumping needs a lagoon to pump from each period	NLGN
51	Lagoon pumping at any concentration needs a lagoon	NLGN
52	There can be only one depth of pit, if there is a pit	NBWP
53	Pumping pit volume can fall into only one volume segment	IPPP
54	Liquid manure from a pit can be pumped only if that pit exists	NPT•min(NLGN,1)
55	Pitless transfer can occur only if a pit is not used	NBWP•min(NLGN,1)
56	Use of tank wagon applied land in a given class cannot exceed supply	NDIST•min(NCI+NCC,1)
57	Use of land for irrigation in a given class cannot exceed its supply	NIRD•min(NIP,1)

Table A-3: (Continued)

Constraint Class No.	Identification	Number of separate constraints
58	Borrowed capital cannot exceed specified limit	IBRC
59	Limitations on area under particular patterns	NUMCON

Activity Classes

(1) O(I,J(I),K,O,P(O),Q): grow crop O using application pattern P(O) on land class Q by applying liquid manure from pit J(I) in building I using tank wagon K without an injector (acres).

(2) W(I,J(I),K,O,P(O),Q): as for (1) but this time with an injector, (acres). Individual patterns may differ from those in (1).

(3) and (4) Null classes.

(5) CNOWAS (O): grow crop O without manure application (acres).

(6) PITARE (I,J(I)): area of pit of depth J(I) used in building I (sq. ft.),

(7) PSTO (I, L): Volume of liquid manure stored in building I from time period L to L+1 (cu.ft.).

(8) TRL(I,J (I)*,L, M): Volume of liquid manure passed from building I using pit J (I)* in time period L to lagoon M. The index J(I)* is identical to J(I) with the addition of an extra "null depth" or "no pit" transfer from building I (cu.ft.).

(9) LSTO (L, M, N): volume of liquid stored in lagoon M during time period L at a concentration N (cu.ft.).

(10) LNWS (M): volume of new construction for lagoon type M (cu.ft.).

LSIZ (M): volume of lagoon type M (cu.ft.).

LEXV (M): volume that lagoon type M exceeds the minimum volume for that type by (cu.ft.).

LVOW (M): total annual volume of liquid entering lagoon type M (cu.ft.).

LTON (M): total annual weight of nitrogen entering lagoon type M (lbs.).

(11) CI (M, N, O, P (O), Q): grow crop O using irrigation application pattern P(O) land class Q by applying effluent from lagoon M at a concentration N (acres).

(12) IRSY (S): proportion of irrigation scheme S that is implemented.

IMNS: length of new mains conveying effluent to the irrigation scheme area (yds.).

(13) EXMN: length of existing mains used instead of new mains (yds.).

FEXS: fraction of existing irrigation system used.

(14) BCAP: borrow capital ($).

(15) RLND: rent additional land (acres).

(16) HLBR (L): hire labor in time period L (hrs.).

(17) PVOL (T): proportion or weight attached to pumping pit T.

PSVP: volume of pumping pit (cu.ft.).

(18) NETRETN: annual net return to fixed resources ($).

INVCAP: capital invested in manure dissipation facilities ($).

WASTLABR: annual labor spent on manure dissipation (hrs.).

(19) PMPB (I): 0-1 variable, 1 allowing pumping from building I.

(20) PVSERE (I, J (I)): 0-1 variable, 1 representing the use of pit J (I) in building I.

(21) TWAG (K): 0-1 variable, 1 representing purchase of tank wagon K.

(22) INJ: 0-1 variable, 1 representing purchase of injection equipment.

(23) LUSE (M): 0-1 variable, 1 allowing the use of lagoon type M.

(24) EXLG (M): 0-1 variable, 1 representing the use of an existing lagoon as lagoon type M.

(25) PMLI (L, M): 0-1 variable, 1 allowing pumping from lagoon M in time period L.

(26) PMLS (M, N): 0-1 variable, 1 allowing pumping from lagoon M at concentration N.

(27) NWIR: 0-1 variable, 1 representing purchase of a new irrigation system.

(28) EXIR: 0-1 variable, 1 representing use of an existing irrigation system.

(29) PPVS (U): 0-1 variable, 1 representing the consumption of a pumping pit of size between the Uth and (U+1)th pumping pit volume sizes.

(30) HGOP: size of the hog production operation (100's lbs average liveweight carried).

(31) Null class.

(32) LOVF (L, M): volume of overflow from lagoon M in time period L.

(33) POVF (I,L): volume of overflow from house I in time period L.

Constraint Classes

(1) OPSZ:

HGOP = size.

The size of the hog production operations must equal the prior specified size (100's lbs average liveweight inventory).

(2) PARQ (I):

$\sum$PITARE (I, J (I)) - A2HGOP·HGOP = 0, for all houses (I) with pits.

The total area of pit provided must equal the total area of pit the hog operation requires (sq. ft.).

(3) WVAC (I, L):

PSTO (I, L) - PSTO (I, L-1) + $\sum$[A3O·O(I, J(I), K, O, P(O),Q)]

+ $\sum$[A3W·W (I, J(I), K, O, P(O), Q)] + $\sum$TRL (I, J(I)*, L,M)

- $\sum$[A3PITARE·PITARE (I, J(I))] - A3HGOP·HGOP + POVF(I,L) = 0

for all I and L.

The manure volume produced in building I in time period L, or transferred to it from the previous period, or contributed as pit water, must be accounted for by storage to the following period, transferred to lagoons, or application to land, unless overflow is allowed (cu.ft.).

(4) MSTB (I, L):

$$PSTO(I, L) - \sum[A4PITARE \cdot PITARE(I, J(I))] \leq 0, \text{ for all}$$

I with pits, and all L.

The liquid volume stored in building I from time period L to (L+1) cannot exceed the storage capacity in that building (cu. ft.).

(5) and (6) Null classes.

(7) NTOT(M):

$$\sum[A7TRL \cdot TRL(I, J(I)^*, L, M)] - LTON(M) = 0 \text{ for all M.}$$

The annual total nitrogen passed to lagoon M is defined as the sum of all individual transfers to that lagoon (lbs).

(8) LSZE(M):

$$LSIZ(M) = A8EXLG \cdot EXLG(M) - LNWS(M) = 0, \text{ for all M.}$$

The size of an operating lagoon type M must equal the supply of new lagoon of this type plus the size of the existing lagoon if that lagoon is used as type M (cu. ft.).

(9) LCAP (L, M):

$$\sum[LSTO(L, M, N)] - LSIZ(M) \leq 0 \text{ for all L, and M.}$$

The volume of liquid stored in lagoon type M from time period L to L+1 cannot exceed the capacity of that lagoon type (cu. ft.).

(10) LMNC (L, M):

$$\sum[LSTO(L, M, N)] - A10LSIZ \cdot LSIZ(M) \geq 0 \text{ for all L and M.}$$

The volume stored in lagoon M from time period L to L+1 must be at least a fraction (A10LSIZ) of the full capacity of the lagoon in order to prevent fouling (cu. ft.).

(11) NEQL(L,M):

$$A11LTON \cdot LTON(M) - \sum[A11TRL \cdot TRL(I, J(I)^*, L, M)] \leq 0 \text{ for all}$$

L and M.

The quantity of nitrogen transferred to lagoon M at time L must be more than a fraction A11LTON of the total annual nitrogen transferred to that lagoon. This is to ensure stable lagoon loading (lbs).

(12) LLDR(M):

$$LSIZ(M) - A12LTON \cdot LTON(M) = 0, \text{ for all M.}$$

The size of lagoon M must be A12LTON times the annual total nitrogen passed to that lagoon. This equation thus established a loading rate for the lagoon, and while defined in terms of nitrogen, it is also defined in terms of organic matter, since N: organic matter is assumed fixed (cu.ft.).

(13) IRLN(R):

$$\sum[A13CI \cdot CI(M, N, O, P(O), Q)] - \sum[A13IRSY \cdot IRSY(S)]$$

$$- (A13FEXS \cdot FEXS) \leq 0, \text{ for all R.}$$

The demand for acres of irrigated land in month R cannot exceed the area under irrigation (acres).

(14) EXMA:

$$EXMN \leq SEXMN.$$

The use of existing mains cannot exceed the available length of existing mains (yds.).

(15) LBAC (L):

$$\sum[A15O \cdot O(I, J(I), K, O, P(O), Q)] + \sum[A15W \cdot W (I, J(I), K,$$

$$O, P(O), Q)] + A15HGOP \cdot HGOP + \sum[A15CNOWAS \cdot CNOWAS (O)] +$$

$$\sum[A15CI \cdot CI (M, N, O, P(O), Q)] - HLBR(L) \leq SEXLB(L),$$

for all L.

The demand for labor in time period L cannot exceed the supply of labor provided from the farm or by hiring during that period. The farm supply of labor is that made available for manure dissipation and competing activities, or equivalently, the total available farm labor less that allocated to the given hog production operation (hrs.).

(16) PPVD:

$$PSVP - \sum[A16PVOL \cdot PVOL(T)] = 0.$$

The pumping pit volume made available is defined as a convex combination of the specified pit volume sizes (cu. ft.).

(17) SPLN(R):

$$\sum[A17O \cdot O(I,J(I), K, O, P(O), Q)] + \sum[A17W \cdot (I,J(I), K, O$$

$$P(O), Q)] + \sum[A17CNOWAS \cdot CNOWAS(O)] + \sum[A17LUSE \cdot LUSE(M)] +$$

$$\sum[A17LEXV \cdot LEXV(M)] + \sum[A17IRSY \cdot IRSY(S)] + (A17FEXS \cdot FEXS) -$$

$$\sum[A17EXLG \cdot EXLG(M)] - RLND \leq SLND, \text{ for all } R.$$

The land used for cropping, for irrigation, or for lagoons cannot exceed the existing supply of land plus rented land plus land "released" by use of an existing lagoon instead of constructing a new lagoon (acres).

(18) SINC:

$$\sum[A18PITARE \cdot PITARE (I, J(I))] + \sum[A18IRSY \cdot IRSY(S)]$$

$$+ (A18IMNS \cdot IMNS) + \sum[A18LUSE \cdot LUSE(M)] + \sum[A18LEXV \cdot LEXV(M)]$$

$$+ \sum[A18TWAG \cdot TWAG(K)] + (A18INJ \cdot INJ) +$$

$$\sum[A18PVOL \cdot PVOL(T)] + (A18HGOP \cdot HGOP)$$

$$+(A18EXIR \cdot EXIR) + (A18FEXS \cdot FEXS) - BCAP - \sum[A18EXLG \cdot$$

$$EXLG(M)] \leq VEXIR.$$

The investment in new facilities plus the investment in saleable irrigation equipment must be less than the value of the existing irrigation system plus borrowed capital plus any investment in any existing lagoon if this is used ($).

(19) LCTS(M):

$$\sum TRL (I, J(I)^*, L, M) + [A19LUSE \cdot LUSE(M)] + [A19LEXV \cdot LEXV(M)]$$

$$- LVOW = 0, \text{ for all } M.$$

The total volume passed to lagoon M in a year is defined as the sum of all transfers to that lagoon plus the net rainfall entering the lagoon.

(20) DINV:

$$\sum[A20PITARE \cdot PITARE (I, J(I)] + \sum[A20IRSY \cdot IRSY(S)]$$

$$+ (A20IMNS \cdot IMNS) + \sum[A20LUSE \cdot LUSE(M)] + \sum[A20LEXV \cdot LEXV(M)]$$

$$+ \sum[A20TWAG \cdot TWAG(K)] + (A20INJ \cdot INJ) + \sum[A20PVOL \cdot PVOL(T)]$$

$$+ (A20EXMN \cdot EXMN) + (A20EXIR \cdot EXIR) + (A20FEXS \cdot FEXS)$$

$$+ (A20HGOP \cdot HGOP) - INVCAP = 0.$$

The investment in manure dissipation facilities is the sum of individual investments ($).

(21) DLBR:

$$\sum[A210 \cdot O(I, J(I), K, O, P(O), Q)] + \sum[A21W \cdot W(I, J(I),$$

$$K, O, P(O), Q)] + \sum[A21LUSE \cdot LUSE(M)] +$$

$$\sum[A21CI(M, N, O, P(O), Q)] + A21HGOP \cdot HGOP - WASTLABR = 0.$$

The labor spent on manure disposal activities is the sum of amounts spent on individual activities (hrs.).

(22) DNRV:

$$\sum[A220 \cdot O(I, J(I), K, O, P(O), Q)] + \sum[A22W \cdot W(I, J(I), K,$$

$$O, P(O), Q)]$$

$$+ \sum[A22\ CNOWAS \cdot CNOWAS(O)] + \sum[A22CI \cdot CI(M, N, O, P(O), Q)]$$

$$+ \sum[A22EXLG \cdot EXLG(M)] - (A22HGOP \cdot HGOP) - (A22IMNS \cdot IMNS)$$

$$- \sum[A22IRSY \cdot IRSY(S)] - \sum[A22LUSE \cdot LUSE(M)] - \sum[A22TWAG \cdot TWAG(K)]$$

$$- \sum[A22LEXV \cdot LEXV(M)] - (A22EXMN \cdot EXMN) - (A22EXIR \cdot EXIR)$$

$$- (A22FEXS \cdot FEXS) - (A22INJ \cdot INJ) - \sum[A22HLBR \cdot HLBR] - (A22BCAP \cdot BCAP)$$

$$- \sum[A22PITARE \cdot PITARE(I, J(I))] - (A22RLND \cdot RLND)$$

$$- \sum[A22PVOL \cdot PVOL(T)]$$

$$- NETRETN + \sum[A22LOVF \cdot LOVF(L, M)] + \sum[A22POVF \cdot POVF(I,L)]$$

$$= -90{,}000.$$

NETRETN is defined as the sum of net revenues of all activities plus $90,000. The latter has been chosen to be large enough to ensure NETRETN is non-negative. Note, too, the + sign on EXLG, reflecting the fact that use of an existing lagoon will save expenditure on a new lagoon ($).

(23) RINJ:

$$\sum W(I,J(I),\ K,\ O,\ P(O),\ Q) - 2 \cdot INJ \leq 0.$$

Acts requiring an injector are allowed only if an injection is purchased (acres).

(24) RLAG(M):

$$\sum LSIZ(M) - 2 \cdot LUSE(M) \leq 0, \text{ for all M.}$$

The size of lagoon type M is zero unless the right to have that lagoon is granted (cu. ft.).

(25) RPML (L, M):

$$\sum CI\ (M,\ N,\ O,\ P(O),\ Q) - 2 \cdot PMLI\ (L,M) \leq 0, \text{ for all L and M.}$$

Activities needing pumping from lagoon M at time T are forbidden unless the right to pump has been granted (acres).

(26) RTWG(K):

$$\sum O(I,J(I),\ K,\ O,\ P(O),\ Q) + \sum W\ (I,\ J(I),\ K,\ O,\ P(O),\ Q)$$

$$- 2 \cdot TWAG(K) \leq 0, \text{ for all K.}$$

Acts using tank wagon K are forbidden unless that wagon has been purchased (acres).

(27) RSPL(M, N):

$$\sum CI\ (M,\ N,\ O,\ P(O),\ Q) + \sum LSTO\ (L,M,N) - 2 \cdot PMLS\ (M,N) \leq 0,$$

for all M and N.

To store or pump from lagoon M at concentration N requires that the right to do so has been granted.

(28) IRMN:

$$\sum O(I,J(I),\ K,\ O,\ P(O),\ Q) + \sum W(I,J(I),\ K,\ O,\ P(O),\ Q)$$

$$- (A28IMNS \cdot IMNS) - A28EXMN \cdot EXMN) + (2 \cdot NWIR) + (2 \cdot EXIR) \leq 2.$$

If irrigation is used as well as tank wagon application, then irrigation mains pipe is needed to bring water to the center of the irrigation area (acres).

(29) PVST (L, M):

$$\sum LSTO\ (L,M,N) - [A29LSIZ \cdot LSIZ(M)] - [2 \cdot PMLI(L+1,M] \geq -2$$

for all L and M.

If there is pumping from lagoon M at time L+1, then the storage to that period must have been at least a fraction (A29LSIZ) of capacity. This ensures that the pumping concentration will be close to the desired level in-so-far as the lagoon is operating near design level when pumping occurs (cu. ft.).

(30) PMNC (M, N):

$$LTON(M) - [A30LVOW \cdot LVOW(M)] - 2 \cdot PMLS\ (M, N) \geq 2, \text{ for all M and N.}$$

To pump from lagoon type M at concentration level N requires that actual nitrogen concentration exceed A30LVOW, or total nitrogen exceed A30LVOW · LVOW (lbs).

(31) PMXC (M, N):

$$LTON(M) - (A31LVOW \cdot LVOW) + (2 \cdot PMLS\ (M, N) \leq 2, \text{ for all M and N.}$$

To pump from lagoon type M at concentration level N requires that actual nitrogen concentration be less than A31LVOW, or total annual nitrogen in the lagoon be less than A31LVOW · LVOW (lbs).

(32) LVAC (L, M):

$$\sum [A32CI \cdot CI\ (M, N, O, P(O), Q)] + \sum LSTO(L, M, N)$$

$$- \sum LSTO(L-1, M, N)$$

$$- (A32\ LUSE \cdot LUSE(M) - (A32LEXV \cdot LEXV(M)) - \sum TRL(I, J(I)^*, L,M)$$

$$+ LOVF\ (L, M) = 0, \text{ for all L and M.}$$

The volume of liquid entering a lagoon type M in time period L by storage transfer or net rainfall must equal the volume removed by application, or storage, or overflow (if allowed) (cu.ft.).

(33) FEXI:

$$FEXS - EXIR \leq 0.$$

The fraction of the existing irrigation system used must be less than the quantity (0-1) granted for use.

(34) IRCV:

$$\sum IRSY(S) - NWIR = 0.$$

A convexity constraint, forcing some combination size of new irrigation system to be installed if the right for a new system is granted.

(35) RPMB(I):

$$\sum[A35PITARE \cdot PITARE\ (I, J(I))] - PSVP + 2 \cdot PMPB\ (I) \leq 2,$$

for all I.

If the right to pump from building I is to be granted, then the pit volume in the building must be less than the pumping pit volume. If no pumping occurs from building I, the pumping pit need not exceed the size of the pit in that building (cu. ft.).

(36) LVOL(M):

$$LSIZ(M) - A36LUSE \cdot LUSE(M) - LEXV(M) = 0, \text{ for all M.}$$

The capacity of lagoon of type M is a minimum amount (A36LUSE) if the lagoon is used plus any excess amount over this minimum (cu. ft.).

(37) RPTB(I):

$$\sum U\ (I, J(I), K, 0, P(0), Q) + \sum W\ (I, J(I), K, 0, P(0), Q)$$

$$- 2 \cdot PMPB(I) \leq 0 \text{ for all I.}$$

Unless the right to pump from building I is granted, there can be no pumping from that building (acres).

(38) RPIT (I,J(I)):

$$PITARE\ (I, J(I)) - 2 \cdot PVSERE\ (I, J(I)) \leq 0, \text{ for all I and J(I).}$$

The area of pit of depth type J(I) in building I is zero unless that pit is used in that building (sq.ft.).

(39) PVCV:

$$\sum PVOL(T) - \sum PPVS(U) = 0.$$

Since the PPVS(U) members are mutually exclusive 0-1 variables, if the pumping volume falls in one of the segments, then the weights assigned to the end points of that segment must equal 1. If there is no pumping pit, the weights are all zero.

(40) PVSG(1):

$$PVOL(1) - PPVS(1) \leq 0.$$

The weight attached to the smallest pit volume defining size is zero unless the actual volume falls in the first volume segment range.

(41) PVSG(T):

$$PVOL(T) - PPVS(T) - PPVS(T-1) \leq 0, \text{ for } T = 2,3.$$

The weight attached to the 2nd and 3rd pit volume defining sizes is zero unless the actual pit volume lies in the segment immediately up or down from the defining size.

(42) PVSG(4):

$$PVOL(4) - PPVS(3) \leq 0.$$

The weight attached to the largest pit volume defining size is zero unless the actual volume falls in the final segment volume range.

(43) RAPP (I, J(I)):

$$\sum O(I, J(I), K, 0, P(0), Q) + \sum W(I,J(I), K, 0, P(0), Q)$$

$$- 2 \cdot PVSERE(I, J(I)) \leq 0, \text{ for all I and J(I).}$$

The application of liquid manure from pit J(I) in building I is zero unless that pit exists (acres).

(44) ONEI:

$$NWIR + EXIR \leq 1.$$

New and exacting irrigation systems are mutually exclusive.

(45) IRQL:

$$NWIR + EXIR - \sum LUSE(M) \leq 0.$$

To use an irrigation system requires a lagoon.

(46) LRQI:

$$A46NWIR \cdot NWIR + A46EXIR \cdot EXIR - \sum LUSE(N) \geq 0$$

$$- KONS \cdot \begin{matrix} 1 \text{ if overflow allowed,} \\ 0 \text{ if not allowed} \end{matrix} .$$

To have a lagoon requires an irrigation system. Where lagoon overflow is permitted, this constraint is relaxed so that an irrigation system is not required. KONS is a positive constant greater than number of lagoons available for choice.

(47) ONET:

$$\sum TWAG(K) \leq 1.$$

At most there can be only one tank wagon.

(48) ONEC(M):

$$\sum PMLS(M,N) \leq 1 \text{ for all M.}$$

Pumping from lagoon M is feasible at only 1 concentration.

(49) IRQT:

$$INJ - \sum TWAG(K) \leq 0.$$

If using an injector, there must be a tank wagon.

(50) PMPL(M):

$$\sum PMLI(L, M) - A50LUSE \cdot LUSE(M) \leq 0, \text{ for all M.}$$

The right to pump from lagoon M in any time period requires that that lagoon exists.

(51) PMLC(M):

$$\sum PMLS(M, N) - LUSE(M) \leq 0, \text{ for all M.}$$

The right to pump from lagoon M at any concentration requires that that lagoon exists.

(52) ONEP(I):

$$\sum PVSERE(I, J(I)) = 1, \text{ for all I with pits.}$$

If a building has a pit, there can be only one depth of pit.

(53) ONEV:

$$\sum PPVS(V) \leq 1.$$

The pumping pit volume can lie in only one defining segment at most.

(54) TRNR(I,J(I)):

$$\sum TRL(I, J(I), L, M) - 2 \cdot PVSERE(I, J(I)) \leq 0, \text{ for all I with pits,}$$

and all pits in such buildings.

There can be no transfer from a given pit unless that pit is used (cu. ft.).

(55) PLTR(I):

$$\sum TRL(I, J(I), L, M) + 2 \cdot \sum PVSERE(I, J(I)) \leq 2, \text{ for all I with pits.}$$

In a building with a pit, there can be 'pit-less' transfer from the building only if the pit is not used.

(56) LDCT(Q):

$$\sum O(I,J(I), K, O, P(O), Q) + \sum W(I, J(I), K, O, P(O), Q)$$

$$\leq SPLD(Q) \text{ for all Q.}$$

The area to which liquid manure is applied on land class Q cannot exceed the supply of land in that class (acres).

(57) LDCI(Q):

$$\sum CI(M, N, O, P(O), Q) \leq SPIRLD(Q), \text{ for all Q.}$$

The area of land in class Q under irrigation cannot exceed the supply of land in that class (acres).

(58) MAXB:

$$BCAP \leq MAXBOR.$$

The amount of capital borrowed cannot exceed the limit MAXBOR ($).

(59) AREA(S):

$$\sum O(I_s, J(I)_s, K_s, O_s, P(O)_s, Q_s) + \sum W(I_s, J(I)_s, K_s, O_s, P(O)_s, Q_s)$$

$$+ \sum CNOWAS(O_s) + \sum CI(M_s, N_s, O_s, P(O)_s, Q_s) \begin{matrix} \leq \\ = \\ \geq \end{matrix} AARE(s) \text{ for all s.}$$

The area of specific crop patterns is restricted to AARE(s) (acres).

APPENDIX B

EDITORIAL COMMENTS

As stated in the "Acknowledgements", this report was principally written by Ross G. Drynan, former Research Associate, Department of Economics and Business, under the direction of J. C. Williamson, former Professor in the same Department. The material that went into the report was a collective effort of Drynan and Williamson as well as Philip W. Westerman and Stuart Crane (Associate Professor and former Research Associate, respectively, Department of Biological and Agricultural Engineering). Drynan left the project after he had drafted this report. Unfortunately, the computer model was not completely "debugged" when Drynan left and he had performed only a few analyses using a limited version of the computer model. After reviewing Drynan's draft report, Williamson decided to perform further economic analyses for the final report. However, he changed jobs and left the University without revising the draft. Also, the computer model materials (cards, disk storage, etc) were inactivated or lost from the Department of Economics and Business after Williamson left. Therefore, Drynan's draft report was edited by Westerman and printed with only minor changes as the final report.

Review of the draft report by Westerman and Crane revealed some deficiencies in Drynan's documentation of assumptions and equations which he used. However, because the economic analyses were based upon the technical data which Drynan presented, the technical and cost data were not changed. New calculations using revised equations for certain items indicated that Drynan's costs for certain items were slightly low but were not seriously in error.

Items which were not well documented or were based on poor assumptions are addressed here.

1. Tables 30 and 31 - It is not clearly stated why it takes less time to empty a deeper pit and why it is cheaper to transport manure from a deeper pit on a per 100 lbs N basis. However, it must be based on concentration differences, probably related to assumptions about differences in pit - bottom wash practices. The deeper pit was taken to have higher N concentrations, but the differences are relatively small.

2. Table 34 - Most of the values in this table of lagoon parameters could not be duplicated using the equations presented in Section 2.8.2. However, the equations are correct and new calculation of items in this table resulted in cost figures within about 10% of the costs listed in this table. Therefore, the lagoon cost figures were essentially verified, but other values given in Table 34 should not be utilized without verification.

3. Some of the statements concerning aeration in Section 2.8.3 are not in line with normal recommendations. Generally, each kilowatt of power should serve no more than 1350 ft^2 (not 4,400 ft^2 as stated) of surface area, and oxygenation capacity should be 50-90% of input BOD_5 (not 90% of daily COD input). However, the estimated cost of \$91.36/1000 ft^3 lagoon is only slightly low (about 10-15%).

4. The equation for lagoon concentration in Section 2.8.5 is not well documented. It was not determined which k value should be used in estimating lagoon collection area by the equation:

$$\frac{2\ k\ L\ N_D}{(H + E)}$$

However, using different equations, independent estimates of the contribution of net precipitation to total effluent volume yielded slightly lower but very similar values as those which appear in Table 39.

5. The major void in documentation of the computer model is not having an actual listing of the model. Although the basic model is described in Section 3.2 and the listing of activities and constraints for the linear programming model are given in Appendix A, reconstruction of the computer program would require a major effort and a high level of computer programming expertise.

Although the computer model is not presently available for further development and research, the listing of model activities and constraints and presentation of the equations for the subsidiary models for computing various technical and cost coefficients represent a major contribution in regards to methods for analyzing waste management systems. The partial budget economic analysis of system components (such as tank wagons, storage, irrigation, etc.) and the limited analyses using the linear program also resulted in several pertinent conclusions which have been stated in the report.