ENERGY CONSUMPTION IN BEEF PRODUCTION SYSTEMS AS INFLUENCED BY TECHNOLOGY AND SIZE

Dissertation for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

HAROLD ARTHUR HUGHES

1973

This is to certify that the

thesis entitled

ENERGY CONSUMPTION IN BEEF
PRODUCTION SYSTEMS AS INFLUENCED
BY TECHNOLOGY AND SIZE

presented by

Harold Arthur Hughes

has been accepted towards fulfillment
of the requirements for

Doctoral degree in Agricultural Engineering

C. J. Mackson
Major professor
C. J. Mackson

Date 9/14/73

ABSTRACT

ENERGY CONSUMPTION IN BEEF PRODUCTION SYSTEMS
AS INFLUENCED BY TECHNOLOGY AND SIZE

by

Harold Arthur Hughes

The objectives of this study were to develop a system model of a beef farm, develop subsystem models for some parts of the system and to evaluate the energy costs of producing beef in systems using various technologies over a range of capacities.

The system model was used to determine the flows of materials into and out of the system as well as between components of the system. The material flows were all related to the flow of beef produced by the system by a set of technical coefficients. Cost of beef produced by the system was measured in terms of six energies: capital, land, fossil energy, electrical energy, labor and dollar cost. The energy cost of beef was related by the technical coefficients to the energy cost of each input material and the processing energies required for the system to operate. Three subsystem models were used to estimate the processing energies. The models were for the field machinery, farmstead, and transportation systems.

The field machinery model was used to select a set of tractors and field machines required for the field operations involved in producing and harvesting the crops. The set of field operations and

the land area depends on system technology and capacity as well as crop yields. After the system was designed, the model estimated the amount of each of the six processing energies needed for the system to operate.

The farmstead was taken to include the feedlot, feed storages and other components concerned with confining and caring for the cattle. The model specified the size of each structure, calculated the price of the farmstead equipment and estimated the quantity of each of the six processing energies required.

Transportation was the link between the field crop production model and the farmstead model. The transportation model determined the number of each kind of transportation equipment needed and evaluated the processing energies required for transportation.

The quantity of each energy required per unit of beef output could be varied by altering the system technology or by changing the system capacity. To evaluate the influence of various parts of the system on the energy costs, a number of systems were compared. The set of technologies analyzed included four feedlot types, two ration, four feed storage systems, two waste handling systems and two animal types. The same crop production and transport technology was used throughout the study. System capacities ranged from 100 to 1000 head.

Conclusions from the study included the following:

1. There is little reduction in dollar cost per hundred pounds of weight gain by the animals, produced in any of the systems analyzed in this study, if the system is increased past about 500 head.

2. Labor requirements in systems using the same technology, decrease to a minimum then begin to increase as system capacity is increased. The system capacity at which the minimum is reached depends on the size of the farm and the capacity of the transport and feeding equipment.
3. Restricting the size of tractors used for field crop production increases the capital and labor required for operating the crop production system.
3. Peak labor requirements occur during the silage harvest season.

Approved: ______________________
Major Professor

Approved: ______________________
Department Chairman

ENERGY CONSUMPTION IN BEEF PRODUCTION SYSTEMS

AS INFLUENCED BY TECHNOLOGY AND SIZE

by

Harold Arthur Hughes

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

1973

This work is dedicated to my wife

Beatrice

and to our children

Christopher, Trevor and Hal,

for their love, understanding, encouragement and sacrifice.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support of the many individuals and organizations who contributed to this study and particularly wishes to express his appreciation to the following:

To Dr. C. J. Mackson, my major professor, for his counsel and friendship for many years.

To Dr. J. B. Holtman, my thesis advisor, for his assistance and guidance in setting up and conducting this study and preparing this thesis.

To Dr. L. J. Connor and Dr. J. R. Black, of the Agricultural Economics Department, who also served on my guidance committee for their helpful suggestions and continued interest.

To the other members of the Agricultural Engineering Department for suggestions and assistance in locating data for the study.

To Mr. David Filpus for his assistance in programming and running the computer.

To the National Science Foundation who provided financial support for the study through the project on Design and Management of Environmental Systems.

To the typist, Beatrice Hughes for being willing to work from a continually changing manuscript.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure | Page

1. INTRODUCTION

Total beef production in Michigan is small in comparison to U. S. production. Less than two percent of the nation's supply of beef comes from Michigan. In fact, Michigan feedlot operators do not produce enough to satisfy the demands of people residing in the state (17).

Michigan beef production systems are unlike the better known western systems in several important ways. Western beef is most often finished on all grain rations in large open lots. Feedlot volumes are large, frequently exceeding 10,000 head per year (10). Grain for the ration is purchased from local growers or feed dealers who import it from grain growing areas. Waste disposal is complicated by sheer volume and by the lack of cropland for spreading. As a consequence, many other approaches to waste handling are being used, such as lagoons and driers.

In Michigan, a variety of feedlots exist. Feed is usually produced on the same farm and often includes a large proportion of corn silage. Waste from the feedlot is recycled back onto cropland. Michigan feedlots tend to be considerably smaller than western units. While there was an average of 210,000 cattle on feed in the state in the period 1969-1971, the average feedlot turned out 175 head per year and only one percent of the feedlots in the state produced over 5000 head (16).

Henderson, et al. (16), using projections of increased per capita consumption, population projections and extrapolating from past production figures, predict that beef production in the state will increase and that individual systems will get larger. Specifically, they predict that by 1985, Michigan feedlot operators will market 532,000 head from 1000 installations. Thus, by 1985, the average feedlot will be as large as the largest one percent is at present. This expansion will require that many new facilities be built and that many existing facilities be altered and expanded.

1.1 SOCIAL IMPLICATIONS

The type and size of feedlots to be built is obviously of concern to present or potential feedlot operators. Less obviously, the public at large also has concern about these same two factors. Feedlot size is an issue because many people feel that large operators try to exert control over markets, and technology is an issue because of the impact it can have on the environment.

Waste Problems

Koenig, et al. (25), discussing labor efficiency in agricultural operations observes that concentration of agricultural production into large units, such as the western type feedlots, has caused urban waste disposal problems to increase. They state that:

> "...since in agricultural processes the size of machines is specific to the size of the land holdings on which they operate, the drive for labor efficiency through the use of larger machines has a partidularly high social and environmental impact. Indeed it has all but eliminated the "family farm" and with it the relatively small ...villages and cities distributed rather

> uniformly over the landscape where their wastes were reasonably well matched to the carrying capacity of the landscape."

They go on to note that all of the food necessary for the people who have, as a consequence, migrated to the cities must be moved to the cities. The resulting wastes are concentrated in small areas with the attendant problems of treatment and disposal. In fact, after whatever processing is available has been completed, the wastes are usually discharged into the nearest lake or stream.

Increased labor efficiency also leads to increased specialization and spatial concentration of agricultural production units, such as beef feeding operations. The resulting agricultural waste control problem for beef is well recognized. Maddex (16) observes that:

> "...manure handling and disposal is today's greatest challenge facing the beef industry. With increased urbanization and concern for environmental quality, the challenge will become greater. Changes will have to be made in accepted ways of housing and managing cattle."

Power Over Markets

Discussing the issue of control over markets, Sundquist and Guither (36) state that:

> "Many nonfarmer residents of rural communities are concerned that any takeover of farming by large scale production units will squeeze out small farmers and small farm supply and marketing businesses. They also feel that large corporations will be less inclined to support high-quality public services such as schools, health care facilities and roads and recreational facilities.

> Concerns of the general public, including consumers and taxpayers, center on at least four broad issues: 1) they want dependable supplies of low cost and high quality food, 2) they want to curtail agricultural practices that adversely affect environmental quality and the availability of open spaces, 3) they want tax costs of any policy to be in line with the benefits realized, 4) they want a fair share of the benefits of farm programs to accrue to smaller (as contrasted to large scale) producers. Though some think that large scale farming will be low cost and efficient others think big farm corporations will try to gain monopoly controls and raise food prices."

Purpose of the Study

From the foregoing discussion, it can be seen that both rural and urban residents have concerns regarding the type and size of beef systems to be used. Present systems, as noted in the quote by Maddex (16), are not likely to be satisfactory. Changes are needed. Maddex (16) went on in the same article to state that research information and analytical techniques are not available to predict the direction the changes will take.

Society determines the direction of change in accordance with societal goals. The decision, made by trading off desirable and undesirable features of candidate systems, is implemented by the use of economic or legal controls or by the use of some other appropriate social mechanism.

The purpose of this study was to expedite this process by developing a means of analyzing and comparing beef production systems in terms of certain physical characteristics for a selected set of technologies and sizes.

Since the variations in technology are practically unlimited, the set of technologies had to be limited. The technologies chosen

for evaluation will be described along with the design procedures in Chapters 3, 4 and 5.

1.2 MEASURES OF EFFECTIVENESS

A beef farm can be conceptualized as a "black box" wherein input materials of various kinds are transformed into finished beef animals and waste materials, as shown in Figure 1.1. Energy is needed to effect the material combination. Figure 1.1 shows a vector of the required energies. Monetary energy (capital) is required to initiate the system and to supply input materials and replacement equipment. Fossil and electrical energy are used to operate machines. Solar energy is necessary for crop growth. Human energy is used to manage and control the system, operate machines and to perform various unmechanized functions. Dollar cost is an economic "weighted" function over all the other energy requirements.

Systems, distinguished by size and technology, require different quantities of each kind of energy. For a particular situation, it may be desirable or necessary to minimize or limit consumption of one or more of the energy types. For example, the present "energy crisis" in this country demands that fossil energy consumption be held to a minimum. Consumption of each energy type, quantity of beef produced and cost of beef produced are the measures of effectiveness of a system (20,42). The "best" system for a particular situation depends on the ordering placed upon these measures of effectiveness as well as others not considered in this study.

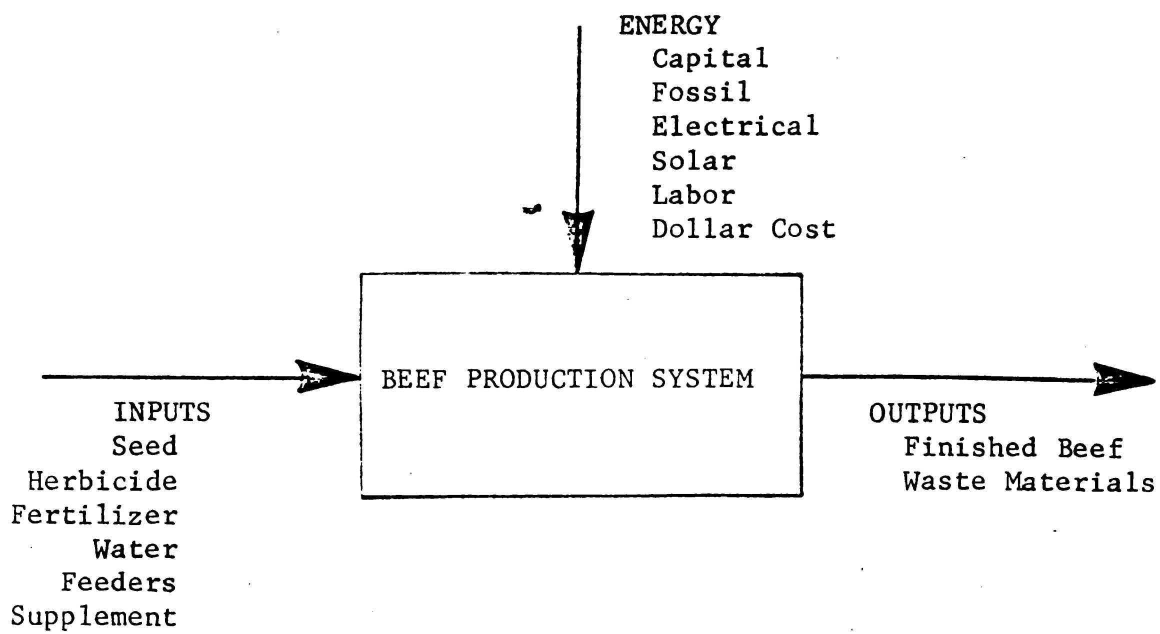


Figure 1.1. Beef Farm as a "Black Box"

1.3 OBJECTIVES OF THE STUDY

In consideration of the preceding discussion the following objectives for the study were formulated:

1. Develop a model of the beef production system that will allow evaluation of the cost of producing beef and the energy consumed by the system.
2. Develop subsystem models for selecting the components needed for a system of a given size and technology.
3. Evaluate the energy and dollar cost of producing beef in systems using certain technologies over a range of sizes.

2. SYSTEM MODEL

The objective of the study was to evaluate systems over a range of capacities for a selected set of technologies. There are two ways to approach such a study (20). Actual operating systems using each technology, of sizes distributed over the desired range, can be located and analyzed from information gathered on site. This approach is difficult because comparable systems using the same technology and similar management over a suitable range of sizes must be located. This difficulty is compounded by the necessity of obtaining co-operation from the operators after the suitable systems have been found. Accordingly, the alternative, a modeling approach was adopted.

The next problem to be considered was whether to use a static or dynamic model. A dynamic model is useful for analyzing the operations of an individual system to find information such as peak labor useage or the effect of a disturbance such as bad weather on the system (20). This study, however, was designed for comparison of a large number of systems. Static models are simpler and more suitable for an application of this type. Therefore, static models were used for the study.

2.1 FORMULATION OF THE MODEL

Koenig and Tummala (24) discuss a modeling technique in which a system is decomposed into a set of components described in

terms of their mass-energy characteristics. When each component is assumed to operate independently of the remainder of the system, alternative system designs can be evaluated by replacing components.

For the beef model, components are of two generic types: material transformation and transportation. A material transformation component is one that transforms input material into output materials. The mix of input and output materials achieved by the component is described by the technical coefficients for the component. An alternate component, of a different technology, performs the same material transformations, but might have a different set of technical coefficients. The transformations are effected by the application of processing energy.

Transportation components do not perform a material transformation. There is, however, a processing energy cost (24).

A notational scheme has been adopted for the formulation of component models. Material flow rates of material i into or out of component j are denoted Y_{ij} (i.e., Y_{ij} has units of quantity of material per unit time). The amount of energy m associated with this same material is denoted X^m_{ij} (i.e., X^m_{ij} has units of quantity of energy m per unit quantity of material). The product $X^m_{ij} \cdot Y_{ij}$ then denotes an energy flow rate.

2.2 COMPONENT MODELS

Feed Production Subsystem

The feed production subsystem includes shelled corn production and transportation components, silage production and transportation components and component for mixing the ration to be fed to the cattle.

The corn and silage production components are shown in Figures 2.1 and 2.2, respectively. The two components have similar inputs, but the units of output are different, being bushels of shelled corn per year and tons of corn silage per year, respectively.

The material flow model for corn production takes the form:

$$Y_{i1} = K_{i1}\, Y_{01} \qquad i = 1,2\ldots6 \qquad (2\text{-}1)$$

where K_{i1} is the quantity of material i1 required to produce one unit (bushel) of shelled corn.

The output, Y_{01}, determines the quantities of the other flows and is called the stimulus variable. The flow other than the stimulus are called response variables. The K_{i1}'s are the technical coefficients for the component.

Similarly, the material flow model for silage production is:

$$Y_{i2} = K_{i2}\, Y_{02} \qquad i = 1,2\ldots7 \qquad (2\text{-}2)$$

Ration production, another material combination component is shown in Figure 2.3. Ration is produced by combining, in the proper proportions, corn and silage, which has had protein supplement added to it before storage. The mathematical expression for the material combination is:

$$Y_{i3} = K_{i3}\, Y_{03} \qquad i = 1,2 \qquad (2\text{-}3)$$

Associated with each edge (material flow) is a vector of values representing the energy per unit of the material required to put the material into its current state. Elements of the energy cost vector are denoted by X_{ij}^{m} (m indicates the energy type) where:

m = 1 : capital ($)
m = 2 : labor (man hours)
m = 3 : fossil energy (horsepower hours)

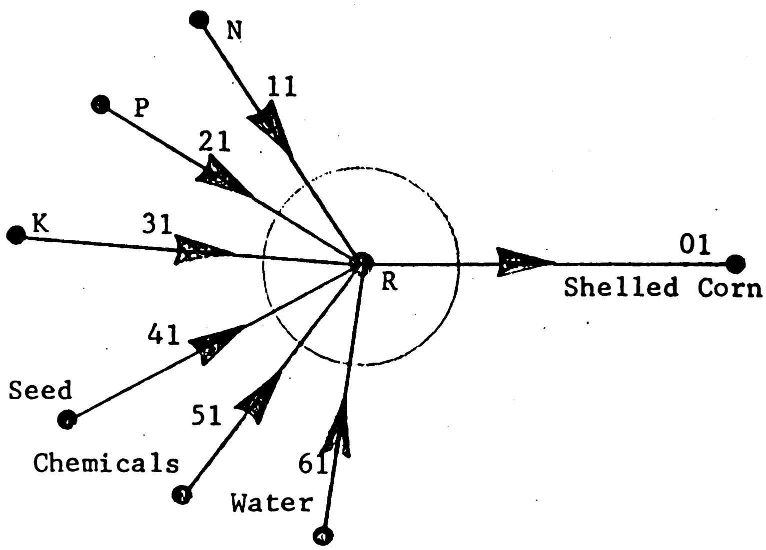


Figure 2.1. Corn Production Component

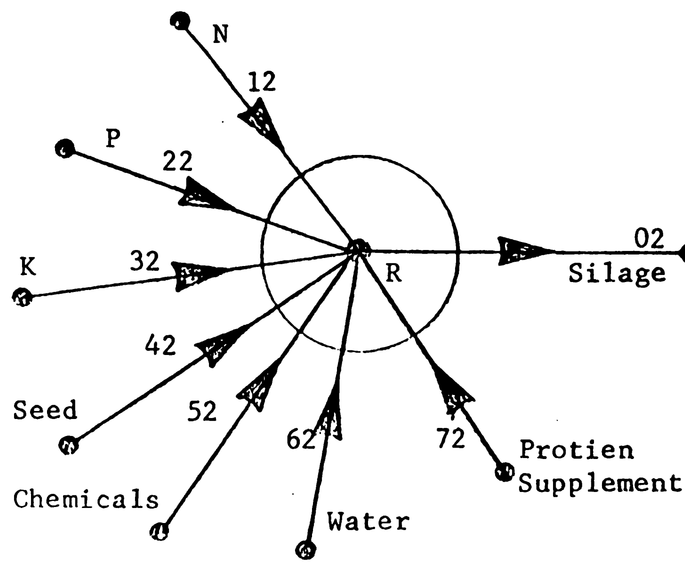


Figure 2.2. Silage Production Component

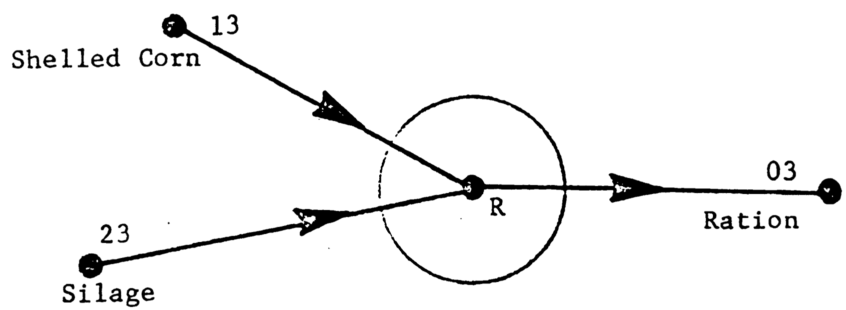


Figure 2.3. Ration Combination Component

m = 4 : electrical energy (kilowatt hours)
m = 5 : land (acres)
m = 6 : dollar cost ($)

Land is a measure of the solar energy needed to produce the crop. X^6_{ij}, the unit dollar cost of material i for component j, is, among other things, a scalar function of the energy costs of the other five energy forms. The value of X^6_{ij} depends on the relative availability of the five forms of energy and the preference society places on each of the input materials.

Examples of costs are: X^5_{51} is the land required to produce one bushel of seed corn and X^2_{02} is the labor in man hours needed to produce one ton of silage, including the labor required to produce the quantity of each of the input materials used to produce one ton of silage.

Employment of the conservation of energy principle implies that the net energy flow into the component plus the applied processing energy must equal zero. The expression:

$$\sum_{i=1}^{6} K_{i1} X^m_{i1} \qquad m = 1,2...6$$

is an accumulation of the amount of energy m in the input materials required to produce one bushel of shelled corn.

Processing energy costs include the cost of machinery, buildings, labor, fuel, taxes, depreciation, etc. The processing energy cost function is typically a non-linear function of the production level. The amount of processing energy m required for one bushel of shelled corn is:

$$f^m_1(Y_{01}) \qquad m = 1,2...6$$

Energy relations in each of the m types are expressed below for the shelled corn, silage, and ration components, respectively:

$$X_{01} = -\sum_{i=1}^{6} K_{i1} X_{i1}^{m} - f_1^m(Y_{01}) \qquad m = 1,2 \ldots 6 \qquad (2\text{-}4)$$

$$X_{02} = -\sum_{i=1}^{7} K_{i2} X_{i2}^{m} - f_2^m(Y_{02}) \qquad m = 1,2 \ldots 6 \qquad (2\text{-}5)$$

$$X_{03} = -\sum_{i=1}^{2} K_{i3} X_{i3}^{m} - f_3^m(Y_{03}) \qquad m = 1,2 \ldots 6 \qquad (2\text{-}6)$$

After each crop has been harvested, it is transported to storage. The model contains components for the transportation of both feeds, of the type shown in Figure 2.4. Since the same material flows into and out of a transportation component, and it is assumed that no losses are incurred, only processing energy costs need be considered. The cost models for the transportation components for shelled corn and silage are:

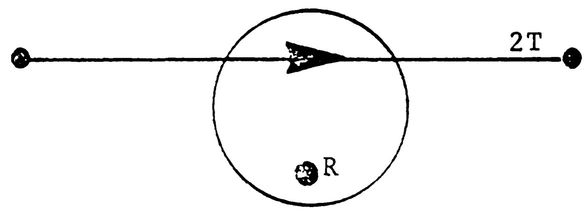
$$X_{2T}^{m} = -f_{2T}^{m}(Y_{2T}) \qquad m = 1,2 \ldots 6 \qquad (2\text{-}7)$$

$$X_{3T}^{m} = f_{3T}^{m}(Y_{3T}) \qquad m = 1,2 \ldots 6 \qquad (2\text{-}8)$$

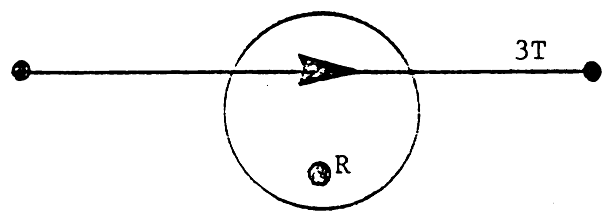
The combination of components that make up the crop production subsystem are connected as shown in Figure 2.5. Energy costs of crop production, transportation of each crop, and the energy costs of the ration can be evaluated from the model of the sub-system.

Feedlot Component

After the ration has been produced and transported to storage, it is moved to the animals in the feedlot, as shown in Figure 2.6. The mathematical form of the feedlot component model is:



(a) Component 2T for Shelled Corn



(b) Component 3T for Silage

Figure 2.4. Transport Components for Feed

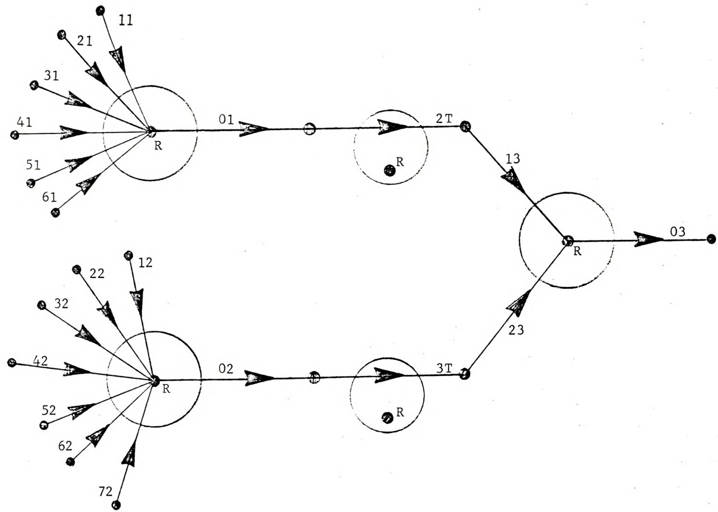


Figure 2.5. Feed Production Sub-system

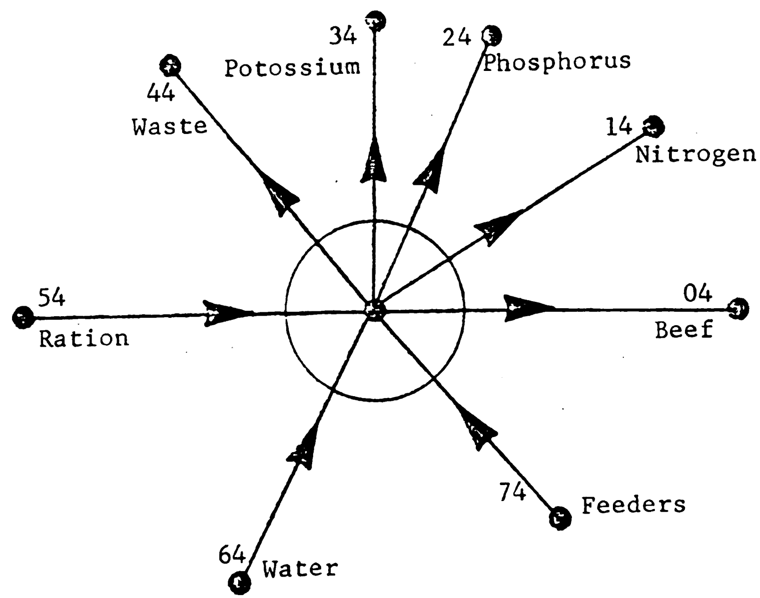


Figure 2.6. Beef Feedlot Component

$$Y_{i4} = K_{i4}Y_{04} \qquad i = 1,2\ldots7 \qquad (2\text{-}9)$$

and

$$X^m_{04} = -\sum_{i=1}^{7} K_{i4}X^m_{i4} - f^m_4(Y_{04}) \qquad m = 1,2\ldots6 \qquad (2\text{-}10)$$

The waste material flow from the feedlot is decomposed into the flows Y_{14}, Y_{24}, Y_{34}, and Y_{44}. The first three are re-cyclable nutrients N, P, and K (Nitrogen, Phosphorus, and Potassium) respectively. The flow Y_{44} represents the flow of waste water and other inert or non-nutrient portions of the animal manure.

An alternative description of this component would show a single output of waste material. The four-output form was selected because changes in animal type, ration, or feedlot type are expected to affect both the composition and quantity of waste material (i.e., technology change alters technical coefficients).

Waste Storage

As waste material is held in a manure pack, liquid tank, or elsewhere, there are losses to the environment. Waste water runs off, evaporates, or infiltrates into the soil, carrying some of the nutrients along. Volatilization and other losses occur which also reduce the quantity of each nutrient to be re-cycled. There are similar components to account for the loss for each of the waste material flows of the type shown in Figure 2.7. The mathematical form of the model is:

$$Y_{iL} = K_{iL}Y_{0L} \qquad i = 1,2; \quad L = 5,6,7,8 \qquad (2\text{-}11)$$

and

$$X^m_{0L} = -\sum_{i=1}^{2} K_{iL}X^m_{iL} - f^m_L(Y_{0L}) \qquad m = 1,2\ldots6 \qquad (2\text{-}11)$$

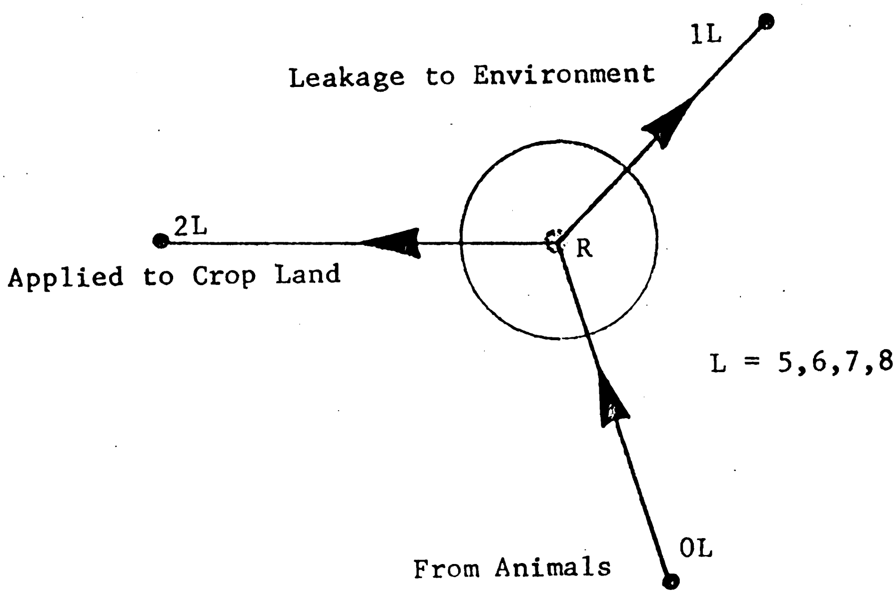


Figure 2.7. Typical Waste Storage Component

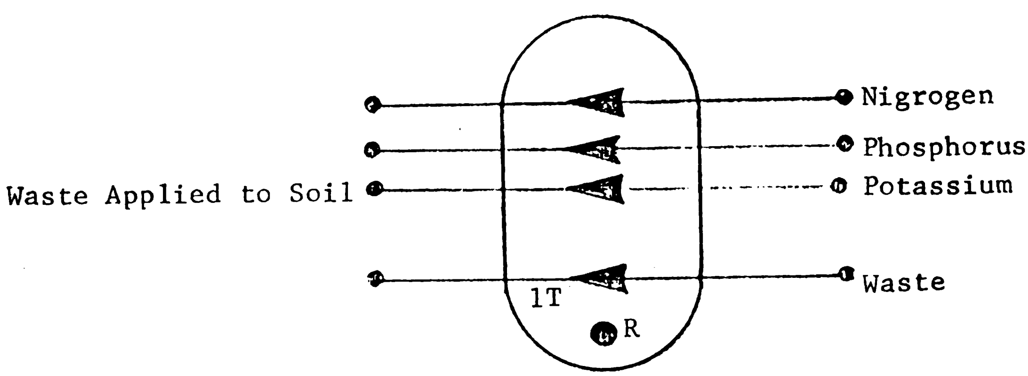


Figure 2.8. Waste Transport Component

where: L = 5 : non-nutrient material
L = 6 : potassium
L = 7 : phosphorus
L = 8 : nitrogen

Waste Transport

The non-nutrient waste and fertilizer equivalents of N, P, and K that remain after storage losses have occurred must be transported to the field for application to the soil. The waste transport component is shown in Figure 2.8. The energy costs for the component are evaluated using the "common carrier" concept discussed by Koenig and Tummala (24). The energy costs are allocated according to the relation:

$$X^m_{1T} = c_i F_{1T}(Y_{1T}) \qquad i = 1,2,3,4; \quad m = 1,2\ldots6 \tag{2-13}$$

where: $$Y_{1T} = \sum_{i=1}^{4} c_i Y_i$$

The c_i are factors which convert all material flows to the same weight base. Y_{1T} is the total weight of the four materials which are transported together.

In this case, the nutrient flows are stated in units of fertilizer equivalents (equivalent to commercial fertilizer), and the actual weight of N, P, and K is not important. Only total weight of nutrient and non-nutrient material is important relative to transport cost. Therefore, the c_i's for the flows of N, P, and K were arbitrarily set to zero and the c_i for total waste mass flow was set to one. In effect, for the purpose of evaluating transport costs, all mass is viewed as passing through the flow of waste material with the nutrient flows being massless fertilizer equivalents.

Commercial Fertilizer

The quantity of each fertilizer constituent (N, P, K) required is determined by the crop production components. A steady-state nutrient equilibrium was assumed (nutrients applied equal nutrient uptake by plants plus losses). The amount of each nutrient to be applied as commercial fertilizer is the difference between the quantity required by both crops and the quantity available from the waste, as shown in Figure 2.9. The commercial fertilizer requirements are:

$$Y_{0N} = Y_{21} + Y_{22} - Y_{18} \quad (2\text{-}14)$$

$$Y_{0P} = Y_{31} + Y_{32} - Y_{17} \quad (2\text{-}15)$$

$$Y_{0K} = Y_{41} + Y_{42} - Y_{16} \quad (2\text{-}16)$$

The cost X^m_{0i} i = N, P, K: m = 1,2...6 of the commercial fertilizer purchased is the cost of the material supplied to the farm.

2.3 BEEF FARM MODEL

The diagram in Figure 2.10 shows the entire system. Each material flow in the system depends on the quantity of beef produced. The energy costs per unit of beef also depend on the system size.

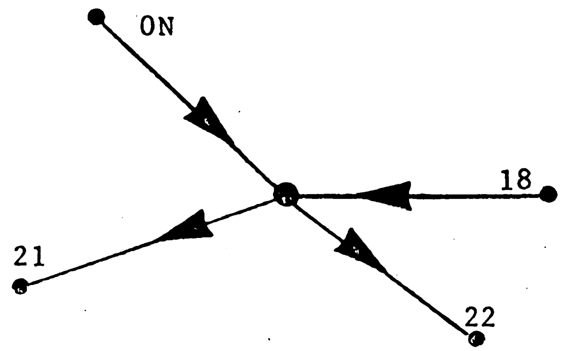
The method advocated by Koenig and Tummala (24) and illustrated by Holtman, et al., (22) was used in deriving the following system material flow relations. The flows are:

$$Y_{64} = K_{64}Y_{04}$$

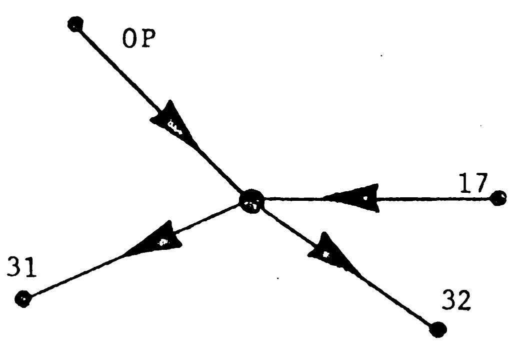
$$Y_{74} = K_{74}Y_{04}$$

$$Y_{52} = K_{52}K_{23}K_{54}Y_{04}$$

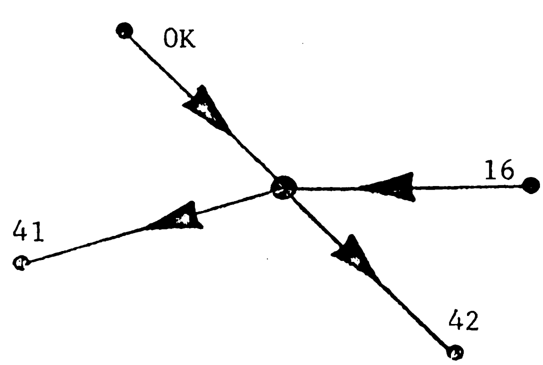
$$Y_{62} = K_{62}K_{23}K_{54}Y_{04}$$



(a) Commercial Nitrogen Requirement



(b) Commercial Phosphorus Requirement



(c) Commercial Potassium requirement

Figure 2.9. Commercial Fertilizer Requirement

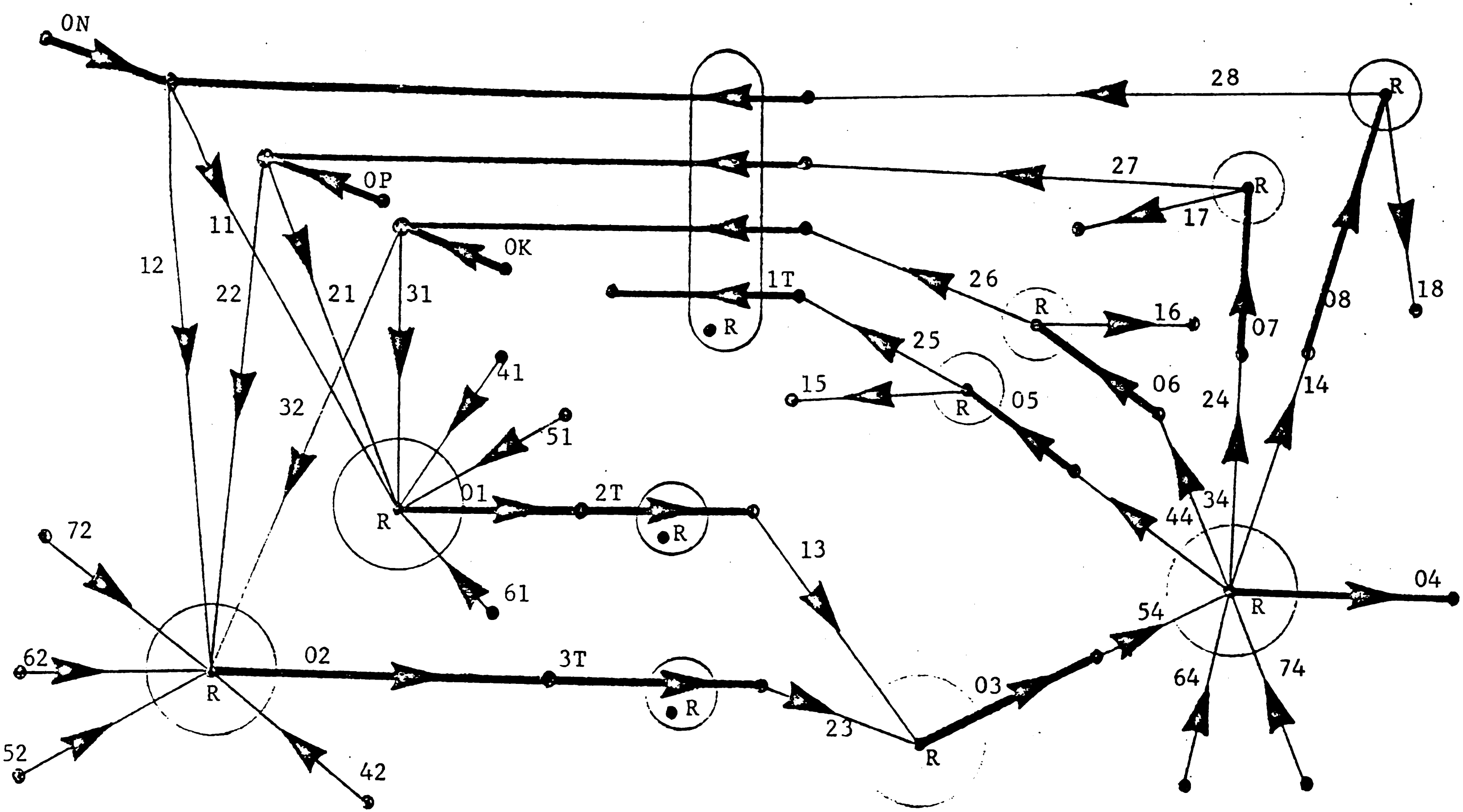


Figure 2.10. Material Flows in a Beef Production System

$$Y_{72} = K_{72}K_{23}K_{54}Y_{04}$$

$$Y_{82} = K_{82}K_{23}K_{54}Y_{04}$$

$$Y_{51} = K_{51}K_{13}K_{54}Y_{04}$$

$$Y_{61} = K_{61}K_{13}K_{54}Y_{04}$$

$$Y_{71} = K_{71}K_{13}K_{54}Y_{04}$$

$$Y_{15} = K_{15}K_{44}Y_{04}$$

$$Y_{16} = K_{16}K_{34}Y_{04}$$

$$Y_{17} = K_{17}K_{24}Y_{04}$$

$$Y_{18} = K_{18}K_{14}Y_{04}$$

$$Y_{0N} = (K_{54}(K_{12}K_{23} + K_{11}K_{13}) - K_{28}K_{14})Y_{04}$$

$$Y_{0P} = (K_{54}(K_{22}K_{23} + K_{21}K_{13}) - K_{27}K_{24})Y_{04}$$

$$Y_{0K} = (K_{54}(K_{32}K_{23} + K_{31}K_{13}) - K_{26}K_{34})Y_{04} \qquad (2\text{-}17)$$

In effect, the set of equations above transforms the entire system model into a component model with seventeen material flows to and from the environment. A consistent set of flows and coefficient units are shown in Appendix A. The flow Y_{04} (output of beef) is the stimulus variable that dictates the remaining flows. The energy cost per unit of output beef is expressed in the following relationship:

$$\begin{aligned} X^m_{04} = \; & (K_{11}K_{13}K_{54} + K_{12}K_{23}K_{54} - K_{28}K_{14})X^m_{0N} \\ & + (K_{21}K_{13}K_{54} + K_{22}K_{23}K_{54} - K_{27}K_{24})X^m_{0P} \\ & + (K_{31}K_{13}K_{54} + K_{32}K_{23}K_{54} - K_{26}K_{34})X^m_{0K} \\ & - K_{13}K_{54}(K_{51}X^m_{51} + K_{61}X^m_{61} + K_{71}X^m_{71}) \end{aligned}$$

$$- K_{23}K_{54}(K_{52}X_{52}^{m} + K_{62}X_{62}^{m} + K_{72}X_{72}^{m} + K_{82}X_{82}^{m})$$

$$- K_{64}X_{64}^{m} - K_{74}X_{74}^{m}$$

$$- (K_{15}K_{44}X_{15}^{m} + K_{16}K_{34}X_{16}^{m} + K_{17}K_{24}X_{17}^{m} + K_{18}K_{14}X_{18}^{m})$$

$$- K_{13}K_{54}f_{1}^{m}(K_{13}K_{54}Y_{04})$$

$$- K_{23}K_{54}f_{2}^{m}(K_{23}K_{54}Y_{04}) - K_{54}f_{3}^{m}(K_{54}Y_{04}) - f_{4}^{m}(Y_{04})$$

$$- K_{44}f_{5}^{m}(K_{44}Y_{04}) - K_{34}f_{6}^{m}(K_{34}Y_{04}) - K_{24}f_{7}^{m}(K_{24}Y_{04})$$

$$- K_{14}f_{8}^{m}(K_{14}Y_{04}) - K_{25}K_{44}f_{1T}^{m}(K_{25}K_{44}Y_{04})$$

$$- K_{13}K_{54}f_{2T}^{m}(K_{13}K_{54}Y_{04}) - K_{23}K_{54}f_{3T}^{m}(K_{23}K_{54}Y_{04}) \quad (2\text{-}18)$$

The first three terms are the cost of commercial fertilizer added to crop land. The following two terms are the costs of other materials used for crop production. The next two are the costs of inputs to the feedlot component (water and feeders, respectively). The following term is the cost of the materials leaked to the environment. The remaining terms represent the processing energies used to convert the input materials into finished beef.

The model expresses all input and output material flows, for a given system, and the cost of beef produced by the system as functions of the technical coefficients (technology) and the amount of beef produced by the system (size). Given the set of technical coefficients, the processing energy function, and system capacity, beef production systems can be analyzed to find the quantity of material flows to and from the environment and the cost of beef produced.

2.4 TECHNICAL COEFFICIENTS

The technical coefficients and the processing energy functions are not all readily available. Some, like K_{13} and K_{23} (amounts of silage and corn fed per animal/day) can be found in the literature. Others must be evaluated by different means. The processing energy functions are universally unknown. The estimates of energy consumption that are available (1,11,32,37) often do not consider variations with farm size. They are usually averaged over whatever farm sizes that were available when the information was collected.

It was necessary, therefore, to analyze each component to find some of the energy costs. Discussion of the approach is divided into three chapters 1) crop production, 2) farmstead, and 3) transportation.

3. FIELD MACHINERY

The field machinery system includes only those operations which take place in the field and are needed for tilling the soil or planting and harvesting the crops used for the ration. Referring to Figure 2.10, this field machinery system model estimates the requirements for each of six processing energy types for field crop production. Energy associated with the input materials will be discussed below.

The machinery model selects a machinery complement, including power units, which is capable of performing all field operations at a rate sufficient to achieve a successfull crop. The model begins by estimating horsepower needed for the cropping operations. Then the tractors and field machines are selected and the processing energies are calculated.

3.1 POWER REQUIREMENT

Power required for field operations depends on the amount of work to be done and the time available. Work to be done depends on: 1) the acreage of each crop to be grown, 2) soil characteristics, 3) field operations required for planting, cultivating, and harvesting the crops and 4) the technology (kinds of machines) being used. The time available for completion of field work depends on 1) weather and soil characteristics, 2) hours worked per day, 3) number of days

allowed for completion of field operations, 4) scheduling efficiency, 5) machine reliability and 6) field efficiency.

The method described in this section is taken from Hughes, et al. (23) and is shown in Figure 3.1.

Field Operations Required

The set of field operations to be performed depends on the crops to be produced and the production technology adopted. In its simplest terms, production technology refers to the particular set of field operations used to grow the crop. Zero tillage, where the seed is planted in the soil without any preliminary tillage, is an example of a production technology.

Subsets of Field Operations

The set of field operations are organized into subsets. Each subset is a group of field operations that must be performed either simultaneously or sequentially during a specific time period. No particular order of operations within the subset is assumed.

A subset can consist of a single field operation, such as combining grain corn or it may include several operations such as the plowing, tilling, and planting that occurs in the spring. Starting and ending dates for the subset may be dictated by cropping characteristics, by weather and soil conditions, or by management requirements. The spring operation subset, for example, cannot begin until soil conditions are suitable for tillage. The ending date for the subset is the target date for completion of planting, a management decision based on crop growth characteristics and the prevailing climate.

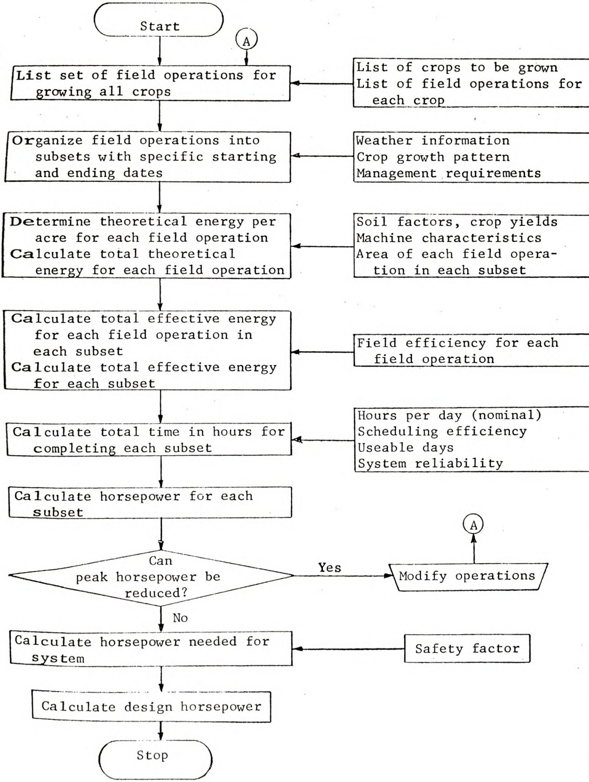


Figure 3.1. Procedure for Estimating Horsepower Requirement

Theoretical Energy

Theoretical energy consumption is a familiar subject which has been discussed by many authors (1,3). It is the energy, in horsepower hours, that would be consumed in performing a particular field operation if there were no field inefficiencies such as wheel slippage, overlap, etc. Theoretical energy consumption by a field machine is situation specific and depends on factors wuch as soil characteristics, crop yields and machine characteristics.

The assumption is often made (3) that theoretical energy required per acre for a particular machine is speed invariant. This is not always true, particularly for tillage machines such as moldboard plows for which energy consumption increases as some power of speed (3). However, if machine speed is restricted to a narrow range, the theoretical energy can be assumed to be constant. This procedure was selected.

Theoretical energy can be calculated from Equation 3-1, where the first bracketed term is the horsepower requirement and the second term is the theoretical time per acre:

$$E_{Tj} = \left(\frac{U_j K_j S_j}{375}\right)\left(\frac{8.25}{K_j S_j}\right) \qquad j = 1,2\ldots n \qquad (3\text{-}1)$$

where:

E_{Tj} = theoretical energy for field operation j (hp-hr/acre)

U_j = unit draft of machine j (pounds/unit of size)

K_j = size or capacity of machine j (units of size)

S_j = assumed speed of machine j (mph)

n = number of field operations

For example, a harrow will have U_j given in pounds per foot of width and K_j given in feet. It can be seen in Equation 3-1 that K_j

and S_j both cancel out of the relation. Thus, theoretical energy is not a function of machine size or speed. It is, rather, a function of the unit energy which depends on an interaction between soil conditions and the design of the machine.

Total theoretical energy required for a field operation ($TOTE_{Tj}$) is the product of the theoretical energy per acre (ET_j) and the acreage for which the field operation is required (a_j), as shown in Equation 3-2.

$$TOTE_{Tj} = E_{Tj} \cdot a_j \qquad j = 1,2...n \qquad (3\text{-}2)$$

Effective Energy

Field efficiency is a measure of time losses in the field due to overlap, wheel slippage, turning, plugging, etc. Several of these factors increase the energy that must be expended before a field operation on a particular area is completed, and all of them require that the rate of energy expenditure (power) be increased if the operation and others in the same subset are to be completed without violating the subset time constraints.

Field efficiency tends to decrease as machine size increases (1) and to increase as field size gets large. Usually, large machines are located on large farms which tend to have large fields. This balancing effect is the justification for the assumption that field efficiency is independent of machine speed. It is felt that the inaccuracies introduced by the assumption are negligible.

The total effective energy required for each field operation ($TOTE_{Ej}$) is the total theoretical energy divided by the field efficiency (eff_j) of the operation as shown in Equation 3-3.

$$TOTE_{Ej} = TOTE_{Ej}/eff_j \qquad j = 1,2...n \tag{3-3}$$

The total effective energy for a subset ($EFEN_i$) is found by adding the total effective energies for all field operations in the subset, as shown in Equation 3-4 where i is the subset number and n is the number of operations in the subset.

$$EFEN_i = \sum_{j=1}^{n} TOTE_{Ej} \tag{3-4}$$

Subset Time

Time available for completing the operations in a subset depends on 1) hours the machines work per day, 2) number of working days for completion of the subset, 3) percentage of working days that are useable and 4) machinery system reliability.

The hours of machine use per day equals the operator's nominal work day less the time spent in activities such as road travel, hitching, and others that take place outside the field. Scheduling efficiency, the percent of scheduled work time that the machine and operator are in the field, is a measure of this type of time use.

Tulu (32) developed a method for determining the percent useable work days, at a specific location, based on a soil moisture budget and a tractability criterion. The model was evaluated, by comparing predicted tractability with actual tractability conditions which occurred on certain farms, and found to be an effective predictor of tractability.

The percent useable days for each subset, in this study, were determined by Tulu's method (using sixteen years of weather data from the Detroit City Airport), using his combine tractability

criterion for the shelled corn harvest and his tillage criterion for all other operations. The percentages will be presented in Chapter 6.

The number of working days is the number of days from the beginning to the ending dates for the subset, less days when no work is done, such as Sundays and holidays.

Machine reliability is a measure of the percentage of time, when the machine is in the field, that it is in operating condition. Time lost because of repairs reduces the time available for completing the operation. Machine system reliability is an overall figure applied to all machines in the system.

Time for completion of a subset can be calculated from Equation 3-5:

$$SST = (BDAY - FDAY - HDAY)(HRSDA)(USEDA)(RE)(SCED) \qquad (3\text{-}5)$$

where SST = subset time (hours)

BDAY = beginning day number (day)

FDAY = final day number (day)

HDAY = non-working days (day)

HRSDA = nominal hours worked per day (hours/day)

USEDA = percent useable days (decimal fraction)

RE = system reliability (decimal fraction)

SCED = scheduling efficiency (decimal fraction)

The total effective horsepower needed for the operations in each subset is found by dividing the effective energy required for the subset by the subset time as shown in Equation 3-6. This calculation must be made for each subset.

$$EHP_i = \frac{EFEN_i}{SST_i} \qquad i = 1,2\ldots n \qquad (3\text{-}6)$$

where: EHP_i = effective horsepower needed for subset i (hp)

$EFEN_i$ = effective energy for subset i (hp-hr)

SST_i = time for subset i (hours)

n = number of subsets

The set of effective horsepower requirements by subset gives the distribution of horsepower requirements throughout the year. Often power reductions are possible by modification of the order of operations, time constraints or the production technology. If any reduction can be made, the process should be started over, as shown in Figure 3.1, with the new input information.

The effective horsepower required for the system (ESHP) is the maximum of that required for any one subset. It should be noted, however, that effective horsepower is the minimum that is capable of completing the field operations under the assumed conditions. If conditions are such that more power is required than has been estimated, the effective horsepower would not be adequate and either the work schedule would have to be extended or the quantity of work reduced.

To circumvent this possibility the effective system horsepower (ESHP) is increased by a factor of safety (MFAC) to a design horsepower (DHP) as shown in Equation 3-7.

$$DHP = ESHP/MFAC \qquad (3\text{-}7)$$

MFAC is normally in the range of 0.7 to 0.8 (6). The additional horsepower is available for handling unexpected situations such as extra field operations, modified soil conditions, etc. Another effect of increasing power to DHP is that the average loading rate of the tractor is reduced to some percentage of its rated power. The reduction also promotes engine life and reliability.

The power determination has been made by use of anticipated loads on the tractor. Thus, the power requirements that have been estimated are all drawbar horsepower.

Self-propelled Machines

The preceeding discussion was for tractor powered machines. Obviously, all operations do not require input of tractor power. The selection model can also be used for self-propelled machines. The only restriction is that self-propelled machine operations must be placed in subsets separate from tractor powered operations. The subset dates can overlap the tractor powered subsets, since separate equipment is to be used in each.

The self-propelled machine power is then calculated via procedures parallel to that used with the tractor powered operations. As many "parallel paths" as needed may be defined.

3.2 TRACTOR SELECTION

The size and number of tractors needed depend on the design horsepower for the system (DHP) and the size range of tractors available in the marketplace. The number of tractors (NTR) must, of necessity, be an integer. The minimum number of tractors needed is found by taking the ratio of design horsepower to the maximum tractor drawbar horsepower (MAXHP) and rounding up to the next integer. Many combinations of NTR tractors with total horsepower equal to DHP are usually available.

Two courses can be followed at this point to select a particular set of tractors: 1) use all possible combinations of tractors with total horsepower equal to DHP, select a machinery system for each, and choose the combination which best satisfies some preset criteria, or 2) select a particular set of tractors which is assumed to be best for a particular situation.

Initially, the first approach was used. An algorithm was prepared which would produce all combinations of tractors of integer sizes with a total horsepower equal to DHP. Machinery was then selected for each tractor combination, using the method which will be described in the following section. The complete system with lowest total annual operating cost was then selected.

The best system, including both tractors and machinery, was observed to consistently be of one characteristic type. It had all but two of the tractors as large as possible with the remaining horsepower distributed between the other two tractors. One of these was as large or as small as possible.

Accordingly, the original algorithm was modified to the form shown in Figure 3.2 which produces a single combination of NTR tractors with horsepower distribution as described above.

An exception to the preceeding rule can occur if the power from the tractors can not all be used because of field machine operating limits. For example, harrowing 1000 acres in five hours, with a unit draft of 150 pounds per foot of width and MFAC equal to 0.75, requires 73.4 effective system horsepower, 98 design horsepower and an effective field capacity of 20 acres per hour. The algorithm in Figure 3.2 would select one 98 horsepower tractor for this situation.

From Table C.4, maximum width and operating speed for a harrow are, respectively, 30.0 feet and 6.0 miles per hour (reasons for these limits are discussed below). To operate at 20 acres per

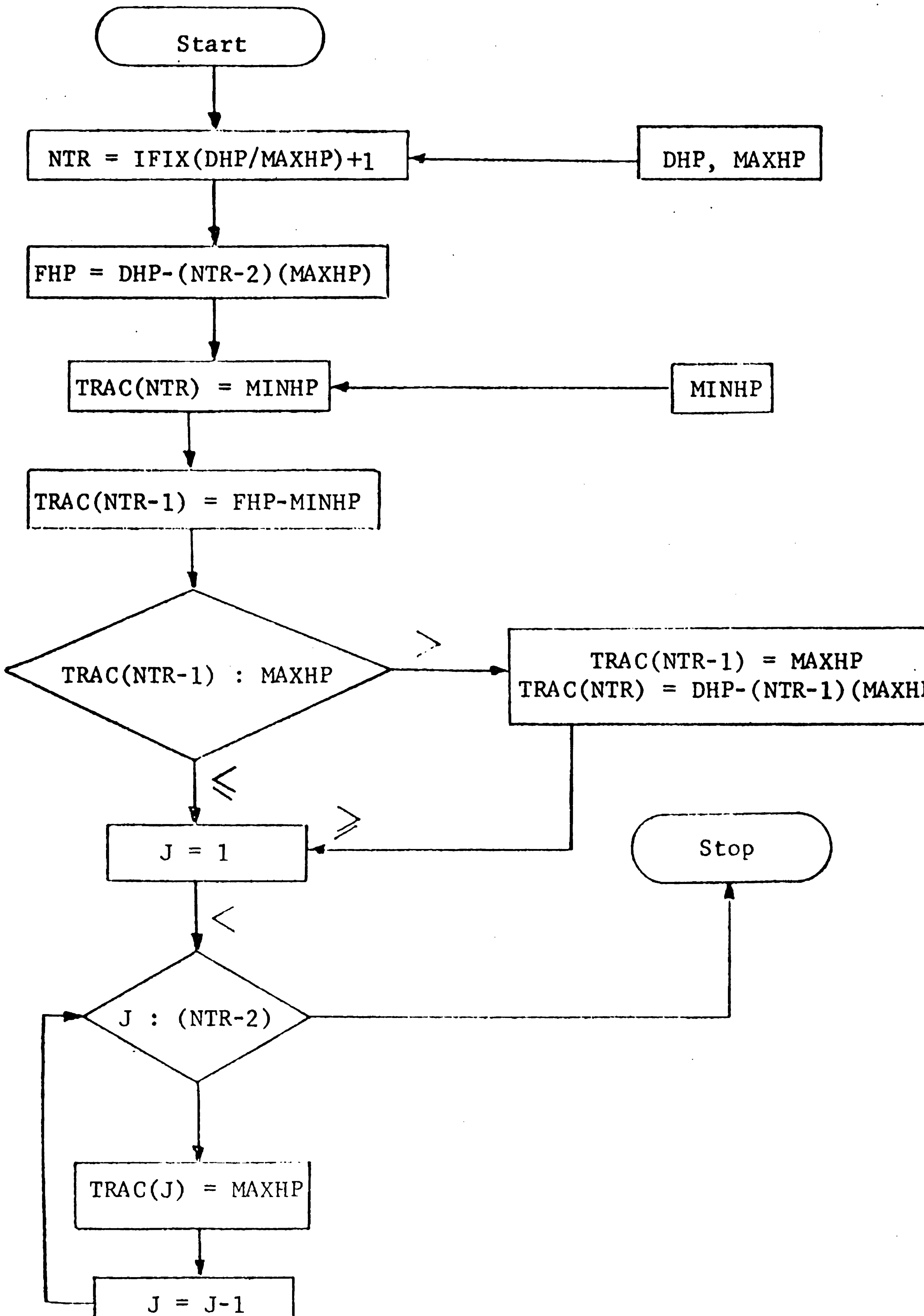


Figure 3.2. Tractor Horsepower Determination

hour, the tractor can pull a 30 foot harrow at 6.2 miles per hour or a 30.5 foot harrow at 6.0 miles per hour. Neither of these solutions is acceptable because one of the constraints is violated in each case. The effective system horsepower cannot be used because of the operating limits on the field machine.

The solution to problems of this type is to increase the number of tractors. For the example, two tractor-harrow combinations, with a total of 98 horsepower, could be used so that the limits on harrow size and speed are not exceeded.

For this study, since enough time was alloted for the completion of each subset of field operations, problems of the perceeding type did not arise. Therefore, no modification was ever made to the set of tractors selected by the use of the procedure of Figure 3.2.

The effect of restrictions on power level can be evaluated, simply by changing MAXHP. It should be noted that the system chosen by the method of Figure 3.2 may only be best for the set of crops and the production technology being used in this study. Inclusion of other field operations, or a change in production technology might alter the best system characteristic form.

3.3 MACHINERY SELECTION

The method used for selecting field machines is a modification of the process presented by Connor, et al., (12) which was also developed by this author. Before selecting the field machines, a work schedule must be constructed for tractor use to determine which tractor powered each machine.

Several procedures can be used, and were evaluated for allocating field operations to be powered by each tractor. The method chosen, which is presented below, was considered to be the most realistic. The work to be done by each tractor in each subset of operations is first determined.

Allocation of Tractor Energy in Subsets

The method for assigning a quantity of work from each subset to be done by each tractor is shown in Figure 3.3. Before this procedure is initiated, the number of tractors (NTR), the horsepower of each tractor (TRAC(J), J - 1,2...NTR), the number of subsets (NSETS), the work time for completing the subsets (SST(I), I = 2... NSETS) and the total effective energy required for each subset (EFEN (I), I = 1,2...NSETS) will all be known.

For each subset I, the maximum amount of energy (TEN(I,J)) that tractor J can be expected to develop in time SST(I) is calculated. It is assumed that the tractor operates at an effective horsepower which is its rated horsepower (TRAC(J)) multiplied by the factor MFAC. Thus:

$$\text{Ten(I,J)} = \text{MFAC} * \text{TRAC(J)} * \text{SST(I)} \qquad \begin{array}{l} \text{I} = 1,2\ldots\text{NSETS} \\ \text{J} = 1,3\ldots\text{NTR} \end{array}$$

For the subset, the tractors are all checked, from smallest to largest in order, to determine if any one can develop enough energy to power all the field operations in the subset. If one tractor is capable of powering all the work in the subset, then it is assigned to supply all the energy required for the subset of operations.

If no single tractor can power all the operations, then the largest tractor is assigned to work at capacity, for the time SST and

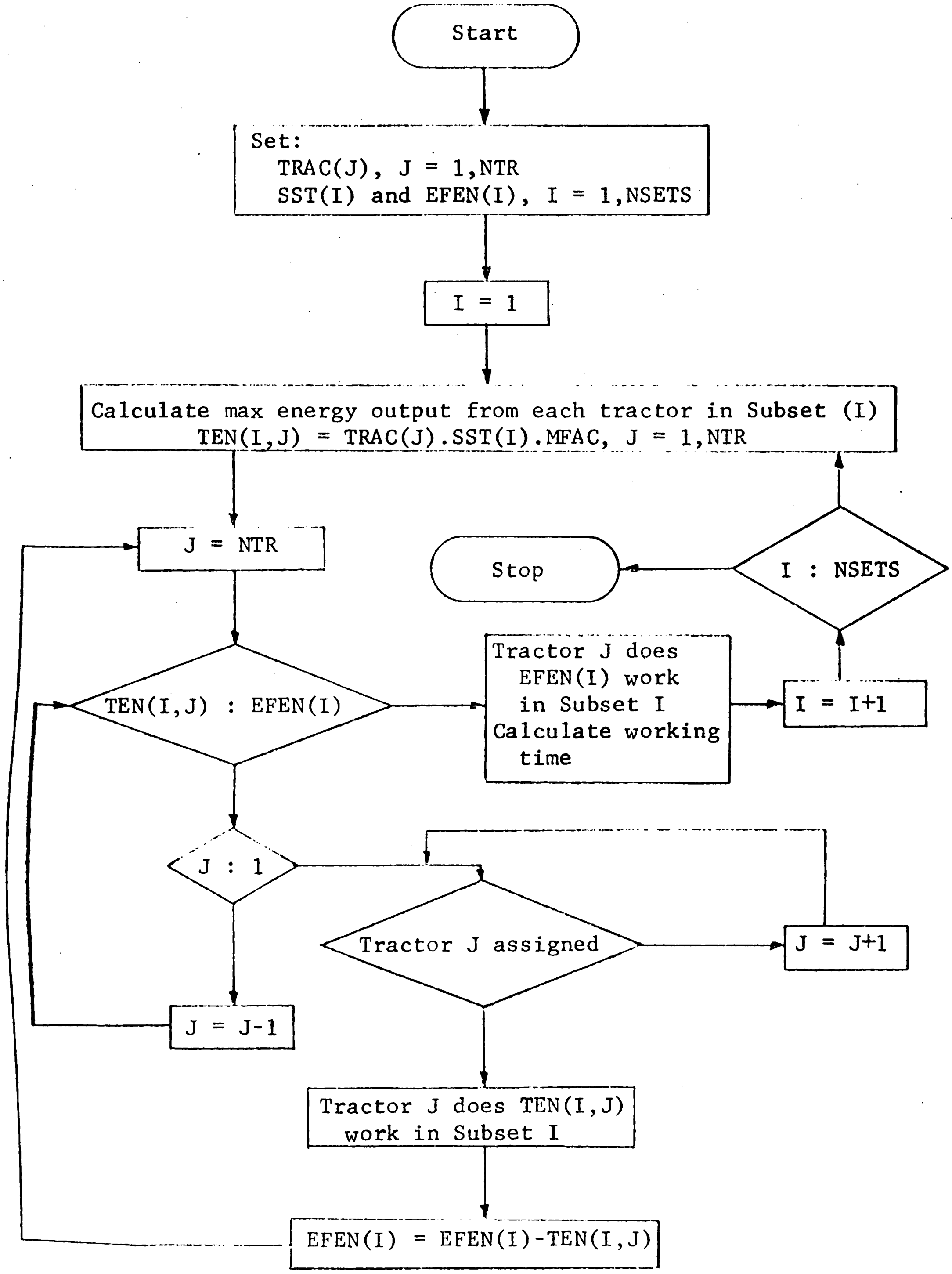


Figure 3.3. Allocation of Tractor Energy in Subsets

develop energy equal to TEN(I,J). The procedure is then repeated in allocating the remaining work to the remaining tractors. Table B.2 is an example of the energy allocation for the field operations and subsets shown in Table B.1.

After energy to be supplied from each tractor for use in each subset has been allocated, specific field operations in each subset must be assigned to each tractor. Several methods are available for the assignment process. The one used in this study is described below. Of course, if only one tractor is used, the allocation problem is non-existent, since the one tractor powers all operations.

Allocation of Tractors to Field Operations in a Subset

If subset I has field operations requiring energy from more than one tractor, tractor J (the largest tractor scheduled for use during the subset) is assumed to power the largest possible portion, of the earliest field operation, that has an energy requirement less than or equal to TEN(I,J). If TEN(I,J) exceeds the energy required for the earliest operation, subsequent operations and/or a fraction of an operation are assigned to tractor J until the total energy required for the assigned operation equals TEN(I,J). Usually this process will leave a fraction of one of the operations unassigned, which is then taken as the starting point for the assignment of field operations for the next smaller tractor scheduled to power operations in the subset. The procedure is continued until all field operations in the subset are assigned to tractors and is then repeated for the other subsets.

Since the power rating of each tractor and the energy requirement for each field operation are known, the time required to complete each operation can be calculated. Dividing the energy requirement in horsepower hours by the product of tractor horsepower and MFAC yields the time to complete the operation in hours.

Thus, the acreage and time for each field operation can be calculated. The effective field capacity of each field operation powered by each tractor can be found by dividing the acreage by the required time. Table B.3 shows the assignment of field operations for the example in Appendix B. Disking in Subset 1 and plowing in Subset 5 are examples of field operations divided between two tractors.

Machine Selection

Machine selection begins by establishing limits on the size of machine that can be used for each machine-tractor combination specified in the previous section. These limits are established by using size and speed constraints. Each particular machine is assumed to be available in a range of sizes from a minimum to a maximum width, and to operate properly over a range of speeds from a minimum to the maximum allowable. For a particular technology, these are obviously realistic assumptions. Table C.3 shows the size and speed limits for each of the machines in the example.

When an operation in a subset is divided between tractors, or when the same operation is performed in more than one subset, the use time and size limits should be checked to determine if the same machine can be applied to more than one of the uses.

If an operation in a subset is performed by more than one tractor, if the size limits overlap, and if the total time for the field operation is less than the subset time, then one machine will satisfy the need. If, on the other hand, time for the field operation exceeds the subset time, multiple machines will be needed.

Similarly, if the same operation is performed in more than one subset, and the size limits overlap, one machine will suffice. If the size limits do not overlap, multiple machines will be needed.

After all possible combinations of this type have been found, the annual time each machine is used is found as the sum of the several times the machine is used, and the size limits are reset to the widest pair that satisfies all of the limits. Table B.4 shows the results of this procedure for the example.

Machine Costs

Since the entire selection procedure was based on energy consumption, it was considered that service life should also be based on energy consumption. After machine life was expressed as quantity of energy, the service life would be found by dividing the service life energy by the annual energy consumed for operating the machine.

For example, if the average horsepower to pull a harrow was known, the machine life in horsepower hours could be calculated by multiplying by the average harrow life in hours (1,6). This method is advantageous because it takes into account the severity of machine use. Two similar machines used under different conditions for the same amount of time would be found to have different service life periods. Also for this study, where the soil is assumed to be the same for farms of all sizes, changes in energy consumption due to differing soil types would not have to be considered.

However, reliable estimates of machine life in energy terms could not be readily made, so machine life was determined from the annual hours of use. A service life in hours was assumed for each machine. Then after the annual hours of use were determined, the service life was calculated by dividing machine life in hours by annual use.

The original cost of each machine and tractor was calculated from a regression relationship relating cost per unit of size to machine size. The regressions were developed from information supplied by a machinery manufacturer (13). These regression relationships are shown in Table C.6.

Depreciation was calculated by the straight line method. Repair costs over the life of the machine were taken as a fixed percentage of the original cost of the machine and were prorated according to annual machine use. Annual cost for interest, housing, taxes, and insurance were calculated as annual percentages of the purchase cost of the machine.

The self-propelled machines, if any, are selected by the same procedure discussed for the pull type machines. Costs for self-propelled machines and the tractors were evaluated similarly to the machine costs.

3.4 PROCESSING ENERGIES

The preceeding portions of this chapter have explained the selection and assumed mode of operation of the field machinery system.

From the information that has been developed totals of each of the six processing energies can be found.

If the analysis is repeated several times using the same technology and over a range of sizes, the processing energy function $f_1^m(Y_{03})$ can be developed.

Capital

Capital requirement in dollars is the sum of the initial costs for the tractors, field machinery, and self-propelled machines.

Labor

Total labor needed in the field equals the sum of operating times for each tractor and the self-propelled machines plus an allowance for scheduling inefficiencies, and an additional allowance for administration.

Fossil Energy

Fossil energy in horsepower hours is the sum of the energy requirements for each of the subsets.

Land

Land cost is equal to the area required for all crops.

Electricity

There is no electricity consumed by the field machinery system.

Dollar Cost

Dollar cost per year is the sum of the operating cost for each machine, tractor, and self-propelled unit plus the dollar cost of each of the other energies used. Table B.6 shows the energy costs for the example system.

4. FARMSTEAD SYSTEM

The farmstead system includes the equipment and operations connected with feeding and handling the cattle. Referring to Figure 2.10, this model is used to estimate the requirements for each of the six processing energies for the farmstead operations. Energies associated with the input materials will be discussed later.

The farmstead system components were first designed; then the processing energies were estimated for the system. A straight forward design process was used in all cases. Components to be designed included the feedlot, the feed storages, and the liquid waste tank, if needed. In addition, equipment such as waterers, silo unloaders, and liquid waste pumps were specified.

4.1 COMPONENT DESIGN

Feedlot

The four types of feedlots considered were: 1) completely open, unpaved lot, 2) completely covered, 3) partially covered, with hard surfaced lot, and 4) partially covered, with unsurfaced lot (26). The floor in the completely sheltered feedlot was either solid concrete or slotted, depending on the waste handling system (11).

The feedlot layout can be completely specified by five parameters if the basic layout shown in Figure 4.1 is assumed. The necessary data are 1) inches of feedbunk per animal (INHD), 2) final weight of the animals (ENDWT), 3) area (square feet) of open lot and

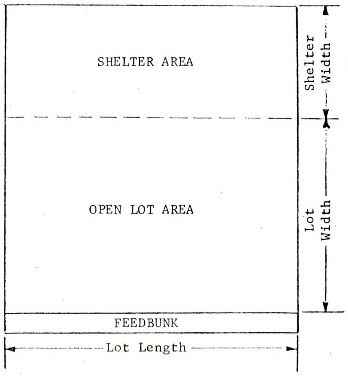


Figure 4.1. Assumed Feedlot Layout

shelter per 100 pounds of final animal weight (CLOT and CSHEL respectively) and 4) feedlot capacity (HDFB).

Feedlot length equals feedbunk length which is the product of INHD and HDBF. Open lot area per animal is the product of CLOT and total final hundred weight of animals. Shelter area per animal is similarly calculated from CSHEL. Width of open lot (WLOT) and shelter (SHEL), respectively, can be found from the following relations:

$$WLOT = \frac{(CLOT)(ENDWT/100)}{(INHD/12)} \qquad \text{(feet)}$$

$$WSHEL = \frac{(CSHEL)(ENDWT/100)}{(INHD/12)} \qquad \text{(feet)}$$

The size of the constants CSHEL and CLOT depend on the technology being used. They can be zero in some cases. CSHEL for the fully sheltered feedlot also depends on the waste handling system being used. A slotted floor liquid waste system will usually have less area than a solid waste system.

The final animal weight (ENDWT) is the average for all animals in the lot. It depends on the kind of animal being fed in the lot (calves or yearlings).

Feedlot capacity is the largest number of fully grown animals that can be housed simultaneously in the feedlot. Feedlot volume, or the number of animals produced per year is proportional to capacity. The constant depends on days on feed, which varies with animal type, ration and feedlot type.

Feed Storage

Two feeds were required for the two assumed rations (4). Corn silage, which is in both rations, can be stored in tower or bunker silos. Grain corn, which is in one ration, was assumed to be handled as "high moisture" corn stored in sealed tower silos. Other handling and storage systems were not evaluated.

Sealed Tower Silos for Moist Corn

Tower silos for moist corn were selected under a minimum capital criterion. These units are available in a finite set of diameters, and in multiples of a height increment up to a maximum height for each diameter. Cost varies with diameter and height (37).

The quantity of corn to be stored depends on feedlot capacity and average daily corn feeding rate (4). For the conversion to volume, moisture content of the corn was needed since corn weight and volume per bushel both depend on moisture content.

The procedure began by assuming a diameter for the silos. Total silo height was easily calculated from volume and diameter. If the total height exceeded the available maximum height for the diameter (37), multiple units were purchased until the average height was less than the maximum. The height of individual silos was adjusted to the next higher or lower multiple of the height increment until total height was within one height increment in excess of the total height required. The cost of the silos was then estimated from a price function. The procedure was repeated for each of the available diameters and the lowest cost combination was selected.

Additional equipment included a silo unloader for each unit, permanently installed blower pipe and a roller mill for preparing the corn to be fed.

Tower Silos for Corn Silage

Concrete tower silos are available in diameters ranging in incremented steps between a minimum and maximum diameter. There is a maximum height available for each diameter. Silo heights are also available in increments. Silo cost is a function of diameter and height.

Silage must be removed from a tower silo at a minimum removal rate (TSRR) to retard spoilage. This minimum removal rate was used to determine the maximum allowable diameter of the silos (34). The following function, where TSDEN is silage density in storage in pounds per cubic foot, LBS is daily silage fed per animal in pounds and TSRR is expressed in inches/day yields the maximum diameter:

$$\text{MAXD} = \frac{(48)(\text{LBS})(\text{HDEF})}{(3.14)(\text{TSDEN})(\text{TSRR})}$$

The silo diameter selected was the next smaller available diameter.

The quantity of silage to be placed in storage depends on 1) feedlot capacity, 2) daily silage feeding rate and 3) the amount of silage expected to be lost because of spoilage (19). The required volume depends on the density of silage. Total height was then calculated from the diameter and volume, the number of silos was determined using the maximum height for the selected diameter, and the average silo height was calculated.

The height of individual silos was then adjusted up or down from the average height to an adjacent multiple of the height increment until the total height of the individual silos was within one incremental unit greater than the total height needed.

No further evaluation of alternatives was made. Study of the cost function clearly indicated that tower cost per ton of material stored increased as height increases and as diameter decreases. Another reason for holding the silos to approximately the same height was to avoid the high energy cost for blowing silage into a tall silo.

Additional equipment included with the tower silos were permanently installed blower pipes and a silo unloader for each unit.

Bunker Silos for Silage

The quantity of silage to be placed in the bunker silo is determined the same way as for tower silos. Typically, loss in storage is greater with a bunker silo than in a tower silo.

There is also a minimum removal rate (MRR) for bunker silos. That much silage must be removed from the face of the silo per day to retard spoilage. If MRR is removed each day, then the minimum bunker silo length is (MRR)(365).

Bunker silo costs are expressed as the sum of two figures, dollars per square foot of floor and wall (19). Preliminary analysis showed that if endwalls are neglected, and depth and length kept constant, silo cost per unit of volume decreases as width increases up to some maximum width where the cost becomes essentially constant. Until this maximum (WMAX) is reached, the silo cost per unit volume increases with increased depth. However, once the width reaches the maximum, increasing depth decreases cost per unit volume.

Following the preceding guidelines, bunker silos were designed by the rule:

> Set minimum length defined by the minimum inches removed per day. Set depth at the minimum. Then increase width from zero until it either reaches WMAX or the structure volume equals the required storage volume. Once the width reaches WMAX, increase height by one increment and repeat the process. Length is only increased after both width and height have reached the maximum. The only additional equipment needed is a front end loader for removing silage.

Liquid Waste Tank

If a liquid waste handling system is used, a tank and a slotted floor must be included (11). Weight of waste (flow Y_{44}) was calculated as a percentage of body weight. Required tank volume was determined by dividing by the waste material density.

Slotted floors are made up of units of a particular length. The ends of the floor units are supported on the outside walls or on internal walls included for the purpose. The tank width is taken as an integer multiple of the slotted floor unit length. The tank length is assumed to be equal to the length of the building. Depth is determined by dividing the volume by tank width and length. The tank contains internal walls, as needed, to support the ends of the slotted floor units.

4.2 PROCESSING ENERGIES

There are many ways a feedlot can be operated after the basic components have been specified. The operation depends on the physical layout of the system and managerial preferences, and can affect some of the processing energies. Therefore, the operation assumptions that were made for analysis of the system, are incorporated into the following discussion of processing energies.

Capital

Because of the variation of interest rates with length of investment, two classes of capital were considered. Long term capital included the initial cost of the feedlot, shelter building, fence, feedbunk, concrete slabs, liquid manure tank, well and feed storages. Short term capital included the initial cost of waterers, gates, silo unloaders, roller mill, blower pipe, silage blowers, front end loader, liquid manure pump, feeding wagon and feedlot tractors. The number of blowers, and the number and horsepower of the feedlot tractors had to be designed in conjunction with the transportation system and thus are not discussed in this chapter. The energy costs for the blowers and tractors, however, were assigned to the feedlot.

Labor

Total feedlot labor includes the labor required for feeding the cattle each day, for packing the bunker silo, and for cleaning the lot and loading the waste plus allowances for scheduling efficiency and administration.

Feeding time is made up of the time for removing the feed from storage, feed wagon travel and unloading the wagon. It was assumed that silage was removed from storage and loaded immediately into the feed wagon. Corn was removed from silage, passed through a roller mill, then loaded directly into the feed wagon. Time delay involved in the grinding operation was considered to be negligible.

When tower silos were used for silage, the time for unloading corn and silage were calculated and the larger was taken as the feed wagon loading time, since the two operations were considered to be done at the same time. For systems using a bunker silo, the feed wagon loading time was the sum of the corn and silage unloading times, since it was assumed that the two operations must, because of the necessary layout, occur sequentially.

Feed storages were assumed to be located near one end of the feedbunk. The loaded wagon was pulled to a point on the feedbunk where unloading was commenced. The wagon was then pulled along a section of the feedbunk while the ration was unloaded. After completion of unloading, the empty wagon was pulled past the rest of the feedbunk, turned around and returned to the feed storage area.

Travel around the feedbunk area was assumed to be at a preset speed, and unloading was at a preset rate. Unloading time was taken as a constant for a load unless feed wagon capacity was changed. The length of feedbunk filled by each load was determined from the number of times the animals were fed per day, the total quantity of feed and feed wagon capacity. Round trip distance equalled twice the length of the feedbunk plus the distance for turning at the end. For each trip, the travel distance equalled the round trip distance less the length of feedbunk filled by each load. Travel time per load was calculated from travel distance for each load and travel speed.

The number of loads per day was the total weight of feed per day divided by feed wagon capacity and the number of trips along the feedbunk equalled the number of loads rounded up to the next integer. Daily feeding time equalled the number of loads per day multiplied by the sum of loading and unloading time per load plus the number of trips per day multiplied by the travel time per day.

Bunker silo packing rate is determined from the quantity of silage divided by the time required for harvest or by a preset minimum packing rate, which ever is larger. Silo packing time was determined from the quantity of silage and the silo packing rate.

It was felt that solid manure loading rate was more dependent on operator skill than on tractor horsepower. Loading rate was, consequently, assumed to be independent of tractor size. Waste loading time was taken as a quantity of waste divided by the loading rate.

Fossil Energy

Depending on the technology, fossil energy was consumed in the feedlot for some of the following operations: 2) feeding the cattle, 2) blowing silage and grain corn into tower silos, 3) packing the bunker silo, 4) unloading the bunker silo, 5) pumping liquid manure and ¢0 loading solid manure.

Energy for feeding was consumed for loaded travel, unloading the feed wagon and unloaded travel. The average distance a loaded feed wagon was transported equalled one-half the length of the feedbunk. Force to pull the wagon equalled the combined weight of the wagon and load multiplied by the coefficient of rolling resistance for the farmstead (1). Loaded travel energy per load was the product of loaded travel distance and force. Unloaded travel distance equalled one and one-half the length of the feedbunk plus turn around distance. Unloaded travel energy per load was calculated the same way as the loaded energy. Unloading energy per load equals the unit energy for unloading multiplied by feed wagon capacity. Total feeding energy per day was the sum of these three energies multiplied by the number of loads per day.

Energy for blowing silage and corn, packing the bunker silo, unloading the bunker silo, pumping liquid manure and loading solid manure was determined from the unit energy and quantity of each material. The energies were preset except for the unit blowing energy which was a function of the height of the silos.

Land

Land required for the farmstead was equal to the area of the feedlot, feed storages and roads plus an allowance for easy access to these components.

Electricity

Electricity was consumed for lighting, pumping water, unloading corn and silage from tower silos and grinding corn. The energy required for each operation was determined from the quantity of each material and the unit energy for each operation.

Dollar Cost

Dollar cost per year was the sum of the fixed and variable costs for all components plus the dollar cost of each of the other energies used in the farmstead.

5. TRANSPORTATION

The transportation system is the link between the field crop production and the feedlot and other farmstead components. On a beef farm, the transportation system moves feed to the farmstead, and returns waste to the field for disposal. For the technologies being used in this study, the transportation system consisted of a subset of the following five kinds of components: 1) corn wagons, 2) silage wagons, 3) liquid manure spreaders, 4) solid manure spreaders and 5) transport tractors. This chapter describes the way a set of components was selected to form a system capable of fulfilling the necessary transport functions on a beef farm of a particular size and technology.

Assumptions

The following assumptions, discussed below, were made:

1. The transport distance between field and farmstead is strongly influenced by farm layout. An accurate assessment of this phenomenon would require information on the variation of transport distance with farm size. Since such information was unavailable, it was assumed that all farms were square and that the average transport distance was equal to the length of one side multiplied by 0.707.

2. Weights, capacities and all other relevant information about transport system components are known.

3. A maximum average speed exists which a unit can not exceed.

4. Variations in speed do not affect the energy required for a trip of a particular distance.

Discussion of Assumptions

The distance from the center of the farm to one corner was the assumed average transport distance for each load. Implicit in this first assumption are the additional assumptions that 1) production of each crop is distributed over the farm and 2) waste is applied to all parts of the farm. It does not require that waste be applied to all parts of the farm every time the feedlot is cleaned or that each crop has to be uniformly distributed over the farm. It does mean that "the center of gravity" of the application area and the crop area coincide with the geographical center of the farm.

Location of the farmstead on one corner is arbitrary. A similar analysis can be made using any layout, as long as the average distance the loads are transported can be determined. It is probably true that transport distances are underestimated for the large units relative to the smaller ones.

Component capacities are determined externally and used as input parameters to the model. A system is specified by determining the number of each type of component needed. A model capable of selecting component capacity as well as the number needed would have to have a more complicated logical structure. This was considered to be unnecessary, since the object of the study was analysis, not design. If desired, the effect of component capacity can be measured by using a different set of parameters and re-evaluating the number needed.

It is reasonable to assume that an upper limit on speed exists. The speed is limited by ground conditions as well as tractor power.

Most transportation systems are more efficient users of energy at lower speeds. On a farm, however, the transport speed range is limited. The highest speeds are seldom over ten miles per hour with a loaded unit pulled by a tractor and these speeds are atainable only under good conditions where the rolling resistance is low. Under these conditions, it is reasonable to assume constant energy requirements

5.1 WASTE TRANSPORT

The quantity of waste to be transported depends on the waste handling technology in use. Liquid systems collect and store all animal waste material and a liquid spreading system must transport this entire quantity of material. A solid system has less to transport since runoff, evaporation and infiltration of the liquid fraction reduce the weight of material by about 85 percent (10,11).

Time Per Load

Time per load, or round trip time, has to be determined before the number of spreaders can be calculated. It can be decomposed into four parts; loading time, loaded travel time, unloading and spreading time and unloaded travel time. Loading and unloading times are determined by the loading and unloading rates, respectively. Loaded and unloaded travel time depend on average speed and distance traveled. Unloaded travel is assumed to occur at the maximum allowable travel speed. Loaded travel speed is determined by transport tractor horsepower as long as the upper limit on transport speed is not exceeded.

Number of Spreaders

The number of loads to be transported depends on the total quantity of waste and spreader capacity. The average time between loads depends on the number of loads and the allotted time for cleaning and spreading.

If the time required for one spreader load exceeds the average time between loads, multiple spreaders are needed. The number of spreaders can be found from the ratio of time per load to the average time between loads rounded up to the next integer number.

5.2 FEED TRANSPORT

All of the systems being analyzed use silage in the ration and require silage transport. Corn transport is only needed for those systems using corn in the ration.

Silage is handled in self unloading wagons. The unloading function can be powered by the transport tractors or by an output shaft on the silage blower. For this study, the wagons are assumed to be powered by the tractors. Corn is assumed to be handled in side unloading "gravity boxes". The same tractors are used to transport silage and corn as well as waste. The number of loads, time between loads and travel time per load can be determined the same way as for waste transport.

For silage, loading time need not be considered since the wagons are pulled by the field machinery tractors while being filled. However, time for unhitching from one wagon and hitching to another must be included in the time per load. Corn loading time depends on harvest rate. Unloading time is governed by blower capacity as the corn is blown into the storage.

Number of Blowers

Blowers are used for elevating corn silage and shelled corn into tower silo storages. If the system uses a bunker silo rather than tower silos, one blower is still required for those systems which include corn in the ration. An all silage ration, with bunker silo storage, eliminates the need for blowers completely.

When putting silage into tower silos, total blower capacity must be equal to or greater than the total forage chopper capacity. Lower capacity will cause wagons to queue up to unload and force idle time on the forage harvesters which, as a consequence, will not be able to complete the harvest on schedule.

The average time between loads (TBL) filled by the choppers is found by dividing the total harvest time by the number of loads. The minimum time (MINTIM) a blower can elevate a load of silage into a particular silo depends on the maximum tractor horsepower, silo height and MFAC. The number of blowers needed was taken to be the ratio of MINTIM to TBL, raised to the next higher integer.

Silage Wagons for Tower Silo Systems

One wagon is assumed to be required with each chopper and blower plus one or more in transit. The number in transit (NIT) can be calculated from Equation 5-1, where HTIM is the field hitching time, OUTIM is the time to make the unloaded trip and INTIM is the time for travel with a loaded wagon.

$$NIT = (HTIM + OUTIM + INTIM)/TBL \quad (5\text{-}1)$$

NIT is rounded up to the next higher integer.

The maximum time available for unloading a wagon into a blower (ULTIM) in a system with IBL blowers is:

$$ULTIM = (IBL)(TBL)$$

The unloading time affects the horsepower of the tractor used to power the blower.

Silage Wagons for Bunker Silo Systems

Wagons are assumed to be unloaded as fast as possible into a bunker silo. Unloading time (ULTIM) is determined by wagon capacity and transport tractor horsepower. The time per load (TPL) is the sum of HTIM, INTIM, OUTIM, and ULTIM. The number of wagons required is found from the ratio of TPL to TBL raised to the next integer plus the number of forage harvesters working in the field.

Wagons for Corn Transport

The number of corn wagons required can be determined from the ratio of time per load to time between loads as discussed in the previous section.

Transport Tractors

Transport tractors are usually small used tractors. Their only function is supplying drawbar and PTO power for wagons of the type previously discussed. The number of tractors needed is the maximum of the number needed for transporting waste, silage or corn. Usually, for the systems considered, the maximum is the number required for silage transport.

5.3 FEEDLOT TRACTORS

Feedlot tractors were sized by the power requirements for putting silage into storage.

Time for packing a load of silage has been discussed previously. The packing horsepower was determined from the quantity of silage per load, the unit energy for packing and the packing time as long as the power required did not exceed the maximum allowable power. It was assumed that this tractor was adequate for other feedlot operations.

When tower silos were used, each feedlot tractor (there could be several) size was determined from the silage blowing requirements. The horsepower was determined from wagon capacity, unit blowing energy and unloading time. The number of tractors was equal to the number of blowers. Energy costs for the feedlot tractors were included with other feedlot equipment.

5.4 ENERGY COSTS

Capital

Capital requirements equal the purchase price of spreaders, silage wagons, corn wagons and transport tractors.

Labor

Labor requirements can be found by multiplying the time per load by the number of loads for each material which is transported plus an allowance for scheduling efficiency.

Fossil Energy

Fossil energy for transportation is the product of the average force of pulling the wagons and the average travel distance. Fossil energy for unloading silage and waste can be found from the unit unloading energies and the total quantity of each material.

Land

There is no land required specifically for transportation.

Electricity

There was no electricity required for transportation.

Dollar Cost

Dollar cost per year was the sum of the operating cost for each wagon and tractor plus the dollar cost of each of the other energies used.

6. IMPLEMENTATION OF THE MODEL

The definition of systems to be analyzed included the type of feedlot, feeding storage, waste handling, animal and ration. Table 6.1 shows the set of component types used. Table 6.2 shows a set of forty feasible combinations and the identification number assigned to each.

All other aspects of the technology used for the systems were fixed. The same soil, climate, field operations, time constraints and machine characteristics were applied to all systems, and thus were assumed to have no influence on the comparisons to be made between systems.

It was originally intended to perform the calculations needed for making the analyses manually. However, the experience gained in designing and analyzing the assumed operations for one system clearly indicated that the volume of work involved would be excessive. Accordingly, the procedures involved, which have been discussed in Chapter 2 through 5 were automated by use of a computer program. Using the computer with appropriate data for each size-technology combination, allowed the analysis to be carried out. The use of the computer had the added advantage of insuring a consistent application of procedures and assumptions without the probability of human error.

Table 6.1. Components Included in Technology Definitions

Type of Feedlot

01 - Partial shelter, unpaved lot
02 - Partial shelter, paved lot
03 - Open unpaved lot
04 - Completely covered

Type of Feed Storage

01 - Moist corn storage, tower silos for silage
02 - Moist corn storage, bunker silo for storage
03 - Tower silos for silage
04 - Bunker silo for silage

Type of Animal

01 - Calves
02 - Yearlings

Type of Ration

01 - All silage
02 - Corn and silage

Type of Waste Handling

01 - Liquid
02 - Solid

Table 6.2. Set of Technologies Selected for Analysis

FEEDLOT	FEED STORAGE	HANDLING	RATION	ANIMAL	TECHNOLOGY NUMBER
1	3	2	1	1	24
2	3	2	1	1	25
3	3	2	1	1	26
4	3	2	1	1	27
4	3	1	1	1	11
1	4	2	1	1	28
2	4	2	1	1	29
3	4	2	1	1	30
4	4	2	1	1	31
4	4	1	1	1	15
1	3	2	1	2	88
2	3	2	1	2	89
3	3	2	1	2	90
4	3	2	1	2	91
4	3	1	1	2	75
1	4	2	1	2	92
2	4	2	1	2	93
3	4	2	1	2	94
4	4	2	1	2	95
4	4	1	1	2	79
1	1	2	2	1	48
2	1	2	2	1	49
3	1	2	2	1	50
4	1	2	2	1	51
4	1	1	2	1	35
1	2	2	2	1	52
2	2	2	2	1	53
3	2	2	2	1	54
4	2	2	2	1	55
4	2	1	2	1	39
1	1	2	2	2	112
2	1	2	2	2	113
3	1	2	2	2	114
4	1	2	2	2	115
4	1	1	2	2	99
1	2	2	2	2	116
2	2	2	2	2	117
3	2	2	2	2	118
4	2	2	2	2	119
4	2	1	2	2	103

Many input values are dependent on the technology being used. Others are constant for all systems. Appendix C shows the complete set of data used.

Table C.1 is a listing of parameters taken as constants for all the systems. Only those constants required were used for each technology. For example, CLOAD which is the load capacity of the shelled corn wagon in pounds is only needed for systems using ration 2 (corn and silage). Table C.1 gives the name and definition for each variable, the value assigned and the reference, if any, where the value was found. Reliable estimates of some parameters could not be found, so estimates were made by the author, using any information which could be found. The values so estimated are noted. Table C.2 gives the areas of shelter and open space required for each type of feedlot, per hundred pounds of final animal body weight (26). Table C.3 shows expected feed consumption and rates of gain for each animal ration and feedlot combination (4).

Data for field machinery characteristics are shown in Table C.4 (1,3,6,13). Percent useable days are given in Table C.5 (33,38). The five time periods given in the table correspond to the dates for the five subsets of field operations given in Table B.1. Initial cost of the field machinery was calculated from functions shown in Table C.6. Table C.6 also contains functions for estimating initial cost of tower silos for silage and corn (5,37). The cost functions for field machinery were developed from cost data made available by a manufacturer (13,35).

The required amount of each input material is shown in Table C.7 (5,37). The dollar cost of the materials is also given (5,37).

These values are not of themselves the technical coefficients for the system, but a number of the coefficients can be derived from the values. All other energy costs for input materials were set to zero. The energy requirements determined were strictly those internal to the system. It was felt that determining the total energy consumption was outside the scope of this study. Unit dollar costs for the materials are shown in Table C.7.

To the labor identified by the various parts of the system, 30 percent was added for miscellaneous labor. An additional 1000 hours of administration time was assumed for all systems.

Comparisons

Using the data in Appendix C and the computer program, discussed previously, analyses of systems were made to determine the following:

1. The effect of feedlot type on energy cost of beef
2. The effect of ration on energy cost of beef
3. The effect of type of feed storage on energy cost of beef
4. The effect of waste handling system on energy costs of beef
5. Breakdown of fossil energy consumption by the field machinery, farmstead and transportation systems as influenced by system capacity
6. The effect of animal type on energy cost of beef
7. Breakdown of labor requirements by the field machinery, transportation and farmstead systems as influenced by system capacity.

8. The effect of maximum allowable tractor size on capital and labor required for the field operations.

9. Breakdown of labor requirements during the year.

7. RESULTS

Fossil energy consuption for systems using tower silos was found to be strongly influenced by silo height. Dollar cost and consumption of other energies were observed to change rapidly for smaller (100 to 300 head capacity) systems. For these reasons, and since the computer was available to make the computations, more systems were analyzed than had been originally intended.

Systems using tower silos for silage storage were analyzed at 25 head intervals from 100 to 1000 head capacity. Other systems were analyzed at 25 head intervals from 100 to 300 head and at 100 head intervals from 400 to 1000 head capacities.

Appendix D, Table D.1, is a set of selected results from the analyses that were performed by the computer. In addition to the information in Appendix D, printouts showing component selection, dollar cost of components and energy consumption by various parts of the system could be produced, if desired. Appendix B was derived from such a complete printout. It has been reorganized somewhat to improve readability. Information of this type was used to find explanations for differences between systems which were found.

The curves presented in this chapter were developed from the information in Appendix D or other computer printouts. The curves showing energy costs for systems were smoothed and plotted on an X-Y plotter controlled by the computer.

The curves in the figures are identified by the technology number, as explained in Chapter 6. In the discussion of the figures, systems are identified by both the technology number and by some characteristic feature which distinguishes the system from others being discussed. This is done to reduce the amount of "decoding" necessary to understand the figures.

7.1 EFFECT OF FEEDLOT TYPE

The effect of type of feedlot on quantity of beef and the cost of beef produced were found by analyzing systems which were similar except for the feedlot. The systems being compared all used yearlings, one percent concentrates ration, bunker silo storage, and solid waste handling. The feedlot types were 1) partial shelter with unpaved lot, 2) partial shelter with paved lot, 3) open and 4) completely sheltered, corresponding to technology numbers 116, 117, 118 and 119, as shown in Table 6.2.

Capital

Figure 7.1 shows the variation with system capacity of capital per hundred pounds of weight gain for the four systems. Hundred-weight of gain was used as the basis of comparison because weight gain accounts for the variation in productivity between systems. Feed efficiency of the animals is affected by the type of housing, by the ration and by the type of animal. Those combinations which cause the animals to gain weight faster will have greater productivity than other systems of the same capacity.

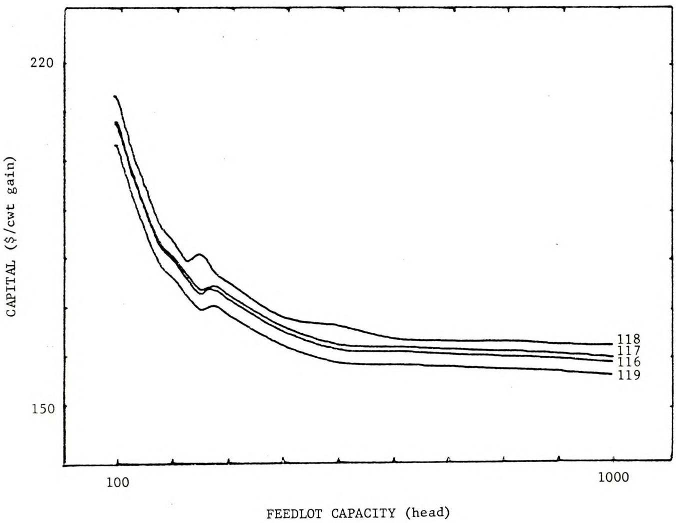


Figure 7.1. Effect of Feedlot Type on Capital Requirements

Capital is defined to include all initial investments for building, land, and equipment plus the annual investment for animals, fertilizer, chemicals, seed and supplement. Small systems used small field equipment and small feed storage which tend to have higher initial cost per bushel or per ton of feed handled than larger units. This higher initial cost is part of the reason for the high capital per hundred weight of gain shown in Figure 7.1 for the small system.

In addition, certain pieces of equipment must be used for the system to conform to the specified technology. In some cases, even the smallest available units are not used to capacity. Equal capital is required whether or not the machine is used to capacity. A notable example is the self-propelled combine used to harvest shelled corn. The capital for this and other pieces of equipment are spread over greater total weight gain in larger systems. The net effect of these two factors on capital per hundred-weight of gain is shown by the shape of the curves in Figure 7.1.

The highest and lowest capital per hundred weight of gain were required for system 118 (the open feedlot) and system 119 (the completely covered feedlot), respectively. The partial shelter systems, numbers 116 and 117, had capital requirements midway between the other two systems. The differences are due to two factors, total capital and total hundred-weight of gain. From Table D.1, it can be seen that even though system 113 had the lowest total capital requirement, the low feed efficiency brought about by lack of shelter caused the hundred-weight of gain to also be the lowest of the four systems. The total hundred weight of gain was low enough to cause the capital per hundred-weight of gain to be higher than for the other systems.

So the differences between systems are affected by the feed efficiency of the animals, which is a result of housing type.

Local Irregularity

A "local" irregularity in the capital per hundred-weight of gain curves occurs at 250 or 275 head capacity for all of the systems. The temporary increase is the result of the addition of equipment to the field machinery and transportation system. Specifically, system 119 requires 118 horsepower at 250 head capacity. For 275 head, the power requirement is 130 horsepower which exceeds the present maximum allowable horsepower. Two tractors (100 hp and 30 hp) are needed. Both of these cost more per horsepower than the 118 horsepower tractor used for the 250 head capacity system, which increases the capital per hundred-weight of gain requirement slightly. Of greater importance, is the fact that a second forage harvester and an additional silage wagon are required. The net effect of these factors is to cause a "bump" on the capital curve at 275 head for system 119.

The "bump" occurs at 250 head for system 118, the open feedlot. From Table C.3, it can be seen that each animal in the open feedlot consumes an average of 1.4 pounds of silage per day more than it would in the covered feedlot. For the 250 head system an extra 22.6 tons of silage are required for feeding the animals in the open feedlot per year. This extra feed production is sufficient to cause the local increase to occur for the 250 head system with technology 118 rather than at 275 head for the others.

Irregularities of this type are present throughtout the results. In all cases they are due to causes like the one previously discussed. Unless some particular significance is involved, there will be no further discussion of the irregularities.

Electrical Energy

Electricity consumption per hundred-weight of gain for the same four systems is shown in Figure 7.2. A pattern similar to the capital requirements is exhibited, with high per unit consumption in small systems. Electricity cost is small when compared to other costs in the system. For example, Table B.16 shows that the electricity cost for the example system is only 23 cents per head.

Reduction in consumption with an increase in system capacity is due to the lighting energy being spread over more animals. The lights specified were large units, and were assumed to be adequate to light one acre of feedlot. One light was required for each complete acre or fraction of an acre. Other electricity consumption for water pumping and feed handling is directly related to the amount of each material used. Differences in energy consumption between systems shown in Figure 7.2, result from the higher feed efficiency of the animals in the sheltered systems.

Fossil Energy

Fossil energy consumption per hundred-weight of gain for the four systems is shown in Figure 7.3. Fossil energy is consumed for the field operations, in the feedlot and for transportation. Variation in energy consumption with system capacity is mostly attributable to transportation. Figure 7.4 shows a breakdown of fossil energy consumption by the three parts of system 119 as an example. Fossil energy consumption per hundred-weight of gain in the feedlot is a small

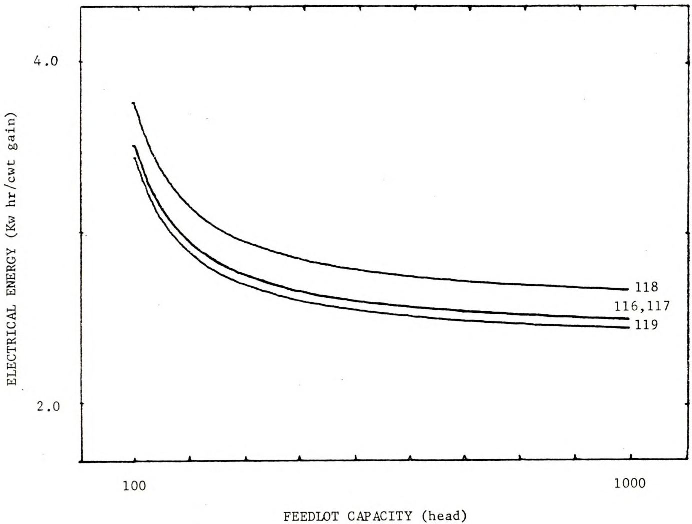


Figure 7.2. Effect of Feedlot Type on Electrical Energy Consumption

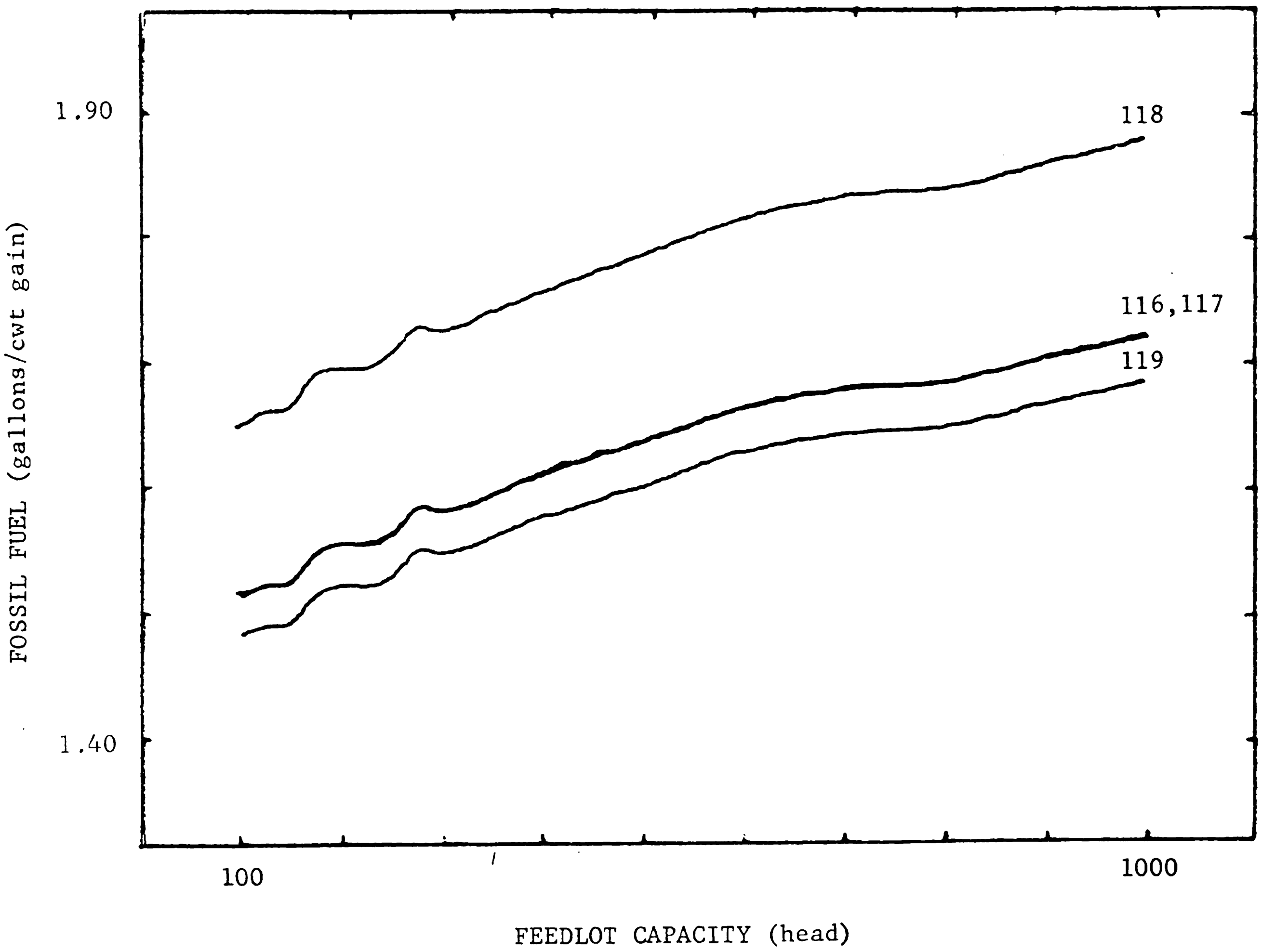


Figure 7.3. Effect of Feedlot Type on Fossil Fuel Consumption

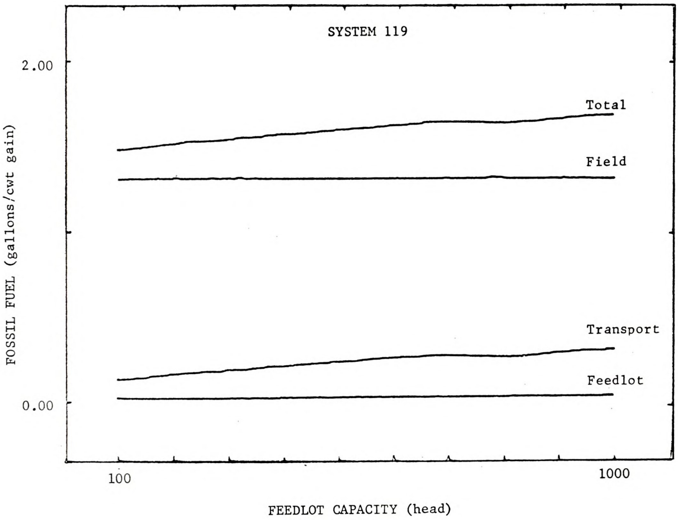


Figure 7.4. Breakdown of Fossil Fuel Consumed by Parts of a System

percentage of the total and is nearly constant. Fossil energy per hundred-weight of gain for field operations is independent of capacity. Transport energy increases monotonically, but at an ever decreasing rate, because the required fractional increase in average transport distance is smaller than the fractional increase in system capacity. For the technology shown, the smaller system requires about 10 percent of total fossil energy consumption for transportation. For the largest system, the transportation system requires about 18 percent of the total. Differences in fossil energy consumption between the systems is attributable to differences in feed efficiency as has been explained.

Labor

Labor per hundred weight of gain required for the system is shown in Figure 7.5. Labor requirements, similar for the four systems, were again lowest for the fully sheltered and highest for the open systems primarily because of the feed efficiency of the animals in the systems.

The shape of the labor requirement curves results from the use of labor by various parts of the systems, as shown in Figure 7.6. For systems with low capacity, the administration time per hundred-weight of gain is high, since total administration time is constant (1000 hrs) for all systems. Field crop production labor per hundred-weight of gain is high for small systems because small machines are used which tend to spread machine use over the allowable subset time (see discussion in Chapter 2).

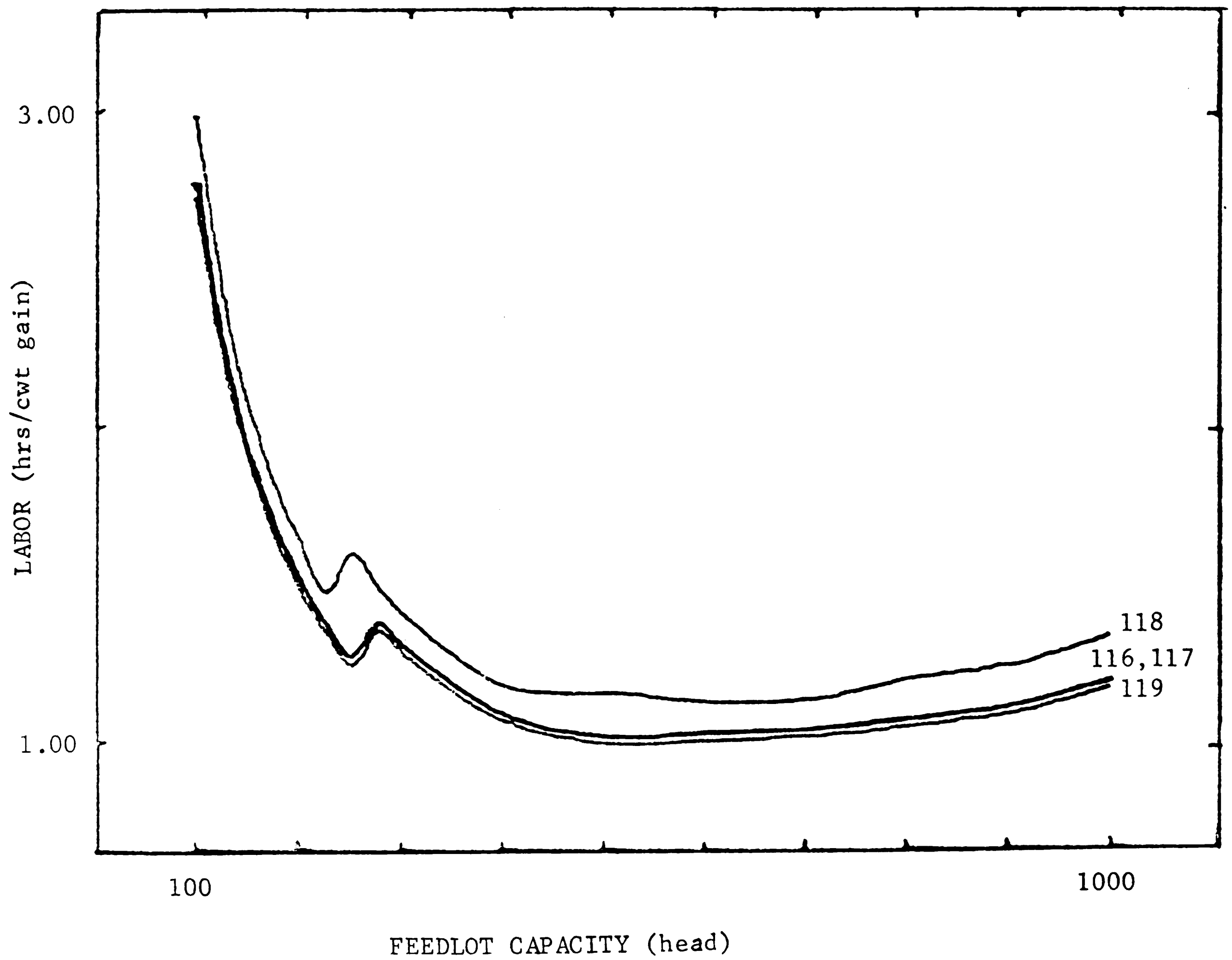


Figure 7.5. Effect of Feedlot Type on Labor Requirements

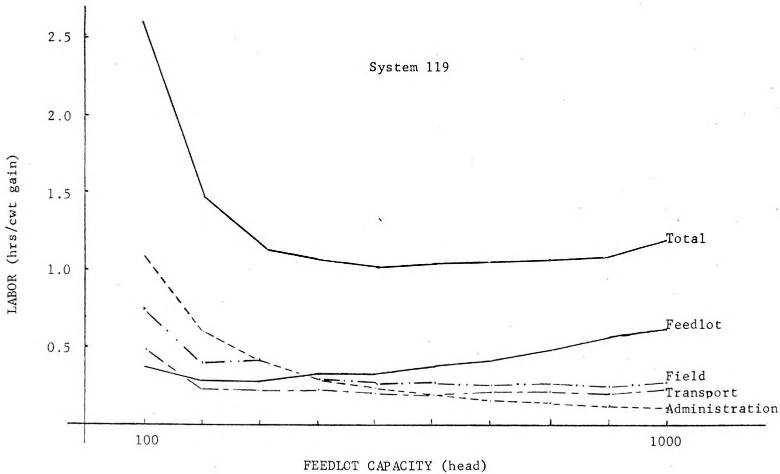


Figure 7.6. Breakdown of Labor Required by Parts of a System

At the upper end of the capacity range, feedlot and transport labor per hundred-weight of gain increases fast enough to more than counteract the decrease in administrative and field labor. Total labor, the sum of the three parts, increases after reaching a minimum as shown in Figure 7.6.

Use of larger capacity feedlot equipment or higher transport speeds shifts the minimum toward the larger systems. All systems, however, eventually show the increased labor requirement as capacity is increased.

Land

Land requirements are shown in Table 7.1 for all of the systems to be discussed in this chapter. For the four systems being evaluated in this section, the open lot required the most land. The partial shelter system required 91.9 percent as much land as the open lot and the completely sheltered system required 90.4 percent as much.

Dollar Cost

Dollar cost per hundred-weight of gain is shown in Figure 7.7. System 119, with the covered lot is the most economical for all system sizes and system 118, the open lot, has the highest cost. The dollar cost difference between the two systems ranges from $2.66 per hundred-weight of gain for 100 head capacity systems to $1.63 per hundred-weight of gain for the 1000 head system. Cost per hundred-weight of gain for the partial shelter systems falls about half way between the other two systems.

Table 7.1. Land Requirements for 1000 Head Capacity Systems

SYSTEM IDENTIFICATION NUMBER	LAND (acres)	MEAT (cwt gain)	LAND/cwt (acres/cwt gain)	PERCENT OF MAXIMUM
55	746	7482	.0997	73.3
91	801	7482	.107	78.7
95	839	7482	.112	82.4
103	1051	8577	.123	90.4
115	1022	8577	.119	87.5
116	1051	8395	.125	91.9
117	1051	8395	.125	91.9
118	1069	7847	.136	100.0
119	1051	8577	.123	90.4

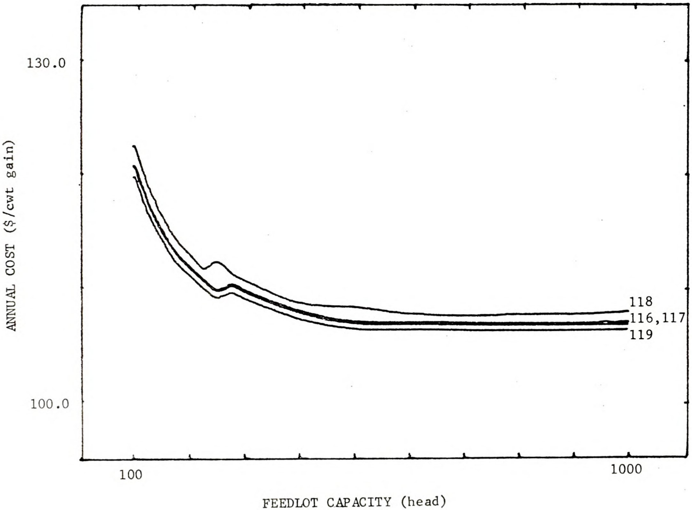


Figure 7.7. Effect of Feedlot Type on Dollar Cost of Beef

7.2 EFFECT OF RATION AND FEED STORAGE

Four systems were selected to illustrate the effect of ration and feed storage on energy costs and system productivity. The systems used solid waste handling, yearlings and the completely covered feedlot. Ration and storage type for the silage for each system are:

91 - all silage - tower silos
95 - all silage - bunker silo
115 - corn and silage - tower silos
119 - corn and silage - bunker silo

The shelled corn for systems 115 and 119 is as usual, stored in sealed tower silos. Shape of the energy curves results from the same factors as discussed in section 7.1. So, for simplicity, only differences between systems are discussed. Also, mention of an energy can be taken to mean energy per hundred weight of gain unless otherwise specified.

Capital

Capital requirements are shown in Figure 7.8. Systems 95 and 119, using bunker silos, require less capital than the two systems using tower silos.

For the systems using tower silos, system 91, with the all silage ration, requires less capital than system 115 if the capacity is smaller than 400 head. Above 400 head, the situation is reversed and the all silage system requires more capital. The all silage system has lower capital requirements for all sizes when bunker silos are used.

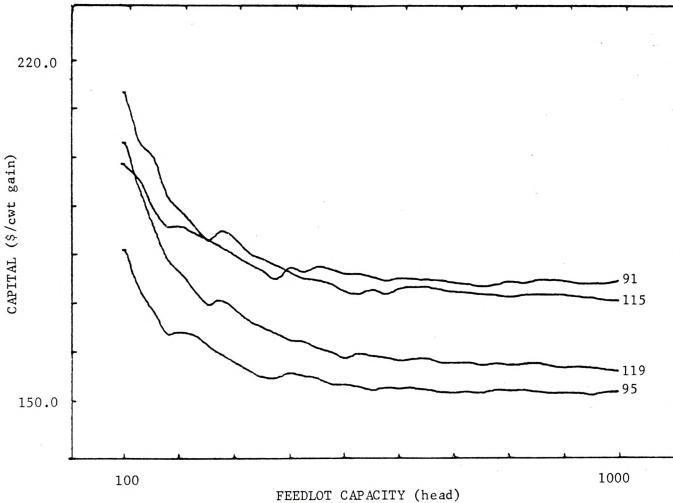


Figure 7.8. Effect of Ration and Feed Storage Systems on Capital Requirements

Land

Land requirements are given in Table 7.1. The all silage system required less land than the systems using the mixed ration. Bunker silo systems, for both rations, required more land than tower silo systems to compensate for the higher rate of spoilage in bunker silos.

Electrical Energy

The systems using tower silos require more electric energy than the bunker silo systems, as shown in Figure 7.9, because of the extra load for the silo unloaders. Where bunker silos were used, the electrical energy consumption was higher for system 115, with the mixed ration. This was expected because of the energy needed for unloading and grinding corn. However, when tower silos are used, the electrical energy for handling the all silage ration is higher than for the mixed ration because of the greater quantity of material handled.

Fossil Energy

Fossil fuel consumption is shown in Figure 7.10. Systems 119 and 95 with bunker silos require less fossil energy than the tower silo systems. The packing operation consumes less energy than blowing silage into tower silos (the difference depends on silo height) but part of the advantage is lost in the energy expended to produce and transport the extra silage needed to compensate for higher bunker silo losses.

The mixed ration requires more energy than the all silage ration because the corn must be elevated into the silo. When tower

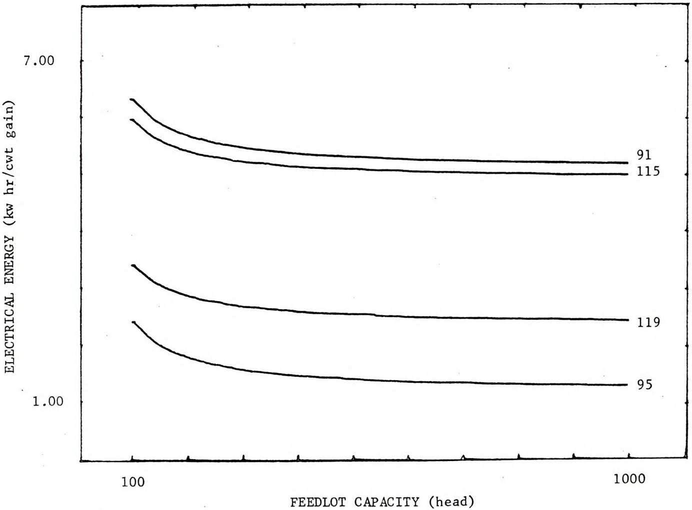


Figure 7.9. Effect of Ration and Feed Storage Systems on Electrical Energy Consumption

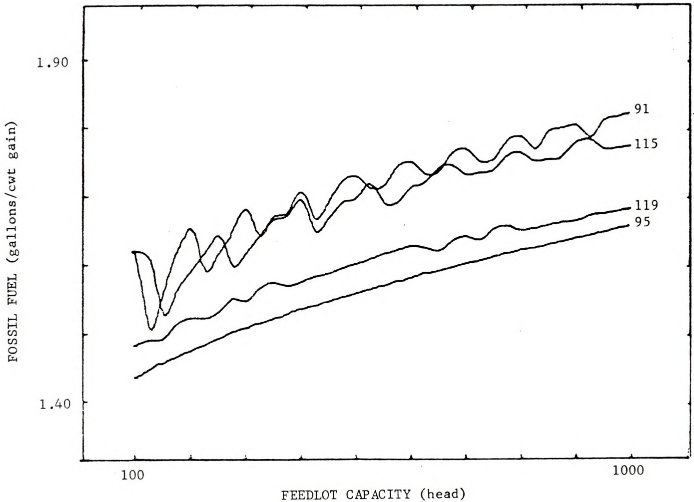


Figure 7.10. Effect of Ration and Feed Storage System on Fossil Fuel Consumption

silos are used for silage, the mixed ration requires less energy in general. Although, as can be seen in Figure 7.10, the energy for a system of a given size is highly size specific, the greater weight of the all silage ration causes the energy required for system 91 to exceed that for system 115 for most capacities.

Labor

The plots of labor requirement, shown in Figure 7.11, show that, for small systems, the corn and silage ration requires more labor and for systems larger than about 250 head capacity, the all silage system requires more labor.

The high labor requirement for the large all silage systems results from two factors. More labor is required in the field to complete the harvest and more transport labor is consumed. The all silage system requires more loads of silage than total loads of both feeds when the mixed ration is used.

Dollar Costs

Dollar cost of beef production, shown in Figure 7.12 is lower for systems using bunker silos than for systems using tower silos for all capacities evaluated. The mixed ration has a lower cost than the all silage ration for most sizes. However, for tower silo systems, smaller than 200 head capacity and bunker silo systems smaller than 400 head, the all silage ration has a lower cost.

7.3 EFFECT OF WASTE HANDLING SYSTEM

System 103 and 119 were compared to evaluate the effect that the method of waste handling has on energy costs. System 103 is

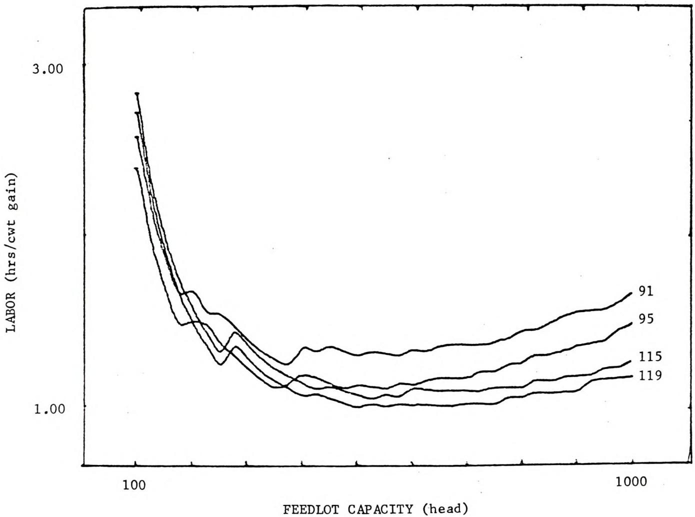


Figure 7.11. Effect of Ration and Feed Storage System on Labor Requirements

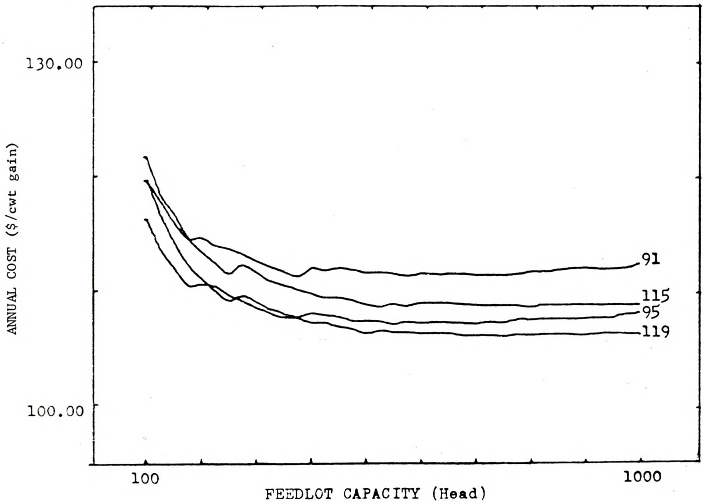


Figure 7.12. Effect of Ration and Feed Storage System on Dollar Cost of Beef

the same as 119 except that a liquid waste handling system is substituted for the solid waste handling system.

Capital

Capital requirements, shown in Figure 7.13, are higher for the liquid system. The liquid tank, slotted floor and liquid manure pump are capital expenditures needed by a liquid system that are not required for a solid system. Also, since more liquid material is moved, extra spreaders may be required for some systems.

The systems have equal electricity requirements as shown in Figure 7.14. It is assumed that the liquid manure pump is powered by the feedlot tractor.

Fossil Fuel

The fossil fuel requirements, shown in Figure 7.15, are higher for the liquid system. The additional liquid material which must be hauled requires more fossil energy for loading and transporting.

Labor

Labor required for the liquid system, shown in Figure 7.16, is higher than for the solid system because of the greater transport effort needed for the liquid. The irregularity in the labor curve at 275 head capacity occurs because of a change in the field machinery system and is not related to the waste handling system.

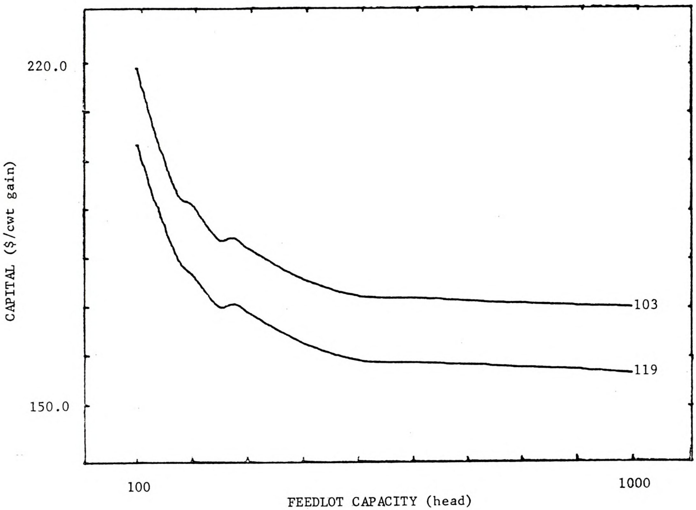


Figure 7.13. Effect of Waste Handling System on Capital Requirements

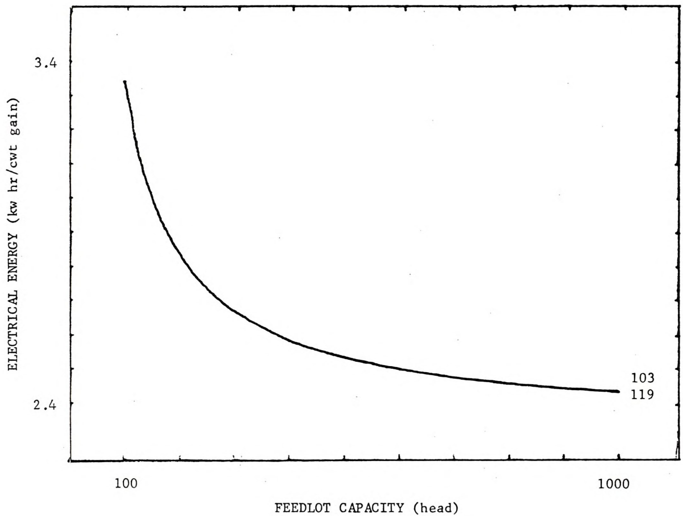


Figure 7.14. Effect of Waste Handling System on Electrical Energy Consumption

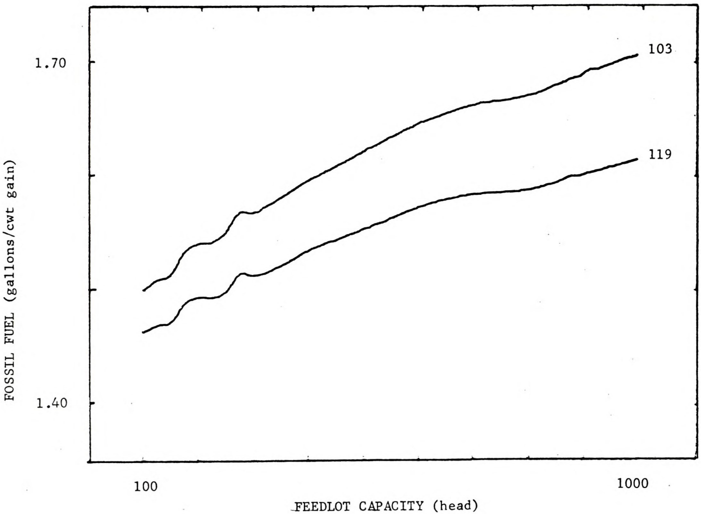


Figure 7.15. Effect of Waste Handling System on Fossil Fuel Consumption

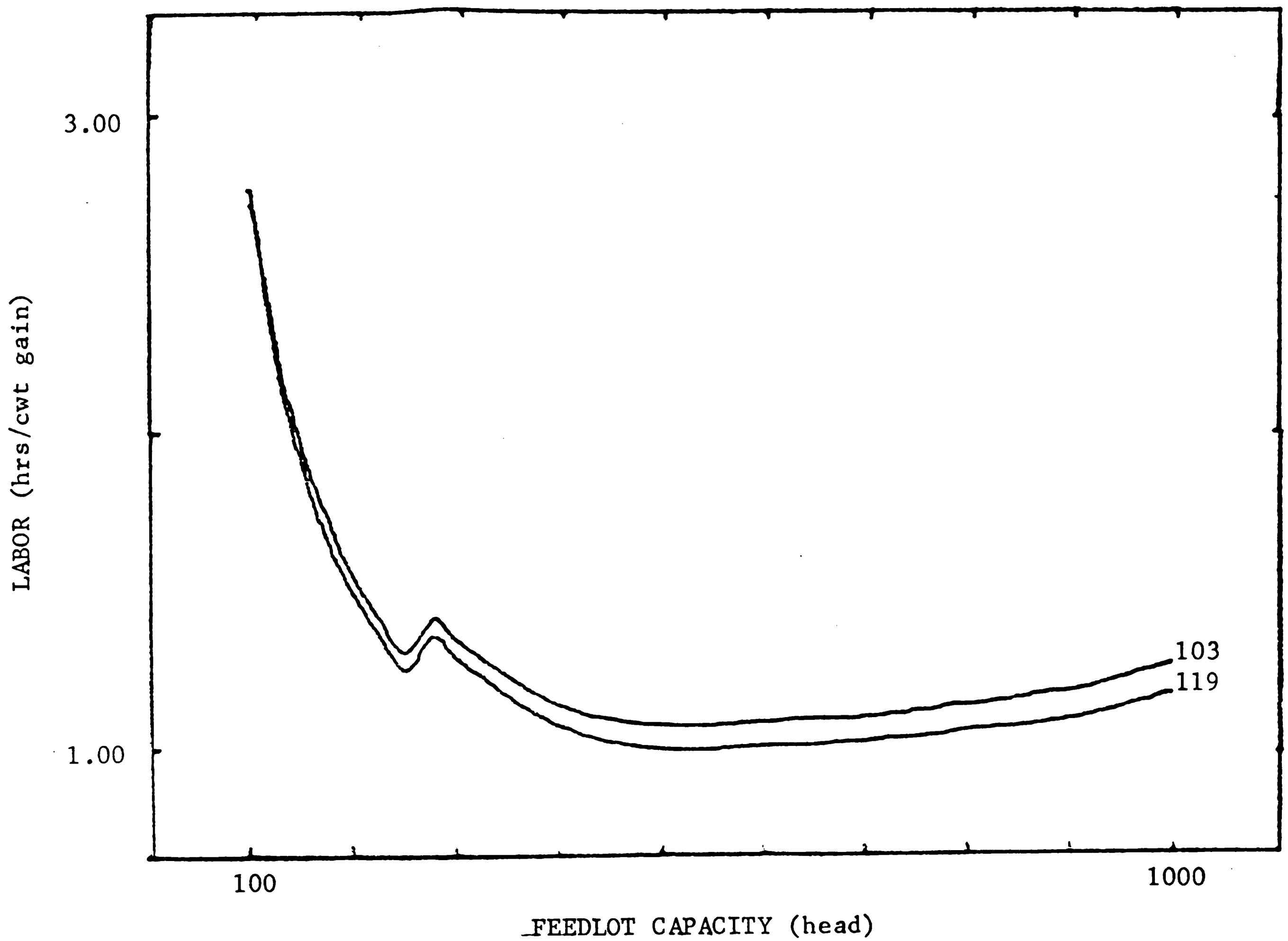


Figure 7.16. Effect of Waste Handling System on Labor Requirement

Dollar Cost

Dollar cost for producing beef is higher when the liquid manure system is used. The dollar cost reflects the greater capital, labor and fossil fuel requirements for the liquid system. Costs for the systems are plotted in Figure Figure 7.17.

7.4 EFFECT OF ANIMAL TYPE

To evaluate the effect of animal type on the cost of beef, systems 55 and 119 were compared. The systems were alike except for the type of animal used. System 55 used calves and system 119 used yearlings. The results of the comparisons are shown in Figures 7.18 through 7.23.

Capital required per hundred pounds of weight gain is shown in Figure 7.18. On this basis, and using the definition of capital which included the cost of the feeders as previously discussed, the calves have a much lower capital requirement. However, Figure 7.18 does not reflect the difference in turnover rate between the two systems. The calves, in system 55, are finished in 294.3 days while the yearlings, in system 119, require only 170.6 days. Using the prices for feeders presented previously, the total annual capital required for yearling feeders is $690.15 per head of feedlot capacity. For calves, the capital requirement for feeders is $273.42 per head of capacity. The amounts of weight gain produced by the systems are 856 and 744 pounds per head of capacity for the yearling and calf systems, respectively. Thus, the capital required per hundredweight of gain to put feeder cattle in the lot is $8.06 and $3.68, respectively, for the yearlings and calves. Of the difference shown in Figure 7.18, $4.38 is due to the capital required for the feeders

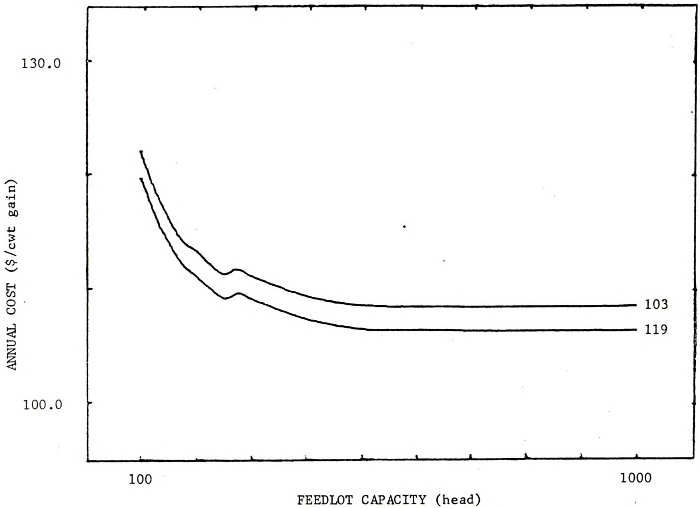


Figure 7.17. Effect of Waste Handling System on Dollar Cost of Beef

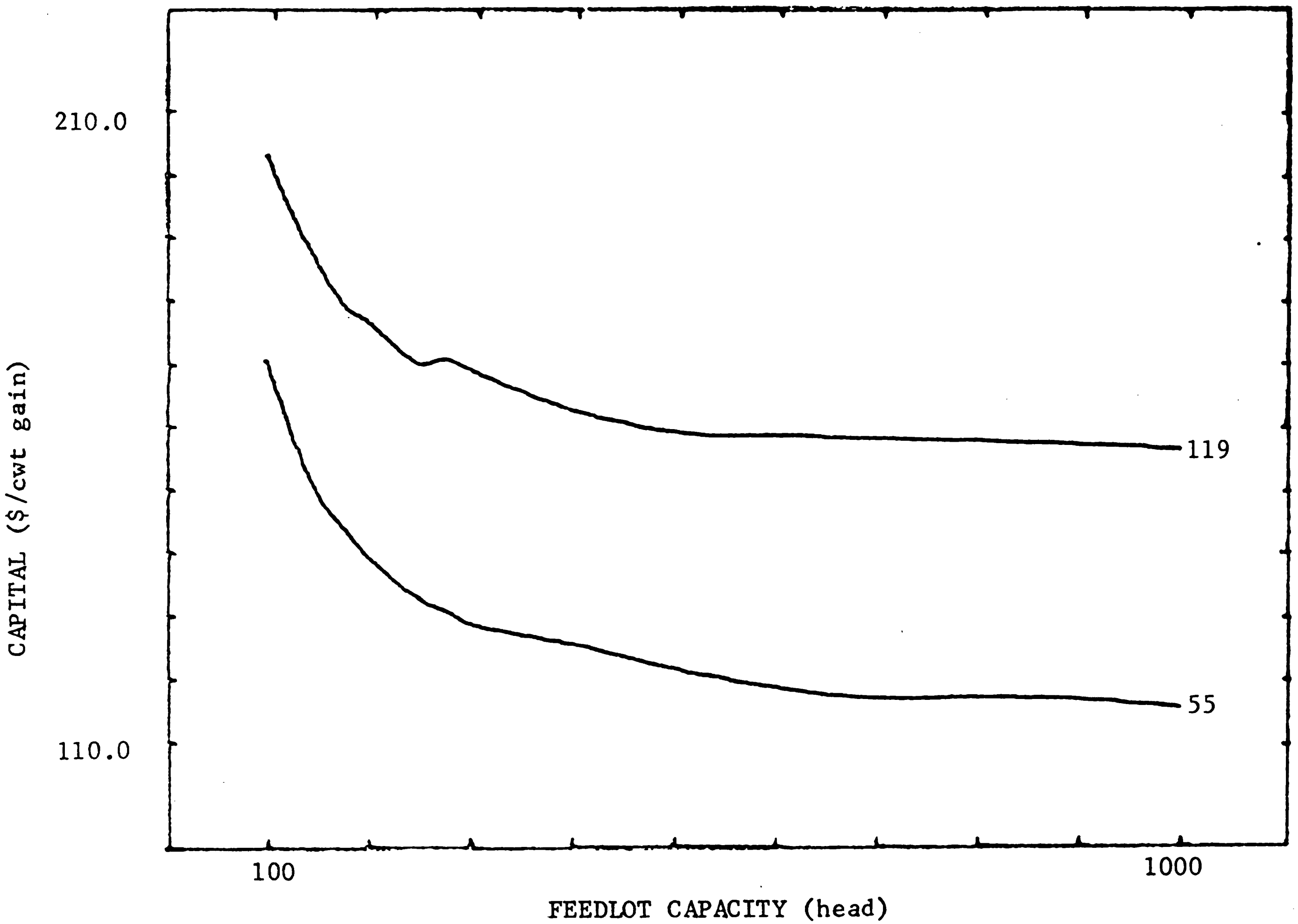


Figure 7.18. Effect of Animal Type on Capital Requirements

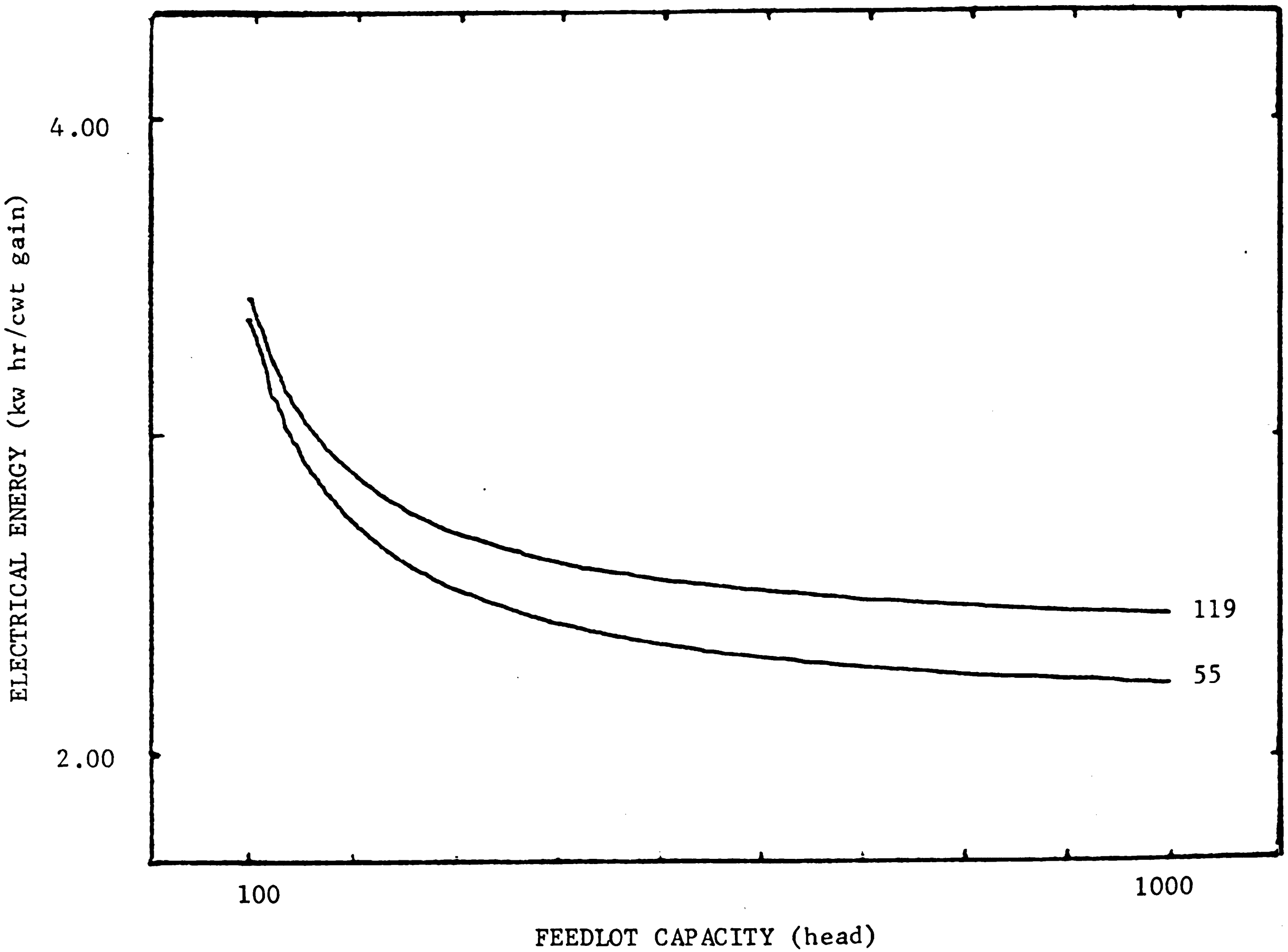


Figure 7.19. Effect of Animal Type on Electrical Energy Consumption

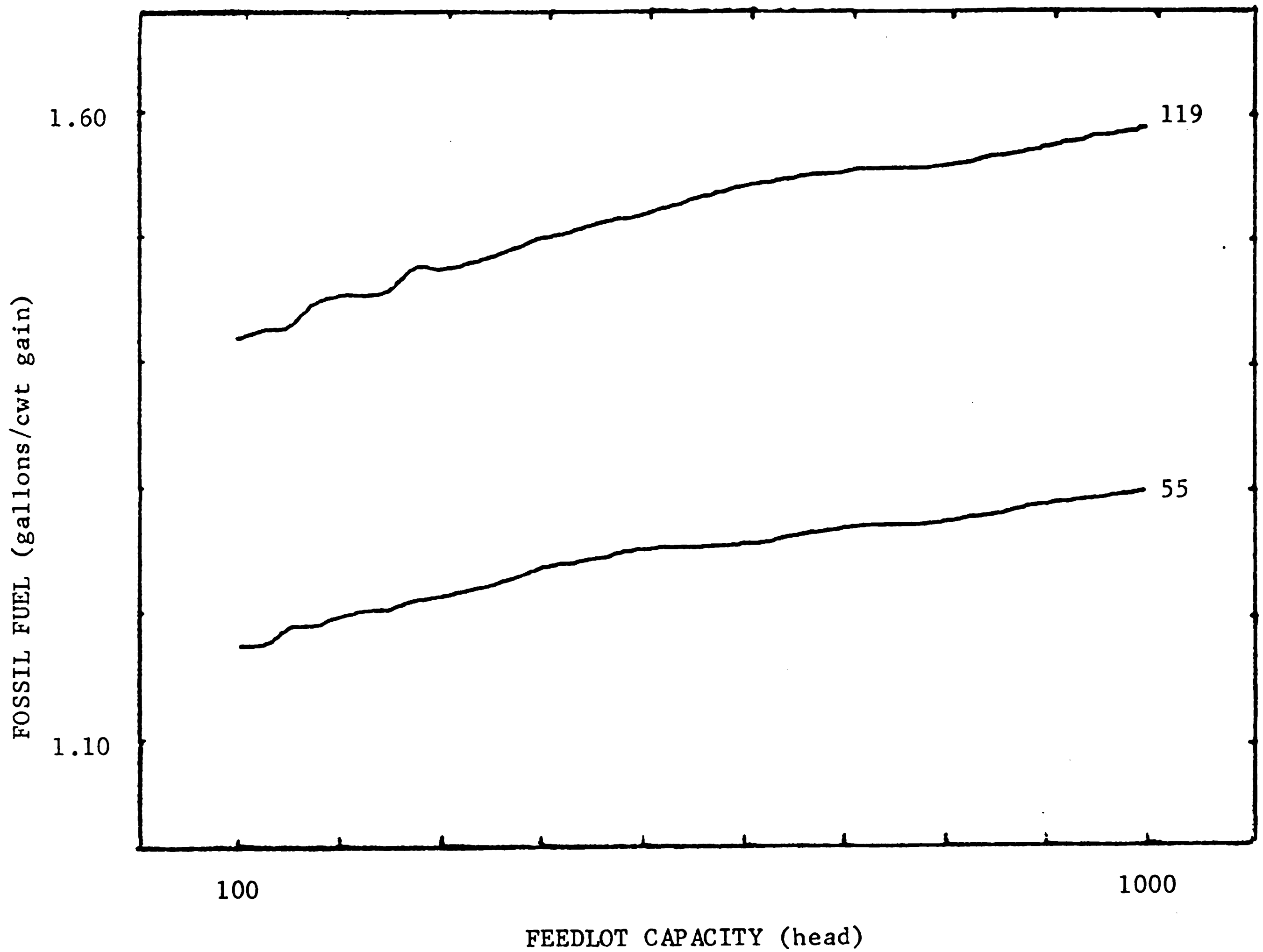


Figure 7.20. Effect of Animal Type on Fossil Fuel Consumption

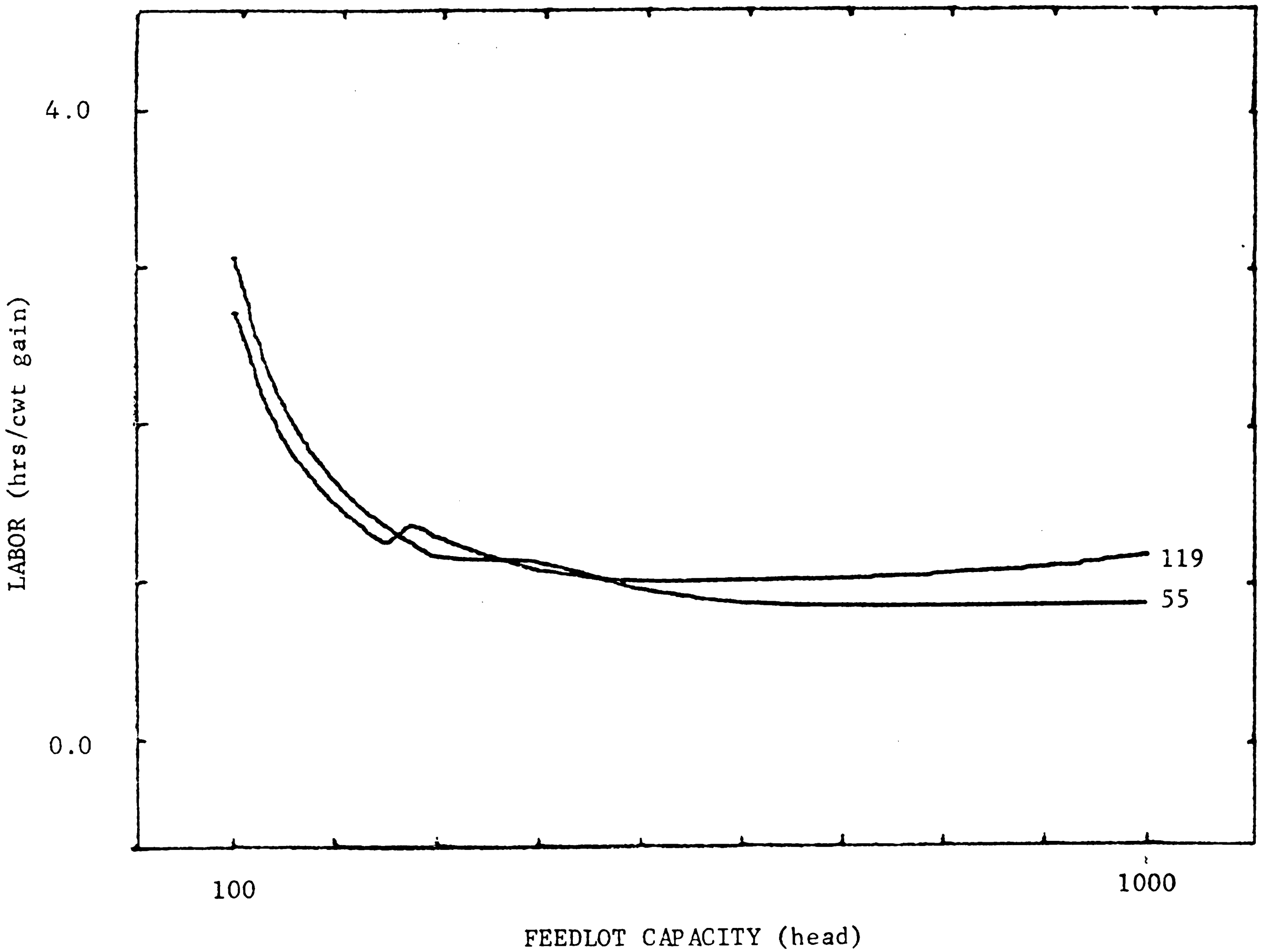


Figure 7.21. Effect of Animal Type on Labor Requirements

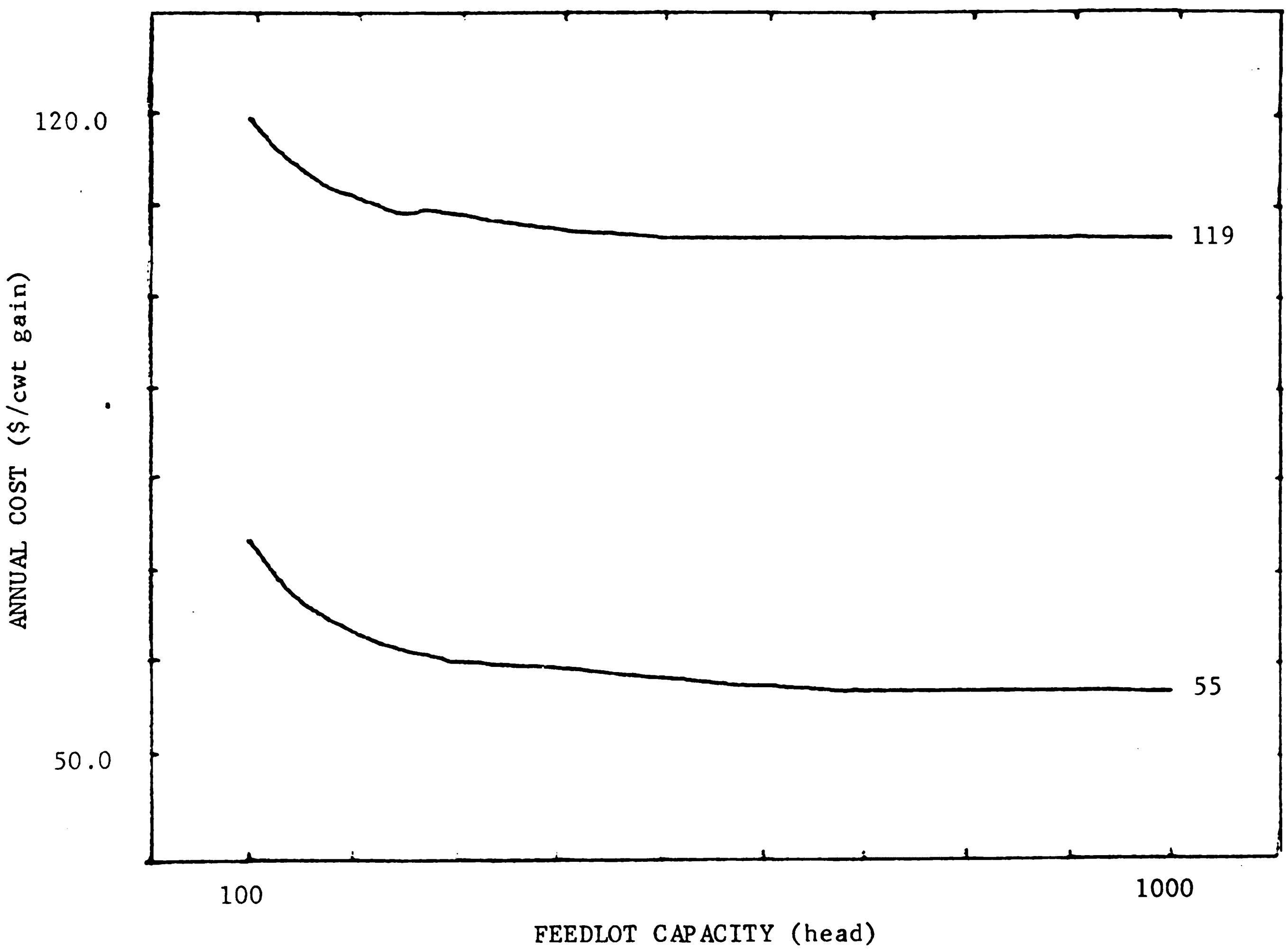


Figure 7.22. Effect of Animal Type on Dollar Cost per Hundred Pounds of Weight Gain

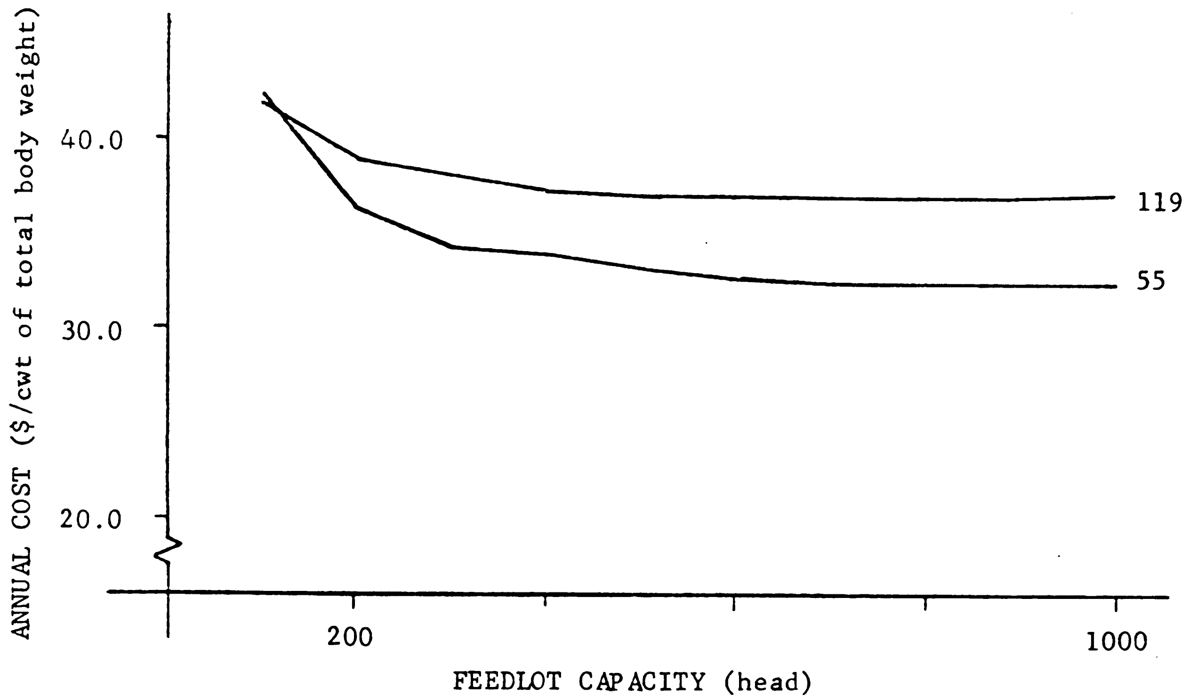


Figure 7.23. **Effect of Animal Type on Dollar Cost per Hundred Pounds of Total Body Weight**

The calf system requires considerably less capital than the yearling system, primarily because of the difference in land required for the two systems. From Table 7.1, system 55 requires only 81.05 percent as much land as system 119. As a result, system 55, using calves, requires less capital for land and crop production equipment.

The calf system also required less electrical and fossil energy than the yearling system, as shown in Figure 7.19 and 7.20. Labor requirements, shown in Figure 7.21, were lower when yearlings were used for capacities up to about 450 head. Systems with capacity in excess of 450 head required less labor per hundred pounds of weight gain when calves were used.

Dollar cost per hundred-weight of gain is shown in Figure 7.22. The cost per hundred-weight of gain is about $50 lower when calves are used. However, as discussed in the section on capital, the dollar cost per hundred weight of gain includes the cost of the animals but does not account for the original weight of the animals passing out of the system. Figure 7.23 makes the allowance by showing the dollar cost per hundred-weight of the output animal.

The cost per hundred pounds of body weight is generally lower for calves than for yearlings. For a capacity of 100 head, the yearlings cost less to produce, because the annual cost of equipment such as the combine and feed storages are spread over more total body weight.

7.5 EFFECT OF ALLOWABLE TRACTOR HORSEPOWER

Maximum allowable tractor horsepower is used to determine the number of tractors needed to power a particular system. The number of tractors, in turn, affects the number and size of each field machine needed, and the capital required. The number and size of tractors also affects the labor required to operate the system (Chapter 3).

The influence of maximum allowable tractor size on capital and labor required for the field machinery system are shown in Figures 7.24 and 7.25, respectively. Both labor and capital requirements are increased when tractor horsepower is restricted. Capital requirements are lower when large tractors can be used because of the lower cost per housepower for the large tractors and because fewer pieces of machinery are needed. The difference in capital required becomes larger as more horsepower is needed, as shown in Figure 7.24.

The labor requirements for each tractor size, shown in Figure 7.25, increases sharply when an additional tractor is added to the system. For example, a change from one to two tractors takes place between 200 and 300 head capacity when 120 horsepower tractors are used. From 300 to 500 head, two tractors are sufficient and a much slower increase in field labor requirements is exhibited.

Fossil energy and land requirements remain constant regardless of tractor size. Since there is no electrical energy consumption, the dollar cost for operating the field machinery system depends only on the amount of capital and labor required. Both capital and labor increase when maximum allowable tractor size is limited. Consequently, using small tractors where large tractors could otherwise be employed will increase the dollar cost for operating the crop production machinery.

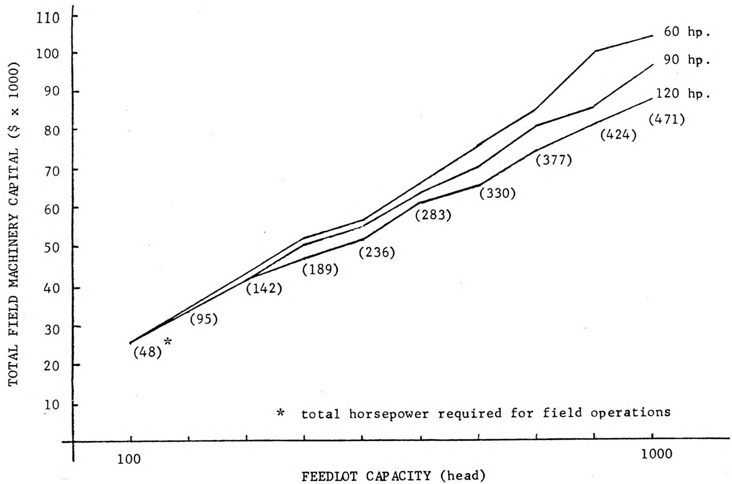


Figure 7.24. Effect of Maximum Allowable Tractor Power on Capital Required for Field Machinery

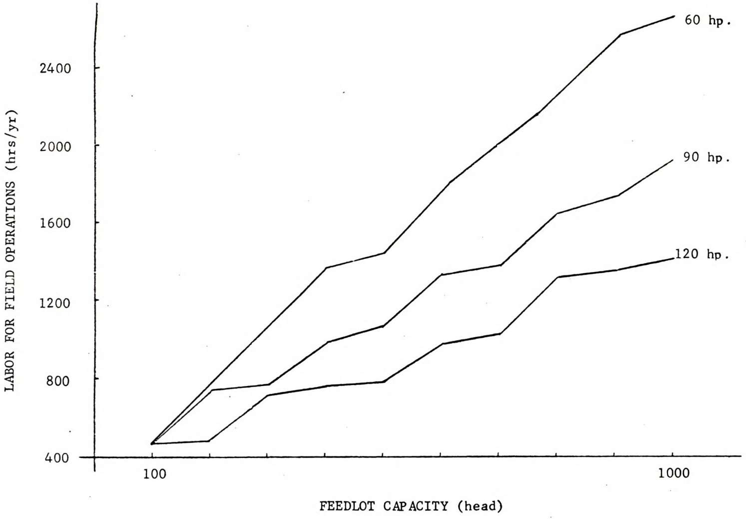


Figure 7.25. Effect of Maximum Allowable Tractor Horsepower on Labor Required for Field Operations

7.6 DISTRIBUTION OF LABOR REQUIREMENTS DURING THE YEAR

Labor requirements, which reflect the work schedule, vary throughout the year. Labor requirements for selected periods of the year are shown in Table 7.2 for an example system of 500 head capacity using technology 119. From Table 7.1, it can be seen that times exist during the year when the only work scheduled is feeding the animals, which requires an average of 3.53 hours per day. Peak labor requirements occur during the harvest season. During silage harvest, an average of 43.28 man-hours per day are needed. Average labor requirement for harvesting corn is lower at 17.38 man hours per day.

The peak labor requirements are higher than the averages given in Table 7.2. Some days are unuseable because of tractability conditions, but were included when the average hours of labor per day was calculated. An estimate of peak labor use can be found by dividing the sum of field and transport time by the percent useable days, and adding the time required for feeding the cattle. However, the estimated peak labor requirement may be in error because the time required to feed the cattle actually depends on the age of the cattle. Only the average feeding time has been used in this study.

The labor requirements shown in Table 7.2 include an allowance for scheduling efficiency and miscellaneous operations but do not include administration time. It would seem logical to expect the operator to carry out administrative activities when other labor requirements are low. A total of 195 days during the year require only 3.53 hours of labor. Using the remaining 6.47 hours of a ten hour day, a total of 1261.55 hours are available. Of course, some

Table 7.2. Labor Required During the Year by a 500 Head Capacity Beef Farm Using Technology 119

DATES	DAYS	TOTAL* FEEDLOT TIME (hrs)	TOTAL* FIELD TIME (hrs)	TOTAL* TRANSPORT TIME (hrs)	TOTAL# TIME (hrs)	AVERAGE# DAILY TIME (hrs)	USEABLE+ DAYS (decimal)	ESTIMATED PEAK LABOR REQUIREMENT (man hrs/day)
01/01 - 04/16	106	373.5	-----	----	373.5	3.53	----	3.53
04/17 - 05/30	44	155.0	251.3	77.4	483.7	10.99	.385	22.96
05/31 - 06/04	5	17.7	-----	----	17.7	3.53	----	3.53
06/05 - 06/24	20	70.5	43.0	----	113.5	5.68	.606	7.08
06/25 - 08/31	68	239.6	-----	----	239.6	3.53	----	3.53
09/01 - 09/24	24	84.5	291.6	662.1	1038.2	43.28	.629	66.71
09/25 - 10/24	30	105.7	191.0	224.6	521.3	17.38	.664	24.39
10/25 - 12/14	51	179.7	104.1	77.4	361.2	7.08	.152	26.94
12/15 - 12/31	16	56.4	-----	----	56.4	3.53	----	3.53

* Includes anallowance for scheduling efficiency and miscellaneous operations

\# Does not include administrative time

\+ Useable days only applies to field and transport activities

administrative activity has to be carried on while other operations are being conducted, so it can not all be done during the slack days.

8. CONCLUSIONS

In the course of conducting the study and preparing this report, the following items have been accomplished:

1. A model of a single enterprise beef production system has been developed. The model determines the identifiable material flows in the system and the energy cost of beef produced by the system.
2. Subsystem models were developed for field crop production, transportation, and farmstead operation which determine the structures and equipment required and the processing energies for the system.
3. The effect of type of feedlot, feed storage, ration, waste handling and animal on energy cost of beef production was evaluated.

The following conclusions were reached:

1. The components of the beef system (Figure 2.10) are not independent. The transportation system, in particular, depends on other parts of the system. The number of wagons, for example, depends on the number of field choppers in use, which is determined independently. The farmstead tractors used for operating blowers and packing silage are selected in conjunction with the transport system design. Amalgamation of the

farmstead and the transportation as a single component can be considered to be independent, as well as crop production, if it is assumed that equipment does not perform operations for both systems. All equipment must be assigned to a single component.

2. Technology can affect the energy cost of beef produced by a system of a particular capacity. In particular, the following items were shown.

   a. Labor requirements per hundred pounds of weight gain increases for the transport and feedlot components as capacity increases. Total labor requirements per hundred-weight of gain tend to reach a minimum and then increase as system capacity is increased. The system capacity at which the increase is initiated depends on acreage of the farm and the capacity of the transport and feeding equipment.

   b. Transport fossil energy per hundred-weight of gain increases at a decreasing rate as capacity increases because the fractional increase in average travel distance is smaller than the fractional increase in capacity. Feeding energy per hundred-weight of gain increases at an increasing rate because of the higher proportion of unloaded travel in the larger feedlots. However, the feedlot fossil energy consumption is small when compared to that used for field operations and transport. Fossil energy consumption per hundred-weight of gain is constant with capacity for the field operations.

c. Land required per hundred-weight of gain is constant with capacity for a particular technology.

d. Electrical energy consumed per hundred pounds of weight gain decreases as system capacity increases. However, electrical energy consumption is small and the cost is small when compared to other energy costs.

e. Capital required per hundred-weight of gain decreases with increasing system capacity up to about 500 head capacity. Larger systems have nearly constant capital requirements per hundred-weight of gain.

f. Dollar cost per hundred-weight of gain decreases with increased system capacity for systems smaller than about 500 head capacity. For larger systems the dollar cost of a hundred pounds of gain is nearly constant.

g. If other parts of the system are similar, cattle produced in a completely covered feedlot require less capital, fossil energy, electrical energy, land and labor per hundred-weight of gain than animals held in open or partially sheltered feedlots. The dollar cost per hundred-weight of gain is also lower for the animals held in the covered feedlot.

h. If the technologies used in other parts of the system are the same, the capital, labor, fossil energy and dollar cost per hundred-weight of gain are higher when a liquid waste handling system is used than when the "conventional" solid system is used. Waste handling technology does not affect the requirements for electrical energy and land.

i. A system of a given capacity, using an all silage ration, rather than a mixed corn and silage ration requires less capital, land, electrical energy and fossil energy per hundred-weight of gain if the systems are otherwise equivalent. For large systems, more labor is required per hundred-weight of gain when the all silage ration is used.

j. When a bunker silo is used, rather than tower silos in otherwise equivalent systems, the energy costs per hundred-weight of gain are lower except for land and labor. Labor is higher for all silage systems with capacity greater than about 250 head. Land cost is higher for the all silage system because of the higher storage loss.

k. Use of calves, rather than yearlings, in otherwise equivalent systems, reduces the energy costs per pound of total body weight of the animals produced by the system.

l. Limiting the horsepower of the tractors used for the field work increases the capital and labor required for a system of a particular capacity.

m. Peak labor use for beef production occurs during the silage harvest season.

9. SUGGESTIONS FOR FURTHER STUDY

It is recommended that this study be expanded in the following five ways.

1. Include pecuniary economics of scale such as expressing the cost of input materials as a function of the quantity purchased.
2. Include an evaluation of carcass quality in addition to the quantity of meat produced by each system.
3. Expand the set of technologies for evaluation by including other feed production systems, waste handling techniques, animal type, rations and transport methods.
4. Include energy costs other than dollar cost for the input materials.
5. Allow substitution of custom operations as an alternative to ownership of certain pieces of equipment.

It is also recommended that the following studies be initiated:

1. Modify the existing model, or develop a new model, to deal with a multiple enterprise farm.
2. Modify the existing model, or develop a new model, to deal with the dynamics of adjustment to changes in capacity or technology of an operating system.

3. Model other agricultural operations such as poultry, swine, dairy, cash grain, fruit and vegetable production to find the energy costs. Then use these models, together with the beef model and models of manufacturing and business enterprises of various types and sizes to cause the consumption of energy throughout the year to have a desired characteristic in a particular region.
4. Develop procedures to guide the design of systems to optimize the consumption of each type of energy according to a utility function.

Various phases of this study were limited by the unavailability of data. The following areas where either more data or data of a different type are needed are suggested for further study.

1. More information is needed about the costs of components, both initial cost and operating costs. The initial costs should be expressed as functions of the size, dimensions or capacity of the component or given as a breakdown for the parts of the component. For example, cattle shelter costs could be given as a cost per foot of side wall plus the cost per square foot of roof as a function of the building width. The costs of feed storage structures were functionalized in this study. However, the cost function for sealed tower silos used for storing corn was based on very limited data. More sealed tower silo prices, over a wide range of heights and diameters are needed to improve this function. Similar comments could

be made about several other functions which were developed for and used in the study.

2. The data on energy consumption in the farmstead operations, available at this time, is inadequate. Areas which need further work include 1) packing a bunker silo as influenced by silo dimensions and rate of filling, 2) scraping the feedlot, 3) loading manure with a front end loader, 4) loading liquid manure with a pump, 5) unloading a bunker silo with a front end loader, and 6) operating self-unloading forage wagons and mixer-feeder wagons.
3. The capacity of material handling equipment, such as front end loaders, is needed. The capacity should be expressed as a function of power input and material being handled.
4. The rate of packing silage in a bunker silo as a function of silo dimensions, rate of filling and packing tractor horsepower and weight is needed.
5. The influence of crop production technology on yield of corn and silage is needed so that additional crop production systems can be evaluated.

APPENDIX A

Table A.1. Material Flow Units

FLOW	UNITS OF MATERIAL FLOW
Y_{01}	Bushels of shelled corn per year
Y_{11}	Pounds of nitrogen per year*
Y_{21}	Pounds of phosphorus per year
Y_{31}	Pounds of potassium per year
Y_{41}	Bushels of shelled corn seed per year
Y_{51}	Units of chemicals applied per year**
Y_{61}	Acrefeet of water per year
Y_{02}	Tons of silage per year
Y_{12}	Pounds of nitrogen per year
Y_{22}	Pounds of phosphorus per year
Y_{32}	Pounds of potassium per year
Y_{42}	Bushels of silage corn seed per year
Y_{52}	Units of chemicals applied per year**
Y_{62}	Acrefeet of water per year
Y_{72}	Pounds of protien supplement per year
Y_{03}	Units of ration per year**
Y_{13}	Bushels of shelled corn per year
Y_{23}	Tons of silage per year
Y_{04}	Pounds of finished beef per year
Y_{14}	Pounds of nitrogen per year
Y_{24}	Pounds of phosphorus per year
Y_{34}	Pounds of potassium per year
Y_{44}	Pounds of waste per year
Y_{54}	Units of ration per year

Table A.1. (cont'd.)

Y_{64}	Gallons of water per year
Y_{74}	Number of animals per year
Y_{05}	Pounds of waste per year
Y_{15}	Pounds of waste per year
Y_{25}	Pounds of waste per year
Y_{06}	Pounds of potassium per year
Y_{16}	Pounds of potassium per year
Y_{26}	Pounds of potassium per year
Y_{07}	Pounds of phosphorus per year
Y_{17}	Pounds of phosphorus per year
Y_{27}	Pounds of phosphorus per year
Y_{08}	Pounds of nitrogen per year
Y_{18}	Pounds of nitrogen per year
Y_{28}	Pounds of nitrogen per year
Y_{0N}	Pounds of commercial nitrogen fertilizer per year
Y_{0P}	Pounds of commercial phosphorus fertilizer per year
Y_{0K}	Pounds of commercial potassium fertilizer per year
Y_{1T}	Pounds of waste material per year
Y_{2T}	Bushels of shelled corn per year
Y_{3T}	Tons of silage per year

* All plant nutrient flows are expressed as equivalent to the commercial fertilizer.

** Units of chemicals and units of ration are defined below Table B.15.

Table A.2. Technical Coefficients

TECHNICAL COEFFICIENT	UNITS
K_{11}	Pounds of nitrogen/bushel of shelled corn
K_{21}	Pounds of phosphorus/bushel of shelled corn
K_{31}	Pounds of potassium/bushel of shelled corn
K_{41}	Bushels of seed/bushel of shelled corn
K_{51}	Units of chemicals*/bushel of shelled corn
K_{61}	Acrefeet of water/bushel of shelled corn
K_{12}	Pounds of nitrogen/ton of silage
K_{22}	Pounds of phosphorus/ton of silage
K_{32}	Pounds of potassium/ton of silage
K_{42}	Bushels of seed/ton of silage
K_{52}	Units of chemicals/ton of silage
K_{62}	Acrefeet of water/ton of silage
K_{72}	Pounds of supplement/ton of silage
K_{13}	Bushels of corn/unit of ration*
K_{23}	Tons of silage/unit of ration
K_{14}	Pounds of Nitrogen/pound of finished beef
K_{24}	Pounds of phosphorus/pound of finished beef
K_{34}	Pounds of potassium/pound of finished beef
K_{44}	Pounds of waste/pound of finished beef
K_{54}	Units of ration/pound of finished beef
K_{64}	Gallons of water/pound of finished beef
K_{74}	Feeder animals/pound of finished beef

Table A.2. (cont'd.)

K_{15}	Pounds waste/pound waste
K_{25}	Pounds waste/pound waste
K_{16}	Pounds nitrogen/pound nitrogen
K_{26}	Pounds nitrogen/pound nitrogen
K_{17}	Pounds phosphorus/pound phosphorus
K_{27}	Pounds phosphorus/pound phosphorus
K_{18}	Pounds potassium/pound potassium
K_{28}	Pounds potassium/pound potassium

* Units of chemicals and units of ration are defined below Table B.15.

APPENDIX B

Table B.1. Power Requirement Analysis for Field Operations

OPERATION	ENERGY	HOURS	HORSEPOWER	ACRES
Subset 1	04/17-05/30		38.5 Percent Usable Days	
Plow	9240.0	66.7	138.4	349.9
Disk	3208.6	23.1	138.4	525.0
Harrow	1925.1	13.9	138.4	525.0
Plant	2843.3	20.5	138.4	525.0
TOTAL	17217.2	124.3		
Subset 2	06/05-06/24		70.6 Percent Usable Days	
Cultivate	1443.8	87.5	16.4	525.0
TOTAL	1443.8	87.5		
Subset 3	09/01-09/24		62.9 Percent Useable Days	
Chop Silage	19860.4	112.4	176.6	314.2
TOTAL	19860.4	112.4		
Subset 4	09/25-10/24		66.4 Percent Usable Days	
Combine Corn	9367.1	146.9	63.7	211.3
TOTAL	9367.1	146.9		
Subset 5	10/25-12/14		15.2 Percent Usable Days	
Chop Stalks	2535.7	20.2	125.2	211.3
Plow	4620.0	36.8	125.2	174.9
TOTAL	7155.7	57.1		

TOTAL ENERGY = 55044.4

TOTAL HORSEPOWER WHICH MUST BE PURCHASED = 236

Table B.2. Allocation of Tractor Energy to Subsets

SET	TRACTOR	HORSEPOWER (hp)	ALLOCATED ENERGY (hp-hr)	TIME	AVAILABLE TRACTOR ENERGY (hp-hr)
1	1	120	11191.94	124.3	11191.94
1	1	116	6025.25	79.1	10814.10
2	1	120	0.00	0.0	7875.00
2	2	116	1443.89	16.5	7612.50
3	1	120	10120.94	112.4	10120.94
3	2	116	9739.54	111.9	9778.80
5	1	120	5142.05	57.1	5141.90
5	2	116	2013.70	23.1	4967.70

Table B.3. Tractor and Machine Schedule

SUBSET	TRACTOR HORSEPOWER	OPERATION	ENERGY	ACRES	TIME	FIELD CAPACITY	MINIMUM WIDTH	MAXIMUM WIDTH
1	120	Plow	9240.0	349.9	102.6	3.4	8.0	10.6
1	120	Disk	1951.9	319.3	21.6	14.7	23.0	30.0
1	116	Disk	1256.7	205.6	14.4	14.2	22.0	30.0
1	116	Harrow	1925.1	525.0	22.1	23.7	30.0	30.0
1	116	Plant	2843.3	525.0	32.1	16.0	30.0	30.0
2	116	Cultivate	1443.8	525.0	16.5	31.6	20.0	20.0
3	120	Chop	10120.9	160.1	112.4	1.4	5.0	5.0
3	116	Chop	9739.5	154.0	111.9	1.3	5.0	5.0
5	120	Stalk Chop	2535.7	211.3	28.1	7.5	13.0	15.0
5	120	Plow	2606.2	98.7	28.9	3.4	8.0	10.6
5	116	Plow	2013.7	76.2	28.1	3.2	8.0	10.6

Table B.4. Annual Machine Use

Machine	MACHINE NUMBER	ACRES	MACHINE TIME (hrs)	MACHINE ENERGY (hp-hr)	MACHINE SIZE RANGE SMALL (ft)	LARGE (ft)
Plow	1.0	524.9	154.7	13859.9	8.0	10.6
Disk	1.0	525.0	36.1	3208.6	23.0	30.0
Harrow	1.0	525.0	22.1	1925.1	30.0	30.0
Plant	1.0	524.9	32.6	2843.3	30.0	30.0
Cultivate	1.0	525.0	16.5	1443.8	20.0	20.0
Chop Silage	1.0	160.1	112.4	10120.9	5.0	5.0
Chop Silage	2.0	154.0	111.9	9739.5	5.0	5.0
Chop Stalks	1.0	211.3	28.1	2535.7	13.0	15.0

Table B.5. Summary of Farm Machinery Costs

MACHINE	WIDTH	INITIAL COST ($)	SERV LIFE (yr)	ANNUAL DEPREC ($/yr)	ANNUAL INTER ($/yr)	ANNUAL SHELTER ($/yr)	ANNUAL TAX ($/yr)	ANNUAL INS ($/yr)	ANNUAL REP ($/yr)	ANNUAL TOT COST ($/yr)
Plow	8.0	1614.39	9.6	166.57	60.53	32.28	0.00	12.91	199.89	472.20
Disk	23.0	2354.93	20.0	117.74	88.31	47.09	0.00	18.83	141.29	413.29
Harrow	30.0	1280.87	20.0	64.04	48.03	25.61	0.00	10.24	76.85	224.79
Plant	30.0	2305.25	20.0	115.26	86.44	46.10	0.00	18.44	115.26	381.52
Cultivate	20.0	1558.07	20.0	77.90	58.62	31.16	0.00	12.46	77.90	257.86
Chop Silage	5.0	2880.00	13.3	215.91	107.99	57.59	0.00	23.04	172.73	577.28
Chop Silage	5.0	2880.00	13.3	214.94	107.99	57.59	0.00	23.04	171.95	575.53
Chop Stalks	13.0	1532.93	20.0	76.64	57.48	30.65	0.00	12.26	61.31	238.37
TOTALS		16406.48		1049.03	615.24	328.12	0.00	131.25	1017.20	3140.86

Table B.6. Energy Costs for the Field Machinery System

Capital outlay for the system	51647.99	dollars
Annual depreciation	2811.10	$/year
Annual interest on machinery	1936.79	$/year
Annual shelter cost totals	1032.95	$/year
Annual tax charge totals	0.00	$/year
Annual insurance charge totals	407.95	$/year
Annual repair charges total	3131.69	$/year
Annual operating costs total	9320.52	$/year
Labor use by the system totals	778.65	hrs/year
Fossil fuel consumption totals	5304.44	gal/year
Energy input to the soil totals	55044.48	hp-hr/year

Table B.7 Parameters for Feedlot Design

Feedlot Type	4
Feedlot Capacity	500
Finished Weight	1150.
Shelter/100 lbs	2.0
Lot Area/100 lbs.	0.0
Bunk (in/hd)	9.0
Waterers (hd per)	75
Head per Pen	150
Extra Gates	2
Apron Width	0.0

Table B.8. Report of Feeding Component Selection

COMPONENT	DIMENSIONS	UNIT COST	TOTAL COST
Shelter Area	375.0 x 30.6	1.60	18400.00
Lot Area	375.0 x 0.0	0.01	0.00
Feed Bunk	375.00	7.5	2812.50
Fence	597.00	2.00	1194.00
Waterers	7	300.00	2100.00
Gates	6	65.00	390.00
Concrete	0.00	0.65	0.00

Table B.9. Report on the Feed Storage System for a Beef Feedlot

Feedlot Capacity	500
Annual Feedlot Volume	1072.1
Average Pounds Corn/Head/Day	8.20
Average Pounds Silage/Head/Day	47.70
Feed Storage System Type	2

Moist Corn Storage System

Total Bushels Stored Per Year	22137.57
Sealed Tower Silo Diameter	23
Number of Units	1

Silo	Height	Cost
1.	80.	24931.43

Total Cost	24931.43
Cost of Corn Unloaders	3680.00
Horsepower of Corn Unloaders	5.00
Corn Storage System Cost	28611.43

Corn Silage Storage in Bunker Silo

Total Tons Stored	4787.88
Bunker Silo Depth	14.0
Bunker Silo Width	90.0
Bunker Silo Length	189.9
Cost of Bunker Silo	21754.48
Silage Storage Cost	21754.48

Table B.10. Acreage Determination

Corn Bushels Stored	22137.5
Silage Tons Stored	4787.8
Corn Yield Per Acre	110.0
Silage Yield Per Acre	16.0
Corn Acres Grown	211.3
Silage Acres Grown	314.2
Total Crop Acres	525.5
Average Haul Distance	3362.6

Table B.11. Report on Feeding and Waste Handling

Waste System Type	1
Quantity of Liquid Waste (lb)	5985000.80
Quantity of Solid Waste (lb)	0.00
Liquid Tank	
Tank Depth (ft)	8.58
Tank Width (ft)	30.00
Tank Length (ft)	375.00
Tank Cost	$56584.10
Number of Loads	599
Number of Liquid Spreaders	4
Number of Solid Spreaders	0
Cost of Spreaders	$9200.00
Total Hours of Labor Per Year	295.76
Number of Pumps	1
Pump Cost	$2000.00
Number of Loaders	0
Cost of Loader	0.00
Time Breakdown Per Load (hr)	
Loading	0.03
Loaded Travel	0.17
Unloading Time	0.10
Return Travel	0.10
Total Time Per Load	0.14
Report on Feeding Time	
Feed Storage System	2
Corn Unloading Time (hr)	0.30
Silage Unloading Time (hr)	0.79
Total Unloading Time (hr)	1.09
Daily Loads of Feed	3.99
Feeding Time (hr)	0.07
Travel Time (hr)	0.23
Total Daily Feeding Time (hr)	2.71
Feed Wagon Cost	$1960.00
Total Annual Feeding Time (hr)	992.55

Table B.12. Report of Fossil Energy Consumption in a Farmstead

Total Tons of Silage	4787.8
Total Bushels of Corn	22137.5
Total Silage Acres	314.2
Total Corn Acres	211.3
Average Length of Haul	3382.6
Quantity of Solid Waste	0.0
Quantity of Liquid Waste	5985000.8

Breakdown of Fossil Energy Consumption in Horsepower Hours

Silage Transport	5655.6
Corn Transport	852.2
Unloading Forage Wagons	239.3
Blow Corn Into Silo	1795.7
Blow Silage into Silos	0.0
Pack Silage in Bunker Silo	1915.1
Unload Bunker Silo	957.5
Load Solid Waste	0.0
Unload Solid Waste	0.0
Transport Solid Waste	0.0
Load Liquid Waste	598.4
Transport Liquid Waste	3772.9
Unload Liquid Waste	149.6
Fence Line Feeding	625.8
Total Fossil Energy	16562.7

Table B.13. Electrical Energy Use

Daily Gallons Water	5937.50
Pumping Energy	4334.37
Night Light Watts	400.00
Lighting Energy	960.00
Corn Unloading Energy	1870.62
Corn Grinding Energy	3741.24
Silage Unloading Energy	0.00
Total Electrical Energy	10906.25

Table B.14. Silage and Corn Transport and Feedlot Tractor Size

SILAGE	
Silage Load (lb)	14000.00
Empty Wagon Weight (lb)	2680.00
Average Distance Hauled (ft)	3382.60
Loaded Speed (ft/hr)	14244.60
Transport Tractor Horsepower	40.00
Breakdown of Transport Time Per Load (hr)	
Time to Haul Load	0.23
Unloading Time	0.17
Return Time	0.10
Hitching Time	0.08
Total Time Per Load (hr)	0.60
Wagons Needed	6
Transport Labor (hr)	529.10
Packing Labor Time (hr)	112.40
Total Silage Labor (hr)	641.60
Total Cost of Wagons	$10350.00
Transport Tractor Cost	$ 4000.00
Packing Tractor Cost	$ 7381.10
Blowers Needed	1
Blower Total Cost	$ 712.00
Blower Tractors Needed	1
Blower Tractor Horsepower	0.00
Blower Tractor Cost	0.00
Total Cost	$21731.10
CORN	
Corn Load (lb)	9000.00
Empty Wagon Weight (lb)	1500.00
Loaded Speed (ft/hr)	22628.57
Breakdown of Transport Time Per Load (hr)	
Time to Haul Load	0.14
Unloading Time	0.07
Return Time	0.10
Hitching Time	0.08
Total Time Per Load	0.41
Wagons Needed	1
Transport Labor (hr)	172.80
Total Cost of Wagons	$ 900.00

Table B.15. (cont'd.)

Y(0,7) = 17,337.151 lb/yr		
Y(2,7) = 6,102.68 lb/yr		
Y(1,7) = 11,234.47 lb/yr		
Y(0,8) = 69,348.602 lb/yr		
Y(2,8) = 45,770.08 lb/yr		
Y(1,8) = 23,578.52 lb/yr		
Y(0,N) = 26,761.07 lb/yr	1204.25	0.045/lb
Y(0,P) = 10,712.72 lb/yr	2206.82	0.206/lb
Y(0,K) = 26,370.40 lb/yr	1582.22	0.060/lb

(1) Unit for herbicide is the yearly application per acre = 2 quarts Lasso, 1.5 pounds Atrazine, and 2.5 pounds Sevin, an insecticide.

(2) Units for ration are the total ration consumed by one animal in one cycle through the feedlot.

Table B.16. **Energy Costs for a Complete System**

	PER YR	PER HD
TOTALS FOR RATION		
Cost for Input Materials	$ 20929.80	$ 19.52
Cost for Electric Power	0.00	0.00
Cost for Fossil Fuels	1210.97	1.12
Cost for Labor	4536.74	4.23
Taxes on Labor	585.57	0.54
Taxes on Capital	866.24	0.80
Insurance	407.95	0.38
Depreciation	2811.10	2.62
Interest on Capital	26367.03	24.59
Repairs	4164.65	3.88
Total Yearly Cost	$ 61080.09	$ 57.71
TOTALS FOR FEEDLOT		
Cost for Input Materials	$ 407660.47	$ 380.21
Cost for Electric Power	249.38	0.23
Cost for Fossil Fuels	364.38	0.33
Cost for Labor	9701.19	9.04
Taxes on Labor	1252.17	1.16
Taxes on Capital	377.02	0.35
Insurance	336.98	0.31
Depreciation	11232.91	10.47
Interest on Capital	28943.44	26.99
Repairs	5054.80	4.71
Total Yearly Cost	$ 465172.47	$ 433.85
TOTALS FOR OPERATION		
Cost for input Materials	$ 366710.17	$ 342.02
Cost for Electric Power	249.38	0.25
Cost for Fossil Fuels	1575.35	1.46
Cost for Labor	14237.94	13.27
Taxes on Labor	1837.75	1.71
Taxes on Capital	1243.27	1.15
Insurance	744.94	0.69
Depreciation	14044.01	13.09
Interest on Capital	55310.48	51.58
Repairs	9219.46	8.59
Total Yearly Cost	$ 465172.47	$ 433.85
CAPITAL INVESTMENT		
For the Feedlot	$ 168493.66	
For Growing Feed	51647.99	
For Land	288750.10	
Initial Short Term Investment	232586.23	
TOTAL	$ 741477.91	

APPENDIX C

Table C.1. Constant Values Used in the Program

VARIABLE	VALUE	DEFINITION	REFERENCE
RR	0.25	Coefficient of rolling resistance (decimal	1
MXSPD	31680.	Maximum allowable transport speed (ft/hr)	*
SWLD	9000.	Solid waste spreader load (lbs)	13,31
SLCAP	60000.	Solid waste loading capacity (lbs/hr)	*
SWEMP	1489.	Solid spreader empty weight (lbs)	13,31
SLOAD	14000.	Silage wagon capacity (lbs)	13
SEMPT	2680.	Silage wagon empty weight (lbs)	13
CLOAD	9000.	Corn wagon capacity (lbs)	37
CEMPT	1500.	Corn wagon empty weight (lbs)	*
FLD	7000.	Feed wagon capacity (lbs)	13
FEMPT	2630.	Feed wagon empty weight (lbs)	13
TSMAX	30.	Tower silo maximum diameter (ft)	32,34,37
TSMIN	12.	Tower silo minimum diameter (ft)	33,34,37
TSINC	2.	Tower silo diameter increment (ft)	32.34,37
MTINC	5.	Tower silo height increment (ft)	34,37
HMAX	14.	Bunker silo maximum depth (ft)	34, 8,37
HMIN	10.	Bunker silo minimum depth (ft)	34, 8,37
HINC	1.	Bunker silo depth increment (ft)	*
MRR	2.	Minimum tower silo removal rate (in/day)	32,34
TSRR	3.	Minimum bunker silo removal rate (in/day)	32,34
BSDEN	40.	Bunker silo density (lbs/cubic ft)	34
TSDEN	50.	Tower silo density (lbs/cubic ft)	34
TWAST	0.05	Tower silo loss rate (decimal)	19
BWAST	0.10	Bunker silo loss rate (decimal)	19
CSINC	5.	Corn storage weight increment (ft)	5,38
CWPB	67.6	Corn weight per bushel (lbs/bu)	5,37
CVPB	1.44	Corn volume per bushel (cubic ft/bu)	5,37
LCOST	1200.	Front end loader cost ($ ea)	13
CUCAP	200.	Corn storage unloader capacity (bu/hr)	37
LSLOT	10.	Slotted floor unit length (ft)	8

Table C.1. (cont'd.)

LWLD	10000.	Liquid spreader load (lbs	31
LWEMP	2380.	Liquid spreader empty weight (lbs)	31
LLCAP	600000.	Liquid waste loading capacity (lbs/hr)	8
SPTIM	7.	Length of spreading season (days)	*
FRAC	.15	Part of defected waste left as solid (decimal)	10,29
TTHP	40.	Transport tractor size (db hp)	*
GPCWT	1.25	Daily water requirement (gal/100 lbs)	32
LPA	400.	Lighting requirement (wats/acre)	32
TTCST	1000.	Transport tractor cost ($ ea used)	31
MXULR	100.	Maximum silage wagon unloading rate (tons/hr)	13
BCOST	712.	Silage blower cost ($ ea)	13,31
WCOST	1725.	Silage wagon cost ($ ea)	13
CWCST	900.	Corn wagon cost ($ ea)	37
PKRAT	120.	Bunker silo packing rate (ton/hr)	*
SLOSS	0.05	Silage harvest and transport loss (decimal)	*
CLOSS	0.05	Corn harvest and transport loss (decimal)	*
HTIM	0.0833	Wagon hitching time (hr)	*
PLDEP	8.	Flowing depth (in)	1, 3
RWWD	2.5	Row spacing (ft)	3
IRATE	0.075	Interest rate (decimal)	5
HCR	0.02	Housing cost rate (decimal)	1
TAXR	p.0	Tax rate on field machinery (decimal)	5
INSR	0.008	Insurance rate (decimal)	5
DWAG	1960.	Feed wagon cost ($ ea)	13
IWAT	75.	Waterer capacity (hd/waterer)	36
PENHD	150.	Maximum animals per pen (hd/pen)	26
INHD	9.	Feedbunk requirement (in/hd)	8,26
TA	130.	Turn around travel (ft)	*
SPED	3.	Travel speed with feed wagon (mph)	*
ROWS	2.	Row crop machine size unit (rows)	*
UCLSP	2300.	Liquid waste spreader cost ($ ea)	31
UCPMP	2000.	Liquid manure pump cost ($ ea)	8
UCSSP	1244.	Solid waste spreader cost ($ ea)	13,31

Table C.1 (cont'd.)

UCSLT	2.	Slotted floor cost ($/sq ft)	8
UCSDW	2.	Bunker silo wall cost ($/sq ft)	8
UCCON	0.65	Concrete floor cost ($/sq ft)	8
UCSHL	1.6	Shelter cost ($/sq ft)	26
UCLOT	0.01	Open lot land leveling cost ($/sq ft)	26
UCBNK	7.5	Feedbunk cost ($/ft)	26
UCWAT	300.	Waterer cost ($ ea)	26,37
USFNC	2.	Fence cost ($/ft)	26
UCGAT	65.	Gate cost ($ ea)	26
EGYLD	0.2	Front end loader energy (hp-hr/ton)	6
EGYUL	0.05	Wagon unloading energy (hp-hr/ton)	*
EGYPK	0.35	Bunker silo packing energy (hp-hr/ton)	*
EGYUS	0.05	Solid waste unloading energy (hp-hr/ton)	*
EGYLU	0.05	Liquid waste unloading energy (hp-hr/ton)	*
EGYIL	0.20	Liquid waste loading energy (hp-hr/ton)	*
EGWAT	2.	Water pumping energy (kw-hr/1000 gal)	32
EGLIT	240.	Lighting energy (kw-hr/1000 wats)	32
EGUCS	2.5	Silo unloading energy (kw-hr/ton)	32
EGGR	5.	Corn grinding energy (kw-hr/ton)	32
HOUR	10.00	Nominal work schedule (hr/day)	*
SCED	0.85	Scheduling efficienty (decimal)	*
MFAC	.75	Portion of tractor horsepower to be used (decimal)	6,40
BSHL	110.	Corn yield (bu/hr)	5
YLD	16.	Silage yield (tons)	5

* Value is unavailable in literature or is a "management decision".

Table C.2. Feedlot Area Requirements

FEEDLOT TYPE	01	02	03	04
CLOT[1]	15.0	3.0	20.0	0.0
CSHEL[2]	2.0	2.0	0.0	2.5[5]
EGATE[3]	3	3	2	2
WAPR[4]	10.0	0.0	10.0	0.0

1. CLOT is shelter area required (ft^2/100 lbs of final body weight).
2, CSHEL is lot area required (ft^2/100 lbs of final body weight.
3. Gates needed in excess of one per pen.
4. Width of concrete aprons beside feed bunk.
5. CSHEL = 2.0 if slotted floor is used.

Table C.3. Relationship Between Animal Type, Housing System and Ration

	CALVES			YEARLINGS		
	Feedlot Type			Feedlot Type		
	Open Lot	Partial Shelter	Complete Shelter	Open Lot	Partial Shelter	Complete Shelter
Initial Weight	450	450	450	750	750	750
Final Weight	1050	1050	1050	1150	1150	1150
Ration 01						
Daily Corn (lbs)	-----	-----	-----	-----	-----	-----
Daily Silage (lbs)	45.23	44.06	44.06	65.10	63.70	63.70
Average Daily Gain (lbs/day)	1.55	1.75	1.80	1.85	2.00	2.05
Ration 02						
Daily Corn (lbs)	6.40	6.40	6.40	8.20	8.20	8.20
Daily Silage (lbs)	32.80	31.60	31.60	49.10	47.70	47.70
Average Daily Gain (lbs/day)	1.80	2.00	2.05	2.15	2.30	2.35

Table C.4. Assumed Field Machine Data

OPERATION	SIZE RANGE Small	SIZE RANGE Large	SPEED RANGE Slow (mph)	SPEED RANGE Fast (mph)	LIFETIME REPAIRS (% 1st cost)	FIELD EFFICIENCY ($)	UNIT ENERGY	MACHINE LIFE (hours)
Flow	2*	8	2.5	4.5	120	0.80	10 lbs/in^2	1500
Disk	6**	30	3.0	6.0	120	0.90	250 lbs/ft	2000
Harrow	8**	30	3.5	6.0	120	0.90	150 lbs/ft	2500
Plant	2***	12	3.0	6.0	100	0.65	400 lbs/row	1200
Cultivate	2***	8	1.0	5.7	100	0.80	250 lbs/row	2000
Chop Silage	2***	2	0.5	4.5	80	0.67	1.5 hp-hr/ton	1500
Shell Corn	2***	8	1.0	4.0	120	0.67	****	1200
Chop Stalks	3**	15	1.0	6.0	80	0.83	3.0 hp-hr/ft/mph	1500

* Plow sizes are given in number of 16 inch bottom

** Tillage tool widths are given in feet

*** Row machines have width specified in number of rows

**** Unit draft of combine includes factors for yield and weight of machine as shown below, where RR is the coefficient of rolling resistance.

0.13 hp-hr/bu+(61.6)(RR)

Table C.5. Percent Useable Work Days for Subsets

SUBSET NUMBER	BEGINNING DATE	ENDING DATE	PERCENT USEABLE DAYS
1	04/17	05/30	0.385
2	06/05	06/24	9.606
3	09/01	09/24	0.630
4	09/25	10/24	0.665*
5	10/25	12/14	0.159

* Percentage holds only for harvesting operation.

Table C.6. Functions for Determining First Cost of Field Machinery and Tower Silos for Corn and Silage

MACHINE	INITIAL COST	LIMITS	
Moldboard Plow	FC*= (144.5-0.55(WIDTH**/1.33))(WIDTH/1.33)	WIDTH	5.4
	FC = (304.23-1.00(WIDTH/1.33))(WIDTH/1.33)	WIDTH	5.4
Disk Harrow	FC = (93.73-2.5(WIDTH))(WIDTH)	WIDTH	11.0
	FC = (87.66+1.135(WIDTH))(WIDTH)	WIDTH	11.0
Springtooth Harrow	FC = (18.34+.97(WIDTH))(WIDTH)		
Planter	FC = (221.25-.65(WIDTH/25))(WIDTH/2.5)		
Cultivate	FC = (243.36-3.37(WIDTH?2.5))(WIDTH/2.5)		
Field Chopper	FC = 3200.00		
Stalk Chopper	FC = (111.13+1.53(WIDTH))(WIDTH)		
Corn Combine	FC = 13439	WIDTH =	7.5
	FC = 16852	WIDTH =	10.0
	FC = 21089	WIDTH =	15.0
	FC = 26592	WIDTH =	20.0
Tractor	FC = (145.094-.306(DBHP***)(DBHP)	30 DBHP	120
Moist Corn Storage	FC = VOL# (0.92614118-0.000005288(VOL))		
Tower Silos	FC = 51.73435487+DIAM## (0.01198467(DIAM)-1.31521494) +HT### (0.00238741(HT)-0.51004589) +0.00719841(DIAM)(HT)		

* First cost or purchase price ($)
** Machine width (ft)
*** Tractor size (DBHP)

\# Moist corn storage volume (cu ft)
\## Tower silo diameter (ft)
\### Tower silo height (ft)

Table C.7. Input Material Requirements and Costs

Input Flow	Material	Requirements	Cost ($)
21	Nitrogen	1.113 lb/bu	.045/lb
31	Phosphorus	.300 lb/bu	.206/lb
41	Potash	.727 lb/bu	.060/lb
51	Seed Corn	.0022 lb/bu	14.000/bu
61	Chemicals	.009 (1)/bu	6.550/(1)
71	Water	--------	------
22	Nitrogen	10.00 lb/ton	.045/lb
32	Phosphorus	2.125 lb/ton	.206/lb
42	Potash	10.00 lb/ton	.060/lb
52	Seed Corn	.0152 bu/ton	14.000/bu
62	Chemicals	.0625 (1)/ton	6.550/(1)
72	Water	--------	------
82	Supplement	170.2128 lb/(2)	------
64	Water	--------	------
74	Feeders	(3)	(4)

(1) Unit of chemicals is 2 qts. LASSO, 1.5 lb. ATRAZINE and 2.5 lbs. of SEVIN.

(2) Ration consumed by one animal in a cycle through the feedlot

(3) Depends on animal type and amount of weight to be gained (see Table C.3)

(4) Calves cost $49.00 per cwt.
Yearlings cost $43.00 per cwt.

Table D.1. Selected Results from the Analysis of Nine Systems

Technology Number	Capacity (head)	Volume (head/yr)	Max Power (db hp)	System Capital ($)	Land (acres)	Electrical Power (kw hr/yr)	Fossil Fuel (gal/yr)	Labor (hr/yr)	Annual Cost ($/yr)	Farmstead Capital ($)	Farmstead Machinery Capital ($)	Transport Capital ($)	Transport Fossil Fuel (gal/yr)	Transport Labor (hr/yr)	Weight Gain (cwt)
116	100	209.	120.	174464.28	105.	2949.24	1274.09	2335.47	101339.99	20885.45	19761.15	6594.00	68.0	311.2	839.
116	200	419.	120.	301937.07	210.	4938.50	2618.11	2546.95	187624.34	36696.59	21650.15	6594.00	188.0	323.4	1679.
116	300	629.	120.	433103.11	315.	6927.74	3986.98	3294.76	276251.65	52069.24	27051.15	11044.00	341.8	469.1	2518.
116	400	839.	120.	555293.60	420.	8917.00	5419.11	3676.09	362145.19	68307.10	27381.15	11044.00	523.1	482.5	3358.
116	500	1049.	120.	678361.06	525.	10906.25	6881.58	4292.29	448782.23	83080.73	30491.15	13769.00	728.0	629.3	4197.
116	600	1259.	120.	811665.51	630.	12895.49	8392.07	5244.51	538267.08	98885.25	35636.15	18219.00	953.9	777.0	5037.
116	700	1469.	120.	943648.62	735.	14884.74	9876.88	6195.69	627313.38	118596.29	41219.15	22188.00	1199.2	925.4	5876.
116	800	1679.	120.	1075219.39	840.	16874.00	11325.61	7308.12	717002.95	134351.87	46029.15	23913.00	1462.2	942.4	6716.
116	900	1888.	120.	1205088.50	945.	18863.25	12878.52	8507.15	806585.57	150792.81	49449.15	26638.00	1741.9	1092.4	7555.
116	1000	2098.	120.	1331613.47	1051.	20852.50	14460.79	10137.29	896821.54	164981.47	53394.15	30263.00	2037.4	1415.9	8395.
117	100	209.	120.	174892.56	105.	2949.24	1274.09	2335.47	101409.51	21278.95	19761.15	6594.00	68.0	311.2	839.
117	200	419.	120.	303194.07	210.	4938.50	2618.11	2546.95	187828.40	37851.59	21650.15	6594.00	188.0	323.4	1679.
117	300	629.	120.	435188.84	315.	6927.74	3986.98	3294.76	276590.23	53985.74	27051.15	11044.00	341.8	469.1	2518.
117	400	839.	120.	558608.50	420.	8917.00	5419.11	3676.09	362683.27	71353.10	27381.15	11044.00	523.1	482.5	3358.
117	500	1049.	120.	682504.81	525.	10906.25	6881.58	4292.29	449454.92	86888.23	30491.15	13769.00	728.0	629.3	4197.
117	600	1259.	120.	816638.23	630.	12895.49	8392.07	5244.51	539074.14	103454.25	35636.15	18219.00	953.9	777.0	5037.
117	700	1469.	120.	949850.70	735.	14884.74	9876.88	6195.69	628320.25	124294.80	41219.15	22188.00	1199.2	925.4	5876.
117	800	1679.	120.	1082249.82	840.	16874.00	11325.61	7308.12	718144.12	140811.87	46029.15	23913.00	1462.2	942.4	6716.
117	900	1888.	120.	1212947.90	945.	18863.25	12878.52	8507.15	807861.41	158014.29	49449.15	26638.00	1741.9	1092.4	7555.
117	1000	2098.	120.	1340701.98	1051.	20852.50	14460.79	10137.29	898296.69	173332.47	53394.15	30263.00	2037.4	1415.9	8395.
118	100	196.	120.	167456.50	106.	2949.24	1294.42	2340.58	96090.31	15828.45	19696.15	6594.00	70.1	312.3	784.
118	200	392.	120.	288273.00	213.	4938.50	2665.29	2558.31	177133.79	26291.79	21585.15	6594.00	194.0	324.5	1569.
118	300	588.	120.	412966.04	320.	6927.74	4062.23	3309.17	260533.07	36578.01	26986.15	11044.00	352.9	469.2	2354.
118	400	784.	120.	528227.02	427.	8917.00	5523.43	3704.34	341167.43	47488.56	27316.15	11044.00	540.0	482.7	3139.
118	500	980.	120.	653173.41	534.	10906.25	7015.85	4563.24	424854.86	57026.90	32151.15	15494.00	751.5	629.6	3923.
118	600	1177.	120.	771546.95	641.	12895.49	8557.10	5321.23	506962.64	67596.11	35571.15	18219.00	984.8	777.3	4708.
118	700	1373.	120.	896616.81	748.	14884.74	10073.41	6289.31	590747.08	81979.90	41154.15	22188.00	1238.0	925.9	5493.
118	800	1569.	120.	1024770.51	855.	16874.00	11554.33	7609.12	676304.50	92500.11	48689.15	26638.00	1509.6	1075.2	6278.
118	900	1765.	120.	1148333.35	962.	18863.25	13140.09	8854.98	760843.46	103705.79	52109.15	29363.00	1798.4	1225.3	7062.
118	1000	1961.	120.	1272953.69	1069.	20852.50	14751.12	10575.19	847164.34	112567.13	55054.15	31988.00	2103.5	1416.6	7847.
119	100	214.	120.	174479.96	105.	2949.24	1274.09	2335.47	102748.77	20261.70	19696.15	6594.00	68.0	311.2	857.
119	200	428.	120.	302556.34	210.	4938.50	2618.11	2546.95	190537.16	35924.42	21585.15	6594.00	188.0	323.4	1715.
119	300	643.	120.	434325.92	315.	6927.74	3986.98	3294.76	280668.53	51148.66	26986.15	11044.00	341.8	469.1	2573.
119	400	857.	120.	557603.90	420.	8917.00	5419.11	3676.09	368144.56	67682.77	27316.15	11044.00	523.1	482.5	3431.
119	500	1072.	120.	681275.08	525.	10906.25	6881.58	4292.29	456285.79	82307.99	30426.15	13769.00	728.0	629.3	4288.
119	600	1286.	120.	815183.24	630.	12895.49	8392.07	5244.51	547274.58	97964.07	35571.15	18219.00	953.9	777.0	5146.
119	700	1501.	120.	948253.98	735.	14884.74	9876.88	6195.69	637903.74	117971.40	41154.15	22188.00	1199.2	925.4	6004.
119	800	1715.	120.	1080427.83	840.	16874.00	11325.61	7308.12	729097.06	133578.51	45964.15	23913.00	1462.2	942.4	6862.
119	900	1929.	120.	1210901.16	945.	18863.25	12878.52	8507.15	820183.93	149871.08	49384.15	26638.00	1741.9	1092.4	7719.
119	1000	2144.	120.	1338513.38	1051.	20852.50	14460.79	10137.29	912002.26	164355.99	53329.15	30263.00	2037.4	1415.9	8577.

Table D.1. (cont'd.)

95	100	187.	120.	135668.40	83.	1826.87	1075.29	1791.77	87053.81	15247.27	15830.15	5694.00	71.2	140.3	748.
95	200	374.	120.	246240.81	167.	2693.75	2213.83	2261.97	165662.33	26319.80	17920.15	7419.00	195.9	150.8	1496.
95	300	561.	120.	354907.14	251.	3560.62	3392.28	2750.07	243763.68	39388.03	21310.15	10144.00	355.3	294.7	2244.
95	400	748.	120.	467836.66	335.	4427.50	4603.98	3587.57	323836.15	52379.60	26060.15	14594.00	542.9	439.6	2993.
95	500	935.	120.	575168.12	419.	5294.37	5845.10	4261.57	402170.95	65447.83	29150.15	17319.00	754.6	585.5	3741.
95	600	1122.	120.	686593.38	503.	6161.25	7113.04	5106.64	481951.87	78516.06	31540.15	19044.00	988.1	599.8	4489.
95	700	1309.	120.	796078.99	587.	7028.12	8405.89	6144.87	561762.77	91507.63	35809.15	23013.00	1241.3	747.2	5237.
95	800	1496.	120.	912638.48	671.	7895.00	9722.19	7557.55	644109.60	104575.88	40624.15	27463.00	1512.8	895.3	5986.
95	900	1683.	120.	1023943.17	755.	8761.87	11060.74	9200.71	725924.03	117644.07	46865.20	32913.00	1801.5	1176.3	6734.
95	1000	1870.	120.	1140172.59	839.	9628.75	12420.57	11168.70	809911.17	130635.66	52214.71	37363.00	2106.2	1325.6	7482.
119	125	268.	120.	207817.66	131.	3446.56	1601.39	2394.54	124946.01	24423.09	21160.15	6594.00	94.2	316.0	1072.
119	150	321.	120.	239495.90	157.	3943.87	1924.88	2441.82	146824.53	28005.33	21831.15	6594.00	123.1	318.3	1286.
119	175	375.	120.	268947.84	183.	4441.18	2280.23	2492.27	168379.59	31695.00	20101.15	6594.00	154.4	320.8	1501.
119	225	482.	120.	333036.34	236.	5435.81	2942.42	2610.67	212253.57	39092.14	22151.15	6594.00	223.6	327.4	1929.
119	250	536.	120.	363980.28	262.	5933.12	3288.04	2670.54	234023.77	43511.31	22161.15	6594.00	261.2	330.2	2144.
119	275	589.	120.	403167.49	289.	6430.43	3666.34	3231.64	258885.66	47621.61	25261.15	11044.00	300.6	465.9	2358.
116	125	262.	120.	207530.14	131.	3446.56	1601.39	2394.54	123141.60	24972.78	21225.15	6594.00	94.2	316.0	1049.
116	150	314.	120.	239420.40	157.	3943.87	1924.88	2441.82	144703.02	28925.62	21896.15	6594.00	123.1	318.3	1259.
116	175	367.	120.	268600.44	183.	4441.18	2280.23	2492.27	165862.42	32541.23	20166.15	6594.00	154.4	320.8	1469.
116	225	472.	120.	332145.19	236.	5435.81	2942.42	2610.67	208945.10	39790.25	22216.15	6594.00	223.6	327.4	1888.
116	250	524.	120.	362817.19	262.	5933.12	3288.04	2670.54	230319.62	44135.35	22276.15	6594.00	261.2	330.2	2098.
116	275	577.	120.	401732.59	289.	6430.43	3666.34	3231.64	254785.92	48171.59	25326.15	11044.00	300.6	465.9	2308.
117	225	472.	120.	333709.60	236.	5435.81	2942.42	2610.67	209199.05	41227.62	22216.15	6594.00	223.6	327.4	1888.
117	250	524.	120.	364688.81	262.	5933.12	3288.04	2670.54	230623.43	45855.10	22276.15	6594.00	261.2	330.2	2098.
117	275	577.	120.	403911.55	289.	6430.43	3666.34	3231.64	255139.62	50173.71	25326.15	11044.00	300.6	465.9	2308.
117	125	262.	120.	208265.70	131.	3446.56	1601.39	2394.54	123260.97	25648.66	21225.15	6594.00	94.2	316.0	1049.
117	150	314.	120.	240062.80	157.	3943.87	1924.88	2441.82	144807.30	29515.87	21896.15	6594.00	123.1	318.3	1259.
117	175	367.	120.	269550.23	183.	4441.18	2280.23	2492.27	166016.56	33413.86	20166.15	6594.00	154.4	320.8	1469.
118	125	245.	120.	199127.77	133.	3446.56	1630.66	2392.86	116571.43	18574.88	21160.15	6594.00	97.3	315.4	980.
118	150	294.	120.	229616.03	160.	3943.87	1963.17	2446.22	136854.20	21278.80	21831.15	6594.00	127.1	318.5	1177.
118	175	343.	120.	257401.38	187.	4441.18	2327.64	2501.51	156736.03	23538.97	20101.15	6594.00	159.4	321.5	1373.
118	225	441.	120.	317042.20	240.	5435.81	2998.87	2612.60	197115.30	28061.96	22151.15	6594.00	230.8	326.4	1765.
118	250	490.	120.	355901.92	267.	5933.12	3353.83	3170.85	220536.81	31215.77	26611.15	11044.00	269.6	462.9	1961.
118	275	539.	120.	382782.73	294.	6430.43	3736.82	3233.68	240231.46	33920.18	25261.15	11044.00	310.3	466.0	2158.
103	125	268.	120.	223489.51	131.	3446.56	1658.07	2443.90	127313.05	35855.44	24216.15	7650.00	138.2	353.9	1072.
103	150	321.	120.	257402.99	157.	3943.87	1997.57	2504.22	149531.65	41502.88	24887.15	7650.00	180.6	366.3	1286.
103	175	375.	120.	289108.28	183.	4441.18	2370.05	2568.45	171432.28	47273.08	23157.15	7650.00	226.4	379.4	1501.
103	225	482.	120.	360206.99	236.	5435.81	3069.52	2716.47	216404.53	58831.29	27507.15	9950.00	327.8	408.8	1929.
103	250	536.	120.	393407.93	262.	5933.12	3435.19	2792.11	238527.71	65330.99	27517.15	9950.00	382.9	423.7	2144.
103	275	589.	120.	434853.22	289.	6430.43	3834.39	3369.54	263744.81	71521.82	30617.15	14400.00	440.7	572.0	2358.
55	125	155.	120.	148164.03	93.	2910.46	1115.91	2344.70	65025.26	20368.18	20066.15	6594.00	55.1	313.6	935.
55	150	187.	120.	167142.14	111.	3300.56	1358.41	2372.79	74780.64	23812.52	19711.15	6594.00	71.9	315.0	1122.
55	175	218.	120.	188195.24	130.	3690.65	1587.93	2405.03	84857.73	27139.68	20081.15	6594.00	90.1	316.6	1309.
55	225	280.	120.	227803.46	167.	4470.84	2065.00	2473.01	104638.17	33336.06	20401.15	6594.00	130.3	320.4	1683.
55	250	311.	120.	247695.49	186.	4860.93	2296.08	2519.77	114544.66	36479.25	20771.15	6594.00	152.2	324.1	1870.
55	275	342.	120.	268706.89	205.	5251.03	2541.13	2557.99	124664.83	39731.40	20781.15	6594.00	175.1	326.1	2057.

Table D.1. (cont'd.)

55	100	124.	120.	127493.57	74.	2520.37	891.44	2293.38	54955.14	17424.46	19316.15	6594.00	39.8	308.4	748.
55	200	249.	120.	207915.33	149.	4080.74	1827.68	2438.88	94705.41	30244.68	20091.15	6594.00	109.6	318.4	1496.
55	300	374.	120.	288307.40	223.	5641.12	2783.56	2597.25	134548.28	43027.48	21156.15	6594.00	199.1	328.1	2244.
55	400	498.	120.	375141.60	298.	7201.49	3780.52	3334.64	177361.41	55104.13	25936.15	11044.00	304.3	470.3	2993.
55	500	623.	120.	453891.77	373.	8761.87	4804.69	3562.43	217049.41	67903.38	26331.15	11044.00	423.3	480.7	3741.
55	600	748.	120.	531894.67	447.	10322.25	5786.80	3868.57	256796.85	81703.90	28366.15	11044.00	554.4	491.8	4489.
55	700	872.	120.	611680.75	522.	11882.62	6838.60	4392.59	297536.31	93966.81	31411.15	13769.00	696.6	635.7	5237.
55	800	997.	120.	701216.12	596.	13442.99	7849.95	5044.76	340385.32	110018.26	34795.15	15494.00	849.2	647.3	5986.
55	900	1122.	120.	783631.99	671.	15003.37	8934.73	5717.59	381914.64	122869.66	39459.15	19463.00	1011.4	792.2	6734.
55	1000	1247.	120.	862010.70	746.	16563.75	10021.10	6428.48	422964.09	135546.77	39789.15	19463.00	1182.6	805.2	7482.
103	100	214.	120.	187901.44	105.	2949.24	1315.99	2372.64	104776.17	29613.50	22752.15	7650.00	99.7	339.8	857.
103	200	428.	120.	327471.05	210.	4938.50	2726.08	2637.61	194337.41	53583.03	26941.15	9950.00	275.6	393.2	1715.
103	300	643.	120.	468254.17	315.	6927.74	4176.77	3449.57	285882.14	77114.07	32342.15	14400.00	501.1	588.2	2573.
103	400	857.	120.	603056.75	420.	8917.00	5703.44	3903.05	375163.52	101970.29	34972.15	16700.00	766.7	657.1	3431.
103	500	1072.	120.	738264.31	525.	10906.25	7271.43	4599.37	465163.58	124902.33	40382.15	21725.00	1066.9	865.5	4288.
103	600	1286.	120.	883720.56	630.	12895.49	8897.26	5638.36	558034.89	148865.25	47827.15	28475.00	1398.1	1079.9	5146.
103	700	1501.	120.	1027013.66	735.	14884.74	10506.37	6681.64	650352.50	177194.70	54466.15	33500.00	1757.4	1299.2	6004.
103	800	1715.	120.	1170756.53	840.	16874.00	12087.67	7892.45	743470.10	201108.56	61576.15	37525.00	2142.9	1391.9	6862.
103	900	1929.	120.	1312807.80	945.	18863.25	13780.90	9195.11	836499.77	225707.96	67296.15	42550.00	2552.7	1621.5	7719.
103	1000	2144.	120.	1454522.45	1051.	20852.50	15510.79	10932.99	930678.54	248514.99	75841.16	50775.00	2985.6	2028.0	8577.
115	100	214.	120.	183268.06	102.	5125.56	1390.87	2433.88	104492.62	27184.79	22769.34	9319.00	64.6	445.7	857.
115	200	428.	120.	324425.51	204.	9291.12	2739.71	2692.67	194531.05	52718.74	28543.97	9319.00	178.7	456.5	1715.
115	300	643.	120.	471738.33	306.	13456.68	4172.87	3507.20	287428.53	78165.00	38913.29	13769.00	324.9	601.2	2573.
115	400	857.	120.	605680.12	408.	17622.25	5827.79	3927.20	376694.80	102859.21	42637.13	13769.00	497.2	614.5	3431.
115	500	1072.	120.	740284.59	511.	21787.81	7290.79	4599.78	466720.94	125004.92	49988.03	16494.00	691.9	761.2	4288.
115	600	1286.	120.	892892.47	613.	25953.37	8837.24	5757.55	561299.77	149898.17	65119.93	23669.00	906.7	1041.0	5146.
115	700	1501.	120.	1035389.98	715.	30118.93	10406.27	6607.12	653182.10	177880.22	73019.27	24913.00	1139.7	1057.1	6004.
115	800	1715.	120.	1176098.26	817.	34284.50	12124.16	7676.20	745485.85	202517.57	81764.26	27638.00	1389.7	1206.2	6862.
115	900	1929.	120.	1326924.09	920.	38450.06	13755.19	9137.97	840792.69	227744.40	91789.52	32088.00	1655.6	1356.0	7719.
115	1000	2144.	120.	1463328.75	1022.	42615.62	15241.16	10897.09	934400.62	249749.82	99346.06	35713.00	1936.3	1679.3	8577.
91	100	187.	120.	148780.09	80.	4733.18	1212.02	1928.12	89561.96	24967.92	19936.86	8419.00	66.8	268.6	748.
91	200	374.	120.	278607.24	160.	8506.37	2478.90	2519.48	171675.18	49752.52	28160.78	10144.00	183.6	283.0	1496.
91	300	561.	120.	404248.44	240.	12279.56	3783.20	3131.89	252902.92	74537.11	37354.40	12869.00	332.8	426.7	2244.
91	400	748.	120.	532979.77	320.	16052.74	5118.72	4074.62	335817.63	99245.03	47448.85	17319.00	508.4	571.5	2993.
91	500	935.	120.	660003.77	400.	19825.94	6481.84	4881.24	417729.82	124029.62	59005.99	20044.00	706.7	717.2	3741.
91	600	1122.	120.	788732.47	480.	23599.12	7870.15	6020.30	501161.51	147400.37	69799.82	24494.00	925.2	863.6	4489.
91	700	1309.	120.	914277.91	560.	27372.31	9281.87	7172.91	583907.90	172108.31	79528.04	28463.00	1162.2	1010.8	5237.
91	800	1496.	120.	1047463.93	640.	31145.49	10715.61	8693.69	669317.66	196892.88	89572.70	32913.00	1416.3	1158.6	5986.
91	900	1683.	120.	1178876.21	720.	34918.69	12170.27	10488.42	754852.78	221677.47	104499.22	38363.00	1686.5	1439.4	6734.
91	1000	1870.	120.	1311457.50	801.	38691.88	13649.64	12468.92	841492.53	246385.38	114746.72	42813.00	1971.7	1588.5	7482.

REFERENCES

REFERENCES

1. American Society of Agricultural Engineers, 1971. Agricultural Engineers Yearbook. St. Joseph, Michigan.

2. Asimow, Morris, 1962. Introduction to Design. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

3. Bainer, Roy, R. A. Kepner and E. L. Barger, 1965. Principles of Farm Machinery. John Wiley and Sons, Inc., New York.

4. Black, J. R. and H. D. Ritchie, 1973. Average Daily Grain and Daily Dry Matter Intake of Various Kinds of Cattle Fed Three Different Rations Under Several Environmental Situations. Staff paper 1973-1, Agricultural Economics Department, Michigan State University, East Lansing, Michigan.

5. Black, J. R., 1973. Assistant Professor of Agricultural Economics, Michigan State University, East Lansing, Michigan. Personal communication.

6. Bowers, Wendell, 1970. Modern Concepts of Farm Machinery Management. Stipes Publishing Co., Champaign, Illinois.

7. Boyd, J. S., 1970. Alternatives for Handling Manure. AEIS No. 257, Agricultural Engineering Department, Michigan State University, East Lansing, Michigan

8. Boyd, J. S., 1973. Professor of Agricultural Engineering, Agricultural Engineering Department, Michigan State University, East Lansing, Michigan. Personal communication.

9. Bureau of the Census, 1972. Census of Agriculture, 1969. Department of Commerce, Washington, D. C.

10. Butchbaker, A. F. et al., 1971. Evaluation of Beef Cattle Waste Management Alternatives. 13040 FXG 11/71, U. S. Environmental Protection Agency, Washington, D. C.

11. Canada Waste Management Guide Committee, 1972. Canada Animal Waste Management Guide. Canada Committee on Agricultural Engineering, Ottawa, Ontario, Canada.

12. Connor, L. J., et al., 1972. Beef Feedlot Design and Management. Article in Volume II of Design and Management of Environmental Systems, Michigan State University, East Lansing, Michigan.

13. Deere and Co., 1971. Whole Goods Price List. Moline, Illinois.

14. Doane Agricultural Service, Inc., 1967. Doane's Agricultural Report, Reference Volume. St. Louis, Missouri.

15. Henderson, H. E., 1967. Some Factors Affecting Rate and Efficiency of Gains in Feedlot Cattle. AH-BC-22, Michigan State University, East Lansing, Michigan.

16. Henderson, H. E., et al., 1973. Michigan's Livestock Industry of 1985. Farm Science Research Report 184, Michigan State University, East Lansing, Michigan.

17. Henderson, H. E., H. D. Ritchie and T. R. Greathouse, 1970. The Michigan Beef Cattle Industry. Publication AH-30-21, Michigan State University, East Lansing, Michigan.

18. Henderson, H. E. and T. R. Greathouse, 1969. Corn Silage for Feedlot Cattle. AH-BC-42, Michigan State University, East Lansing, Michigan.

19. Hildebrand, S. C., et al., 1971. Corn Silage. Extension Bulletin E-665, Farm Science Series, Michigan State University, East Lansing, Michigan.

20. Hillier, F. S. and G. S. Lieberman, 1968. Introduction to Operations Research. Holden Day, Inc., San Francisco, California.

21. Hoglund, C. R., 1971. Economics of Grain Silage Systems. Paper presented to Ontario Silage Conference, Rexdale, Ontario, Canada.

22. Holtman, J. B., et al., 1972. Graph Theory Applied to Systems Analysis Problems. American Society of Agricultural Engineers Paper No. 72-501, St. Joseph, Michigan.

23. Hughes, H. A., et al., 1973. A Method for Determining the Proper Power Output for Multiple Tractor Management. Paper prepared for presentation at ISAE and CIGR Conference, Warsaw, Poland.

24. Koenig, H. E. and R. L. Tummala, 1972. Principles of Ecosystem Design and Management. IEEE Transactions on Systems, Man and Cybernetics, SMC-2, pp. 449-459.

25. Koenig, H.E., W. E. Cooper and J. M. Falvey, 1971. Engineering for Ecological, Sociological and Economic Compatability. IEEE Transactions on Systems, Man and Cybernetics, SMC-2, pp. 319-331.

26. Maddex, R. L., 1971. Feedlots - Types and Construction Costs. AEIS No. 263, Agricultural Engineering Department, Michigan State University, East Lansing, Michigan.

27. Maddex, R. L., 1965. Handling Farm Materials for a Beef Feeding Enterprise. AEIS No. 18, Agricultural Engineering Department, Michigan State University, East Lansing, Michigan.

28. Maddex, R. L., 1965. Liquid Manure Systems. AEIS No. 150, Department of Agricultural Engineering, Michigan State University, East Lansing, Michigan.

29. Miner, J. R., 1971. Farm Animal-Waste Management. North Central Regional Publication 206, Iowa State University of Science and Technology, Ames, Iowa.

30. Mowat, D. N., et al., 1967. Corn Silages. Publication 92, Ontario Department of Agriculture and Food, Toronto, Ontario, Canada.

31. National Farm and Power Equipment Dealers Association, 1972. Official Guide to Tractors and Farm Equipment. St. Louis, Missouri.

32. Ontario Department of Agriculture and Food, 1967. Farm Business Management. Farm Economics, Co-operatives and Statistics Branch, Toronto, Ontario, Canada.

33. Rutledge, P. L. and F. V. Mc Hardy, 1968. The Influence of the Weather on Field Tractability in Alberta. Canadian Journal of Agricultural Engineering, 10:70-73, Ottawa, Ontario, Canada

34. Shook, G. E., et al., 1972. Determine Silo Size. Teleplan Program 38, University of Wisconsin, Madison, Wisconsin.

35. Steele, R. G. D. and J. H. Torrie, 1962. Principles and Prosedures of Statistics. Mc Graw-Hill Book Co., New York, New York.

36. Sandquist, W. B. and H. D. Guither, 1973. The Current Situation and the Issues. North Central Regional Extension Publication No. 32-1, University of Illinois, Urbana, Illinois.

37. Trimble, R. L., L. J. Connor and J. R. Brake, 1971. Michigan Farm Management Handbook. Agricultural Economics Report No. 191, Michigan State University, East Lansing, Michigan.

38. Tulu, M. Y., 1973. Simulation of Timliness and Tractability Conditions for Corn Production Systems. Unpublished Ph. D. Thesis, Department of Agricultural Engineering, Michigan State University, East Lansing, Michigan.

39. United States Department of Agriculture, 1962. Mechanical Silo Unloaders. Farmers Bulletin No. 2188, Washington, D. C.

40. University of Nebraska, 1970. Nebraska Tractor Test Data. Agricultural Experiment Station, Lincoln, Nebraska.

41. White, R. G., 1972. Selecting Machinery for Forage Harvesting. AEIS No. 277, Agricultural Engineering Department, Michigan State University, East Lansing, Michigan.

42. Wymore, A. W., 1970. A Notebook of Systems Engineering Methodology. Department of Systems and Industrial Engineering, University of Arizona, Tucson, Arizona.