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Takako Inagaki

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DEVELOPMENT OF A MACHINERY AND NUTRIENT MANAGEMENT MODEL FOR MANURE TRANSPORT.

By

Takako Inagaki

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ABSTRACT

DEVELOPMENT OF A MACHINERY AND NUTRIENT MANAGEMENT MODEL FOR MANURE TRANSPORT.

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A machinery and nutrient management model was developed to evaluate manure machinery ownership and operating costs, and nutrient use for one- or two-year crop sequences. With the model, hauling requirements and costs for a range of tractor-and truck-drawn spreaders and pipeline systems were compared on representative 150- and 600-cow dairy farms. Corn silage/corn grain, wheat grain/ corn grain, sugar beet/corn grain and alfalfa hay/alfalfa hay sequences were compared to analyze the net cost of manure machinery and providing crop nutrients. A corn silage/corn grain sequence with P-based manure application over two years provided the highest net nutrient value and an alfalfa hay/alfalfa hay sequence had the highest net cost. Nutrient requirements for wheat grain/corn grain and sugar beet/corn sequences better reflected manure nutrient availability resulting in efficient use of applied nutrients. The truck-drawn or box spreader system was the lowest cost at 4.8 km for the 150-cow farm. Irrigation was the lowest cost system on the 600-cow farm when the distance was less than 2 km. The nurse truck system was the lowest cost when the distance was greater than 4.8 km.

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Chapter 1

INTRODUCTION

Agricultural production has greatly increased over the past 40 years due to an increase in irrigation, more land under cultivation, increased use of fertilizer and pesticides, and improved crop varieties. The number of farms decreased from 2,212,960 in 1987 to 2,063,010 in 1996, but the average acreage increased from 451 to 469 acres (USDA, 1997). In the past 10 years, the U.S. hog and pig inventory has climbed about 18 percent while the number of operations has decreased by 72 percent. Cattle feedlots also have dropped in number while becoming much larger, leading to a greater concentration of animals at each location. There are about 150,000 dairy operations throughout the country, down from over 250,000 in just 10 years (Glover, 1996).

This increasing concentration of animals can impact water and air quality. Untimely applications of manure can cause surface and ground water contamination. The Clean Air Act (CAA) of 1970 required uniform air quality standards and emission controls for livestock facilities, and amendments to the act further stiffened the criteria for agricultural producers (Glover, 1996). The CAA has had more attention recently due to an increase in odor-related nuisance suits filed by nearby property owners and activist groups, however, it does not specifically refer to odors but to air quality standards (Glover, 1996).

Runoff of agricultural waste can cause health and environmental problems. Excess nutrients stimulate excessive growth of aquatic vegetation and cause a reduction of animal and plant populations along with odor and appearance problems. Nutrients also can impair groundwater quality. The Environmental Protection Agency (EPA) reported that confined animal feedlot runoff contributes to 7 percent of lake and 13 percent of river impairment of designated uses (Letson and Gollehon, 1996).

Federal, state and local regulations restrict livestock operations and field manure applications. The Clean Water Act (CWA) of 1977 directly affects large livestock operations by designating large operations - 1,000 animal unit (AU) or greater, or 300 animal units that discharge directly into surface water as point-source polluters - subject to regulation under EPA's National Pollutant Discharge and Elimination System (NPDES) (Westenbarger and Letson 1995). The Coastal Zones Act Reauthorization Amendments (CZARA) of 1990 was the first federal program to require specific measures to address nonpoint source pollution from agricultural erosion and runoff (Glover 1996, Letson and Gollehon 1996).

For livestock producers, manure can be a useful resource rather than a pollution source. Manure is a source of nutrients and organic matter. Timely use of manure is a great nutrient management strategy and reduces commercial fertilizer use. Livestock producers must apply manure according to animal population and soil nutrient availability. In some cases, they may either not have enough cropland to utilize the manure that they produce or they may not be able to apply manure on their cropland due to high nutrient levels.

Transportation of manure is an essential component of manure management. Transportation method varies depending on the distance from storage, treatment facilities, and method of usage. To utilize manure effectively and safely, nutrient management, crop rotation and manure uniformity are important. Even though the costs of facilities and equipment increase with long-term storage, it allows for better management of manure.

Livestock producers or farm managers need accurate information about application methods to select the best management system. Several nutrient management models have been developed. One example is the Michigan State University Nutrient Management (MSUNM) program. This computer program tracks the cropping history, soil test analysis information, fertilizer lime and pesticide applications, and tillage planting and harvesting information (MacKellar et al, 1996). Another model is the Vermont Manure Nutrient Manager developed to help formulate nutrient management plans for dairy or other livestock farms by recommending manure application rates and fertilizer needs (Jokela et al, 1995). At Pennsylvania State University, the Farm Nutrient Management Planning worksheet was developed to provide a nutrient management plan for manure and fertilizer (Bohn et al., 1997). The Manure Application Planner (MAP) was developed to measure manure application methods and rate, manure nutrient credits, and commercial fertilizer nutrient value (University of Minnesota, 1997).

Several farm machinery selection models have been developed. Rotz et al (1983) developed an algorithm to select machinery. It includes, (1) type of crop and the cropping sequence, (2) the area to be farmed, (3) the predominant soil type of the farm, (4) geographic location and weather conditions, (5) implements and machines that already exist on the farm, (6) labor availability for peak season demands and (7) field operations to be done through custom hire. Siemens et al (1990) developed a similar machinery selection and management program. It was designed to estimate the field operations for different machinery sets and to compute the total machinery related costs. Both models provide a least cost machinery set, but neither is designed to select manure handling equipment.

Cost and machinery capacity information is needed to compare alternative manure application methods. There is a need for a general model to compare hauling rates and nutrient use for spreader tank and other common manure hauling systems.

1.1 Objectives

The objectives of this work were to:

1. Develop a framework to evaluate costs and labor requirements for manure transportation and nutrient use.
2. Implement this framework in a user friendly computer program.
3. Use this program to draw general conclusions regarding manure transportation and nutrient use for selected transport systems and crop sequences on 150- and 600-cow dairy farms.

Chapter 2

LITERATURE REVIEW

2.1 Regulatory background

Federal, state and local regulations restrict livestock operations and field manure applications. Water pollution from nonpoint sources, including agriculture, is subject to section 319 of the CWA (USDA, 1996). Agricultural nonpoint-source pollution includes nutrients, sediment, animal wastes, salts, and pesticides (USEPA, 1997). Potential pollutants in animal waste are oxygen-demanding substances, nutrients, organic solids, salts, bacteria, viruses and other microorganisms, and sediment (USEPA, 1997). Since nonpoint source pollution is diverse and site-specific, states have been given primary responsibility to control nonpoint source pollution. State and local governments mostly emphasize voluntary actions in controlling nonpoint source pollution (USDA, 1996). The CZARA requires that each state with an approved coastal zone management program submit to EPA and to the National Oceanic and Atmospheric Administration a program to "implement management measures for nonpoint source pollution to restore and protect coastal waters" (USDA, 1996). States can first try voluntary incentive mechanisms, but must be able to enforce management measures if voluntary approaches fail (USDA, 1996). The Michigan Agriculture Commission (1992) has adopted practices relevant to the Michigan Right to Farm Act (P.A. 93, 1981) that specifically addresses soil fertility, fertilizer recommendations, manure analysis, manure nutrient loading, application method and time of application (Michigan Agricultural Commission, 1992).

2.2 Manure use

Land application of manure as a fertilizer for crop production is a traditional waste utilization technique (USDA, 1992). Alternative uses are biogas generation, feed products, compost and biomas protection (Hauck, 1995; MacCaskey, 1995; USDA, 1992). Application of manure nutrients to cropland and pasture typically equals about one-sixth of that supplied by commercial fertilizer (National Research Council, 1993).

2.3 Manure production

Manure production varies due to animal type, diet, age, productivity and management. Data on livestock manure production and its characteristics are available to assist in the planning, design and operation of manure collection, storage, pretreatment and utilization systems. (ASAE, 1997c). The Midwest Plant Service (MWPS) has provided raw manure production information based on ASAE data (MWPS, 1985). A comparison of manure characteristics is listed in Table 2.1. Dilution by added bedding and additional water are not included (Jones and Sutton, 1994). Estimates have been developed by several state universities based on local conditions, experiences and opinions (Jones and Sutton, 1994).

Table 2.1 Comparison of manure characteristics and production by data source.

Animal type	Dry matter	Manure composition					
		SI Units			English Units		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
	[%]	[kg/1000L]			[lb/1000gal]		
MWPS							
Dairy Cows	12.7	4.9	2.0	4.0	41	17	33
Beef cows	11.6	5.4	4.0	4.7	45	33	39
Swine	9.2	7.2	5.4	4.3	60	45	36
Broilers	25.2	16.0	8.2	6.0	133	68	50
Turkeys	25.2	---	---	---	---	---	---
ASAE							
Dairy Cows	14.0	5.2	2.5	4.1	43	21	34
Beef cows	14.7	5.8	3.6	4.4	48	30	37
Swine	13.1	6.1	4.8	4.1	51	40	34
Broilers	25.9	13.0	8.0	5.8	108	67	48
Turkeys	25.5	13.2	11.3	6.2	110	94	52
USDA							
Dairy Cows	12.5	5.5	1.9	3.8	46	16	32
Beef cows	11.5	5.2	4.2	4.9	43	35	41
Swine	10.0	6.7	5.9	4.2	56	49	35
Broilers	25.0	13.9	9.8	7.1	116	82	59
Turkeys	25.0	17.0	14.8	7.8	142	123	65

Source: ASAE, 1997c; MWPS, 1995; USDA, 1992

2.4 Storage options

Manure can be removed from barns by flushing, scrapping, gravity gutters, or pumping and can then be held in storage. Manure production and nutrient availability vary depending on the animal type and operating system. Storage selection depends on the type of manure, operation and local regulations.

Manure can be hauled and spread daily with a short-term storage system or stored long-term and spread at a scheduled time. Long-term storage requires more facilities and equipment (Harrigan et al., 1996), but it is easier to manage spreading time and uniformity of nutrient content (Harrigan. 1997).

2.5 Manure nutrient

Manure contains major nutrients for crop growth such as nitrogen, phosphorus and potassium. Nitrogen and phosphorus are the most important for nutrient management since they most directly impact water quality. The nutrient value of manure varies depending on animal type, storage, application method, weather, and timing of application. Manure nutrient levels can vary considerably depending upon the composition of the diet fed to animals, method and length of storage, and the amount of water, bedding or feed spillage in the manure (Sutton, 1994).

Animal waste plans have frequently been based on nitrogen. However, a number of environmental issues such as eutrophication of surface waters by phosphorus in runoff, the fate of trace elements, antibiotics, pesticides and growth hormones in wastes, and the effects of pathogens in wastes on human and animal health have forced a reevaluation of nitrogen-based management of animal wastes (Sims and Wolf, 1994). When manure is applied to meet the nitrogen requirement of a crop, there is often an over-application of phosphorus and potassium which build up in the soil (Sutton, 1994). Thus, producers have to choose either applying a high rate of manure and rotating the fields or applying lower rates and applying additional nitrogen. (Sutton, 1994)

2.6 Nutrient loss

A loss of nutrients in manure occurs during collection, storage, treatment and application. Nitrogen is lost due to volatilization and denitrification. Nitrogen losses during handling and storage range from 15 to 60 percent for solid manure and 10 to 80 percent for liquid manure depending on the system (MWPS, 1985). Phosphorus and potassium losses are lower. About 20 to 40 percent of the phosphorus and 30 to 50 percent of potassium can be lost by runoff and leaching from open lots, but, these nutrients can often be recovered by proper runoff control (MWPS, 1985).

Nutrient values vary depending upon the management system and type of manure. For instance, dairy manure stored in an open lot in a cool, humid region retains 70 to 85 percent of the nitrogen whereas manure treated in an anaerobic lagoon, after being diluted more than 50 percent, retains only 20 to 35 percent of the nitrogen (USDA, 1992). Nitrogen loss during land application is typically 10 to 35 percent when broadcast on the surface, 1 to 5 percent when broadcast with immediate cultivation, 0 to 2 percent when injected and 15 to 35 percent when irrigated (MWPS, 1985). These losses vary with climate and soil type.

Nitrogen is available in the soil in organic and inorganic forms. The inorganic forms are soluble and available for plant uptake. Organic nitrogen must be in a mineralized form before plants can use it as a nutrient. Mineralization rates vary depending on climate, soil type, manure type, manure handling method and so on. In general, the fresher the waste material, the higher the mineralization rate (Safley, 1994). The range of mineralization rate in the first cropping season is from 25 to 50 percent (MWPS, 1985). During the second, the third, and the fourth cropping seasons after the first manure application, organic nitrogen is released at a rate of 50, 25, 12.5 percent of the organic nitrogen released in the first cropping season (MWPS, 1985).

2.7 Manure application methods

Traditional disposal methods collect and store waste material in large lagoons or separation basins. After solids have been broken down by fermentation, farmers stir the slurry and apply it to fields in much the same way as commercial fertilizer (Westenbarger and Letson, 1995).

Field application of manure can be done by irrigation, injection, or surface spreading. The selection of application method changes depending on the consistency of manure. Manure is classified according to its consistency as solid, semi-solid, slurry and liquid. Solid manure contains 20 percent or more total solids. Semi-solid manure ranges from about 10 to 22 percent of total solid content. Slurry is 5 to 15 percent total solid contents and liquid manure is less than 5 percent total solid content (ASAE, 1997e; MWPS, 1985; USDA, 1992).

2.7.1 Manure spreader systems

A manure spreader is a machine to haul, unload and distribute manure and may be PTO or hydraulically driven (ASAE, 1997d). There are different types of spreaders and these are selected based on the consistency of the manure. Spreaders can be tractor-drawn or truck-mounted.

A box type spreader is used for solid or semi-solid manure (ASAE, 1997d; MWPS, 1985: USDA, 1992). This type of spreader has a horizontal floor, vertical side walls and a vertical or slanted front or rear wall. Manure is conveyed or pushed to the open end where a device, usually a beater, distributes or spreads the material being hauled (ASAE, 1997d). A V-tank ("V" bottom) spreader is used for semi-solid and slurry manure (ASAE, 1997d). It has an open or covered rectangular tank with a Vshaped bottom. A shaft runs the length of the tank at the bottom of the "V" and, with its attachments, agitates and moves the manure to a second device which spreads the manure on the soil surface (ASAE, 1997d).

A tank spreader is used to apply slurry manure. A tank spreader is a completely enclosed horizontal or modified cylinder (ASAE, 1997d). Manure from tank spreaders is typically unloaded under pressure. Manure may be surface applied or injected below the soil surface (Harrigan, 1997). Since these hauling systems require heavy equipment, they can be a source of soil compaction. For hauling over long distances, a nurse truck with a spreader tank combination can increase travel speed and transport efficiency.

2.7.2 Irrigation and drag hose systems

Irrigation and drag hose systems are often used for manure with a solids content below 5 percent. An irrigation system on a large farm can reduce machinery, fuel and labor costs (Borton et al., 1995). Potential problems of irrigation systems are: (1) odor, (2) uneven nutrients distribution, and (3) runoff. The other disadvantage of irrigation is a higher nutrient loss with up to 35 percent of the nitrogen during application (MWPS, 1985).

A drag hose system is also a faster application method compared to hauling liquid manure. The system transports manure through a pipeline and injects manure without using spreaders. This system consists of a storage agitator, a manure pump, a main line from the pump to the field, a drag line to connect the main line, an injection implement and tractors (PAMI, 1997). Major advantages of drag hose systems are reduced nutrient loss and better odor control than with an irrigation system. Since a drag hose system injects manure into the soil, nitrogen loss is about 2 percent or less (MWPS, 1985; PAMI, 1997). A disadvantage of a drag hose system is the high equipment cost. The cost of equipment may be too high for an individual producer, depending upon the size of the operation and the amount of manure (PAMI, 1997).

Irrigation and drag hose systems transport manure from storage to field through pipeline using pumps. Manure can be pumped up to 2 miles (3.2 km) in normal conditions. More pumps are needed to increase pressure head when the field is far from the storage and the pipe system becomes longer. Pressure requirements for irrigation varies in regard to the type of irrigation and equipment. Generally, big gun sprinklers require a nozzle pressure of 414 to 827 kPa (60 to 120 psi) (Cuenca, 1989), and injection systems require lower pressure, around 69 kPa (10 psi) (Goodrich, 1994; PAMI, 1997)

2.8 Manure transportation

Travel distance can greatly influence labor requirements and costs and it is often the most variable factor that effects the manure removal rate (Welty et al., 1986). Many farmers use truck-drawn spreader tanks for rapid and efficient over-the-road transport (Harrigan, 1997). A nurse tank for transport and a spreader tank for application increased the spreading rate and reduced the cost of transportation (Welty et al., 1986; Borton, et al., 1995). The hauling rate of a nurse tank and spreader tank system increased when labor was available to allow parallel operation of the nurse tank with spreaders (Harrigan, 1997).

2.9 Crop nutrient requirement

Macronutrients are generally required in large amounts for plant growth. Macronutrients include nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Micronutrients are required in small amounts but are necessary for plant growth. These include iron, chlorine, copper, manganese, zinc, molybdenum and boron. Crop nutrient requirements are estimated in two ways: (1) by crop nutrient removal, and (2) by fertilizer recommendation. Crop nutrient removal is simply the removal of the nutrient from the field by crop growth and harvest. Fertilizer recommendations are based on soil type and soil fertility test, type of crop grown and expected yield. Michigan State University Extension bulletin E550-A provides fertilizer recommendation for field crops in Michigan (Christenson et al, 1992).

2.10 Nutrient balance models

Nutrient management is the balancing of environmental goals and nutrient demands for crop production. Manure is a good nutrient source for crop growth; however, the nutrient content varies depending on the type of manure and treatment procedures. Klausner (1995) pointed out key aspects of a successful nutrient management plan: (1) the movement and quantity of nutrients entering, leaving, and remaining on the farm needs to be measured, (2) a nutrient application schedule should be maintained to ensure that the rate and timing of manure and fertilizer applications meet the crop requirement, (3) a crop selection and rotational sequence needs to be established in order to ensure efficient nutrient recycling. Figure 2.1 shows the structure of a nitrogen budget. There are ten points to consider when developing a nitrogen budget plan: (1) estimate nutrients in the excreted manure, (2) add nutrients in waste water, feed and bedding, (3) subtract nutrients lost during storage, (4) determine the plant nutrients available in the manure, (5) determine the nutrients required by the crop and soil to produce the yield goal, (6) compute increased nitrogen to compensate for application losses, (7) select nutrients for the calculation of manure application rate, (8) compute the acres of cropland that manure will be applied on, (9) determine the application rate of manure, (10) any other further considerations such as the amount of other nutrients in manure with the nitrogen application rate.

. Nutrient management and nutrient value models have been widely developed. Thompson et al (1997) summarized several computer programs for manure nutrient application and identified basic program components. Basic program requirements were: (1) manure nutrient values were known or default values used, (2) crop nutrient requirements were entered or calculated by soil test or crop removal data, (3) credit was provided for previous manure applications and/or legume crops, (4) available nutrients were estimated as 40 to 100 percent of applied nutrients, (5) an assessment of retained nutrient value, (6) nutrient balance, (7) rate of manure was calculated, and (8) the rate for commercial fertilizer was calculated.

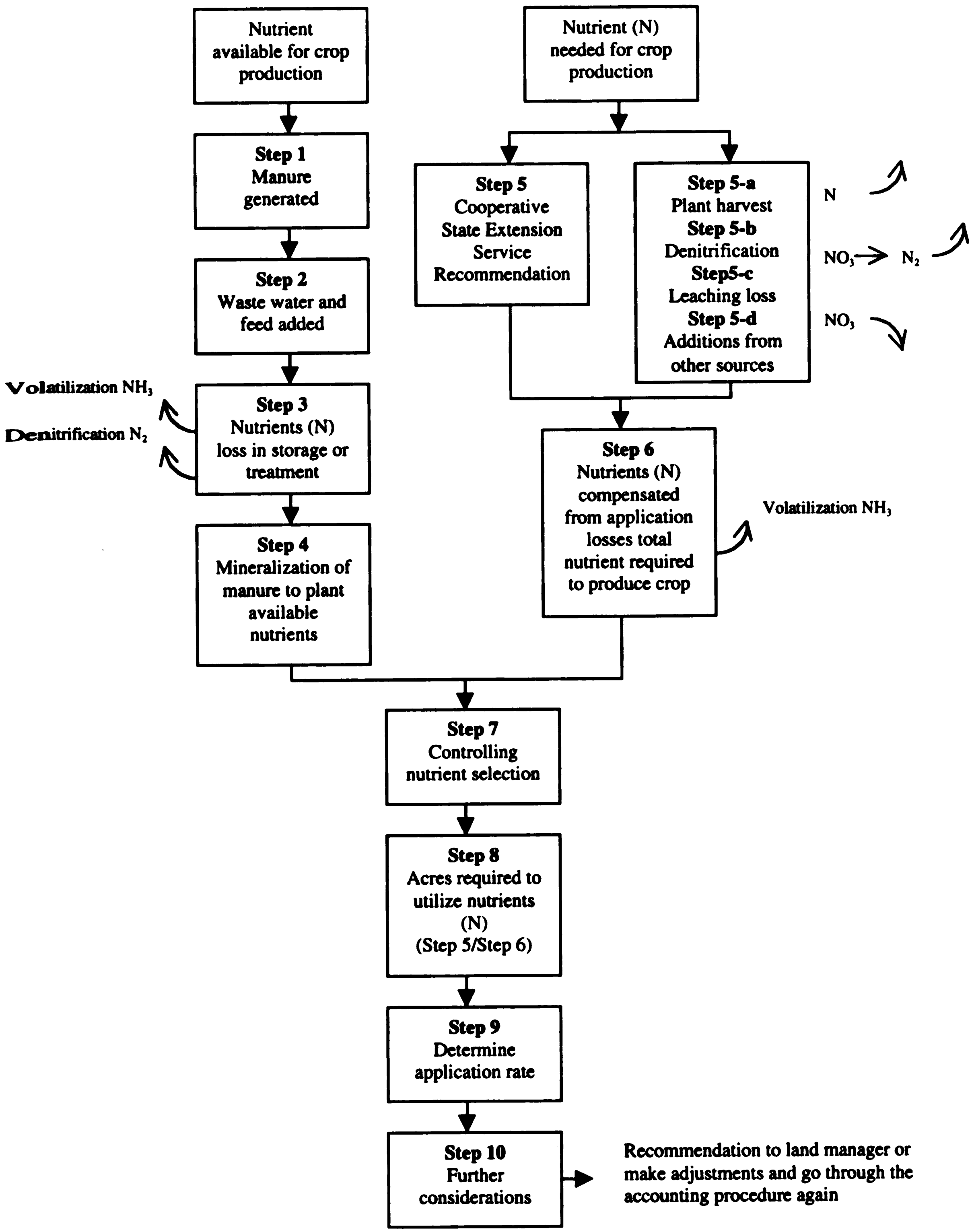

Figure 2.1 Nitrogen transformation in the accounting procedure (USDA, 1992)

Livestock producers or farm managers need reliable information to determine application rates which are environmentally safe and economical. Michigan State University Nutrient Management (MSUMN) is a computer program designed to track cropping history, soil test analysis information, fertilizer, lime and pesticide applications, and tillage, planting and harvesting information. It also manages manure analysis information (MacKellar et al, 1996). The Vermont Manure Nutrient Manager was created to help develop nutrient management plans for dairy or other livestock farms by recommending manure application rates and additional fertilizer needs (Jokela et al, 1995). The Farm Nutrient Management Planning worksheet developed at Pennsylvania State University aids in the development of nutrient management plans for manure and commercial fertilizer (Bohn et al, 1997). The Manure Application Planner (MAP) was developed at the University of Minnesota. It was made for the assessment of manure application methods and rate, manure nutrient credits and commercial fertilizers (University of Minnesota, 1997).

2.11 Economics of manure management

The economics of manure management includes machinery costs, labor costs, nutrient values, and manure nutrient credit. Machinery costs and labor requirements can not be separated from crop and manure nutrient information since quantity and quality of manure application relates to crop nutrient requirements. Bosch and Napit (1992) developed a model to estimate the costs of providing the services needed to use litter for fertilizer and the economic value of litter as a fertilizer. This model estimates the nutrient transfer cost of litter from surplus to deficit counties. Borton et al (1995) compared manure handling operations and found that on a small farm, machinery costs for a slurry system were up to 17 percent higher than for a semi-solid system; fuel costs were about 15 percent higher. Storage costs were low since semi-solid manure was not stored for long periods.

Transport distance has a major effect on manure handling costs. The handling costs increased between 15 to 30 percent from 1 km (0.6 mile) to 5 km (3.1miles) of transport distance (Borton et al, 1995). Transport distance also affects the cost of irrigation. At a 1 km (0.6 mile) transport distance, manure irrigation reduced hauling costs about 30 percent compared to an application with slurry spreaders. Nevertheless, the total cost of irrigation was similar to that of using a nurse tank at a 5 km (3.1 mile) transport distance (Borton et al, 1995).

Chapter 3

MODEL DEVELOPMENT

The proposed manure machinery and nutrient management model has been designed to estimate costs and labor requirements for manure transportation and nutrient use. The model consists of four parts: the hauling rate model, machinery cost model, manure production model and the crop nutrient model.

3.1 Development of the hauling rate model

Machinery performance is evaluated based on the rate of transport and cost of use. A hauling rate and hauling hours were used to evaluate and compare various hauling operations.

3.1.1 Machine cycle time

Cycle time is the time needed to complete a series of machine operations. Typically, a system of machines is used rather than a single machine. Thus, the field capacity of any single machine may be limited by the rate of other operations in the system (Hunt, 1995). An accurate estimate of cycle time for manure hauling operation is needed to create a valid model that will provide useful comparisons of alternative hauling systems (Harrigan, 1997).

In this model, the cycle time of a series of operations was calculated as the sum of loading, maneuvering, traveling and unloading time (Appendix A1). There were three hauling options using parallel machine operations. Firstly, one operator operated both a nurse truck and spreader tank. Secondly, one operator used two nurse trucks to shuttle manure from storage to the field and a second operator ran a spreader tank in the field. Finally, two operators used two nurse trucks to shuttle manure and an operator ran a spreader tank. When one operator ran both nurse truck and spreader tank, the cycle time was estimated by summing all time needed for the series of operations (Appendix A2, A3). The cycle time for the spreader tank operation was calculated as the sum of operation time, maneuvering, transfer, and spreading time (Appendix A4, A6). The cycle time for the nurse truck operation was the sum of maneuvering time, loading time, transfer and travelling time. The cycle time of the nurse trucks and spreader tank was compared and the longer time was selected as representative of the operation. When two or more operators were involved, the cycle time for the nurse trucks and spreader tank were calculated separately. When one operator operated two nurse trucks, a cycle was determined from when the first nurse truck was loaded at storage to when the second truck was ready to be loaded at storage (Appendix A4, A5). When two operators each ran a nurse tank, the nurse cycle time was estimated as half of the individual operation time (Appendix A6, A7). The spreader tank volume was either equal to or one half of the nurse tank volume.

Table 3.1 Manure hauling and transport options.

	Hauling Options	
Series	**Parallel**	**Irrigation and drag hose**
Tank spreader (Truck- or Tractor-drawn)	1-operator, 1-nurse truck and 1-spreader tank	Irrigation
V-tank spreader (Truck- or Tractor-drawn)	2-operators, 2-nurse truck and 1-spreader tank	Drag hose
Box spreader (Truck- or Tractor-drawn)	3-operators, 2-nurse truck and 1-spreader tank	

3.1.2 Hauling Rate

Hauling rate was the volume of material moved per unit time. A theoretical hauling rate for the spreader tank system was calculated as the spreader tank volume divided by cycle time. Pumping rate for irrigation and drag hose systems was assumed to be 1,890 liter per minutes (500 gallons per minute).

Field efficiency is the ratio of a machine under field conditions to a theoretical maximum productivity (ASAE, 1997b). An actual or effective capacity is often less than a theoretical or potential capacity (Hunt, 1995). Harrigan (1997) proposed efficiency for surface spreading of 0.85 to 0.95 and 0.75 to 0.85 for injection. The upper limit of the range applies to well-maintained equipment and the lower limit to older or poorly maintained equipment. Lower efficiencies for injection were used to account for additional downtime for injector repair and to adjust for unloading rates lower than for surface spreading.

3.2 Development of the Machinery Cost Model

Equipment costs were categorized as fixed and variable. Fixed costs were not associated with the amount of use and variable costs varied with use (Hunt, 1995; ASAE, 1997a). Fixed costs included depreciation, interest, housing and insurance. Variable costs included fuel, lubrication, labor, and repair and maintenance.

3.2.1 Depreciation

Depreciation reflects a reduction in the value of an asset with use over time (ASAE, 1997a). An average depreciation was estimated using a straight-line method.

$$Depriciation = \left(\frac{\text{Purchase Price} - \text{Remaning Value}}{\text{Age}}\right) \quad (1)$$

Where:

Purchase price and remaining value in U.S. dollars.

Age was the age of machine in years.

Cross and Perry (1996) developed a remaining value model for farm machinery based on recent patterns of machinery depreciation. Remaining value was calculated as a function of sales price, age, and hours of use. A general functional form with machine specific coefficients was used to calculate a remaining value for a variety of farm equipment including tractors, manure spreaders and other equipment. The remaining value was calculated as:

$$RV = 100 \times (C_1 - C_2(Age)^{0.5} - C_3(Ave.Hours)^{0.5})^2 \qquad (2)$$

Where:

Age was the age of machine in years.

Ave. Hours was the accumulated use of machinery in hours.

$C_{1,2,3}$ were machinery specific coefficients shown in Table 3.2.

Table 3.2 Remaining value coefficients for equipment.

Equipment type	Remaining value coefficients C1	C2	C3
Tractor			
Small < 60 kW (<80 hp)	0.9809	0.0934	0.0058
Medium 60 - 112 kW (80- 150 hp)	0.9421	0.0997	0.0008
Large 112 kW < (150 hp <)	0.9756	0.1187	0.0019
Spreader	0.9427	0.1187	---

Source: Cross and Perry 1996

3.2.2 Interest

A constant annual interest charge was determined by calculating the average investment in the machine over its full life (Hunt, 1995). For this model, the average interest over the life of each machine was estimated by taking an average of the sum of the purchase and remaining value multiplied by the interest rate. The real interest rate was used in this model. The default value of the rate was six present and the value is variable.

3.2.3 Insurance and Housing

An annual charge for insurance was assumed to be from 0.25 to 0.50 percent of the remaining value or 0.25 percent of the original price (Bowers, 1992; Hunt, 1995). A charge for shelter is typically 1 to 2 percent of the remaining value or 0.5 to 1 percent of the purchase price (Bowers, 1992; Hunt, 1995). A combined rate for insurance and housing was estimated as 1 percent of the purchase price.

3.2.4 Repair and Maintenance Costs

Repair and maintenance is necessary to keep machines running effectively. Accumulated repair and maintenance costs were determined by the relationships outlined by ASAE (1997b).

$$C_m = (RF1)P\left(\frac{h}{1000}\right)^{(RF2)} \tag{3}$$

Where:

C_m is accumulated repair and maintenance costs, dollars

RF1 and *RF2* are repair and maintenance factors.

P is machinery purchase price.

h is accumulated use of machine, hours.

An average annual repair and maintenance cost was determined by dividing accumulated repair and maintenance cost by the economic life of the machine.

3.2.5 Fuel and Lubrication Costs

An average fuel consumption was estimated as a function of pto horsepower and hours of use. Tractors consume approximately 0.22 liter of diesel fuel per pto kW-hour (0.044 gallons of diesel fuel per pto horsepower-hour) and trucks consume approximately 0.086 liter of fuel per engine kW-hour (0.017 gallons of fuel per engine horsepower-hour) for diesel engines (Bowers, 1992; ASAE, 1997b). An average fuel cost was estimated as a function of fuel use, hours and fuel price. Other lubrication costs, including engine oil and filters, were estimated as 10 percent of the average fuel costs (Bowers, 1992).

3.2.6 Labor

Labor costs were determined by the number of operators, hours of operation, and a wage rate. The default wage rate was ten dollars and the rate is variable. For parallel machine operations, one to three operators were chosen based on the operation. For irrigation and drag hose systems, the typical number of operators was two but there could be as many as deemed necessary.

3.3 Development of the Nutrient Management Model

Manure production was calculated based upon animal type and size. Manure nutrient content was estimated according to animal type and application method. Manure nutrients availability were compared with crop nutrient removal, nutrient losses, residual nutrients and purchased nutrients. Nutrients calculations were based on either nitrogen use or a phosphorus balance. The volume of manure was calculated based on the amount of the nitrogen removed in the first year for nitrogen use based application. The volume of manure was calculated based on the amount of the phosphorus removed in two years of crop growth for a phosphorus balanced application.

3.3.1 Manure production

The amount of manure produced and the nutrient content of the manure varied by animal type and size. Types of animals used were dairy cows, beef cows, swine, broilers and turkeys. Total manure production was calculated as the sum of manure produced and bedding used. The volume of manure production was calculated as the sum of manure dry matter, bedding dry matter and dilution water. The amount of bedding material was calculated based on the number and size of animals and the type of bedding used (Table 3.3). Dry matter content was 4 percent for liquid manure, 8 percent for slurry and 20 percent for solid manure.

Table 3.3 Bedding requirements for dairy cows.

Type of bedding	Bedding required		Density	
	[kg/day per 1000kg weight]	[lb/day per 1000lb weight.]	[kg/m^3]	[lb/ft^3]
Loose hay or straw	7.4	7.4	57	3.5
Chopped hay or straw	6.5	6.5	105	6.5
Shavings or saw dust	3.1	3.1	170	10.5
Sand or lime stone*	1.5	1.5	1540	95

Source: MWPS, 1985; * USDA, 1992

3.3.2 Manure Nutrient Content

Manure is a source of nitrogen, phosphorus, potassium and organic matter. Nutrient content in manure can be affected by moisture, handling method, application method, and days between spreading and incorporation. Nutrient losses occur while collecting, treating, and applying manure. Nitrogen can be lost by volatilization, leaching and denitrification. Nutrient losses can be estimated to assess the nutrient content available for crop growth.

Nitrogen is present in the soil in two forms, organic and inorganic forms. Mineralization rates vary depending on animal type and manure handling methods. Organic nitrogen must be mineralized or converted into an inorganic form before it is available for plant uptake. The rate of mineralization for organic nitrogen is mineralized at a rate of about 25 to 50 percent of the organic nitrogen present in the manure to estimate how much of this nitrogen will be available for the crop in the first crop year (Table 3.4). The amount of available organic nitrogen was estimated by the amount of organic nitrogen in the manure multiplied by a mineralization factor.

Table 3.4 Percentage of organic nitrogen mineralized in the first crop year.

Animal type	Manure handling	Mineralization factor
Dairy and beef cows	Solid without bedding	0.35
	Solid with bedding	0.25
	Anaerobic liquid	0.3
	Aerobic liquid	0.25
Swine	Fresh	0.5
	Anaerobic liquid	0.35
	Aerobic liquid	0.3
Broilers and Turkeys	Deep pit	0.45
	Solid with litter	0.3
	Solid without litter	0.35

Source: MWPS, 1985

The timing of manure incorporation affects nitrogen loss. Table 3.5 shows the potential amount of remaining ammonium nitrogen available depending on the soil conditions and application methods (MacKellar et al, 1996). Available nitrogen for the first crop year was calculated by adding the amount of available organic nitrogen, adjusted ammonium nitrogen and nitrate. The amount of nitrogen available in the second year was residual organic nitrogen available in the second year.

Nutrient losses for phosphorus and potassium were assumed minimal. Nutrient losses in storage can be accounted for by using an actual nutrient value based on a manure nutrient test.

The volume of manure applied, the land area needed and the available manure nutrients were calculated based on the nitrogen or phosphorus removal of the crops. Manure nutrient values were compared with crop nutrient removal. Manure was applied to meet crop nitrogen or phosphorus requirements. Unused phosphorus and potassium and organic nitrogen were allowed to remain in the soil as residual nutrients. Residual could be used for crop growth in the subsequent years.

Table 3.5 Ammonium nitrogen retention factors by application method and days to incorporation.

Application Method	**Percentage of nitrogen retain value**
Injection	100
Broadcast	
Days to incorporate	
0 - 1	70
2 - 3	40
4 - 7	20
7 or more	10

Source MacKellar et al 1996

3.3.3 Crop nutrient requirements

Crop nutrient requirements can be based on either crop nutrient removal or fertilizer recommendation, type of crop grown and yield expected nutrient availability. Nutrient removal is based on the nutrients a crop will remove from the soil during the growing season. In contrast, fertilizer recommendations based on a soil fertility test results to account for nutrient removal. In this model, nutrient requirements were based on the nutrient removal. Default yield goals are typical for Michigan (MASS, 1997; Christenson, 1997; Jones, 1997; Leep, 1997; Ward, 1997) and these values are variable (Table 3.6).

Table 3.6 Crop yield goals and nutrient removal

Crop Type	Dry matter	SI Units					English Units				
		Yield goal		Nutrient removal N	P_2O_5	K_2O	Yield goal		Nutrient removal N	P_2O_5	K_2O
	[%]		Units	[kg/ha]				Units	[lb/ac]		
Alfalfa, hay	82.5	13	t/ha	282	67	303	6	ton/acre	252	60	270
Alfalfa, wilted silage	32	34	t/ha	235	54	202	15	ton/acre	210	48	180
Barley, grain	90	5220	L/ha	59	26	17	60	bu/acre	53	23	15
Barley, grain & straw	90	5220	L/ha	74	29	75	60	bu/acre	66	26	67
Clover grass, hay	82.5	5	t/ha	230	73	219	5	ton/acre	205	65	195
Corn, grain	84.5	10440	L/ha	121	47	36	120	bu/acre	108	42	32
Corn, silage	30	45	t/ha	210	81	175	20	ton/acre	188	72	156
Dry beans	82	2	cwt/ha	73	25	33	18	cwt/acre	65	22	29
Oats, grain	90	5220	L/ha	41	17	12	60	bu/acre	37	15	11
Oats, grain & straw	90	5220	L/ha	71	24	140	60	bu/acre	63	21	125
Rye. grain	98.5	3220	L/ha	46	17	13	37	bu/acre	41	15	12
Rye, grain & straw	91	3220	L/ha	61	24	48	37	bu/acre	54	21	43
Soybeans	82	5480	L/ha	170	39	63	40	bu/acre	152	35	56
Sugar beets, roots	35	43	t/ha	85	28	71	19	ton/acre	76	25	63
Wheat, grain	87	5220	L/ha	81	41	26	60	bu/acre	72	37	23
Wheat, grain & straw	90	5220	L/ha	103	47	64	60	bu/acre	92	42	57

Source: Christenson et al, 1992

3.3.4 Residual and Purchased nutrients

Residual nutrients were nutrients applied in excess of crop requirements. Residual nutrients were calculated as the differences between the nutrients applied and crop nutrient removal. Purchased nutrients were applied when nutrients from manure were not adequate for crop removal. Purchased nutrients were calculated as nutrients required for crop growth minus nutrients available from the manure.

3.4 Program structure

The program consists of six main modules (Figure 3.1). Each module was independent. Data files were created in the input module and the information was stored. The edit module allowed the changing of existing information. The output module reported input parameters by displaying on a monitor, printing or saving to a file. All these modules were listed in the main menu.

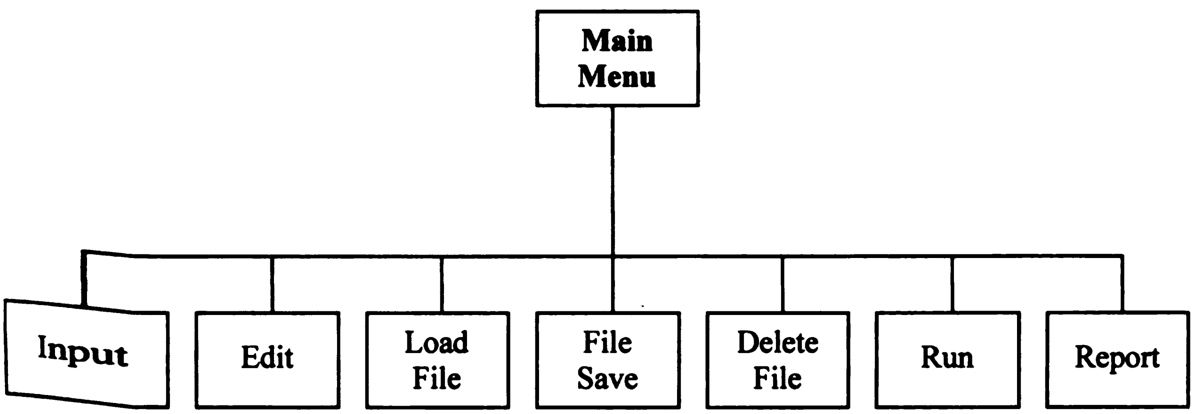

Figure 3.1 Model structure, main frame

3.4.1 Input

The input module creates data files and stores farm operation information. This module is accessible from the main menu. The structure of this module is shown in Figure 3.2. From the input menu, the user can access the four sub modules: animal and crop information, machinery information, storage and parameters.

Parameters are coefficients used for calculations including a list of repair and maintenance coefficients, fuel consumption, travel speed, loading and unloading time, maneuvering time, and price coefficients. These parameters need not be changed; however, the user can review these parameters and change them, if necessary.

3.4.2 Edit

The edit module is used to make minor changes in farm data. This module has a parallel structure so the user can reach this screen directly from two levels of the edit menu (Figure 3.3). The first level indicates information -- machinery, storage or parameters -- that can be changed. The second level allows accessing each screen directly.

Table 3.7 List of input information and parameters.

	Default value	Other options	Input type
Manure and crop information			
Type of bedding	None	Listed in Table 3.3	listed
Animal type	Dairy cow	Beef cow, swine, broiler, turkey	Listed items
Number of animals	---	---	Integer
Animal average weight	640 kg (1,400 lb)	---	Integer
Dry matter produced	---		Calculated, variable.
Dry matter content	6 %	---	Variable
Manure produced	---		Calculated, variable
Manure handling method	---	Listed in Table 3.4	listed
Application method	---	Injection, irrigation	Listed
Days to incorporate	---	Listed in Table 3.5	Listed
Manure Composition	---	---	Calculated, variable
Crop information			
Crop sequences	Alfalfa hay	Listed in Table 3.6	Listed
Yield goal	13 t/ha (6 ton/ac)	Listed in Table 3.6	Listed, variable
Machinery information			
Hauling method	---	Listed in Table3.1	Listed
Machinery size	---	---	Integer
Number of machinery	---	---	Integer
Average Hauling distance	---	---	Integer
Pine line length (irrigation and drag hose)	---	---	Integer
Fitting and supplies (Irrigation and drag hose)	$1,000	---	Integer
Pipe trailer (Irrigation and drag hose)	$1,000	---	Integer
Pump information			
Number of pumps	---	---	Integer
Pump price	---	---	Integer
Number of tractors	---	---	Integer
Tractor size	---	---	Integer
Number of traveler (Irrigation)	---	---	Integer
Traveler price (irrigation)	$3,000	---	Integer
Swath width (Drag hose)	3 m (10 ft)	---	Integer
Number of injectors	6 shawks	---	Integer
Injector price	$8,000	---	Integer
Economic information			
Labor wage rate	$10	---	Integer
Diesel fuel price	$1.0	---	Integer
Nutrient price N	$0.24	---	Integer
P2O5	$0.24	---	Integer
K2O	$0.14	---	Integer
Real interest rate	6 %	---	Integer
Economic life			
Structure	20 years	---	Integer
Tractor	10 years	---	Integer
Spreaders	7 years	---	Integer
Pump/agitator	7 years	---	Integer

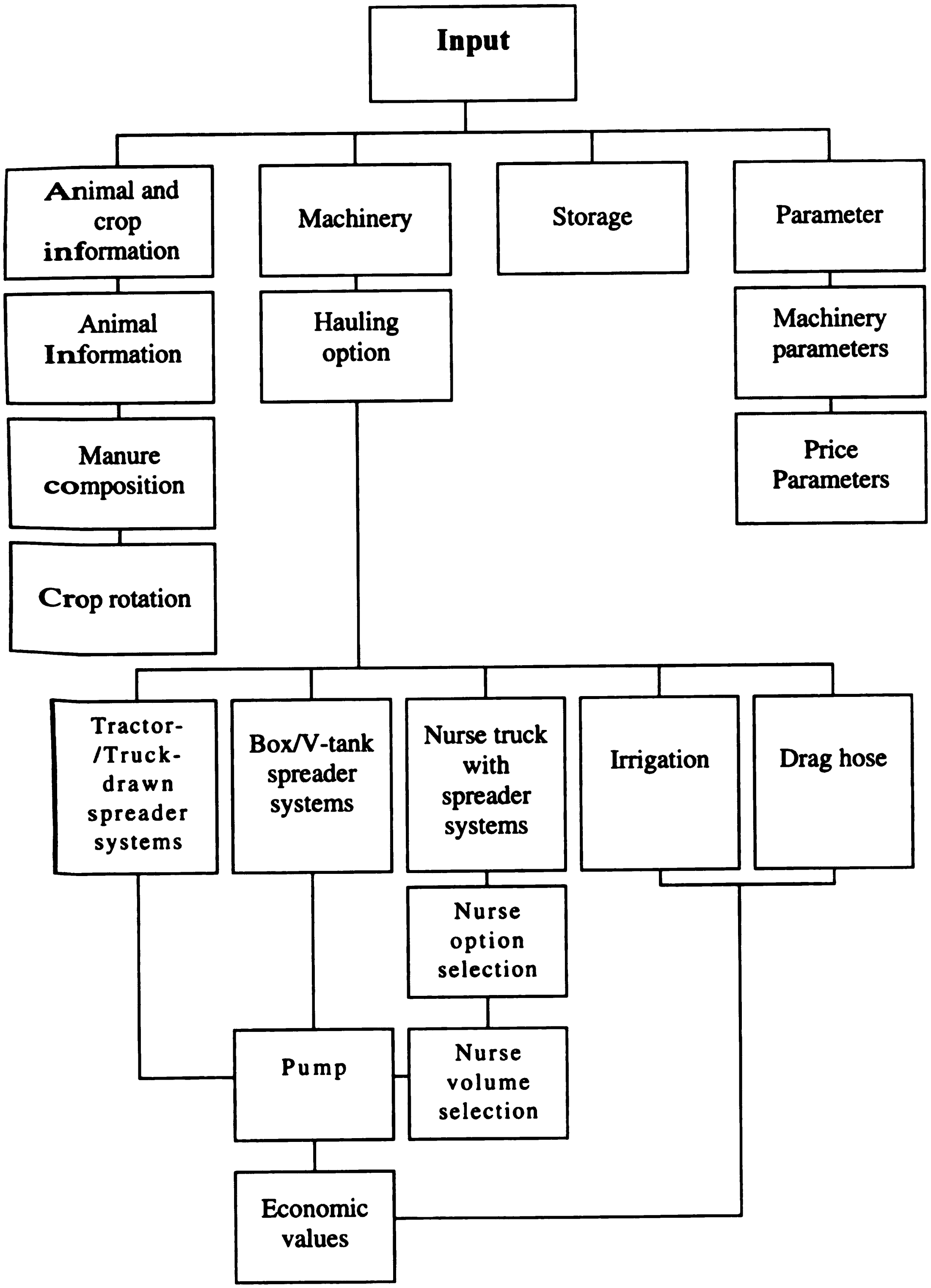

Figure 3.2 Input sub-module structure

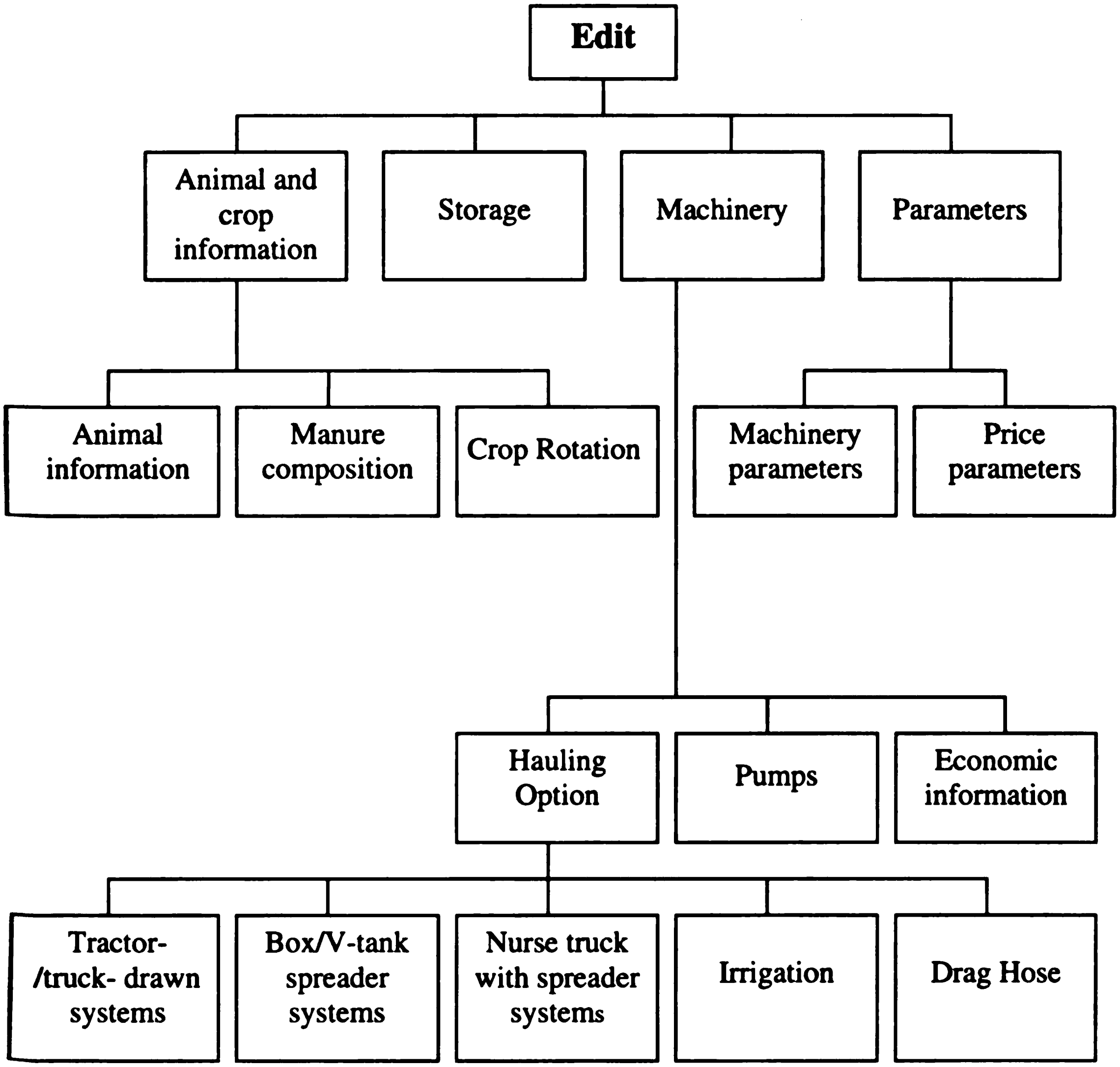

Figure 3.3 Edit sub-module structure

3.4.3 Files

There are three file operation sub modules: save, load and delete files. Once data files are created, the user can save these files with the user name defined. The user defined data files have a .MCP extension at the end of the file name. The save file module creates the user defined data files. The load file module retrieves the data files. The delete module erases the module from the hard disk.

3.4.4 Calculation

The calculation module includes all the calculations for determining values. Data files are generated in the module and redistributed to sub modules for calculation. There are five sub-modules: (1) manure production, (2) crop nutrient balance and manure credits, (3) machinery ownership costs, (4) machinery operating costs and (5) total and units costs (Figure 3.4).

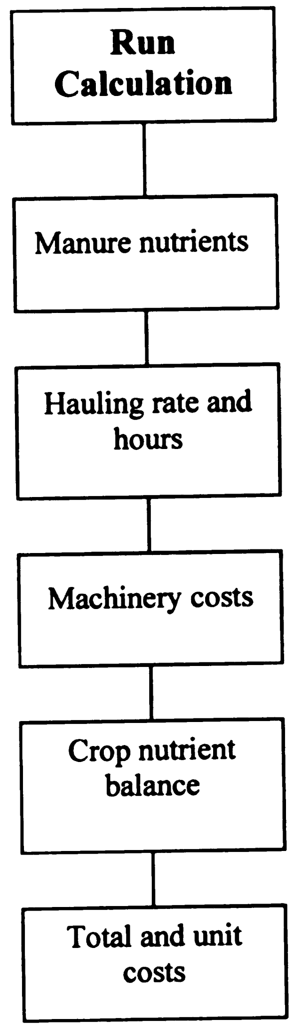

Figure 3.4 Calculation sub-module structure

3.4.5 Report (output)

The output module has four report options: (1) input parameters, (2) machinery report, (3) crop and nutrient report, (4) and all reports (figure 3.5). At the first output menu the user selects an output option including display monitor, printer or saving to a file.

The input parameters report is a summary of machinery, crop, animal and storage information specified for the analysis. The other two options, machinery report and crop and nutrient report, are the calculated values of the analysis. The machinery reports include detailed information of the ownership and operating costs for each machine. The crop nutrient report includes the nutrient balance sheet for nitrogen and phosphorus for one or two crop rotations. It also includes a summary of machinery costs, fertilizer values, manure nutrients and net unit costs.

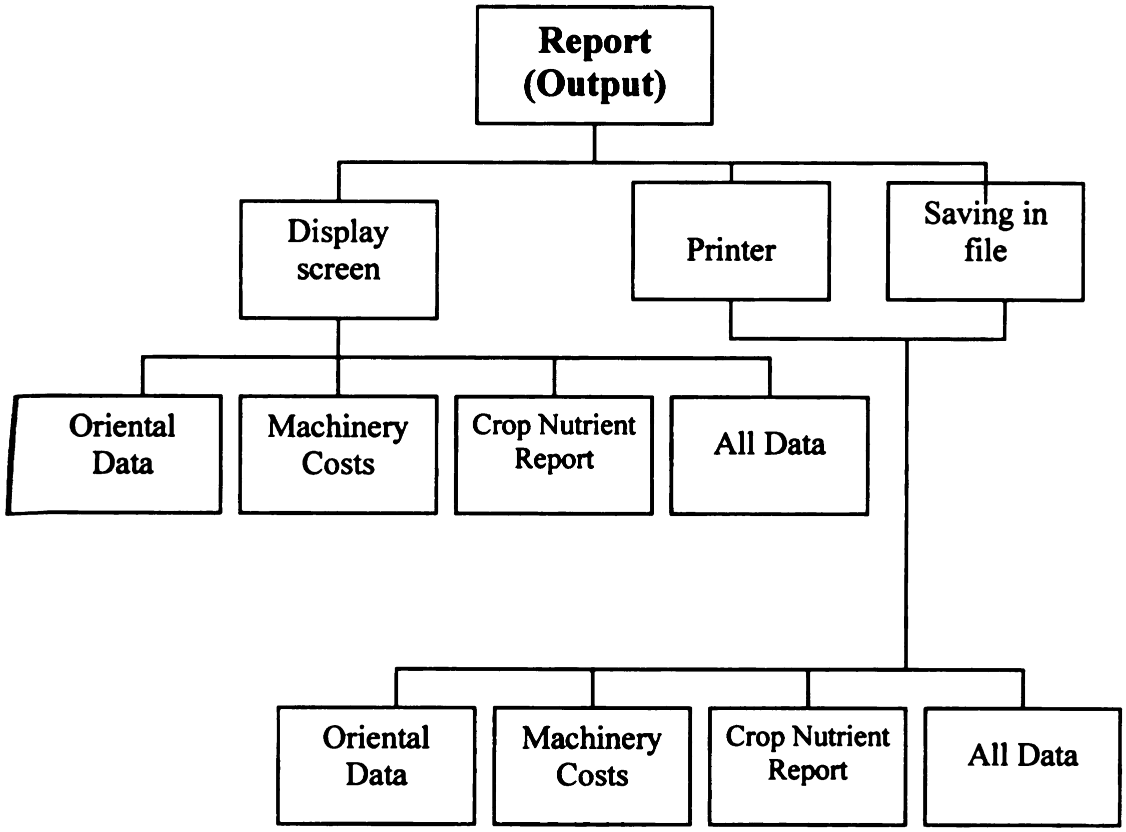

Figure 3.5 Output sub-module structure

Chapter 4

PROCEDURE

An objective of this study was to develop a computer program to evaluate and compare manure transport and application systems. Machinery systems compared include a tractor-drawn tank spreader, box spreader, v-tank spreader, nurse truck with spreader tank, irrigation and a drag hose system. Eight systems were modeled and compared on two representative farms. Four crop sequences were compared to evaluate manure nutrient use. The representative farms were 150 and 600 dairy cows. The range in hauling distance for the tractor and truck drawn systems was 0 to 16 km (0 to 10 miles) and the pumping distance for the irrigation and drag hose systems was 0 to 4.8 km (0 to 3 miles).

4.1 Herd information

The average weight of the cow was 640 kg (1,400 lb) and all animals were assumed to be mature. The size of farm for comparison of the tractor-drawn tank spreader, V-tank spreader and box spreader was 150 cows. A representative herd of 600 cows was used to compare the tractor-drawn and truck-drawn spreader tank, the nurse truck with spreader tank, the irrigation and the drag hose systems. Total solids content was four percent for the irrigation and the drag hose systems, eight percent for the tank spreader systems, twelve percent for the V-tank and twenty percent for the box spreader system. Total production of manure was calculated from raw manure production and bedding material. Chopped straw was selected as bedding.

4.2 Machinery selection

Machinery was divided into three groups based on hauling method and herd size. The first group included a 3,500-gallon tank spreader, a 2,000-gallon V-tank spreader and a 250-bu box spreader (Table 4.1). The second group consisted of two 3,500-gallon spreader tanks working in series, and a 7,000-gallon nurse truck and a 3,500-gallon spreader tank working in parallel (Table 4.2). The third group included an irrigation and drag hose system (Table 4.3, Table 4.4). For the irrigation system, a pto powered pump and tractor were used to transfer manure from storage-to-field. Auxiliary pumps were added at 2 km (1.25 miles) and 4 km (2.5 miles) to increase discharge pressure. A chopper pump was used at the storage pit to ensure a homogenous mixture of manure. For the drag hose system, a pto powered pump and tractor were used to transfer manure to the field with an auxiliary pump added to increase the pressure at 3.2 km (2 miles).

Table 4.1 Manure production, equipment size and price for tank spreader, V-tank spreader and box spreader systems for a representative 150 dairy cow operation.

Equipment	Size		Price
	SI Unit	English Unit	
Tank spreader			
Total manure production	7,900 m^3	(2,082,600 gal)	
Total solid content	8%		
Tractor	105 kW	(140 hp)	$77,000
Spreader tank	13,200 L	(3,500 gal)	$12,500
Lagoon pump			$11,000
Tractor for pump	75 kW	(100 hp)	$55,000
V-tank spreader			
Total manure production	5200 m^3	(1,388,400 gal)	
Total solid content	12 %		
Tractor	67 kW	(90 hp)	$49,500
V-tank spreader	7,600 L	(2,000 gal)	$18,600
Front-end loader	0.67 m^3	(24 ft^3)	$6,000
Tractor	56 kW	(75 hp)	$41,250
Box spreader			
Total manure production	3100 m^3	(90,000 bu)	
Total solid content	20 %		
Tractor	56 kW	(75 hp)	$41,250
Box spreader	8.8 m^3	(250 bu)	$7,900
Front-end loader	0.67 m^3	(24 ft^3)	$6,000
Tractor	56 kW	(75 hp)	$41,250

Table 4.2 Manure production, equipment size and price for the tractor-drawn tank spreader, truck-drawn tank spreader, and nurse truck and tank spreader combination systems for a representative 600 dairy cow operation.

Equipment	Size		Price
	SI Unit	English Unit	
Total manure production	31,500 m^3	(8,330,500 gal)	
Total solid content	8 %		
Tractor drawn spreaders			
Tractor (2)	105 kW	(140 hp)	$77,000
Spreader tank (2)	13,200 L	(3,500 gal)	$12,500
Pump/agitator	Large		$11,000
Tractor for pump	75 kW	(100 hp)	$55,000
Truck-drawn spreaders			
Truck (2)	105 kW	(200 hp)	$20,000
Spreader tank (2)	13,200 L	(3,500 gal)	$12,500
Pump/agitator	Large		$11,000
Tractor for pump	75 kW	(100 hp)	$55,000
Nurse/ spreader combination			
Nurse truck	26,400 L	(7,000 gal)	$20,000
Tractor	105 kW	(140 hp)	$77,000
Spreader tank	13,200 L	(3,500 gal)	$12,500
Pump/agitator	Large		$11,000
Tractor for pump	75 kW	(100 hp)	$55,000

Table 4.3 Manure production, equipment size and price for drag hose system for a representative 600 dairy cow operation.

Equipment	Size		Price
Drag hose			
Total manure production	63,000 m^3	(16,661,100 gal)	
Total solid content	4%		
6 in Al Main line	Distance from storage to field		$3.25/ft
6 in Flex supply line	805 m	2640 ft	$23,760
6 in suction hose	7.6 m	25 ft	$375
5 in drag hose	201 m	660 ft	$7,920
Fittings and supplies			$1,000
Pipe trailer			$1,000
Hydraulic chopper pump			$3,000
PTO pump			$5,000
Tractor(s) for pump	93 kW	125 hp	$68,750
Injectors	6 shanks		$8,000
Tractor for injectors	157 kW	(210 hp)	$115,500

Table 4.4 Manure production, equipment size and price for irrigation system for a representative 600 dairy cow operation.

Equipment	Size		Price
Irrigation			
Total manure production	63,000 m^3	(16,661,100 gal)	
Total solid content	4%		
6 in Al Main line	Distance from storage to field		$3.25/ft
6 in Flex supply line	805 m	2640 ft	$23,760
6 in suction hose	7.6 m	25 ft	$375
5 in supply hose	201 m	660 ft	$5,280
Fittings and supplies			$1,000
Pipe trailer			$1,000
PTO pump			$5,000
Tractor(s) for pump	93 kW	125 hp	$68,750
Hydraulic chopper pump			$3,000
Motorized traveler		(1320 ft hose)	$20,000

4.3 Machinery parameters

Cycle time included loading and unloading time, traveling time and maneuvering time. Traveling speeds varied depending on the tractor or truck was used (Table 4.5). The representative loading and unloading rate used for pumping were 4,900 L/min (1,300 gpm) (Table 4.6). Loading rate for front-end loaders for V-tank and box spreaders was assumed to be 20 seconds per bucket. Unloading rate for the box spreader was assumed to be 4 minutes. Unloading rate for the V-tank spreader was 3,400 L/min (900 gpm). The field efficiency used for each operation was 0.90 for surface application systems. The efficiency for drag hose injection was 0.85.

Table 4.5 Representative of truck and tractor travel speeds

	Tractor			**Truck**	
	Travel speed km/hr (mph)			Travel speed km/hr (mph)	
Transport distance	Loaded	Empty	Transport distance	Loaded	Empty
≤ 0.8 km	19	23	≤ 1.6 km	32	42
≤ 0.5 mi	(12)	(14)	≤ 1.0 mi	(20)	(26)
> 0.8 km	23	27	> 1.6 km	40	50
> 0.5 mi	(14)	(17)	> 1.0 mi	(25)	(31)

Source: Harrigan, 1997

Table 4.6 Representative time of and material flow rates.

Parameters	Value
Loading/unloading time	
Loading rate	
with pump	4,900 L/min (1,300 gpm)
with loader	0.33 min/bucket
Unloading rate	
Tank spreader	4,900 L/min (1,300 gpm)
V-tank spreader	3,400 L/min (900 gpm)
Box spreader	4 min/load
Maneuvering time	
Storage to road	2 min
Road to storage	2 min
Road to start of spreading	2 min
End of spreading to road	2 min
Nurse truck hook up time	1min
Nurse truck road to unloading	2 min
Tractor field to hook up	1 min

Source: Harrigan 1997

Table 4.7 Machinery parameters

	Repair and maintenance		Economic life
Equipment type	RF1	RF2	[yr]
Tractor	0.0069	2.0	10
Spreader	0.26	1.8	7
Pump/Agitators	0.056	2.0	7

Source: ASAE, 1997a

4.4 Economic parameters

Average annual ownership and operating costs were calculated using a period of 10 years for tractors and 7 years for other equipment (Table 4.7). Remaining values of tractors, spreaders and loaders were calculated based on the Cross and Perry model (1996). Remaining value for pumps was 30 percent of purchased price. Real interest rate was six percent and insurance and housing was estimated as one percent of the purchase price. Repair and maintenance costs were based on accumulated use. Fuel and lubrication costs and labor were based on hours of use and diesel fuel price was one dollar per gallon. Labor wage was ten dollars per hour. Nutrient prices were recent value in Michigan (LeCueux, 1997).

Table 4.8 Economic parameters

Economic values		
Real interest rate		6 %
Insurance and housing rate		1 % of purchase price
Labor wage rate		10.00 $/hr
Diesel fuel price		1.00 $/gal
Nutrient purchase price	N	0.24 $/lb
	P_2O_5	0.24 $/lb
	K_2O	0.14 $/lb

4.5 Crop information

Nutrient use for four crop sequences was compared. The first rotation was corn silage and corn grain. The second rotation was wheat grain and corn grain. The third was sugar beet and corn grain. The fourth was alfalfa hay and alfalfa hay. Nutrient requirements were estimated based on crop nutrient removal (Table 3.5). Yield goals were 10,440 L/ha (120 bu/ac) for corn (grain), 45 t/ha (20 ton/ac) for corn (silage), 5220 L/ha (60 bu/ac) for wheat (grain); 45 t/ha (19 ton/ac) for sugar beets, and 13 t/ha (6 ton/ac) for alfalfa hay. These are average yields for Michigan.

Chapter 5

RESULTS AND DISCUSSION

The proposed machinery and nutrient management model is a useful tool for comparing the hauling rate and cost of commonly used manure hauling systems. To illustrate the ability of the model to describe and compare a range of manure hauling operations, three spreader tank systems were compared on 150- and 600-cow dairies. Irrigation and drag hose systems were also compared on the 600-cow farm. Four, two-year crop sequences were compared to demonstrate nutrient application for nitrogen use and a phosphorus balance

5.1 Comparison of Manure Hauling Cost and Resource Use

A manure hauling rate was calculated based on cycle time. Cost information was estimated based on machinery requirements and hours of use and included machinery ownership, repair and maintenance, fuel and lubrication, and labor. Trade-ins, timeliness costs and income taxes were not included.

5.1.1 Manure hauling rate

On the 150-cow operation the hauling rates decreased as hauling distance increased. Since loading, unloading time and maneuvering time didn't change with the hauling distance, the decline in hauling rate was due to increased traveling time. The material hauling rate of the 3,500-gallon tank spreader was almost twice that of the V-tank spreader and box spreader, but the hauling rates were similar when compared on a dry matter basis (Figure 5.1, 5.2).

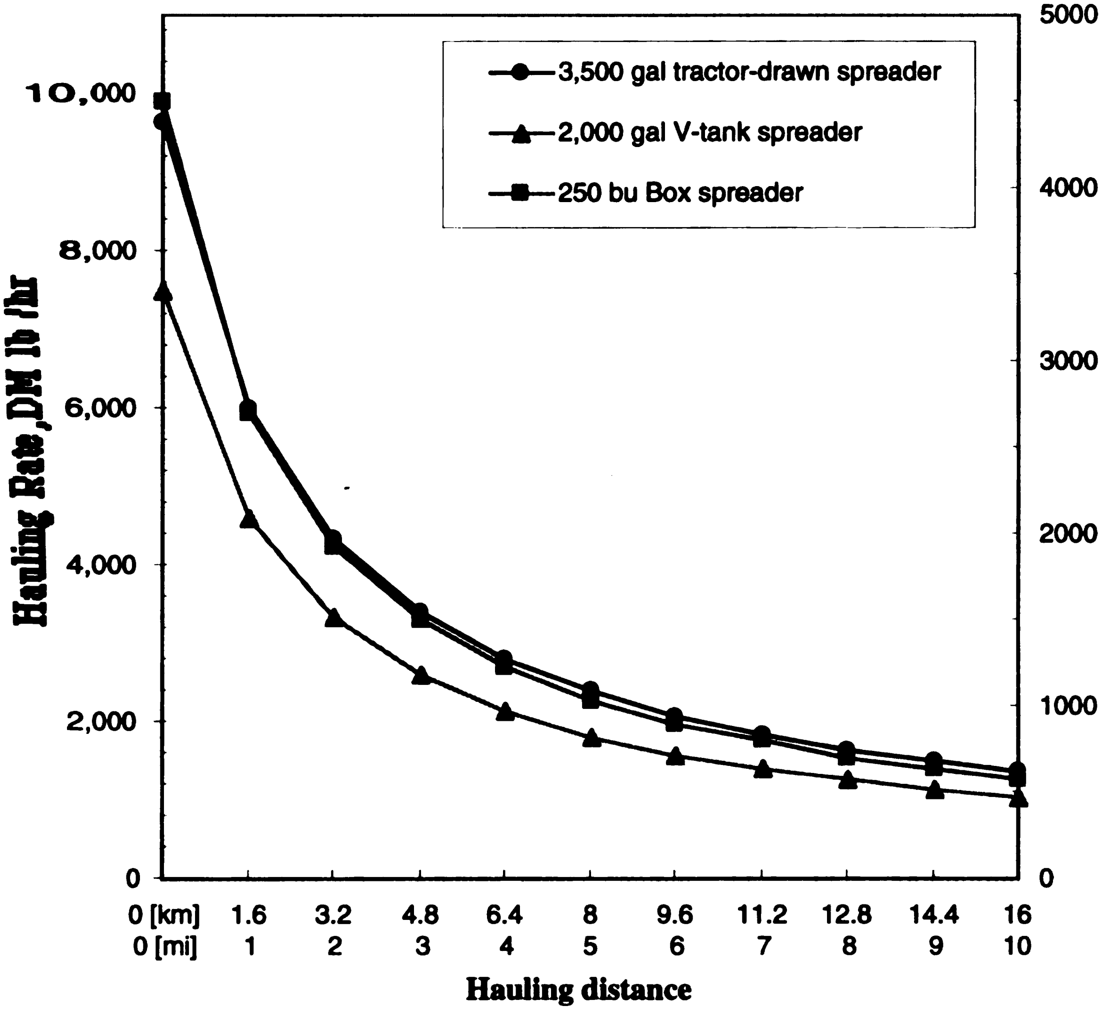

Figure 5.1 Comparison of hauling rate (DM kg/hr and DM lb/hr) of a 2000-gallon v-tank spreader, a 250-bu box spreader and a 3500-gallon tank spreader for a 150-cow operation.

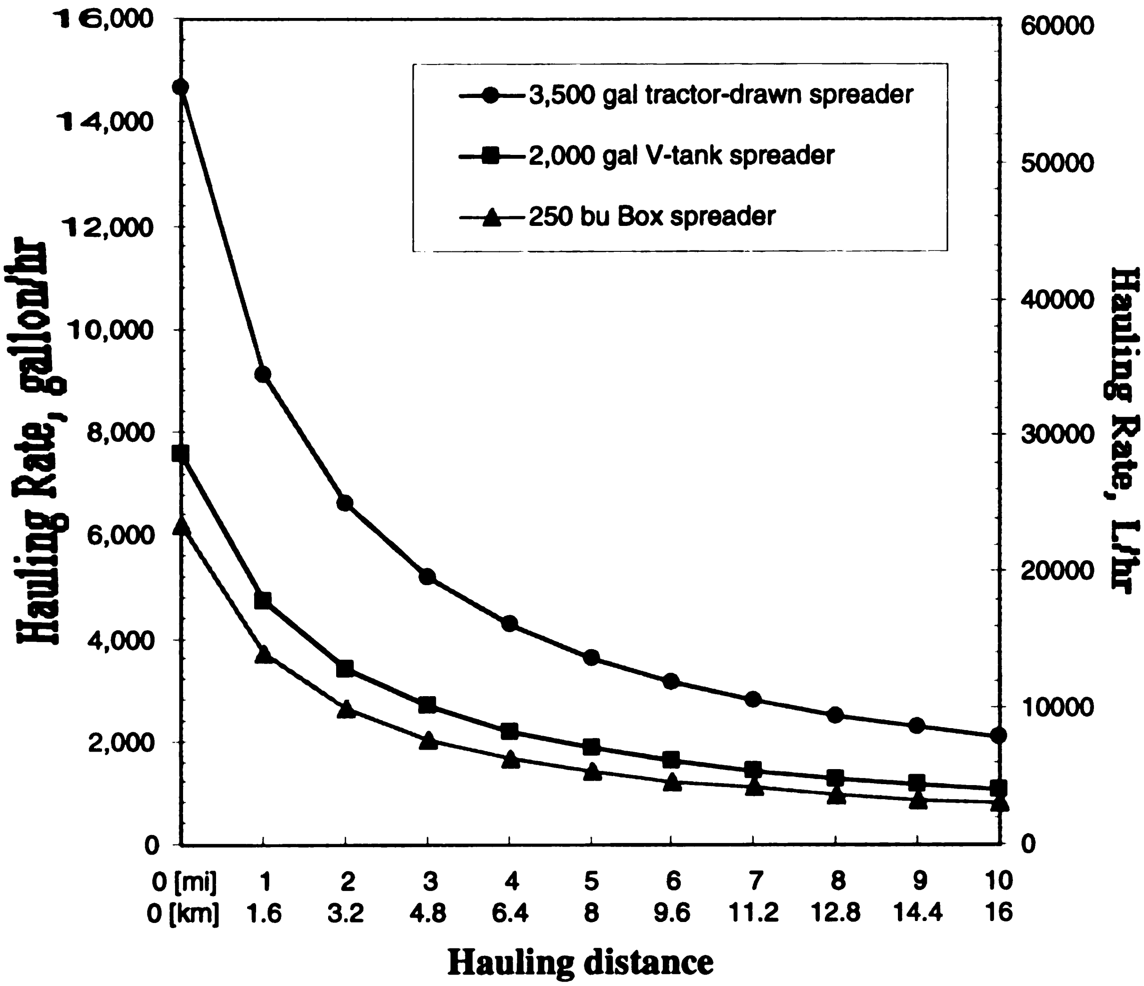

Figure 5.2 Comparison of actual hauling rate of a 2000-gallon v-tank spreader, a 250-bu box spreader and a 3500-gallon tank spreader for a 150-cow operation.

The hauling rate for a nurse truck system was constant over 6.4 km (4 mile) before starting to decline (Figure 5.3). Over this range (0 to 6.4 km), the spreading time of the spreader tank limited the cycle time of the system. Beyond 6.4 km (4 mile), nurse trucks required more time to travel from storage to the field and the spreader had to wait for a nurse truck. The difference in hauling rate between the tractor- and truck- drawn spreader tank was due to travel speed. The truck-drawn spreader tank had an advantage since the travel speed was faster (Table 5.1).

The effective spreading rate of the irrigation system was 93,400 liters per hour (24,680 gal/hr) or 3,680 DM kg per hour (8,100 DM lb/hr). The spreading rate of the drag hose system was 88,500 liters per hour (23,390 gal/hr) or 3,490 DM kg per hour (7,680 DM lb/hr) (Table 5.1). The manure flow rates for the irrigation and the drag hose system was 1,890 L/min (500 gpm). The drag hose system covered 8.1 hectares (20 acres) and irrigation covered 3.4 hectares (8.3 acres)

per hose set. Irrigation needed to reset the system more frequently than the drag hose system and this increased application time.

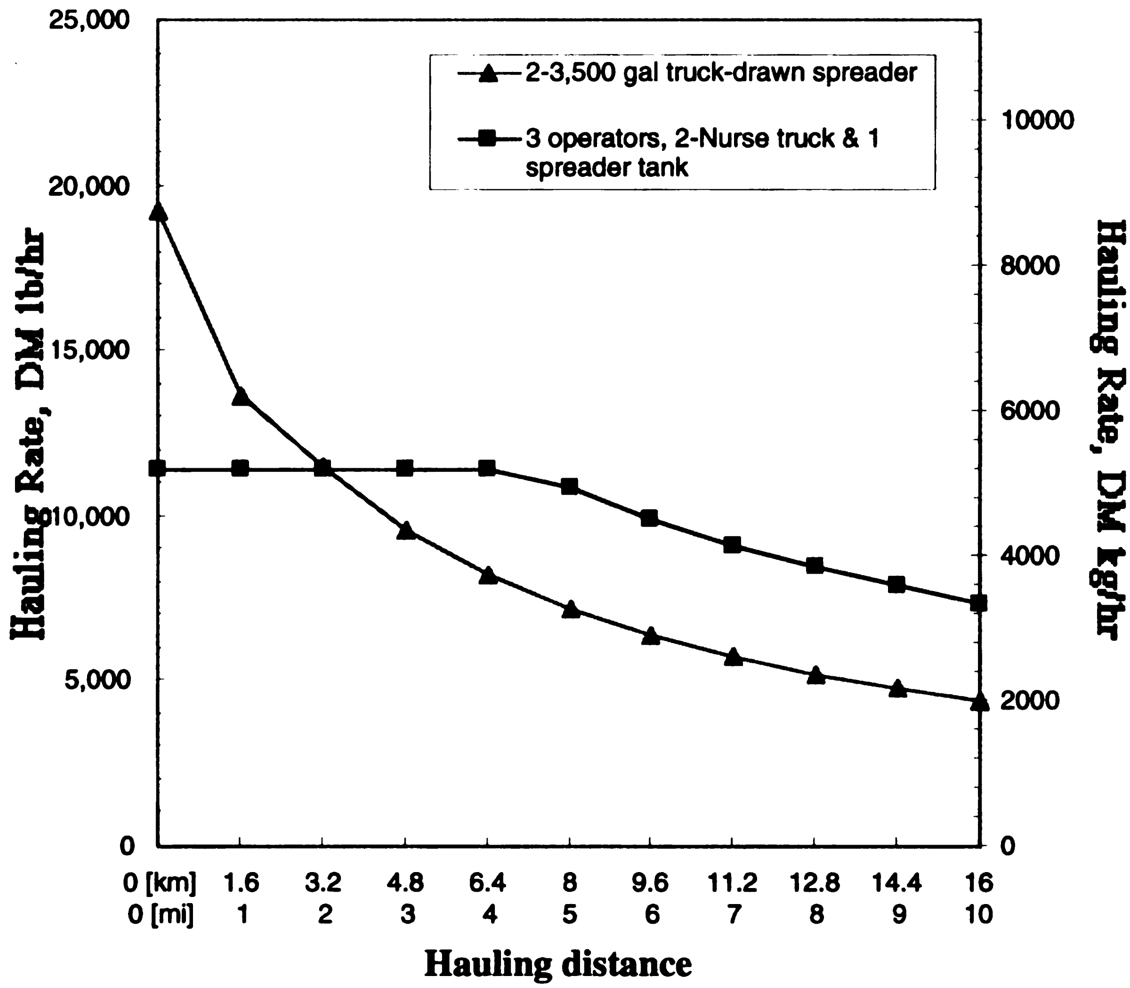

Figure 5.3 Comparison of hauling rates (DM kg/hr and DM lb/hr) for 2-3,500 gallon truck-drawn spreader tanks and 3-operator nurse-spreader combination for a 600-cow operation.

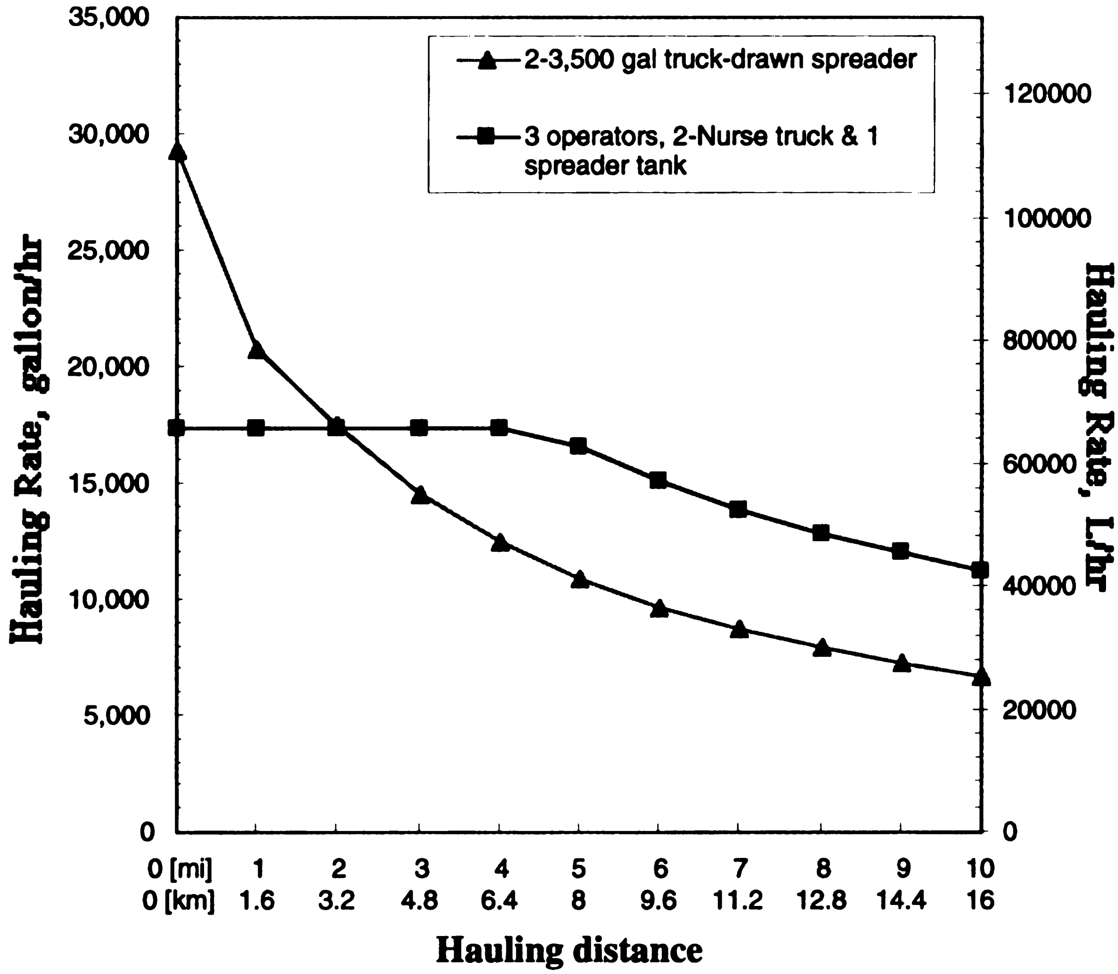

Figure 5.4 Comparison of actual hauling rate for 2-3,500 gallon truck-drawn spreader tanks and 3-operator nurse-spreader combination for a 600-cow operation.

Table 5.1 Comparison of hauling rates over a range of transport distance.

		Average Hauling Distance			
	[km]	1.6	4.8	8.0	16
	[mi]	1	3	5	10
150 cow operations					
3,500 gal tractor-drawn spreader	L/hr	34,600	19,700	13,700	7,800
	gal/hr	9,100	5,200	3,600	2,100
	DM kg/hr	2,720	1,550	1,080	620
	DM lb/hr	6,000	3,420	2,390	1,360
2,000 gal V-tank spreader	L/hr	17,900	10,100	7,100	4,000
	gal/hr	4,700	2,700	1,900	1,100
	DM kg/hr	2,110	1,200	840	470
	DM lb/hr	4,650	2,640	1,840	1,050
250 bu box spreader	L/hr	14,100	7,800	5,400	3,000
	Bu/hr	667	221	154	86
	DM kg/hr	2,770	1,540	1,070	600
	DM lb/hr	6,110	3,380	2,350	1,310
600 cow operations					
2-3,500 gal tractor-drawn spreaders	L/hr	69,100	39,400	27,500	15,700
	gal/hr	18,300	10,400	7,300	4,200
	DM kg/hr	5,450	3,100	2,170	1,240
	DM lb/hr	12,000	6,830	4,780	2,730
2-3,500 gal truck-drawn spreaders	L/hr	78,600	55,200	41,400	25,400
	gal/hr	20,800	14,600	10,900	6,700
	DM kg/hr	6,200	4,350	3,260	2,000
	DM lb/hr	13,650	9,590	7,180	4,420
3 operators, 2-Nurse truck & 1 spreader tank	L/hr	65,700	65,700	62,700	42,500
	gal/hr	17,400	17,400	16,600	11,200
	DM kg/hr	5,180	5,180	4,940	3,350
	DM lb/hr	11,400	11,400	10,800	7,380
Irrigation	L/hr	93,400	93,400	–	–
	gal/hr	24,680	24,680	–	–
	DM kg/hr	3,680	3,680	–	–
	DM lb/hr	8,100	8,100	–	–
Drag hose	L/hr	88,530	88,530	–	–
	gal/hr	23,390	23,390	–	–
	DM kg/hr	3,490	3,490	–	–
	DM lb/hr	7,680	7,680	–	–

5.1.2 Machinery Ownership Costs

Total ownership costs for the 150-cow operation (Table 5.2) with the 3,500-gallon tank spreader increased from $13,780 to $17,370 from a hauling distance of 1.6km (1 mile) to 16 (10 mile). The ownership costs for 2,000-gallon V-tank spreader ranged from $12,300 to $13,930. The ownership costs for 250-bu box spreader increased from $9,920 to $11,350. This increase in ownership cost was due to higher depreciation costs with increased use. The remaining value of the machinery decreased with increasing hours of use.

Machinery ownership costs for the 600-cow operation (Table 5.3) with 2-3,500 gallon truck-drawn spreaders were the lowest. Using more tractors for the operation costs more than using trucks to transport.

The ownership costs for the irrigation and drag hose equipment increased as the pumping distance increased because the system required additional pumps to maintain the discharge pressure. The costs for irrigation were higher because this system required more auxiliary pumps to maintain higher system pressure (Table 5.4). Therefore, ownership costs for pumps were higher than these for a drag hose system. The number of the tractors used in both irrigation and the drag hose systems was the same, but the drag hose system required a larger tractor for injection.

5.1.3 Repair and Maintenance Costs

The highest repair and maintenance cost for the 150-cow operation was the V-tank spreader. The cost was 2.5 times higher than the tank spreader and 4 times higher than the box spreader. Other differences were in loading equipment. Using a pump and a tractor for loading lead to higher repair and maintenance costs than using a loader.

The tractor-drawn spreader had the highest repair and maintenance costs for the 600-cow operation (Table 5.3). At the 16 km (10 mile) hauling distance, the repair and maintenance cost for the tractor-drawn system was nearly eight times higher than the nurse truck operation and the cost for the truck-drawn system was about three times higher than the nurse truck operation. The repair and maintenance costs for tractor- or truck-drawn systems increased rapidly beyond 3 miles. The costs for nurse truck with spreader increased beyond 5 miles.

The repair and maintenance costs increased with pumping distance for both irrigation and drag hose systems. This difference in costs was due to the additional tractors needed to maintain the discharge pressure. At 4.8 km (3 mile), irrigation had higher pump and agitator costs because it required three pumps instead of the two pumps of the drag hose system (Table 5.4).

Table 5.2 Comparison of ownership and repair and maintenance costs for a 150-cow operation at 1, 4.6, 8 and 16 km (1,3,5 and 10 miles) of hauling distance

Equipment		3,500 gal tank spreader				2,000 gal V-tank spreader				250 bu box spreader			
		1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi	1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi	1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi
Ownership costs													
Tractors	$	6,100	6,890	7,410	8,190	4,140	4,670	5,000	5,480	3,250	3,700	3,980	4,410
Trucks	$	0	0	0	0	0	0	0	0	0	0	0	0
Manure Spreaders	$	1,690	1,690	1,690	1,690	2,520	2,520	2,520	2,520	1,070	1,070	1,070	1,070
Pumps/Agitators	$	1,640	1,640	1,640	1,640	0	0	0	0	0	0	0	0
Tractors for pumps	$	4,350	4,920	5,290	5,850	0	0	0	0	0	0	0	0
Front-end loaders	$	0	0	0	0	5,640	5,720	5,790	5,930	5,600	5,680	5,740	5,870
Total ownership costs	$	13,780	15,140	16,030	17,370	12,300	12,910	13,310	13,930	9,920	10,450	10,790	11,350
Repair & maintenance													
Tractors	$	640	1,490	2,650	6,950	600	1,440	2,630	7,090	330	810	1,460	3,900
Trucks	$	0	0	0	0	0	0	0	0	0	0	0	0
Manure Spreaders	$	1,080	2,960	5,630	15,400	2,530	7,000	13,300	36,700	660	2,750	3,680	10,200
Pumps/Agitators	$	220	690	1,410	4,340	0	0	0	0	0	0	0	0
Tractors for pumps	$	460	1,060	1,900	4,960	0	0	0	0	0	0	0	0
Front-en d loaders	$	0	0	0	0	280	870	1,790	5,500	160	790	1,100	3,460
Total Repair & Maintenance	$	2,400	6,200	11,590	31,650	3,410	9,310	17,720	49,290	1,150	4,350	6,240	17,560

Table 5.3 Comparison of an ownership and repair and maintenance costs for a 600-cow operation at 1, 4.6, 8 and 16 km (1,3,5 and 10 miles) of hauling distance

Equipment		2-3,500 gal tractor-drawn spreaders				2-3,500 gal truck drawn spreaders				3-operators, 2-nurse trucks and 1-spreader			
		1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi	1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi	1.6 km 1 mi	4.6 km 3 mi	8 km 5 mi	16 km 10 mi
Ownership costs													
Tractors	$	15,100	16,800	17,900	19,300	0	0	0	0	7,150	7,150	7,220	7,780
Trucks	$	0	0	0	0	4,810	4,860	4,910	5,010	4,440	4,440	4,470	4,710
Manure Spreaders	$	3,370	3,370	3,370	3,370	3,370	3,370	3,370	3,370	1,690	1,690	1,690	1,690
Pumps/Agitators	$	3,280	3,280	3,280	3,280	3,280	3,280	3,280	3,280	3,280	3,280	3,280	3,280
Tractors for pumps	$	10,100	11,200	11,900	12,900	9,850	10,500	11,100	12000	10,200	10,200	10,300	11,100
Front-end loaders	$	0	0	0	0	0	0	0	0	0	0	0	0
Total ownership costs	$	31,850	34,650	37,450	38,850	21,310	22,010	22,660	23,660	26,760	26,760	26,960	28,560
Repair & maintenance													
Tractors	$	3,930	10,000	18,800	52,600	0	0	0	0	1,990	1,990	2,150	4,110
Trucks	$	0	0	0	0	3,210	4,570	6,090	9,920	3,840	3,840	4,020	5,930
Manure Spreaders	$	7,480	20,600	39,200	107,600	5,930	11,100	18,800	45,200	4,100	4,100	4,460	8,980
Pumps/Agitators	$	1,800	5,530	11,300	34,700	1,390	2,810	5,000	13,200	1,990	1,990	2,180	4,750
Tractors for pumps	$	2,620	6,690	12,500	35,100	2,130	3,770	6,140	14,400	2,840	2,840	3,070	5,870
Front-end loaders	$	0	0	0	0	0	0	0	0	0	0	0	0
Total Repair & Maintenance	$	15,830	42,820	81,800	230,000	12,660	22,250	36,030	82,720	14,760	14,760	15,880	29,627

Table 5.4 Comparison of ownership and repair and maintenance costs for pipeline systems for 600-cow operations at 1 and 4.8 km (1 and 3 miles) of hauling distance.

Equipment		Irrigation		Drag hose	
		1.6 km 1 mi	4.8 km 3 mi	1.6 km 1 mi	4.8 km 3 mi
Ownership costs					
Tractors	$	6,690	20,000	17,100	23,800
Trucks	$	0	0	0	0
Manure Spreaders	$	0	0	0	0
Pumps/Agitators	$	750	2,240	750	1,490
Chopper pump	$	450	450	450	450
Motorized traveler	$	2,980	2,980	0	0
Irrigation/Drag hose equipment	$	7,240	12,300	8,380	13,400
Total ownership costs	$	18,110	37,970	26,680	39,140
Repair & maintenance					
Tractors	$	2,610	7,840	5,720	8,320
Trucks	$	0	0	0	0
Manure Spreaders	$	0	0	0	0
Pumps/Agitators	$	720	2,170	720	1,440
Chopper pump	$	430	430	430	430
Motorized traveler	$	2,890	2,890	0	0
Irrigation/Drag hose Equipment	$	7,800	11,900	8,080	13,000
Total Repair & Maintenance	$	14,450	25,230	14,950	23,190

5.1.4 Fuel use

A comparison of fuel use across transport systems and farms is given in Table 5.5. Fuel use increased with hauling distance with each option for the 150-cow operation. The average fuel used per cow-year at 1.6 km (1.0 mile) was 60.8 liters per cow-year (16.1 gal/cow-yr) for the tank spreader, 53.8 liter per cow-year (14.2 gal/cow-yr) for the V-tank spreader, and 37.2 liter per cow-yr (9.8 gal/cow-yr) for the box spreader system. At the 8.0 km (5.0 mile) distance, fuel use was 153 liter per cow-yr (28.2 gal/cow-yr) for the tank spreader, 136 liter per cow-yr (35.8 gal/cow-yr) for the V-tank spreader, and 97 liter per cow-yr (25.6 gal/cow-yr) for the box spreader. The tank spreader had the highest fuel use because of the larger tractor and longer hauling hours. The box spreader had the lowest fuel use as it had the least hauling time and the smallest tractor.

Fuel use for the tractor drawn spreader increased sharply compared to truck-drawn spreaders and nurse trucks for the 600-cow operation(Table 5.5). At the 1.6 km (1.0 mile) transport distance, the fuel use of the truck system was. 39.5 liter per cow-yr (16.1 gal/cow-yr) and the fuel use of the nurse truck system was 65.9 liter per cow-yr (17.4 gal/cow-yr). In contrast, the lowest fuel use at the 8.0 km (5.0 mile) distance was the nurse truck system, 69 liter per cow-yr (18.2 gal/cow-yr) and the highest was the tractor-drawn system, 153 liter per cow-yr (40.3 gal/cow-yr), which was more than double the nurse truck system.

Fuel use for irrigation increased when additional pumps were added to increase pressure, at 2 km (1.25 mile) and 4 km (2.5 mile) transport distance. Fuel use for the drag hose system also increased when pumps were added at 3.2 km (2 mile). At 4.8 km (3 mile), the cost for irrigation was higher than the drag hose since it required more pumps to maintain system pressure.

Table 5.5 Comparison of fuel use at 1, 4.6, 8 and 16 km (1,3,5 and 10 miles) of distance.

		Average Hauling Distance			
	[km]	1.6	4.8	8.0	16
	[mi]	1	3	5	10
150 cow operations					
3,500 gal tractor-drawn	L/cow-yr	60.8	106.7	152.6	267.3
spreader	(gal/cow-yr)	(16.1)	(28.2)	(40.3)	(70.6)
2,000 gal V-tank spreader	L/cow-yr	53.8	94.7	135.6	238.0
	(gal/cow-yr)	(14.2)	(25.0)	(35.8)	(62.9)
250 bu box spreader	L/cow-yr	37.2	67.1	96.9	171.5
	(gal/cow-yr)	(9.8)	(17.7)	(25.6)	(45.3)
600 cow operations					
2-3,500 gal tractor-drawn	L/cow-yr	60.8	106.7	152.6	267.3
spreaders	(gal/cow-yr)	(16.1)	(28.2)	(40.3)	(70.6)
2-3,500 gal truck-drawn	L/cow-yr	39.5	56.2	75.0	122.0
spreaders	(gal/cow-yr)	(10.4)	(14.8)	(19.8)	(32.2)
3 operators, 2-Nurse truck	L/cow-yr	65.9	65.9	69.0	101.8
& 1 spreader tank	(gal/cow-yr)	(17.4)	(17.4)	(18.2)	(26.9)
Irrigation	L/cow-yr	25.3	67.4	---	---
	(gal/cow-yr)	(6.7)	(17.8)	---	---
Drag hose	L/cow-yr	56.3	98.2	---	---
	(gal/cow-yr)	(14.9)	(26.0)	---	---

5.1.5 Labor

Labor required for the 600-cow operations ranged from 1.34 to 2.4 hour per cow-year at the 1.6 km (1.0 mile) distance and from 1.49 to 1.96 hour per cow-year for the 150-cow operation at 1.6 km (1.0 mile) distance (Table 5.6). The differences were greater at the longer hauling distance. The labor requirement ranged from 3.71 to 6.69 hour per cow-year for the 600-cow operations at the 16 km (10 mile) and 6.69 to 8.66 hours per cow-year for the 150-cow operations at the 16 km (10 mile) distance (Table 5.6). The nurse truck system had the lowest labor hours per cow-year at 16 km (10 mile) even though three operators were needed for this system.

The labor for the irrigation and drag hose systems was constant, 2.02 hours per cow-year for the drag hose system and 2.02 hours per cow-year for the irrigation system (Table 5.6). Labor hours depended on number of workers and activity hours. The number of operators was two for both systems. The activity hours included set up, pumping, reset and clean up time. System set up and clean up time was four hours for each system. Reset time between fields were one hour for irrigation and two hours for the drag hose system.

Table 5.6 Comparison of labor at 1, 4.6, 8 and 16 km (1,3,5 and 10 miles) of hauling distance.

	Average Hauling Distance			
[km]	1.6	4.8	8.0	16
[mi]	1	3	5	10
	hr/cow-yr			
150 cow operations				
3,500 gal tractor-drawn spreader	1.52	2.67	3.49	6.69
2,000 gal V-tank spreader	1.96	3.45	4.93	8.66
250 bu box spreader	1.49	2.68	3.88	6.87
600 cow operations				
2-3,500 gal tractor-drawn spreaders	1.52	2.67	3.82	6.69
2-3,500 gal truck-drawn spreaders	1.34	1.90	2.54	4.13
3 operators, 2-Nurse truck & 1 spreader tank	2.40	2.40	2.52	3.71
Irrigation	2.02	2.02	---	---
Drag hose	2.02	2.02	---	---

5.2 Effect of Crop Sequence on nutrient recovery and use

Nutrient recovery varied depending on the crop sequence and nutrient selected for the nutrient balance. Manure nutrients were applied to meet the nitrogen removal for the first crop year or to meet phosphate removal for two years of crop growth. Four crop sequences were evaluated using a nitrogen and phosphorus balance while using a 3,500-gallon spreader for surface spreading and incorporation within one day.

Total nitrogen in the manure was 3.0 kg/1000L (25 lb/1000gal). Available organic nitrogen was 0.69 kg/1000L (5.7 lb/1000gal), ammonium N was 0.42 kg/1000L (3.5 lb/1000 gal) and nitrate was 0.15 kg/1000L (1.25 lb/1000gal). Total available nitrogen in manure for the first year was 1.2 kg/1000L (10.4 lb/1000 gal). Volatilization loss was 0.14 kg/1000L (1.2 lb/1000 gal) and residual unavailable organic nitrogen was 1.6 kg/1000L (13 lb/1000gal). Total nitrogen loss and unavailable organic nitrogen for the first year was 1.7 kg/1000 L (14.2 lb/1000gal). Phosphorus and potassium loss was assumed to be minimal. Only the unused organic nitrogen was available in subsequent years since other unused nitrogen was assumed to be lost by leaching or volatilization.

5.2.1 Corn silage /corn grain sequence

The volume of manure applied in the first year to meet crop requirements for nitrogen use was 169,300 L/ha (18,120gal/ac) and phosphorus balance was 96,900 L/ha (10,400 gal/ac). Manure nutrients applied in the first year for nitrogen use were 211 kg/ha (188 lb/ac) of nitrogen, 223 kg/ha (199 lb/ac) of phosphate, and 385 kg/ha (344 lb/ac) of potash. These nutrient values were adjusted with moisture content and nitrogen losses. All nutrients required for corn silage were supplied by manure. In the second year, 58 kg/ha (52 lb/ac) of organic nitrogen was mineralized and available (Table 5.7), 142 kg/ha (127 lb/ac) of phosphate, and 211 kg/ha (188 lb/ac) of potash available from unused nutrients applied in the first year. Commercial nitrogen was applied in year two to meet crop requirements, but phosphorus and potash requirements were met from manure from the first year. After the second crop year, about 40 percent of phosphate and potash in the manure applied in year one remained in the soil (Table 5.8). Thus, this sequence was not efficient use of phosphate and potash.

Table 5.7 Nitrogen budget for a corn silage/corn grain sequence using an N-based manure application.

		Crop nitrogen removal	Type of manure nitrogen				Commercial Fertilizer	Organic N for subsequence year
			Organic N	Ammonium N	Nitrate N	Total N		
Year 1	kg/ha	211	115	71	25	211	0	58
	lb/ac	188	103	63	22	188	0	52
year 2	kg/ha	121	58	0	0	58	63	29
	lb/ac	108	51.6	0.0	0.0	51.6	56.4	25

Less manure was applied to obtain a phosphorus balance over two years than was needed for nitrogen use in year one. Manure nutrients applied were 121 kg/ha (108 lb/ac) of nitrogen, 128 kg/ha (114 lb/ac) of phosphate and 221 kb/ha (197 lb/ac) of potash. Commercial nitrogen was supplied to meet crop nutrient requirements in the first year. In the second year, manure nutrients were still available to meet phosphate and potash requirements. Organic nitrogen was available in the second year, but additional commercial nitrogen was needed. Therefore, 87 kg/ha (78 lb/ac) of commercial nitrogen was applied in the second year. Most manure nutrients were used in these two crop years and few nutrients were left compared to an application for nitrogen use. Thus, applying manure nutrients for a phosphorus balance provided a more efficient use of manure nutrients (Table 5.9)

Table 5.8 Nutrient use for a corn silage/corn grain sequence using N-based manure application.

		Nitrogen Use							
		Year 1				Year 2			
Crop sequence		Corn (silage)				Corn (grain)			
Application method		Broad cast							
Yield goal		45 t/ha (20 ton/acre)				10440 L/ha (120 bu/acre)			
Volume of manure applied		169,330L/ha (18,120 gallons/acre)							
Land needed		46.6 ha (115 acres)							
Rate		0.20 ha/hr (0.50 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		---	---	---	
	(lb/1000gal)	(10)	(11)	(19)		---	---	---	
Manure applied	kg/ha	211	223	385		---	---	---	
	(lb/ac)	(188)	(199)	(344)		---	---	---	
Crop Nutrient required	kg/ha	211	81	175		121	47	36	
	(lb/ac)	(188)	(72)	(156)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	211	81	175		58	47	36	
	(lb/ac)	(188)	(72)	(156)		(52)	(42)	(32)	
Commercial fertilizer	kg/ha	0	0	0		63	0	0	
	(lb/ac)	(0)	(0)	(0)		(56)	(0)	(0)	
Residual nutrient	kg/ha	58	142	211		29	95	175	
	(lb/ac)	(52)	(127)	(188)		(26)	(85)	(156)	
Manure nutrient applied	$/ha	111.41	113.21	117.07	338.69	---	---	---	---
	($/ac)	(45.12)	(47.84)	(48.20)	(141.16)	---	---	---	---
Manure nutrient value	$/ha	111.41	42.67	53.93	208.01	30.59	24.89	11.21	66.69
	($/ac)	(45.12)	(17.28)	(21.84)	(84.24)	(12.39)	(10.08)	(4.54)	(27.01)
Commercial fertilizer value	$/ha	0.00	0.00	0.00	0.00	33.41	0.00	0.00	33.41
	($/ac)	(0.00)	(0.00)	(0.00)	(0.00)	(13.53)	(0.00)	(0.00)	(13.53)
Residual Nutrient value	$/ha	29.33	70.54	60.15	160..02	15.31	50.57	53.88	119.75
	($/ac)	(12.39)	(30.56)	(26.36)	(69.31)	(6.20)	(20.48)	(21.82)	(48.510)

Table 5.9 Nutrient use for a corn silage/corn grain sequence using P-based manure application.

	Phosphorus Balance	
	Year 1	Year 2
Crop sequence	Corn (silage)	Corn (grain)
Application method	Broad cast	
Yield goal	45 t/ha (20 ton/acre)	10440 L/ha (120 bu/acre)
Volume of manure applied	98,900 L/ha (10,400 gallons/acre)	
Land needed	81.4 ha (201 acres)	
Rate	0.36 ha/hr (0.88 acre /hr)	

		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		—	—	—	
	(lb/1000gal)	(10)	(11)	(19)		—	—	—	
Manure applied	kg/ha	121	128	221		—	—	—	
	(lb/ac)	(108)	(114)	(197)		—	—	—	
Crop Nutrient required	kg/ha	211	81	175		121	47	36	
	(lb/ac)	(188)	(72)	(156)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	121	81	175		34	47	36	
	(lb/ac)	(108)	(72)	(156)		(30)	(42)	(41)	
Commercial fertilizer	kg/ha	90	0	0		87	0	0	
	(lb/ac)	(80)	(0)	(0)		(78)	(0)	(0)	
Residual nutrient	kg/ha	34	47	46		17	0	10	
	(lb/ac)	(30)	(42)	(41)		(15)	(0)	(9)	
Manure nutrient applied	$/ha	63.73	67.56	68.07	199.33	—	—	—	—
	($/ac)	(25.81)	(27.36)	(27.57)	(80.73)	—	—	—	—
Manure nutrient value	$/ha	63.73	42.67	53.93	160.32	17.51	24.89	11.21	53.58
	($/ac)	(25.81)	(17.28)	(21.84)	(64.93)	(7.09)	(10.08)	(4.54)	(21.70)
Commercial fertilizer value	$/ha	47.68	0.00	0.00	47.68	46.49	0.00	0.00	46.49
	($/ac)	(19.31)	(0.00)	(0.00)	(19.31)	(18.83)	(0.00)	(0.00)	(18.83)
Residual Nutrient value	$/ha	17.51	24.89	14.15	56.54	8.74	0.00	2.94	11.68
	($/ac)	(7.09)	(10.08)	(5.73)	(22.90)	(3.54)	(0.00)	(1.19)	(4.74)

5.2.2 Wheat grain/corn grain sequence

The volume of manure applied was 64,900 L/ha (6,940 gal/ac) for nitrogen use in year one and 67,300 L/ha (7,200 gal/ac) for a phosphorus balance over two years. More manure was needed to meet phosphorus needs than nitrogen with this sequence. Manure nutrients applied to meet the nitrogen needs for wheat grain were 81 kg/ha (72 lb/ac) of nitrogen, 85 kg/ha (76 lb/ac) of phosphate and 148 kg/ha (132 lb/ac) of potash. All nutrients were supplied by manure and no commercial fertilizer was used in the first year. Only organic nitrogen was carried over to year two. Phosphorus and potash needs were met by manure in the second year. After the two years of crop sequence, 58 percent of the potash from the manure application in the year one was left in soil (Table 5.10).

Applying manure for a phosphorus balance allowed a higher application rate than for nitrogen use. Nutrients applied for a phosphorus balance were 84 kg/ha (75 lb/ac) of nitrogen, 88 kg/ha (79 lb/ac) of phosphate and 153 kg/ha (137 lb/ac) of potash. Manure nutrients were available for all of the crop nutrient needs in the first year. All of the phosphate and potash and about 15 percent of nitrogen for corn grain in the second year was supplied. After two crop years, about 60 percent of applied potash still remained in the soil (Table 5.11). Only unused organic nitrogen remained and phosphate was completely consumed with both a phosphorus balance and nitrogen use. More commercial fertilizer was purchased in the second year when applying for nitrogen use, but there were less unused nutrients after the two years of crop growth. So, this was a good sequence if the goal was to match nutrients applied with nutrients used.

Table 5.10 Nutrient use for a wheat grain/corn grain sequence using N-based manure application.

		Nitrogen Use							
		Year 1				Year 2			
Crop sequence		Wheat (grain)				Corn (grain)			
Application method		Broad cast							
Yield goal		5220 L/ha (60 bu/acre)				10440 L/ha (120 bu/acre)			
Volume of manure applied		64,850 L/ha (6,940 gallons/acre)							
Land needed		122 ha (300 acres)							
Rate		0.53 ha/hr (1.32 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		—	—	—	
	(lb/1000gal)	(10)	(11)	(19)		—	—	—	
Manure applied	kg/ha	81	85	145		—	—	—	
	(lb/ac)	(72)	(76)	(132)		—	—	—	
Crop Nutrient required	kg/ha	81	41	26		121	47	36	
	(lb/ac)	(72)	(37)	(23)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	81	41	26		22	4	36	
	(lb/ac)	(72)	(37)	(23)		(20)	(39)	(32)	
Commercial fertilizer	kg/ha	0	0	0		100	3	0	
	(lb/ac)	(0)	(0)	(0)		(88)	(3)	(0)	
Residual nutrient	kg/ha	22	44	122		11	0	86	
	(lb/ac)	(20)	(39)	(109)		(10)	(0)	(77)	
Manure nutrient applied	$/ha	42.67	45.23	45.58	133.48	—	—	—	—
	($/ac)	(17.28)	(18.32)	(18.46)	(54.06)	—	—	—	—
Manure nutrient value	$/ha	42.67	22.05	7.88	72.59	11.23	23.19	11.21	46.12
	($/ac)	(17.28)	(8.93)	(3.19)	(29.40)	(4.75)	(9.39)	(4.54)	(18.68)
Commercial fertilizer value	$/ha	0.00	0.00	0.00	0.00	52.27	1.70	0.00	53.98
	($/ac)	(0.00)	(0.00)	(0.00)	(0.00)	(21.17)	(0.695)	(0.00)	(21.86)
Residual Nutrient value	$/ha	11.23	23.19	37.70	72.62	5.85	0.00	25.60	32.37
	($/ac)	(4.75)	(9.39)	(15.27)	(29.41)	(2.37)	(0.00)	(10.37)	(13.11)

Table 5.11 Nutrient use for a wheat grain/corn grain sequence using P-based manure application.

		Phosphorus Balance							
		Year 1				Year 2			
Crop sequence		Wheat (grain)				Corn (grain)			
Application method		Broad cast							
Yield goal		5220 L/ha (60 bu/acre)				10440 L/ha (120 bu/acre)			
Volume of manure applied		67,300 L/ha (7,200 gallons/acre)							
Land needed		117 ha (289 acres)							
Rate		0.51 ha/hr (1.27 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		—	—	—	
	(lb/1000gal)	(10)	(11)	(19)		—	—	—	
Manure applied	kg/ha	84	88	153		—	—	—	
	(lb/ac)	(75)	(79)	(137)		—	—	—	
Crop Nutrient required	kg/ha	81	41	26		121	47	36	
	(lb/ac)	(72)	(37)	(23)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	81	41	26		24	47	36	
	(lb/ac)	(72)	(37)	(23)		(21)	(42)	(32)	
Commercial fertilizer	kg/ha	0	0	0		97	0	0	
	(lb/ac)	(0)	(0)	(0)		(87)	(0)	(0)	
Residual nutrient	kg/ha	24	47	128		11	0	92	
	(lb/ac)	(21)	(42)	(114)		(10)	(0)	(82)	
Manure nutrient applied	$/ha	44.27	46.94	47.28	140.42	—	—	—	—
	($/ac)	(17.93)	(19.01)	(19.15)	(56.09)	—	—	—	—
Manure nutrient value	$/ha	42.67	22.05	7.88	72.59	12.15	24.89	11.21	48.25
	($/ac)	(17.28)	(8.93)	(3.19)	(29.40)	(4.92)	(10.08)	(4.54)	(19.54)
Commercial fertilizer value	$/ha	0.00	0.00	0.00	0.00	51.85	0.00	0.00	51.85
	($/ac)	(0.00)	(0.00)	(0.00)	(0.00)	(21.00)	(0.00)	(0.00)	(21.00)
Residual Nutrient value	$/ha	12.15	24.89	39.41	76.44	6.07	0.00	28.20	34.30
	($/ac)	(4.92)	(10.08)	(15.96)	(30.96)	(2.46)	(0.00)	(11.42)	(13.89)

5.2.3 Sugar beet/corn grain sequence

The volume of manure applied was 68,500 L/ha (7,300 gal/ac) for nitrogen use and 56,700 L/ha (6,100 gal/ac) for a phosphorus balance. Manure nutrients applied to meet the nitrogen requirement for sugar beet in year one were 85 kg/ha (76 lb/ac) of nitrogen, 91 kg/ha (81 lb/ac) of phosphate and 156 kg/ha (139 lb/ac) of potash. This application supplied all nutrients for the first year and all phosphate and potash requirements for the second year. Commercial nitrogen was needed to meet the requirement for corn in the second year and 97 kg/ha (87 lb/ac) of nitrogen was applied. After two crop years, 11 kg/ha (10 lb/ac) of nitrogen, 16kg/ha (14 lb/ac) of phosphate and 44 kg/ha (49 lb/ac) of potash remained unused in the soil (Table 5.12).

The amount of manure applied for a phosphorus balance was lower than for nitrogen use. Manure nutrients applied were 74 kg/ha (66 lb/ac) of nitrogen, 75 kg/ha (57 lb/ac) of phosphate, and 129 kg/ha (115 lb/ac) of potash. The amount of commercial fertilizer applied was about the same for nitrogen use or for a phosphorus balance. Fifteen kg/ha (13 lb/ac) of commercial nitrogen was applied in the first year and 102 kg/ha (91 lb/ac) in the second year. Residual nutrients after two years were lower than with nitrogen use, 10 kg/ha (9 lb/ac) of nitrogen and 22 kg/ha (20 lb/ac) of potash (Table 5.13). The phosphorus balance with this sequence was the most efficient because most of manure nutrients were consumed and less unused nutrients were left after two years even though the amount of commercial fertilizer applied in the second year was almost the same.

Table 5.12 Nutrient use for a sugar beet/corn grain sequence N-based manure application

		Nitrogen Use							
		Year 1				Year 2			
Crop sequence		Sugar beets				Corn (grain)			
Application method		Broad cast							
Yield goal		43 t/ha				4230 L/ha			
		(19 ton/acre)				(120 bu/acre)			
Volume of manure applied		68,450 L/ha							
		(7,330 gallons/acre)							
Land needed		115 ha							
		(284 acres)							
Rate		0.51 ha/hr							
		(1.25 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		—	—	—	
	(lb/1000gal)	(10)	(11)	(19)		—	—	—	
Manure applied	kg/ha	85	91	156		—	—	—	
	(lb/ac)	(76)	(81)	(139)		—	—	—	
Crop Nutrient required	kg/ha	85	28	71		121	47	36	
	(lb/ac)	(76)	(25)	(63)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	85	28	71		24	47	36	
	(lb/ac)	(76)	(25)	(63)		(21)	(42)	(32)	
Commercial fertilizer	kg/ha	0	0	0		97	0	0	
	(lb/ac)	(0)	(0)	(0)		(87)	(0)	(0)	
Residual nutrient	kg/ha	22	63	85		11	16	49	
	(lb/ac)	(21)	(56)	(76)		(10)	(14)	(44)	
Manure nutrient applied	$/ha	45.04	47.75	48.12	140.89	—	—	—	—
	($/ac)	(18.24)	(19.34)	(19.49)	(57.06)	—	—	—	—
Manure nutrient value	$/ha	45.04	14.64	21.68	81.36	12.37	24.89	11.21	48.47
	($/ac)	(18.24)	(5.93)	(8.78)	(32.95)	(5.01)	(10.08)	(4.54)	(19.63)
Commercial fertilizer value	$/ha	0.00	0.00	0.00	0.00	51.63	0.00	0.00	51.63
	($/ac)	(0.00)	(0.00)	(0.00)	(0.00)	(20.91)	(0.00)	(0.00)	(20.91)
Residual Nutrient value	$/ha	12.37	33.11	26.44	71.93	6.20	8.22	15.23	29.65
	($/ac)	(5.01)	(13.41)	(10.71)	(29.13)	(2.51)	(3.33)	(6.17)	(12.01)

Table 5.13 Nutrient use for a sugar beet/corn grain sequence P-based manure application

		Phosphorus Balance							
		Year 1				Year 2			
Crop sequence		Sugar beets				Corn (grain)			
Application method		Broad cast							
Yield goal		43 t/ha (19 ton/acre)				4230 L/ha (120 bu/acre)			
Volume of manure applied		56,700 L/ha (6,100 gallons/acre)							
Land needed		139 ha (343 acres)							
Rate		0.61 ha/hr (1.51 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		---	---	---	
	(lb/1000gal)	(10)	(11)	(19)		---	---	---	
Manure applied	kg/ha	71	75	129		---	---	---	
	(lb/ac)	(63)	(67)	(115)		---	---	---	
Crop Nutrient required	kg/ha	85	28	71		121	47	36	
	(lb/ac)	(76)	(25)	(63)		(108)	(42)	(32)	
Manure nutrient used	kg/ha	71	28	71		19	47	0	
	(lb/ac)	(63)	(25)	(63)		(17)	(42	(32)	
Commercial fertilizer	kg/ha	15	0	0		102	0	0	
	(lb/ac)	(13)	(0)	(0)		(91)	(0)	(0)	
Residual nutrient	kg/ha	19	47	59		10	0	22	
	(lb/ac)	(17)	(42)	(53)		(9)	(0)	(20)	
Manure nutrient applied	$/ha	37.28	39.53	39.83	116.64	---	---	---	---
	($/ac)	(15.10)	(16.01)	(16.13)	(47.24)	---	---	---	---
Manure nutrient value	$/ha	37.28	14.64	21.68	73.58	10.25	24.89	11.21	46.32
	($/ac)	(15.10)	(5.93)	(8.78)	(28.80)	(4.15)	(10.08)	(4.54)	(18.76)
Commercial fertilizer value	$/ha	7.75	0.00	0.00	7.75	53.75	0.00	0.00	53.75
	($/ac)	(3.14)	(0.00)	(0.00)	(3.14)	(21.77)	(0.00)	(0.00)	(21.77)
Residual Nutrient value	$/ha	10.25	24.89	18.15	53.28	5.11	0.00	6.96	12.07
	($/ac)	(4.15)	(10.08)	(7.35)	(21.58)	(2.07)	(0.00)	(2.82)	(4.89)

5.2.4 Alfalfa/ alfalfa sequence

Alfalfa is a legume and it does not require nitrogen fertilizer since it can fix it from the atmosphere. This sequence required a high potash application compared to other sequences. The volume of manure applied was 102,000 L/ha (11,000 gal/ac) for a phosphorus balance. Since alfalfa is legume, nitrogen was assumed not to use by the alfalfa and lost through volatilization, leaching or was unused in organic form. Thus, 127 kg/ha (113 lb/ac) of nitrogen was lost to environment in the first year. Sixty-seven kg/ha (60 lb/ac) of phosphate from manure were used each year and no unused nutrients remained in the soil. Seventy-one kg/ha (63 lb/ac) of commercial potash was supplied to meet the requirement in the first year. In the second year, potash was supplied completely by commercial nutrients (Table 5.14). Thus, this crop sequence was the least efficient in the use of manure nutrient use.

Table 5.14 Nutrient use for an alfalfa hay/ alfalfa hay sequence using P-based manure application

		Phosphorus Balance							
		Year 1				Year 2			
Crop sequence		Alfalfa (hay)				Alfalfa (hay)			
Application method		Broad cast							
Yield goal		13.5 t/ha (6 ton/acre)				13.5 t/ha (6 ton /acre)			
Volume of manure applied		102,000 L/ha (11,000 gallons/acre)							
Land needed		77 ha (191 acres)							
Rate		0.61 ha/hr (1.51 acre /hr)							
		N	P2O5	K2O	Total	N	P2O5	K2O	Total
Manure analysis	kg/1000L	1.2	1.3	2.3		—	—	—	
	(lb/1000gal)	(10)	(11)	(19)		—	—	—	
Manure applied	kg/ha	127	134	232		—	—	—	
	(lb/ac)	(113)	(120)	(207)		—	—	—	
Crop Nutrient required	kg/ha	282	67	302		282	67	302	
	(lb/ac)	(252)	(60)	(270)		(252)	(60)	(270)	
Manure nutrient used	kg/ha	0	232	232		0	67	0	
	(lb/ac)	(0)	(60)	(207)		(0)	(60)	(0)	
Commercial fertilizer	kg/ha	0	0	71		0	0	302	
	(lb/ac)	(0)	(0)	(63)		(0)	(0)	(270)	
Residual nutrient	kg/ha	35	67	0		18	0	0	
	(lb/ac)	(31)	(60)	(0)		(16)	(0)	(0)	
Manure nutrient applied	$/ha	67.06	71.11	71.65	209.83	—	—	—	—
	($/ac)	(27.16)	(28.80)	(29.02)	(84.98)	—	—	—	—
Manure nutrient value	$/ha	0.00	35.56	71.65	107.21	0.00	35.56	0.00	35.56
	($/ac)	(0.00)	(14.40)	(29.02)	(43.42)	(0.00)	(14.40)	(0.00)	(14.40)
Commercial fertilizer value	$/ha	0.00	0.00	21.68	21.68	0.00	0.00	93.33	93.33
	($/ac)	(0.00)	(0.00)	(8.78)	(8.78)	(0.00)	(0.00)	(37.80)	(37.80)
Residual Nutrient value	$/ha	18.42	35.56	0.00	53.98	9.21	0.00	0.00	9.21
	($/ac)	(7.46)	(14.40)	(0.00)	(21.86)	(3.73)	(0.00)	(0.00)	(3.73)

5.3 Net Costs

Net costs represent machinery costs for agitating, pumping and hauling including fuel and lubrication and labor minus the value of manure nutrients used for crop growth. A comparison of net costs is shown in Tables 5.15 and 5.16 for hauling distances of 1.6, 4.8 and 8 km (1, 3 and 5 mile). When comparing manure applications to satisfy nitrogen use in the first year of a two-year sequence or a two-year phosphorus balance, nitrogen use resulted in a higher cost in all cases. This is because more manure was applied for nitrogen use and more of these nutrients were left unused in the soil.

Among sequences, corn silage/corn grain resulted in a higher cost with a nitrogen use, and the alfalfa/alfalfa sequence resulted in a higher cost with the phosphorus balance. These high costs were due to the higher relative machinery costs ($/ha or $/ac) for the corn silage/corn grain sequence and because of high machinery costs and low manure nutrient recovery for the alfalfa/alfalfa sequence. The differences across machinery sets indicate that the V-tank spreader had the highest cost due to its high purchase price.

The lowest cost overall was for the corn silage/corn grain sequence based on a phosphorus balance at 1.6 km (1 mile) with irrigation on the 600-cow dairy. That is consistent with corn being the lowest cost with a phosphorus balance and with irrigation being the lowest cost over a short hauling distance. The overall highest cost was for the V-tank spreader at 8 km (5 mile) on corn with manure applied for nitrogen use. This is consistent with manure applications based on nitrogen use being high cost and the V-tank being a high cost system coupled with the greatest transport distance. In general, machinery costs increased rapidly with an increase in hauling distance. The truck-drawn and the nurse truck systems were preferred when the hauling distance was greater than 4.8 km (3 mile).

The value of manure nutrients used, commercial nutrient costs and unused residual nutrient values are shown in Tables 5.17 and 5.18. Unused residual manure nutrients represent nutrients that could have been used elsewhere and when lying unused in the soil represent a liability. Nitrogen use on corn provided the highest manure nutrient value but resulted in the highest level of unused residual nutrients. This is because the uptake ratio of nitrogen to phosphate or potash for corn was considerably different from the available nutrient ratio in manure, resulting in an excess application of phosphate to meet crop needs.

Among sequences, the corn silage/corn grain sequence under both application objectives had the highest value because corn nitrogen requirements were high relative to other crops, and corn silage effectively used high levels of nitrogen, phosphate and potash. The differences in commercial fertilizer cost and residual nutrient value between the irrigation and drag hose systems was because of the improved nutrient recovery of nitrogen when injected with the drag hose compared to surface applications with irrigation.

Table 5.15 Net cost (machinery cost minus value of manure nutrient used) for 150- and 600-cow operations based on nitrogen use at 1, 4.8 and 8 km (1, 3 and 5 miles) hauling distance.

Operating systems		Corn silage/corn grain			Wheat grain/corn grain			Sugar beet/corn grain		
		1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi	1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi	1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi
150-cow operation										
3,500 gal tank spreader	$/ha	178.67	369.65	584.59	54.91	128.05	210.37	53.48	130.67	217.56
	$/ac	72.36	149.71	236.76	22.24	51.86	85.20	21.66	52.92	88.11
2,000 gal V-tank spreader	$/ha	236.69	421.26	704.52	75.46	146.15	254.62	76.91	151.53	266.05
	$/ac	95.86	170.61	285.33	30.56	59.19	103.12	31.15	61.37	107.75
250 bu box spreader	$/ha	46.27	166.52	305.09	2.52	48.57	101.65	-0.07	48.54	104.57
	$/ac	18.74	67.44	123.56	1.02	19.67	41.17	-0.03	19.66	42.35
600-cow operation										
tractor-drawn spreader	$/ha	90.10	332.42	583.95	20.99	113.80	229.04	17.68	115.63	237.28
	$/ac	36.49	134.63	236.50	8.50	46.09	92.76	7.16	46.83	96.10
Truck-drawn spreader	$/ha	-12.27	77.78	193.06	-18.22	16.27	60.42	-23.70	12.69	59.28
	$/ac	-4.97	31.50	78.19	-7.38	6.59	24.47	-9.60	5.14	24.01
Nurse truck with spreader	$/ha	87.28	87.28	101.11	19.93	19.93	25.21	16.54	16.54	22.12
	$/ac	35.35	35.35	40.95	8.07	8.07	10.21	6.70	6.70	8.96
Irrigation	$/ha	-42.81	207.48	---	-20.37	86.32	---	-25.26	86.35	---
	$/ac	-17.34	84.03	---	-8.25	34.96	---	-10.23	34.97	---
Drag Hose	$/ha	29.01	176.91	---	7.75	70.62	---	4.44	70.27	---
	$/ac	11.75	71.65	---	3.14	28.60	---	1.80	28.46	---

Table 5.16 Net cost (machinery cost minus value of manure nutrient used) for 150- and 600-cow operations with a phosphorus balance at 1, 4.8 and 8 km (1, 3 and 5 miles) hauling distance.

Operating systems		Corn silage/corn grain			Wheat grain /corn grain			Sugar beet/corn grain			Alfalfa/alfalfa		
		1.6 km	4.8 km	8 km	1.6 km	4.8 km	8 km	1.6 km	4.8 km	8 km	1.6 km	4.8 km	8 km
		1mi	3 mi	5 mi	1mi	3 mi	5 mi	1mi	3 mi	5 mi	1mi	3 mi	5 mi
150-cow operation													
3,500 gal tank spreader	$/ha	45.38	154.62	277.56	59.31	135.19	220.59	31.78	95.68	167.60	130.17	245.14	374.54
	$/ac	18.38	62.62	112.41	24.02	54.75	89.34	12.87	38.75	67.88	52.72	99.28	151.69
2,000 gal V-tank spreader	$/ha	49.19	121.41	328.32	60.17	147.43	254.10	33.88	107.36	197.21	124.10	256.30	417.90
	$/ac	19.92	49.17	132.97	24.37	59.71	102.91	13.72	43.48	79.87	50.26	103.80	169.25
250 bu box spreader	$/ha	-47.28	9.26	74.42	-7.58	98.37	76.99	-23.19	9.90	48.02	19.78	79.28	147.88
	$/ac	-19.15	3.75	30.14	-3.07	39.84	31.18	-9.39	4.01	19.45	8.01	32.11	59.89
600-cow operation													
tractor-drawn spreader	$/ha	-5.26	133.31	305.43	24.10	120.40	239.95	2.15	83.23	183.93	76.86	222.74	403.90
	$/ac	-2.13	53.99	123.70	9.76	48.76	97.18	0.87	33.71	74.49	31.13	90.21	163.58
Truck-drawn spreader	$/ha	-63.80	-12.30	53.63	-16.57	19.21	65.01	-32.10	-1.98	36.59	15.23	69.43	138.84
	$/ac	-25.84	-4.98	21.72	-6.71	7.78	26.33	-13.00	-0.80	14.82	6.17	28.12	56.23
Nurse truck with spreader	$/ha	-6.86	-6.86	1.04	22.99	22.99	28.49	1.21	1.21	5.83	75.16	75.16	83.48
	$/ac	-2.78	-2.78	0.42	9.31	9.31	11.54	0.49	0.49	2.36	30.44	30.44	33.81
Irrigation	$/ha	-73.65	57.23	---	-23.36	73.11	---	-33.36	50.81	---	-5.51	131.21	---
	$/ac	-29.83	23.18	---	-9.46	29.61	---	-13.51	20.58	---	-2.23	53.14	---
Drag Hose	$/ha	-29.78	55.60	---	7.63	41.88	---	-7.38	46.96	---	47.95	137.33	---
	$/ac	-12.06	22.52	---	3.09	16.96	---	-2.99	19.02	---	19.42	55.62	---

The alfalfa/ alfalfa sequence had the highest commercial nutrient cost because of its high potash requirement. The alfalfa/alfalfa sequence also included the application of about $58/ha ($23/ac) of nitrogen that could not be used by the crop and was lost to the environment. The wheat grain/corn grain and the sugar beet/corn grain sequences based on nitrogen use did not have high manure nutrient benefits, but crop nutrient requirements were better balanced with manure nutrient composition, and residual nutrient costs were low. All sequences required commercial nitrogen applications in the second year.

Finally, the net of machinery, commercial fertilizer cost and residual nutrient cost minus the value of manure nutrients used is shown in Table 5.19 to integrate the machinery costs and nutrient values. Between the nitrogen use and phosphorus balance schemes, a phosphorus balance had lower net costs because of lower machinery ($/ha or $/ac) and commercial fertilizer costs and a lower residual nutrient value. Among crop sequences, the corn silage/corn grain sequence had the lowest cost. Among size of operations the costs for the150-cow operation were generally higher than the 600-cow operation but not in all cases. For example, the net cost for the 150-cow operation with the box spreader was lower than the costs for the 600-cow operation with the tractor-drawn or the nurse truck at 1.6 km (1mile). Among operating systems, irrigation had lowest cost on the 600-cow farm when the distance was shorter than 4.8 km (3 mile). At 4.8 km (3 mile), the truck-drawn system had the lowest cost. When the distance was greater than 4.8 km (3 mile), the nurse truck system had the lowest cost.

Table 5.17 Value of manure nutrients used, commercial nutrients purchased and residual nutrient value when manure was applied for nitrogen use in year one of a two-year sequence.

Operating systems		Corn silage/corn grain	Wheat grain/corn grain	Sugar beet/corn grain	Alfalfa/alfalfa
Manure nutrient applied					
	$/ha	582.00	223.00	235.00	---
	$/ac	236.00	90.00	95.00	---
Value of manure nutrients used by crop					
Tank spreader and	$/ha	274.69	118.72	134.74	---
nurse tanks	$/ac	111.25	48.08	54.57	---
V-tank spreader	$/ha	274.89	120.47	52.57	---
	$/ac	111.33	48.79	52.60	---
Box spreader	$/ha	273.19	119.83	129.21	---
	$/ac	110.64	48.53	52.33	---
Irrigation	$/ha	275.28	120.64	130.05	---
	$/ac	111.49	48.86	52.67	---
Drag Hose	$/ha	271.83	119.31	128.67	---
	$/ac	110.09	48.32	52.11	---
Commercial Nutrients costs					
Tank spreader and	$/ha	33.41	53.98	51.63	---
nurse tanks	$/ac	13.53	21.86	20.91	---
V-tank spreader	$/ha	33.21	52.20	51.56	---
	$/ac	13.45	21.14	20.88	---
Box spreader	$/ha	34.89	52.86	52.22	---
	$/ac	14.13	21.41	21.15	---
Irrigation	$/ha	32.79	52.05	51.38	---
	$/ac	13.28	21.08	20.81	---
Drag Hose	$/ha	36.25	53.38	52.79	---
	$/ac	14.68	21.62	21.38	---
Residual Nutrients value					
Tank spreader and	$/ha	119.75	32.37	29.65	---
nurse tanks	$/ac	48.50	13.11	12.01	---
V-tank spreader	$/ha	127.11	33.48	32.62	---
	$/ac	51.48	13.56	13.21	---
Box spreader	$/ha	161.38	46.59	46.47	---
	$/ac	65.36	18.87	18.82	---
Irrigation	$/ha	142.94	39.56	39.01	---
	$/ac	57.89	16.02	15.80	---
Drag Hose	$/ha	112.44	27.85	26.69	---
	$/ac	45.54	11.28	10.81	---

Table 5.18 Value of manure nutrients used, commercial nutrients purchased and residual nutrient value when manure was applied for a phosphorus balance with two-year sequences.

Operating systems		Corn silage/corn grain	Wheat grain/corn grain	Sugar beet/corn grain	Alfalfa/alfalfa
Manure nutrient applied					
	$/ha	311.00	201.00	169.00	304.00
	$/ac	126.00	81.00	69.00	123.00
Value of manure nutrients used by the crop					
Tank spreader	$/ha	213.90	120.84	119.93	142.77
and nurse tanks	$/ac	86.63	48.94	48.57	57.82
V-tank spreader	$/ha	209.53	119.56	117.51	139.43
	$/ac	84.86	48.42	47.59	56.47
Box spreader	$/ha	197.48	111.93	111.06	138.35
	$/ac	79.98	45.33	44.98	56.03
Irrigation	$/ha	196.15	114.27	113.04	133.33
	$/ac	79.44	46.28	45.78	54.00
Drag Hose	$/ha	202.89	118.96	116.99	133.33
	$/ac	82.17	48.18	47.38	54.00
Commercial Nutrients cost					
Tank spreader	$/ha	94.17	51.85	61.51	115.01
and nurse tanks	$/ac	38.14	21.00	24.91	46.58
V-tank spreader	$/ha	98.54	53.11	63.95	118.35
	$/ac	39.91	21.51	25.90	47.93
Box spreader	$/ha	110.59	60.77	70.40	119.43
	$/ac	44.79	24.61	28.51	48.37
Irrigation	$/ha	111.95	58.40	68.40	124.44
	$/ac	45.34	23.65	27.70	50.40
Drag Hose	$/ha	105.19	53.70	64.44	124.44
	$/ac	42.60	21.75	26.10	50.40
Residual Nutrients value					
Tank spreader	$/ha	11.70	34.30	12.07	9.21
and nurse tanks	$/ac	4.74	13.89	4.89	3.73
V-tank spreader	$/ha	8.35	31.80	9.98	8.79
	$/ac	3.38	12.88	4.04	3.56
Box spreader	$/ha	6.84	30.05	8.49	7.21
	$/ac	2.77	12.17	3.44	2.92
Irrigation	$/ha	7.60	27.26	6.15	8.00
	$/ac	3.08	11.04	2.49	3.24
Drag Hose	$/ha	7.60	27.26	6.15	8.00
	$/ac	3.08	11.04	2.49	3.24

Table 5.19 Net of machinery, commercial fertilizer, and residual nutrients minus the value of manure nutrients used for 150- and 600-cow operations with 1, 4.8 and 8 km (1, 3 and 5 miles) hauling distance.

Operating systems		Corn silage/corn grain			Wheat grain/corn grain			Sugar beet/corn grain			Alfalfa/alfalfa		
		1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi	1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi	1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi	1.6 km 1 mi	4.8 km 3 mi	8 km 5 mi
Nitrogen Use													
150-cow operation													
3,500 gal tank spreader	$/cow-yr	103.03	162.33	229.07	114.42	173.66	240.34	99.55	158.74	225.36	---	---	---
2,000 gal V-tank spreader	$/cow-yr	119.29	175.11	260.77	126.71	182.64	268.45	120.15	176.16	262.12	---	---	---
250 bu box spreader	$/cow-yr	65.49	97.95	135.37	71.59	103.91	141.18	65.50	97.79	135.00	---	---	---
600-cow operation													
Tractor-drawn spreader	$/cow-yr	75.53	150.77	228.87	86.94	162.12	255.46	72.16	147.34	240.70	---	---	---
Truck-drawn spreader	$/cow-yr	43.75	71.71	107.50	55.18	83.12	118.88	40.40	68.33	104.09	---	---	---
Nurse truck with spreader	$/cow-yr	74.66	74.66	78.95	86.08	86.08	90.36	71.29	71.29	55.49	---	---	---
Irrigation	$/cow-yr	38.31	110.45	---	53.61	133.91	---	46.47	126.10	---	---	---	---
Drag Hose	$/cow-yr	68.28	116.20	---	75.32	128.54	---	67.30	120.09	---	---	---	---
Phosphorus balance													
150-cow operation													
3,500 gal tank spreader	$/cow-yr	82.09	141.37	208.09	113.50	172.71	239.35	97.57	156.75	223.36	131.19	190.48	257.21
2,000 gal V-tank spreader	$/cow-yr	82.55	122.92	238.56	112.07	182.28	268.10	98.34	168.57	254.46	133.63	203.95	289.91
250 bu box spreader	$/cow-yr	41.95	74.31	111.61	68.54	155.79	138.19	54.44	86.78	124.05	79.46	111.76	148.98
600-cow operation													
Tractor-drawn spreader	$/cow-yr	54.61	129.81	223.22	86.10	161.31	254.67	70.23	145.44	238.82	103.70	178.93	272.35
Truck-drawn spreader	$/cow-yr	22.83	50.79	86.56	54.34	82.28	118.05	38.47	66.41	102.18	71.92	99.87	135.66
Nurse truck with spreader	$/cow-yr	53.73	53.73	58.02	85.23	85.23	89.53	69.36	69.36	73.65	102.82	102.82	107.11
Irrigation	$/cow-yr	27.17	104.66	---	61.04	135.24	---	41.67	126.84	---	71.37	148.25	---
Drag Hose	$/cow-yr	49.14	99.69	---	75.47	128.81	---	63.96	118.95	---	101.43	151.69	---

Chapter 6

CONCLUSIONS

The proposed machinery and nutrient management model provides a tool to evaluate costs and labor requirements for manure transportation and nutrient use in manure application.

1. On the 600-cow farm, irrigation was the lowest cost system when the transport distance was 1.6 km (1 mile) or less, the truck-drawn spreaders were the lowest for distances between 1.6 km (1 mile) and 4.8 km (3 mile), and the nurse truck with spreader tank system was the lowest for distances greater than 4.8 km (3 mile).
2. Pipeline system costs increased rapidly beyond 2 km (1.25 mile) for irrigation, and 3.2 km (2 mile) for the drag hose system as additional tractor power units were required to maintain system pressure.
3. Applying manure for a phosphorus balance provided lower net costs than applying for nitrogen use because of lower costs for commercial fertilizer and lower residual nutrient costs. A corn silage/corn grain rotation with manure applied for a phosphorus balance provided the lowest net cost.
4. Wheat grain/corn grain and sugar beet/corn grain rotations did not have great manure nutrient benefit, but few residual nutrients were left unused in the soil because the crop nutrient requirements closely matched the manure nutrients available.

5. A 600-cow operation generally experienced lower net costs than a 150-cow operation.

These conclusions can be summarized as follows: 1) a corn rotation with N-based manure application was the best crop on which to apply manure. 2) For short transport distances, the box spreader or the truck-drawn spreader was economical on the smaller farms. On larger farms, irrigation was the most economical for a distance of 1.6 km (1 mile) or less. For longer distances, the nurse truck system was the most economical. 3) When the value of manure nutrients used and residual nutrients were considered, an application based on a phosphorus balance was better than an application for nitrogen use. 4) Costs for manure handling and land application were generally lower on larger than on smaller farms, but there were examples where smaller farms had lower costs.

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APPENDIX

APPENDIX A

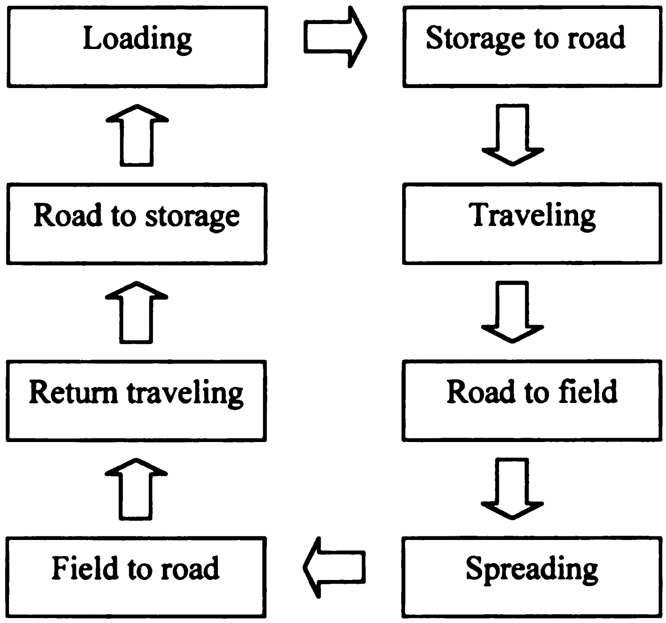

Figure A.1 Hauling cycle of series operation

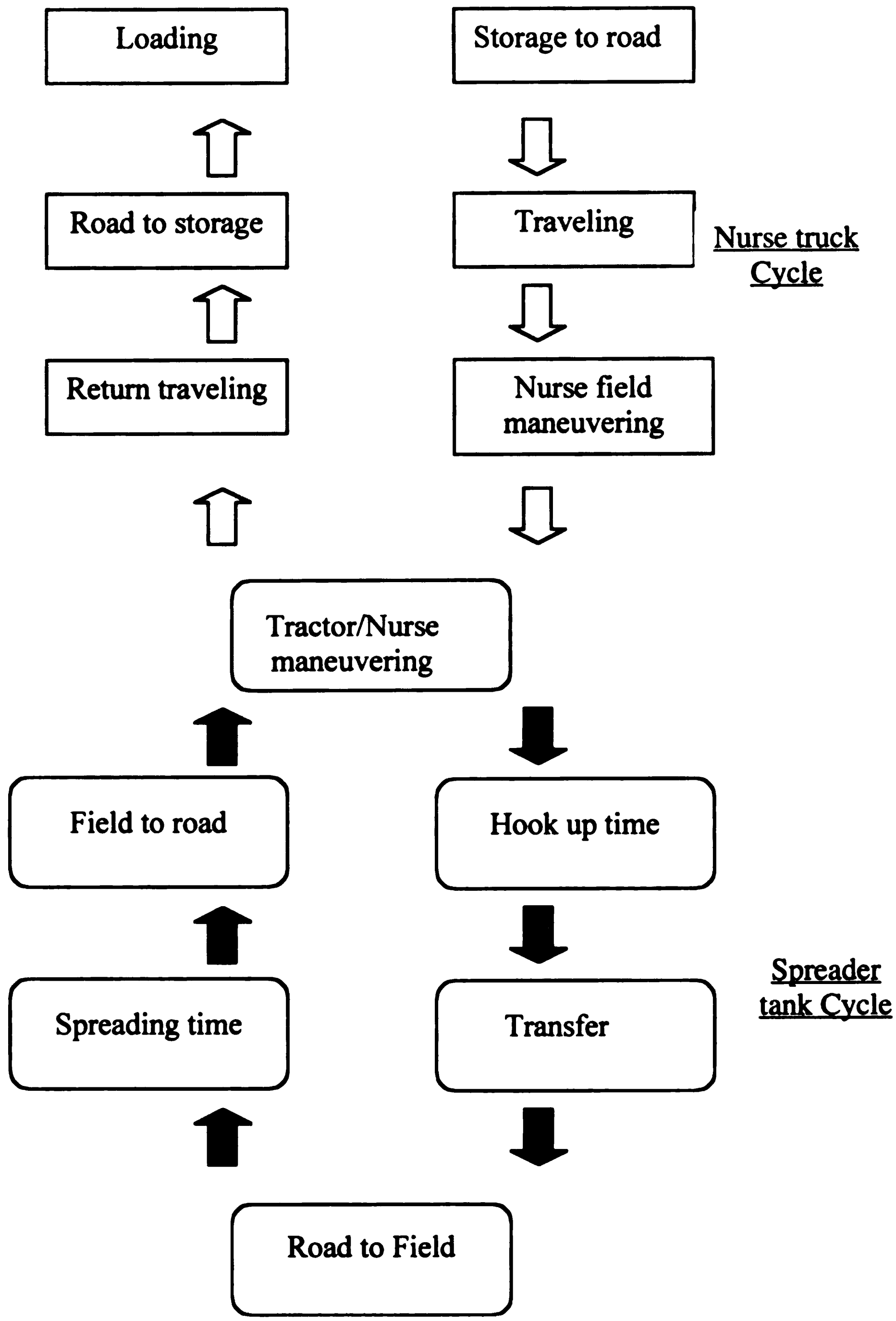

Figure A.2 Spreader tank and equal size nurse tank with a operator system.

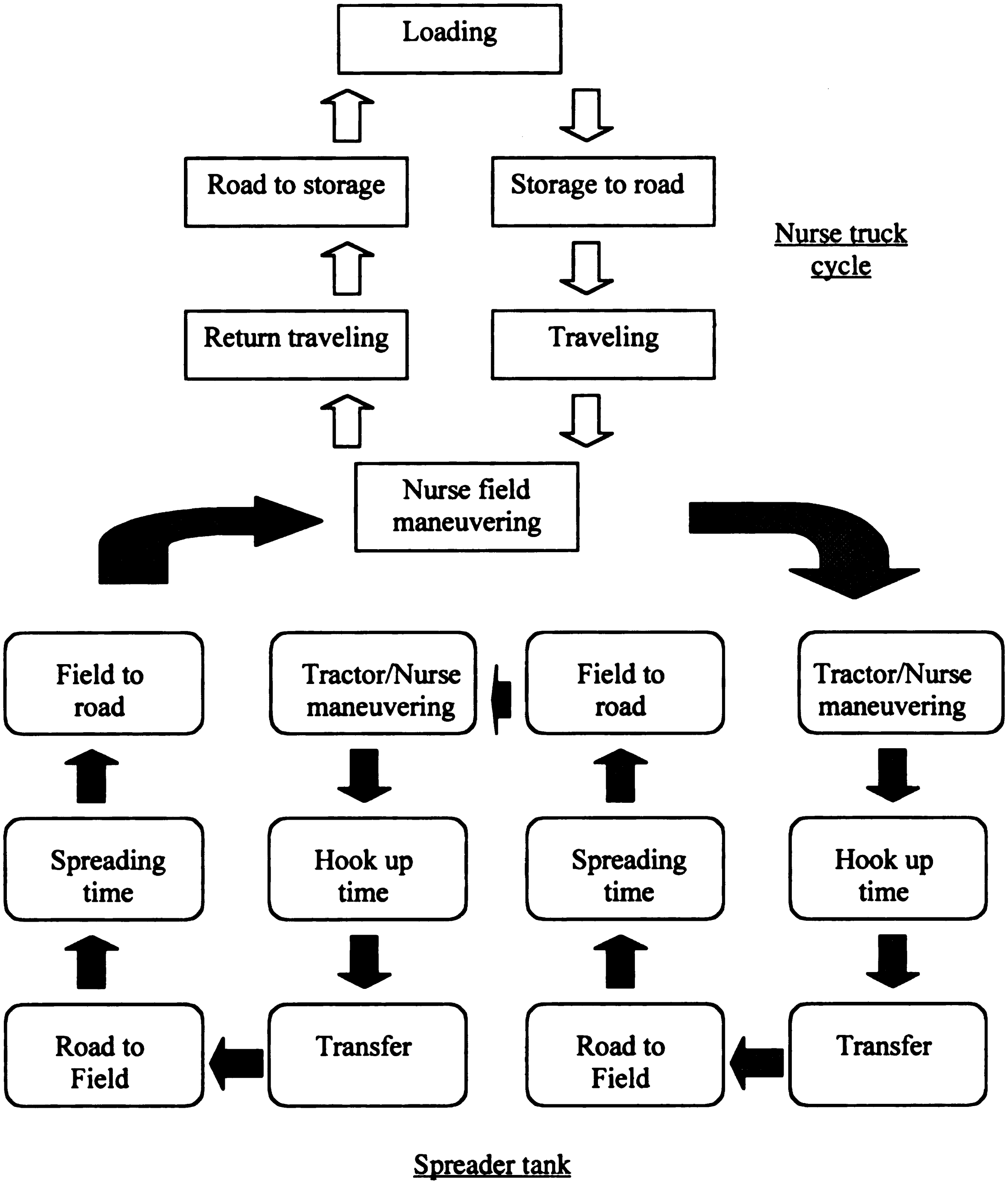

Figure A.3 Hauling cycle of spreader tank and double capacity of nurse truck operation with one operator.

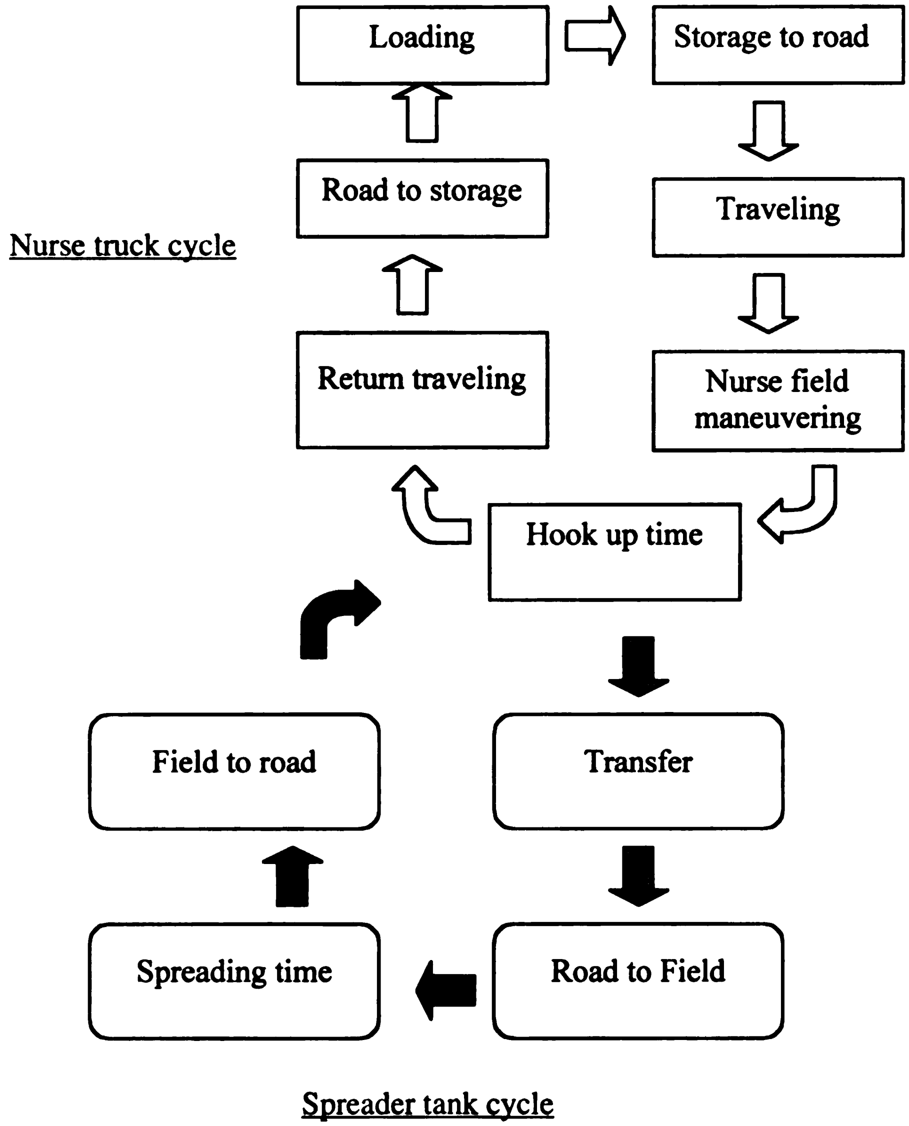

Figure A.4 Hauling cycle of spreader tank and equal size of two nurse truck operation with two operators.

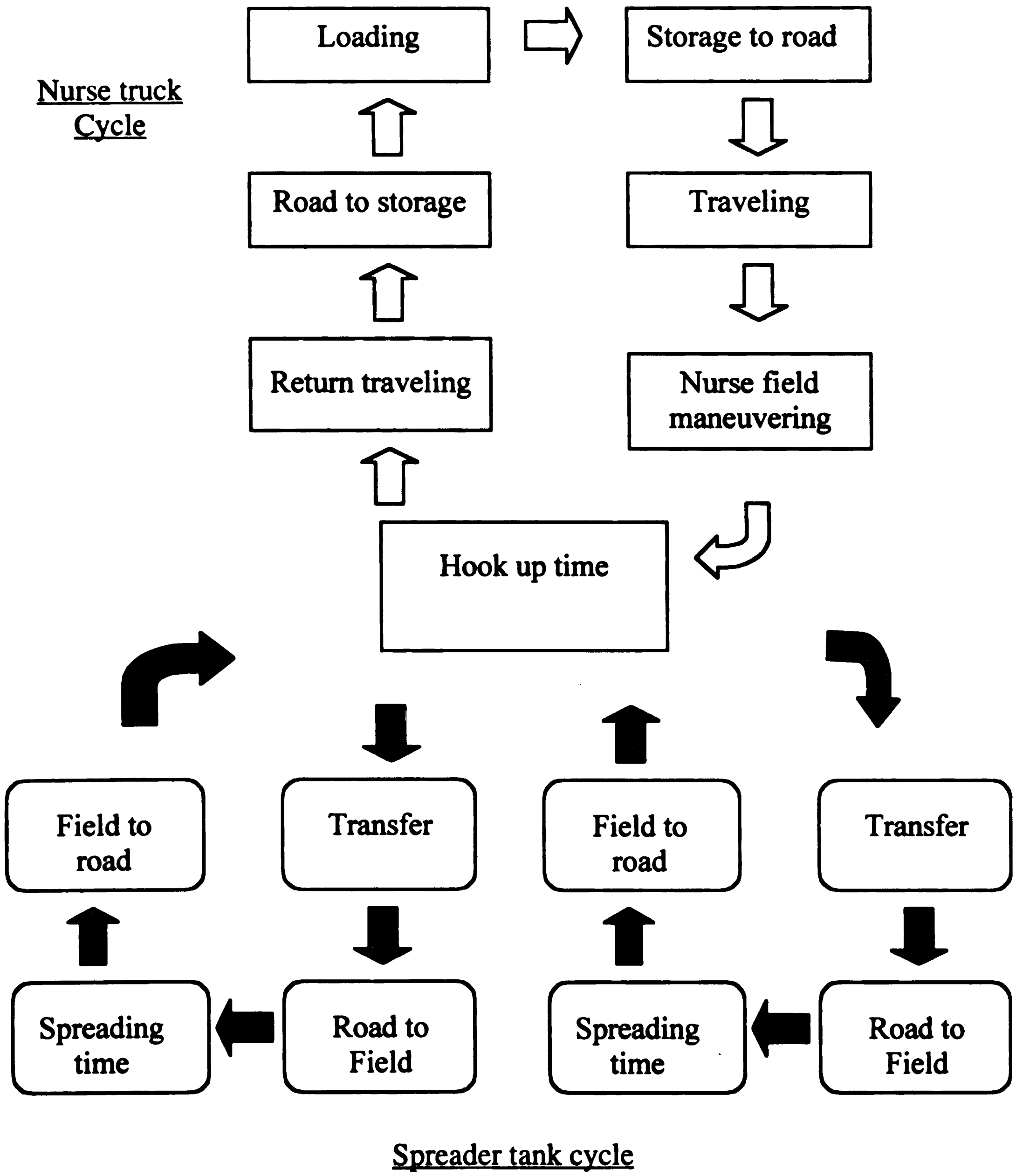

Figure A.5 Hauling cycle of a spreader tank and double capacity of two nurse trucks operation with 3 operators.

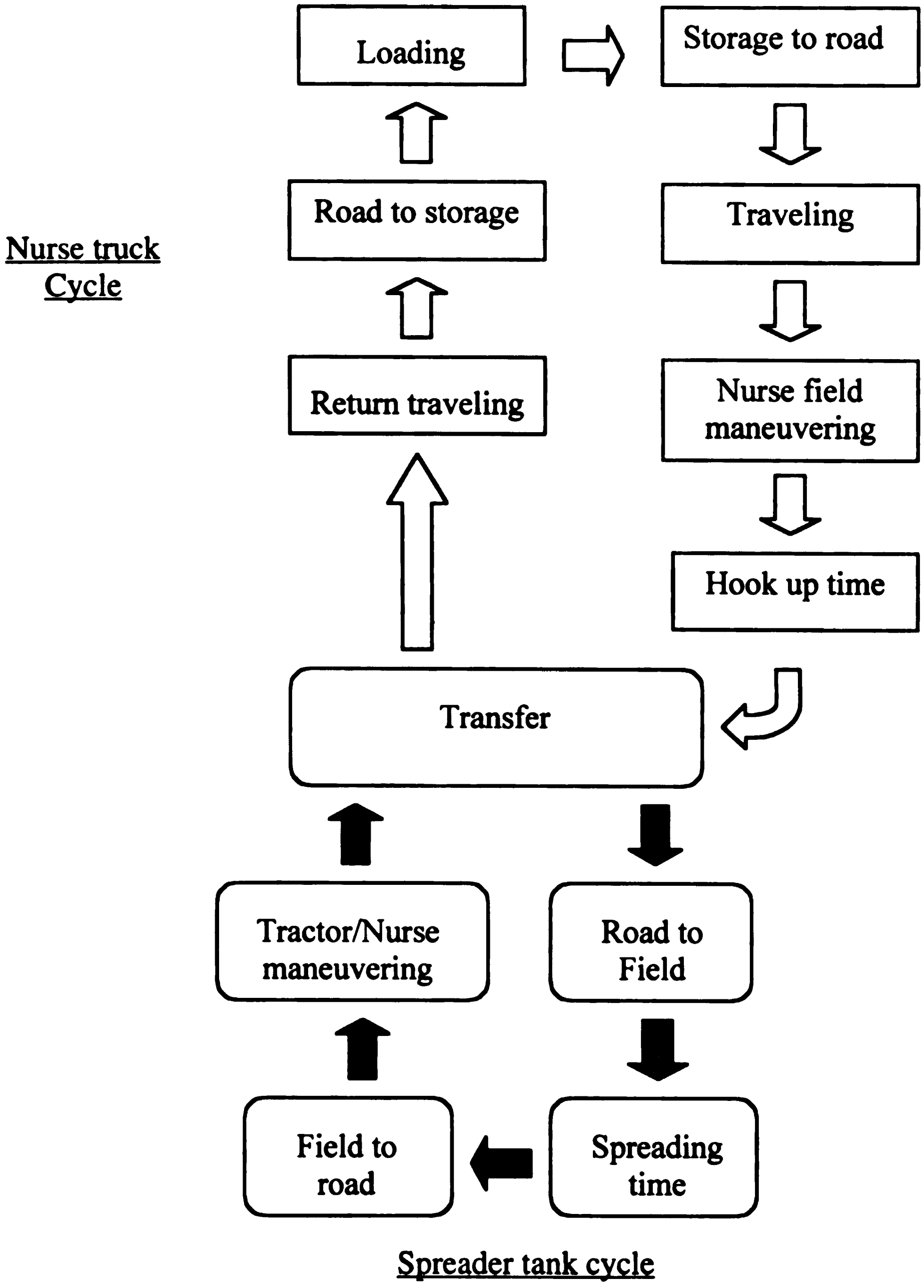

Figure A.6 Hauling cycle of a spreader tank and equal tank capacity of two nurse trucks operation with three operators

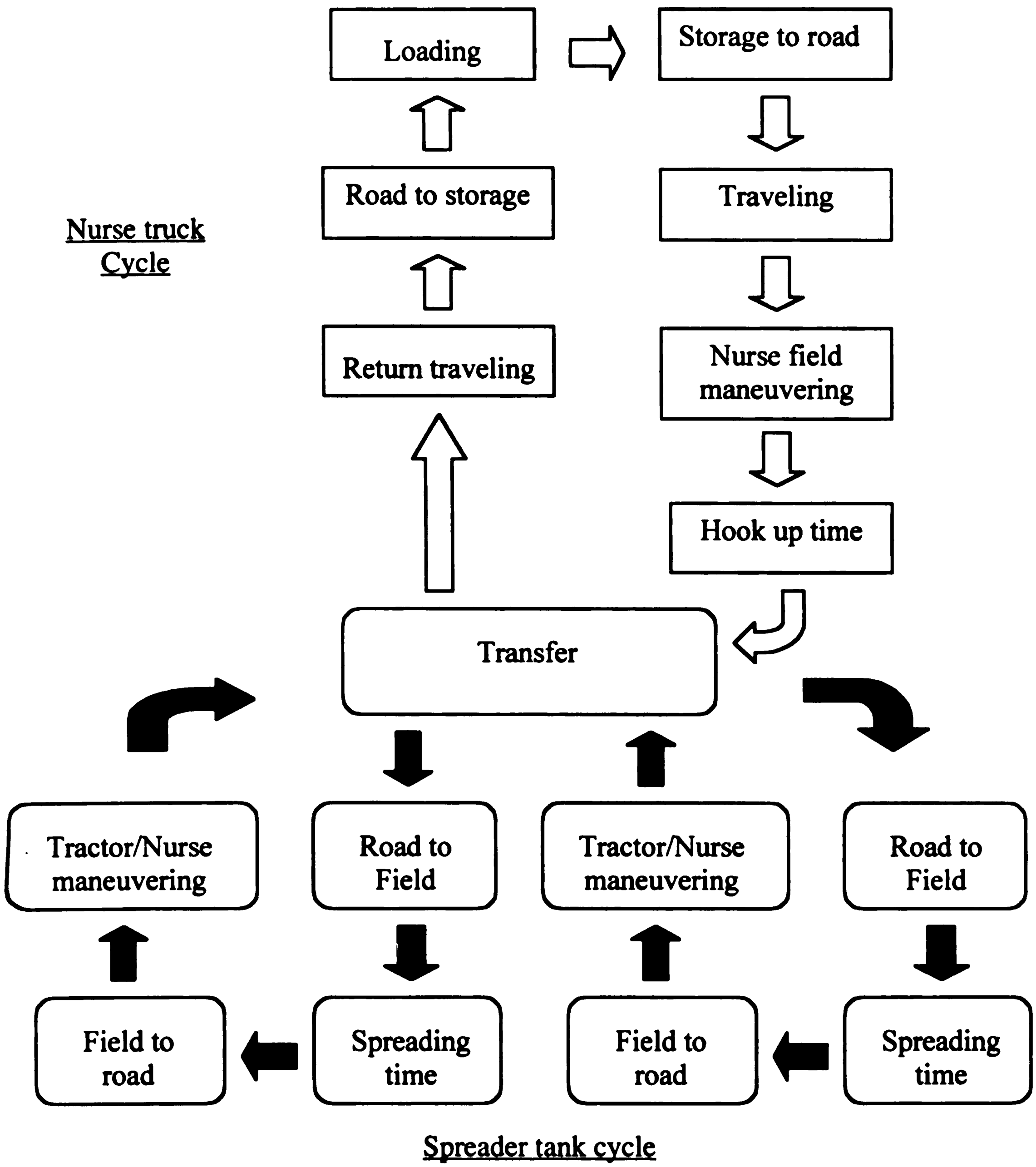

Figure A.7 Hauling cycle of a spreader tank and double capacity of two nurse truck s operation with three operators.