THE UNIVERSITY OF MANITOBA

MACHINERY SYSTEMS AND ECONOMIES OF SIZE ON CEREAL GRAIN FARMS

by

Maurice B. Kraut

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

Department of Agricultural Economics
And Farm Management

WINNIPEG, MANITOBA

May 1982

MACHINERY SYSTEMS AND ECONOMIES OF SIZE

ON CEREAL GRAIN FARMS

BY

MAURICE B. KRAUT

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

Marketing Systems and Economies of Size On Cereal Grain Farms

by

Maurice B. Kraut

Major Advisor: C.F. Framingham

Changing farm numbers and sizes from 1966-1976 suggest some structural and technical changes are occuring in agriculture. It would appear that land to labor and capital to labor ratios are still increasing. The contributors to these changes are of critical concern to agricultural policy markers.

Although government programs may be equitable and increase the income of participating producers, they may also cause the misallocation of capital and land resources. If the trade-offs between technical efficiency and social concerns can be better appraised, then public policies may be more specifically directed to achieving their goals.

The objectives of this thesis are to determine the presence of size economies for cereal grain farms in Manitoba as related to labor and machinery systems; and to provide a model which may be used in the implementation of research into economies of size in cereal grain farms in other parts of the prairies.

The model developed was of a simulation type. It is capable of determining machinery systems for cereal grain farms, reflective of regional soil type, precipitation and temperature. The results generated reflected machinery requirements for farm sizes from 160 to 5,040 acres, although this model can go to a higher number of acres. Basically, the model was designed to measure the extent to which physical capacity of machines will allow expansion in farm size, at minimum labor input.

The results generated by this model indicate that in 1975 the lowest costing machinery system occurred on a farm size of 1,200 cultivated acres. This result was determined solely on the basis of the technical efficiency of machinery systems, without financial constraints, and with good management. Social and policy decisions may limit the extent by which the potential economies may be captured by producers.

ACKNOWLEDGEMENTS

As is usual, in order to successfully complete any thesis, a great many individuals provide significant contributions. Needless to say, without this assistance it would have made completion of a thesis extremely difficult, if not impossible. I would like to express my extreme gratitude to all of them.

Special mention is due to my wife, for without her patience and understanding it is doubtful if this thesis would have been completed.

Further acknowledgement should be given to my advisory committee, comprised of Dr. Ron Britton, Dr. D. Kraft, and foremost to my chairman, Dr. C. Framingham. Their guidance and assistance made this thesis much easier to complete.

Special gratitude is extended to Miss Jane Omichinski for her dedication, preseverance and patience in typing this thesis, in addition to her normal workload.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Chapter I

MACHINERY SYSTEMS AND ECONOMIES OF SIZE ON CEREAL GRAIN FARMS

INTRODUCTION

From 1966 to 1971, the number of farms as emunerated by census in Canada declined by 64,394 or approximately 15 percent[1]. This decline resulted in the average farm size increasing from 404 to 463 acres[2], and total real investment in farm machinery increasing by 3.6 million dollars or 10 percent[3] over this same time period.

The 1976 agriculture census indicates that from 1971-76 the number of farms had decreased a further 18 percent, or 66,000[4]. Correspondingly the average sized farm in Canada increased to 553 acres from 463 acres with considerable farm size variation in the different provinces. While total investment in farm machinery, fueled by inflation has increased 130 percent over the 1971-76 period, in real dollars the increase has only been 10 percent.

---

[1]Statistics Canada, 1971 Census of Canada, Agriculture - Number and Area of Census Farms, Advance Bulletin No. 96-727 (aa-10), (Ottawa: Information Canada, April, 1972).

[2]Ibid.

[3]Statistics Canada, 1971 Census of Canada, Agriculture - Farm Machinery and Equipment, Advance Bulletin No. 96-720 (aa-3), (Ottawa: Information Canada, August, 1972).

[4]Statistics Canada, 1976 Census of Canada, Agriculture - Number and Area of Census Farms, Farm Machinery and Equipment, (Ottawa: Information Canada, August, 1977).

As indicated by these two census periods and in Table 1, agricultural enterprises have shown increasing land to labor and capital to labor ratios. In fact, a quick view of Table 1 would tend to indicate this is the continuation of a trend.

TABLE 1

Selected Physical Changes In Canadian Agriculture

		----------------	----	mlns. dlrs.	----------------
	FARM NUMBERS (ACTUAL)	IMPLEMENTS & MACHINERY (ACTUAL)	1971 CONSTANT DOLLARS	DEBT (ACTUAL)	1971 CONSTANT DOLLARS
1961	480,903	2,308	2,355	1,777	1,813
1966	430,522	3,552	3,259	3,445	3,161
1971	366,128	3,909	3,909	4,715	
1976	338,578	9,034	6,079	9,532	6,415

The relative prices of labor and its availability have provided a stimulus to the growth in farm size through the substitution of capital for labor in the form of machinery investments. Market prices for grain and livestock have also assisted in maintaining this incentive. Technological improvements in machinery and agronomic practices have provided another influence toward substituting capital for labor.

At the same time as this expansion in the average farm size and the substitution of capital for labor was ongoing, there is evidence of an increase in debt on Canadian farms. This changing situation in agriculture raises many questions that should be answered with regard

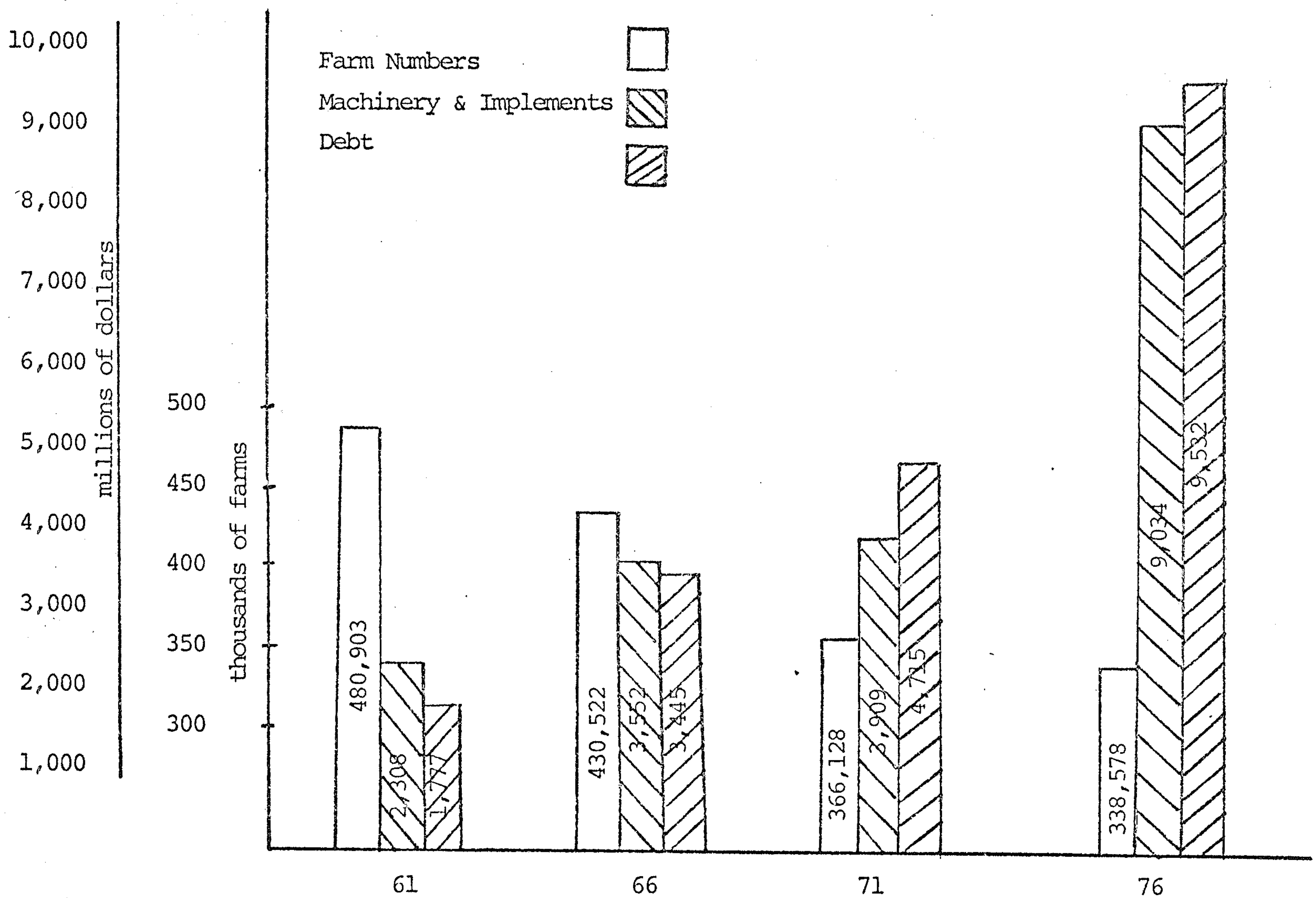

Figure 1: Selected Physical Changes in Canadian Agriculture

to current and proposed programs or policies, and the future structure of agriculture.

The farm size trends discussed above suggest structural change has occurred in Canadian agriculture. It would appear that the land to labor and capital to labor ratios are still increasing. The increase or producer debt also presents a further area for consideration. Whether these changes have been caused by improved machinery technology, higher yielding seed varieties, improved cultural practices, or simply by the reduction of the farm labor supply, becomes a crucial issue for agricultural policy makers.

Public expenditures to maintain or equalize farm income levels may not promote a more efficient and competitive agricultural sector. Although federal and provincial agriculture programs attempt to incorporate factors to deal with both efficiency criteria and income concerns within their programs, the overall policy addressed is the preservation of the 'family farm'. While this may be an admirable objective, in many respects it is difficult to define a 'family farm'. Thus there is no way of knowing whether or not the objective is compatible with efficient agricultural development.

1.1 THE PROBLEM

Although government programs may be equitable and increase the income of participating producers, they may also perpetuate inefficiencies in the production of agricultural products, such as the misallocation of capital and land resources in many instances. For purposes of agricultural policy formulation economies of size have been generally assumed to exist. The results of some studies indicate that production costs are relatively stable over considerable farm size ranges[5]. One objective of this study is to analyze some technological factors contributing to improved economic efficiency. If the trade-offs between technological efficiency and economic efficiency can be better appraised given the analyses, and equity can be measured, then public policies may be more specifically directed to achieving either or perhaps both goals.

In the same context debates on whether a program should promote efficiency or income equalization could then be more clearly focused upon the relevant variables and relationships. Therefore, at the very least a clearer understanding of the relationship between the economic and social concerns within Canadian agriculture could be achieved.

There are several alternatives available to grain producers and governments if in fact technical and pecuniary economies remain to be achieved[6]. Larger farms and correspondingly less farmers may be a solution, if solely technical economies are left to be achieved. On the other hand, if pecuniary economies are still achieveable, there are choices to be made as to whether these advantages could or should be obtained by government involvement through some form of pooling, or by

---

[5] Donaldson, Graham F., Farm Machinery Capacity, 'Royal Commission On Farm Machinery, Study No. 10, (Ottawa: Queen's Printer for Canada, 1970).

[6] Watson, Donald S., Price Theory and Its' Uses, (Houghton Mifflin Company, Boston, Mass., 3rd edition, 1972), pp.184.

the encouragement of producers to develop or adopt methods to achieve the potential savings.

As indicated by the preceding, there are many areas that relate to the problems outlined above. For any one study to attempt to analyze all of the areas of concern would be presumptious. The major consideration of this study is to determine the presence or absence of economies of size in cereal grain farms of Manitoba. Although economies of size in agriculture may exist[7], what has not been determined is the magnitude, size and range over which they occur. This analysis will determine the optimal cereal grain farm size given a specific set of economic, climatological and physical conditions from a machine and labor system perspective.

The results of this analysis will provide a 'yardstick' that could be utilized in comparing the results achieved from the model to existing farm units. The results of such an analysis will provide a better understanding of some of the problems existing in agriculture today such as farm size or financial requirements, and what can be done to affect them by the formulation of policies and programs.

In summary, the objectives of this study are to provide a basis for:

- Determining the presence of size economies for cereal grain farms in Manitoba as related to labor and machinery systems;

---

[7]Donaldson, Graham F., Ibid.

- Provide a model which may be used in the implementation of research into economies of size in cereal grain farms in other parts of the prairies and in other agricultural enterprises.

Chapter II

REVIEW OF OTHER STUDIES

2.1 UNITED STATES STUDIES

United States economists have on numerous occasions researched economies of scale and size in agriculture. Basically, these studies can be divided into two major types, synthetic firm studies, which are primarily designed to discover the existence of technical economies of size under static price competition assumptions, and analysis based on cross-sectional data from actual farm records.

A recent paper by French[8] categorizes several of these analyses into descriptive, statistical, and synthetic studies. The descriptive analysis is the case study approach adopted by traditional farm management specialists. Farm accounts are used as a basis for comparison between selected farm enterprises. A statistical analysis combines accounting data with economic theory to estimate underlying production or cost functions for farm enterprises. The synthetic or economic-engineering approach synthesizes cost and production functions from experimental relationships founded in engineering, biological, or other related disciplines.

---

[8] French, Ben. C., Firm Efficiency Analysis, (Paper presented to the Joint Annual Meeting of The American, Canadian, and Western Agricultural Economics Association, (August, 1977)).

Most of these studies are concerned primarily with 'agribusiness' firms, rather than the basic farm production unit. The method that appears to have been used in most of the studies French reviewed was a cross-sectional survey of a variety of enterprise sizes based on accounting data and a comparison of the results to a synthetic production function simulating the same enterprise sizes and conditions. In most instances the management factor is assumed away as a constant, leaving all variation to be attributed to pecuniary or technical economies of scale and size.

Madden[9] in his selected studies, Economies of Size in Farming points out some of the problems that can be encountered when researchers attempt to determine economies of size directly from a sample of actual firm records, composite firm budgets, standardized or adjusted data. One example of the problems inherent in this approach is seen in a study of feedlots operating in Arizona during 1957. Record analysis showed that the large feedlots had non-feed costs that were lower by two-thirds than small feedlots. However, two factors were pointed out as contributing to a misleading conclusion.

(1) Other studies have shown that average costs decline sharply as the percentage of facility utilization increases. The large feedlots in the Arizona study were observed to be operating closer to full capacity than the smaller ones.

---

[9]Madden, J. Patrick, Economies of Size in Farming, (U.S.D.A. Agricultural Economics Report 107, 1967).

(2) The average cost varies with the length of the feeding period, classes of feeders fed, and the types and quantities of feed used. The observed feedlots in this study varied widely in regard to all these factors.

Consequently Madden concluded, "Slightly different versions of this method have been applied to many other studies. In each case, the findings have been subject to similar limitations. As a result of these weaknesses, this procedure provides very little useful information about the effect of farm size per-se on the average cost of production."

Madden's analysis of these different methods of analyzing studies on economies of size was to determine which technique was appropriate. Madden goes on to state (pp. 29):

> Synthetic-firm analysis is an appropriate technique when either of two research questions is asked:
>
> (1) What is the average cost per unit of output or profit that firms of various sizes could potentially achieve using modern or advanced technologies.
>
> or
>
> (2) What are the differences in average cost per unit of output attributable strictly to differences in size of firm, and not to differences in degree of plant underutilization, use of obsolete technologies, or substandard management practices.

2.2 CANADIAN STUDIES

In Canada, studies of economies of size are quite limited. One of the best examples of an economies of size study in recent years was done by Donaldson[10].

---

[10] Donaldson, Graham F., Ibid.

Donaldson analyzed cereal grain farm operations in specific Saskatchewan locations using a synthetic-firm analysis approach. The results of this analysis were compared to actual farm operations in the areas examined.

The general aim of this study was to assess the machinery system, and consequently the level of investment, that was best suited to the range of crop acreages found on different farms in specified locations. A more explicit objective was to use the results of the analysis to explore some of the farm-level implications of continuing farm mechanization.

The analytical procedure employed by Donaldson, systems analysis, considered the interacting mechanical, biological and weather effects as component parts of the overall field operating system. A computer simulation technique was used to reproduce in abstract, the effects resulting from the interaction of the system variables. These variables were considered to be independent but known probabilities; not as single values.

Donaldson specified three separate models. They were:

(1) A cereal-harvest simulation model which incorporated six harvesting systems over any four locations. Variables in this model included biological tolerances, weather constraints, and machinery systems performance.

(2) This model was almost the same as model (1), except provision had been made for grain drying activities in addition to the other variables.

(3) This model synthesized seeding activities. The variables included all of the ones in model (1), except that the machinery systems were oriented to tilling and seeding requirements.

Donaldson's simulated results when compared to the actual data were remarkably similar (ch. 4, pp. 85). As an indicator of the conditions and problems existing in the farm machinery sector, as well as the complexity of farm managers capital investment decision-making, Donaldson felt that his study raised at least the following questions (ch. 4, pp. 88-90):

(1) Adequacy of Range - Since combines are built for a widely dispersed market, to what extent do these relationships (the results established in Donaldson's study) hold for other areas in North America and elsewhere?

(2) Differences in Flexibility - The difference in the slope of the marginal cost curves suggests greater flexibility for harvesting systems than for tillage systems. Does this help to explain why there are four main alternatives in combine size, but eight or more alternative tractor sizes? Is the major constraint on the acreage of cereals grown per man, or per farm in Canada, the seeding operation, and not as is widely believed, the harvest operation? Should more research be done, therefore, on seeding equipment or on the agronomic characteristics of crops that are related to time of seeding?

(3) Economies of Scale - The long-run cost curves, defined by the least cost range of the series of system cost curves, does show some

economy-of-scale effects. But is this sufficient to justify the claims made for extensive economies associated with mechanization? Given that the best-bet decision policy might be a combination of minimum risk and cost -- suggesting optimal capacity ranges to the left of the least cost ranges -- are there any machinery scale economies at all?

Although Donaldson could only identify the above questions and not answer them, he did reach three significant conclusions:

(1) Farmers are confronted with many choices in the field of farm machinery, very little information related to the production characteristics of each machine, and a great deal of doubt with regards to whether or not there are economies involved in machinery systems.

(2) Machinery might be chosen by farmers on the basis of minimizing expenditures in the long-run, and may also be high risk in the short-run, rather than by technical requirements.

(3) 'Excess capacity' on farms might be explained by some combination of risk and cost minimization. A larger and more expensive machine system may be selected for any given location and size of operation than technically required.

Donaldson's study illustrates the difficulty in assessing agricultural problems, the depth and scope of the variables that must be considered, and the results that may be achieved with the utilization of simulation techniques of the type used to approximate real-life situations.

Donaldson was primarily interested in the relationship of the machinery system that was best suited to the range of crop acreages he was evaluating. Thus there was no real effort (or requirement) made to identify economies of size related to the biological, climatological, or physical limitations developed in his model. Furthermore, the largest farm unit evaluated was two thousand acres.

A more recent study by Furtan and Gray[11] hypothesized the grain farms had a different production relationship than grain livestock farms.

Utilizing available cross-sectional data for the year 1978, Furtan and Gray tested the hypothesis that grain farms had a different production relationship than grain - livestock farms. The hypothesis was examined by evaluating three main characteristics of agriculture production technology:

(1) Well behavedness of the production technology. (Positive marginal products for all inputs and is quasi-concave.)

(2) The separability of inputs - global and pairwise. (The use of all inputs is independent of any one input, or in fact the use of any inputs is not independent of the use of any other input.)

(3) Constant returns to scale (whether an equal increase in all inputs will yield an equal increase in output).

The main conclusions of this study were that:

(1) the production function for grain farms is of the Cobb-Douglas type.

(2) grain farms in this study indicated increasing returns to scale.

---

[11] The Translog Production Function: Application to Saskatchewan Agriculture, W. Hartley Furtan and Richard S. Gray, University of Saskatchewan, CJAE 29(1), February, 1981.

(3) grain - livestock farms appeared to have constant returns to scale.

(4) grain farms can be expected to increase in size simply bacause of available technology.

Although there was no specific information provided in this article to identify the size ranges evaluated, nevertheless it is clear that economies of size appear to exist. However, no real effort has been made to identify some means by which to 'bench-mark' the pressures put on the farm unit due to changing technology. Thus no guidelines into the current or future requirements financial or otherwise can be identified.

Chapter III

THEORETICAL REVIEW

3.1 SIZE ECONOMIES

It is possible when conducting an analysis of economies of size in terms of cost to overlook not only the interrelationships between the physical production factors and costs, but indeed the economic theory that provides the background upon which the understanding of economies of size is based.

While it most certainly is not intended to reiterate the totality of the economic theory in relation to this analysis a few brief comments on the key elements of the background economic theory will provide a firm basis from which to proceed in this study.

3.2 DUALITY OF PRODUCTION AND COST FUNCTIONS

A production function refers to the relationship between the input of a factor or factors and the output of a product. A cost function is the relationship between the expenditure on the varying quantities of the different input factors and the corresponding output.

Mathematically the relationship could be expressed in the following manner:

Given a production and cost function,

$Y_{x(o)}$ is a function of $X_{(o)} / X_{(1)}, X_{(2)}$ --- $X_{(n)}$ and $TC_{x(o)} =$

$P_{x(o)} \cdot X_{(o)} + d.$

Where $X_{(o)}$ is a variable input and all other inputs are fixed, $TC_{x(o)}$ is the total cost function with 'd' representing fixed costs and $PX_{(o)}$ times $X_{(o)}$ representing the variable costs.

The counterparts of the two functions are:[11]

Production Functions	Cost Functions
TP - total product $(Y_{x(o)})$	TVC - total variable cost
AP - average product $(Y_{x(o)}/X_{(o)})$	AVC - average variable cost
MP - marginal product $(dY_{x(o)}/dX_{(o)})$	MC - marginal cost

The relationships are:

Production Functions	Cost Functions
(1) Total product rises first at and increasing, then at a diminishing rate.	(1) Total variable cost rises first at a diminishing, then at an increasing rate.
(2) Average product rises to a maximum, then diminishes.	(2) Average variable cost falls to minimum, then rises.
(3) Marginal product rises, then falls, intersects the average product at its' maximum, and continues to diminish faster than the average product.	(3) Marginal cost falls, then rises, intersects average variable costs at its' minimum, then continues to rise faster than average variable cost.

Thus, the production function and its' relationship are virtually the inverse of the cost function and its' relationships. Simply put, when production reaches its' technical optimum, costs are at their minimum.

---

[11] Watson, Donald S., pp. 191-194, Ibid.

3.3 SIZE

When a firm increases output proportionally by increasing its use of all inputs the input-output relationship is that which represents scale effects. The returns to scale can be increasing, constant, and decreasing. If the increase in output is equal to the proportional increase in the quantities of the inputs, returns to scale are said to be constant. If instead the increase in output is more than equal, returns to scale are increasing. If the increase in output is less than equal returns to scale are decreasing[12].

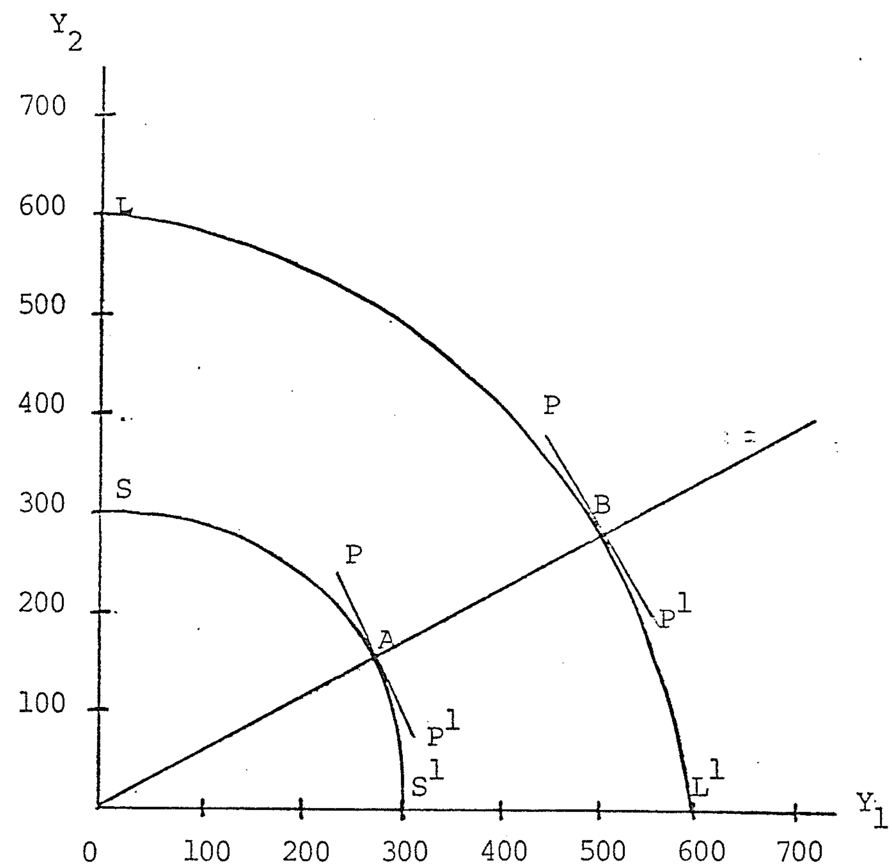

Figure 2: Scale Relationships Between Products Y_1 and Y_2

---

[12] Watson, Donald S., pp. 191-194, Ibid.

Figure 2 is a graphic representation of scale relationships for two products, Y_1 and Y_2.[13]

The substitution curve for the original firm is SS^1 with relative product prices PP^1 and the optimal product combination is A. The firm then doubles its size (the amount of all inputs). The new production possibilities curve is now LL^1. With the same relative prices PP^1 the optimum combination is B. Note that OB = 2OA and the relative mix of the two products is unchanged.

Mathematically all factors of production are assumed to be combined according to:

$$\frac{MP_{x1}}{P_{x1}} = \frac{MP_{x2}}{P_{x2}} = \text{-----} \frac{MP_{xn}}{P_{xm}} = \frac{1}{MC}$$

(For a more detailed discussion of the relationships between production and cost functions see references (12) and (13).

In order to develop a continuous relationships for the production and cost function the following assumptions are used.

(1) divisibility of inputs.

(2) variability of management capacity (although good management in all cases is assumed).

(3) homogeneous product.

(4) the law of variable proportions.

---

[13] White, Kelley T., Jr. and Irwin, George O., Size, Structure and Future of Farms, (Iowa State University Press, Ames, Iowa, 1972), ch. 11.

3.4 ECONOMIES OF SIZE

If the assumption of divisibility of inputs is altered so that a closer representation of actual conditions may be exhibited, reflecting the condition where some inputs are only available in discrete sizes, the production possibility curve might appear as in Figure 3.

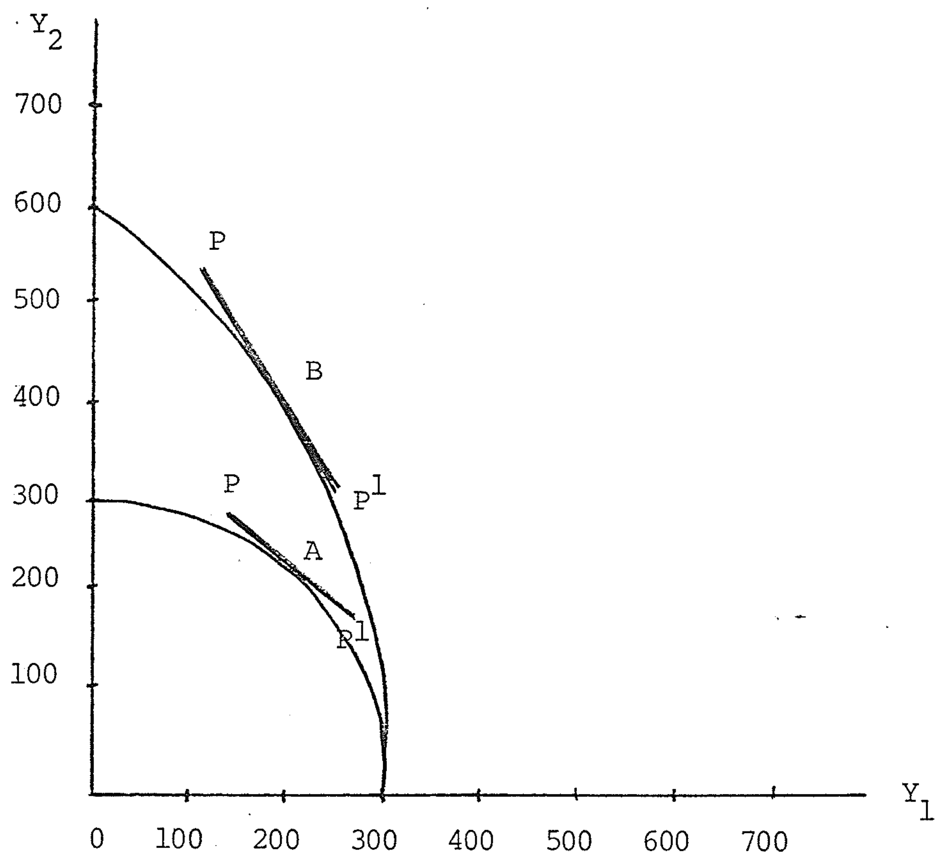

Figure 3 : Production Possibility of Y_1 and Y_2 With Inputs Available In Discrete Sizes Only

Tweeten[14] (pp. 809) has observed that "expansion in the farm firm is generally characterized by increasing the proportion of capital to labor and of variable capital to fixed capital." When the advantages of technological changes such as improved and larger machinery, automated hog or poultry farms are considered, it is reasonable to expect that because of the above factors there will be enterprises that need less than proportional investments to achieve maximum returns. Thus, one might expect to see a degree of production specialization taking place.

Another characteristic of capital inputs in agriculture is that durable capital inputs tend to be available in rather discrete sizes, and to be rather expensive.

As availability of investment capital to a firm may be somewhat limited, a choice of which enterprise to expand may have to be made. In this study the area being examined is the economies of size as related solely to a grain farming enterprise. The enterprise has already made its' choice to specialize. What will be examined, in relation to a number of synthetic farm sizes, is the impact of different machinery systems which are not totally divisible in costs and size.

In an examination of size or scale economies, two major categories pecuniary and technical economies are considered to be the main incentives to growth. Some examples of where these economies can be achieved by a grain producer would be:

---

[14] Tweeten, Luther G., Theories Explaining The Persistence of Low Resource Returns In A Growing Farm Economy, (American Journal of Agricultural Economics, Vol. 51(4), pp. 798-817).

Pecuniary

(a) large volume purchases of inputs at a discounted price.

(b) preferred interest rate on operating capital.

(c) ability to contract out speciality crops related to volume requirements.

Technical

(a) can utilize larger, perhaps more efficient equipment.

(b) will be better able to co-ordinate enterprise requirements (i.e. storage facilities, utilization of chemicals).

(c) 'Best' management is assumed in the selection and operation of technology.

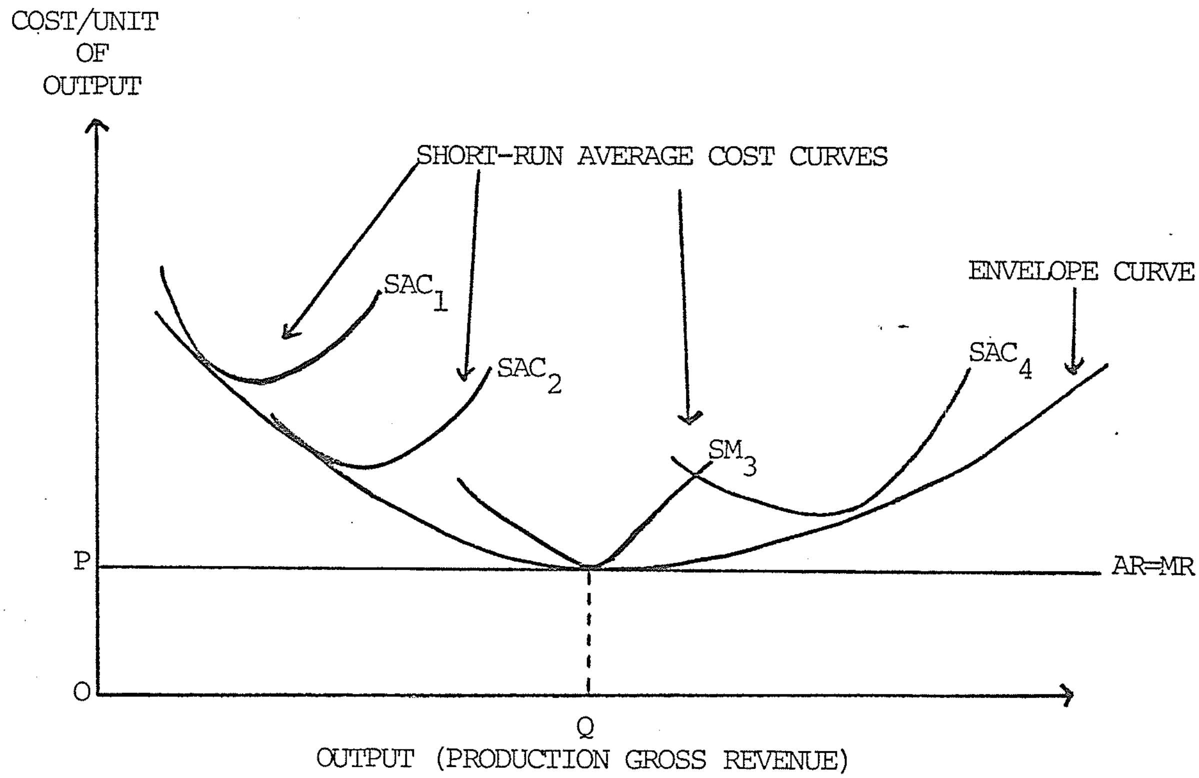

Figure 4: Static View - Economies of Size

Figure 4 is a static view of the economies of size. This relationship between size of firm and average total cost has been examined extensively in the static context[15, 16]. Economies of size analysis is usually couched in terms of long-run and short-run situations. Short-run economies are generally viewed as resulting from fuller utilization of a fixed plant (land base), while long-run economies are viewed as the result of efficiencies obtained by changing plant size, presumably involving a longer time period. In figure 4 the short-run average cost curves (SAC) assume one or more resources to be fixed, available only in specified quantities in the short-run. The U shape of those SAC curves is explained as follows: Average costs per unit of output decline with an initial increase of output as fuller utilization of resources is achieved and fixed costs are spread over more units of production. Eventually, however, average costs level off and then rise, as variable resources must be added in increasing proportions to the fixed resources to reach greater levels of output. A separate SAC curve applies for each level of plant size.

In the short-run certain key resources defining plant size are considered fixed. This has no effect on the shape of the long-run average cost curve (LAC) for it assumes all resources are variable including those designated as fixed in the short-run. A curve drawn

---

[15] Madden, J. Patrick, <u>Economies of Size In Farming</u>, (U.S.D.A. Agricultural Economics Report 107, 1967).

[16] Viner, Jacob, <u>Cost Curves and Supply Curves</u>, (Z. National Okonomie, Vol. 3, Reprinted in Boulding, Kenneth E. and Stiegler, George J., Eds., <u>AEA Readings In Price Theory</u>, Vol. 6, Richard D. Irwin, Chicago, 1952).

tangent to the SAC curves approximates the long-run economies of size curve for that segment of the industry represented by the short-run curves. This curve indicates the average total cost of production that would be experienced by firms of different size under assumed price relationships and technologies.

3.5 THEORETICAL MODEL

The approach taken for this analysis is to recognize that certain inputs into crop production are indivisible. Thus although the 'envelope curve' may still be drawn in a continuous manner, it in fact can be hypothesised to be somewhat discontinuous, or saw-toothed, as represented in Figure 5.

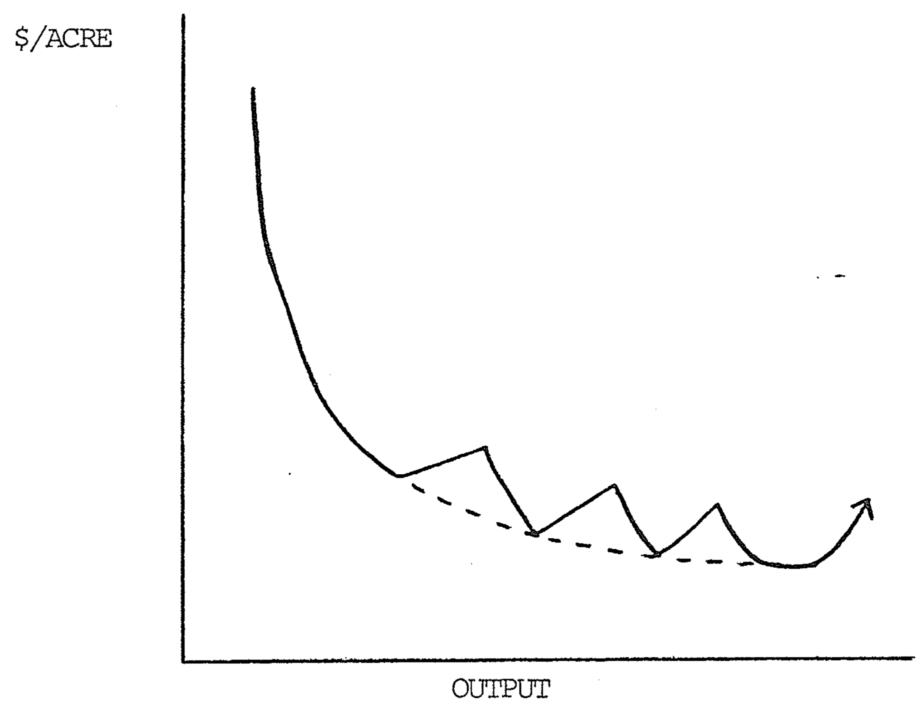

Figure 5: Discontinuous Economies of Size Envelope Curve

Chapter IV

METHODOLOGY

4.1 INTRODUCTION

There are numerous methods available to employ simulation computer models in analysis of the problem addressed herein. In order to maintain simplicity these may be described as part of two main groups, a random number or psuedo-random number generator model (the Monte Carlo Method) or a high probability of occurrence model approach respecting farm conditions.

A random number generator model is of a type used by Donaldson in the study reviewed earlier. The procedure used by Donaldson allowed the evaluation of a probability distribution from the use of a sample from the population being analyzed. This was achieved by selecting values at random and then constraining them to the dimensions of the sample distribution. By using a computer program which generates random numbers, a large number of relatively random observations can be made. If the model is correctly specified, the results of the duplication will simulate the existing conditions in the population.

The high probability of occurrence model is not as flexible as the random generator model in that the probabilities are pre-determined. Thus although one can more readily evaluate a population (for example the amount and distribution of rainfall over time), the random occurrence of an event is eliminated from consideration. In fact, a risk variable which has options for several probabilities reflecting the specific conditions of the population is used.

Although one can use the Monte Carlo technique in this study, the one major reason for selecting the high probability of occurrence model is that Donaldson was interested in determining whether his model, based on a sample was specified correctly so as to duplicate conditions that existed in agriculture during the time period of his study. The study being presented here does not assess actual conditions in agriculture, but rather what potential conditions could be if management was sufficient to assess all the existing machinery alternatives.

The model developed for this analysis is basically a high probability of occurrence model. As this analysis is primarily concerned with determining the effect of farm machine costs on total cost of production over an expanding farm land base, it would appear reasonable that in reality producers will make a machinery purchase relative to the environment they assess themselves to be in.

In the application of the model developed for this research, weather conditions assumed to exist are those that have formed a pattern in the region over a period of years to the extent that risk factors can be allocated (eg. 80, 90, 95 percent of the time weather conditions may be such that it would require a specific size of machine system to complete the farm work in the time available).

The model developed for this study employs the following assumptions:

(1) Indivisibility of some inputs (machinery, land).

(2) 'Best' management technical practices are employed. This implies costs

in themselves are only a consideration in selecting the lowest costing machinery system, other inputs are priced for maximum production, not necessarily profit maximization.

(3) A region is defined as homogeneous in soil type and climate.

(4) The supply of labor is unlimited, except that each hour of labor hired requires five minutes of management time.

(5) Weather conditions are pre-determined.

A simulation approach will allow the calculation in integers of activities within the model's parameters. As labor, machinery, buildings, and land cannot be purchased or leased in small incremental units to coincide with small incremental units of output, it was felt integers were more representative. Other problems such as non-linear size and scale effects can quite easily (in comparison to other techniques) be handled by simulation.

In short, a simulation technique enables the user to take a more realistic approach to the problem being analyzed.

Donaldson in his study provided a major reason for using simulation, rather than other methods (12, pp. 18-21).

> "....this technique permits the user to incorporate several physical relationships which cannot easily be handled by other planning methods."

As this simulation model does not allow all costs to be determined either by economic or technical factors, it does not provide the exact minimum cost point. However, the model will provide an indication of the impact of machinery system sizes and costs on farm size.

4.2 METHOD OF APPLICATION

The sequential process of the developed model is such that:

(a) every size of machinery that is available within the data base is evaluated relative to the total time available for each and every acreage within the model's parameters.

(b) the model will always at the outset seek to minimize the difference between the total time available to complete the field work, and the total time required to do the field work by any one machinery system.

(c) after all the possible combinations are assessed the machinery system is put together and the costs of purchase and operation are applied.

An example of the results of the above process is the summary for a farm size of 960 acres (see Table II).

The calculations in Table II only evaluate the technical efficiency of the machine systems and the related costs. The impact of other input costs and grain prices are assumed constant. However, the results of these calculations can be used to graphically display the short-run average equipment cost curve for 960 acres as well as the minimum point of this curve.

As these calculations were done for farm sizes ranging from 160 to 5,040 acres (in 80 acre increments), a long-run or envelope curve for the region can be developed along the lines described in chapter dealing with size economies and displayed by Figure 6.

Table II

Summary Table of Pull-Type and
Self-Propelled Machine Systems for 960 Acres

System Type	Total System Cost	Annual Average Cost/Acre*	Number of Systems	Number of Men	Size of— Disc Drill No. of Ft.	Harrow No. of Ft.	Swather No. of Ft.	Combine Cylinder Size In Inches	Chisel Plow No. of Ft.	HP Tractor 1	HP Tractor 2
PTO	$29,747.33	$30.99	1	2	18	30	12	18x40	7	62.2	66.7
PTO	$45,355.53	$47.25	1	2	18	30	12	22x50	18	160.0	66.7
PTO	$48,754.37	$50.79	2	2	18	30	12	22x50	7	75.0	75.0
PTO	$37,218.07	$38.77	1	1	32	36	12	18x40	7	118.5	62.2
PTO	$39,849.76	$41.51	1	1	32	36	12	22x50	18	160.0	0
PTO	$57,703.91	$60.11	2	2	32	36	12	22x50	7	118.5	75.0
PTO	$32,358.41	$33.71	2	2	8	24	12	18x40	7	62.2	66.7
PTO	$45,222.21	$47.11	2	2	8	24	12	22x50	18	160.0	29.6
PTO	$52,869.26	$55.07	2	2	8	24	12	22x50	7	75.0	75.0
SP	$37,314.67	$38.87	1	2	18	30	12	19x37	7	66.6	62.2
SP	$52,277.23	$54.46	1	2	18	30	12	22x50	18	160.0	66.7
SP	$47,372.53	$49.35	2	2	18	30	12	20x45	7	66.6	0
SP	$36,595.04	$38.12	1	2	32	36	12	19x37	7	118.5	0
SP	$46,691.94	$48.64	1	1	32	36	12	22x50	18	160.0	0
SP	$58,456.06	$60.89	2	2	32	36	12	20x45	7	118.5	0
SP	$38,098.55	$39.69	2	2	8	24	12	19x37	7	62.2	29.6
SP	$53,061.12	$55.27	2	2	8	24	12	22x50	18	160.0	29.6
SP	$50,971.41	$53.10	2	2	8	24	12	20x45	7	62.2	
					LOWEST COST ALTERNATIVE						
PTO	$29,751.87	$30.99	1	2	18	30	12	18x40	7	66.7	62.2

*Does not include as a cost, land, taxes, nor trucking costs from field to storage.

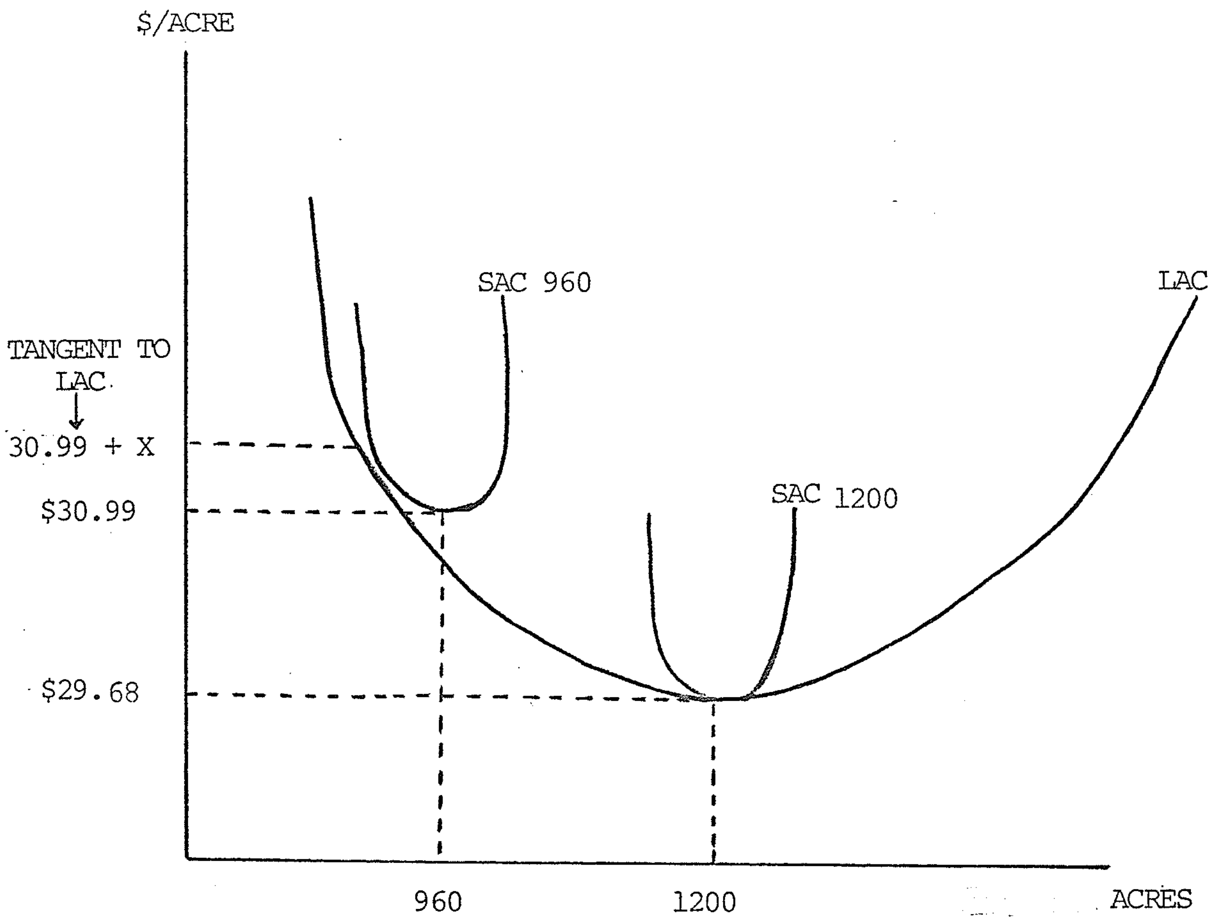

Figure 6: Estimated Economies of Size Envelope Curve

The following flowchart (Figure 7) provides an overview of the model.

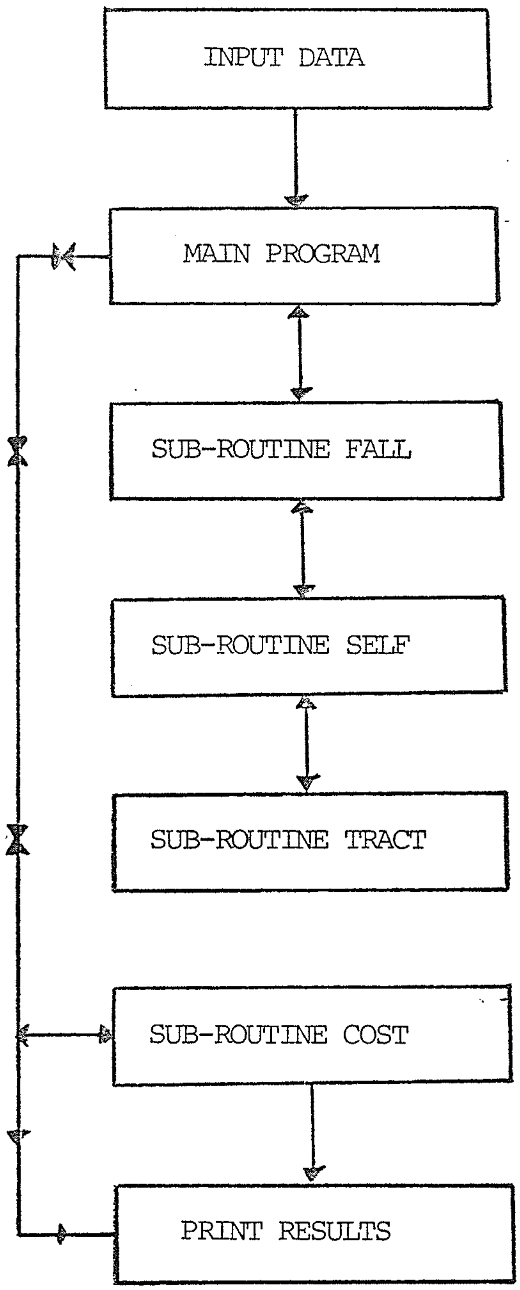

Figure 7: Flow-Chart of Simulation Model

The Main Program contains all the equations for calculating the machinery requirements for seeding, harrowing and swathing the crop. Sub-Routine Fall is that part of the program that calculates the power-take-off combine and fall field work requirements. Sub-Routine Self calculates the self-propelled combine and field work requirements. Sub-Routine Tract calculates the tractor(s) horsepower requirements as specified by the previous three routines. The results of these four routines are then relayed to Sub-Routine Cost and the corresponding costs are then associated with the selected equipment. The results are then printed.

The sequential process is such that first all machinery requirements for the entire range of farm sizes are calculated and stored. Following this all the costs are tabulated and printed (an example of the results as printed by the computer are presented in Appendix B.)

The following is a brief discussion of the environmental and physical limitations used in this model.

4.2.1 ENVIRONMENTAL LIMITATIONS

Environmental limitations considered were:

(1) Temperature ranges pertaining to the requirements of tillage, seeding, and harvesting for the region.

(2) Precipitation levels related to their effect on tillage, seeding, and harvesting requirements for the region.

(3) General soil type for the region.

(4) Yield of crop and type.

The temperature ranges and precipitation levels for the Eriksdale, Stonewall and Arborg regions, as well as their impact on the soil and consequently field operations were calculated outside the model and inserted as parameters. Although the calculated probability factors are available in a range of from 80 to 98 percent and can be utilized on a continuous basis by the model, this analysis was conducted at the 90 percent probability level. The implication of using the 90 percent probability level is that nine years out of every ten covered by the data used, the machinery systems selected will be of sufficient capacity to complete all field work in the available time period.

The maximum and optimum yield of wheat, oats, and barley for the soil type, climatological conditions, economic conditions of the time period were calculated[17]. The maximum yield for wheat was selected as the constraining yield because it was the most constraining crop type to the capacity of the available combines.

4.2.2 PHYSICAL LIMITATIONS

Physical limitations considered were:

(1) Cultivated acreage (per farm basis).

(2) Available labor time (per farm basis).

(3) Cultivatable acreage (per farm).

(4) Cultivation practices.

---

[17] Racz, G.J., Effect of Nitrogen Fertilizer and Water Supply on Yield, Wheat and Barley, 1975.

With regard to the physical limitations, cultivated and cultivatable land are assumed to be the same. The cultivation practices for the region are the ones generally used in the area, rather than the technical 'best'. Labor time available to the individual farm enterprise is assumed to be unlimited, but useable labor time is limited by the management time. The model is designed to measure the extent to which physical capacity of machines will allow expansion in farm size, at minimum labor input.

4.3 MODEL FORMULATION -- CONSTRUCTION OF VARIABLES

4.3.1 PRECIPITATION

The area considered as a homogeneous region was that part of the Interlake area of Manitoba bounded by the weather stations Eriksdale, Stonewall and Arborg that primarily produce grain and are of a similar soil type. The major soil types and their characteristics are listed in Table III. These soils are stony, well to poorly drained with a Bulk Density of 1.25[18]. The effective Field Capacity of these soils is approximately 38.9 percent.

---

[18] Principles and Practices of Commercial Farming, University of Manitoba.

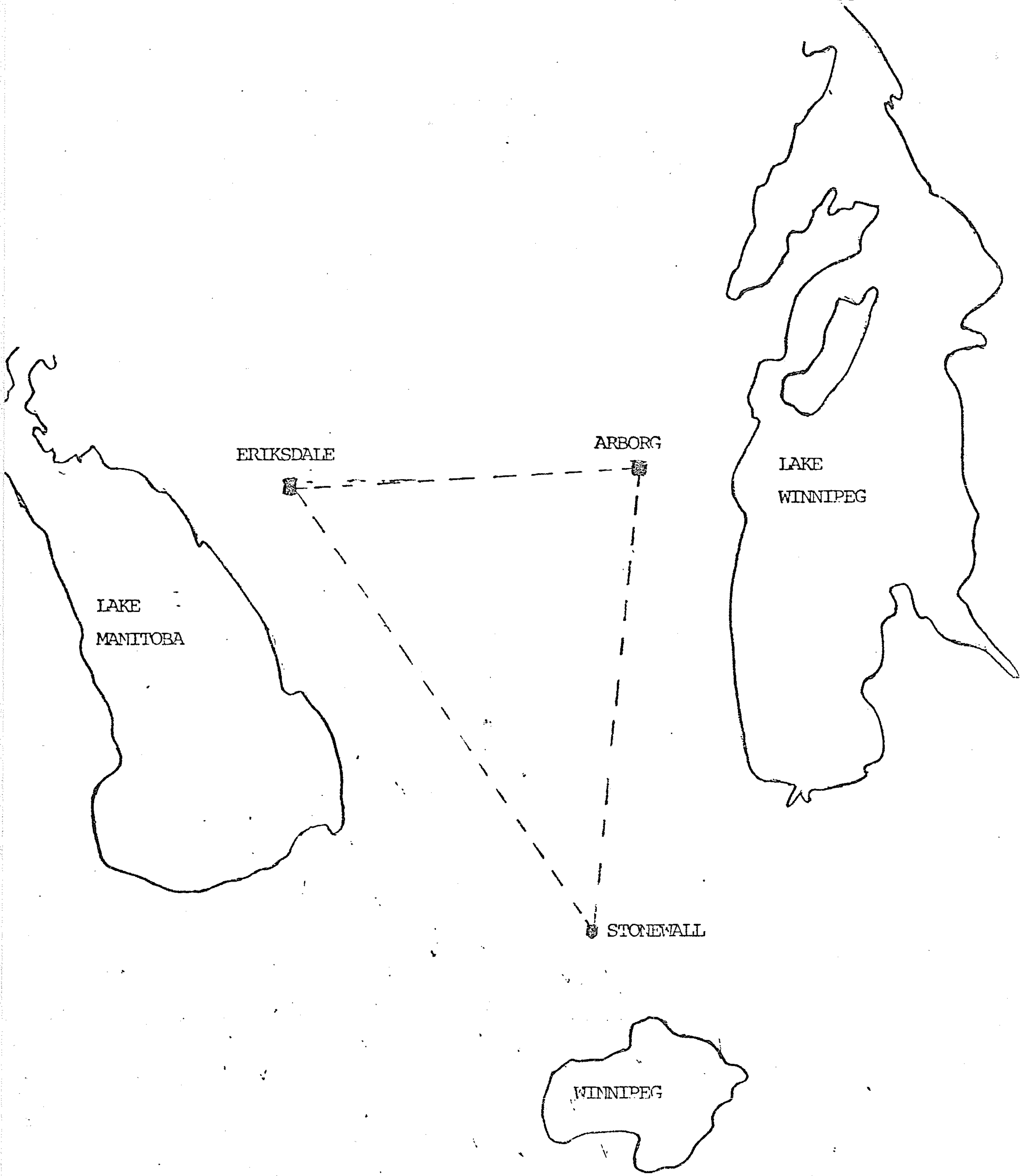

Diagram of Area Sampled For Soil, Temperature and Precipitation Data.

Table III

Predominant Soil Types of the Study Region and Their Characteristics[19]

Type	Horizons	C.E.C. meg./100 gms. soil[1/]	O.M.C.[2/]	Si[3/] %	Sc[4/] %	Cl[5/] %	Texture Class
Orthic							
Dark-Grey	Ahe	6.8	1.5	4	85	11	L.f.s.[6/]
Orthic							
Grey Wooded	Ae	6.0	1.0	38	51	11	L.[7/]

1/ Canion exchange capacity indicating the adhesive qualities of the soil.

2/ Organic matter content of the soil.

3/ Silicone or sand content of soil.

4/ Silt content.

5/ Clay content.

6/ Loamy, fine silty.

7/ Loan soil.

---

[19] Shaykewich, C.F. and Zwarich, M.A., 'Relationship Between Soil Physical Constants and Soil Physical Components of Some Manitoba Soils', (Canadian Journal of Soil Science, Vol. 43, 1968), pp. 199-204.

In order to measure the effect of precipitation on these soils a method of indexing the relative dryness was required. To this end an index entitled the Antecedent Precipitation Index (API)[20, 21] was used. This index could not only account for the relative wetness of the soil in order to determine tractability, but could also be adjusted with an evapotranspiration coefficient to account for the effect of vegetative cover on drying time of the soil after precipitation had fallen.

$$API_t = 0.84\ (API_{t-1} + P_{t-1}) - K \qquad (1)$$

Where: API_t = index level of day t.

API_{t-1} = index level of day t-1.

P_{t-1} = precipitation level of day t-1.

K = evapotranspiration coefficient for a particular month.

The starting point for this index was to assume that the soil initially was totally saturated. Then using equation 1, an estimated number of working days was arrived at. Table IV contains a summary of the results. The values for the API index were arrived at by using 14 years of weather data for this region of the Interlake. After consultation with individuals that have done work in this area, a classification system of values which would indicate the workability of the soil was constructed.

---

[20] Rigaux, L.R. and Singh, R.H., 'Benefit-Cost Analysis of Agriculture Drainage Expenditures', (A report prepared for the Committee to study drainage policies in Manitoba.), March, 1973.

[21] Bruce, J.P. and Clark, R.H., 'Introduction to Hydrometeorology', (Pergamon of Canada Ltd., 207 Queen's Quay West, Toronto), 1966.

Index levels of less than or equal to 0.3 were considered to be completely dry; greater than 0.3 but less than or equal to 0.5 were considered wet, but still workable soil conditions[22]; values in excess of this were considered to be non-working days. The magnitude of the values in excess of 0.5 determined how many days would be lost before work could continue.

Weather data for 14 years from three weather stations, Eriksdale, Stonewall and Arborg was used in calculating the time available for crop production and harvesting. Correlation data to be used in comparison was obtained by using 86 years of Winnipeg precipitation data[23]. API indices for Winnipeg as well as the other three stations were constructed and compared. Table IV results were used to establish the total number of available working days for all the relevant months based solely on precipitation levels. July was not calculated because it was anticipated that all seeding work would have been completed by the end of June.

---

[22] It has been assumed that 'trapped' surface moisture is not a consideration.

[23] Meteorlogists indicate that the weather system dominating the Winnipeg area and the one in the Interlake area are the same. Although there will be some lag in weather conditions occurring, both areas will have the same type of weather.

Table IV

Average of Eriksdale, Arborg and Stonewall API Levels
(Winnipeg API levels in brackets)

	--------API Level-------			
Month	0.3	0.3-0.5	0.5-1.0	1.0
May	79.4 (86)*	10.3 (6.5)	8.2 (5.3)	2.0 (2.5)
June	74.0 (67)	9.8 (10.5)	10.8 (13.7)	5.7 (9.2)
August	86.7 (88)	4.5 (4.9)	5.9 (5.1)	3.3 (2.2)
September	91.7 (89)	3.8 (4.7)	2.8 (5.2)	1.6 (1.6)
October	95.0 (95.0)	2.8 (1.9)	2.4 (2.0)	0.3 (1.1)

(See Appendix A for data details.)

* percentage of the time these API levels occurred

4.3.2 TEMPERATURE

The next restrictive element to be calculated was temperature. Minimum temperature levels were obtained from the same three weather stations for the same period as that used to calculate working days based on precipitation. Three different temperature levels critical in grain farming were selected as indicators for decision criteria.

(1) Minimum daily temperatures greater than or equal to 32 degrees Fahrenheit for five consecutive days were considered to be sufficient to indicate the start of the available seeding period.

(2) In order to minimize the chance of frost damage a daily minimum temperature of 27 degrees Fahrenheit was considered the end point by which swathing had to be completed.

(3) A daily minimum temperature of less than or equal to 10 degrees Fahrenheit was considered to be the determining factor when all combining and fall field work must be completed.

Essentially the seeding, harvesting, and fall field work time segments were divided into two major time periods; seeding and swathing, combining and fall field work. This approach was taken because it was considered that a most important element with a mature crop is to swath it in order to reduce the risk of crop loss (given favorable weather conditions). In order to accomplish this, both the temperature conditions and precipitation conditions had to be appropriate. This would then define the seasonality aspect that was desired.

An example of this might be the following: for seeding to commence the temperature had to be at least 32 degrees Fahrenheit and the API had to be less than or equal to 0.5. This was done at three levels of observed frequency of occurrence (90, 95 and 98 percent levels). For the purposes of this study the 90 percent level was chosen.

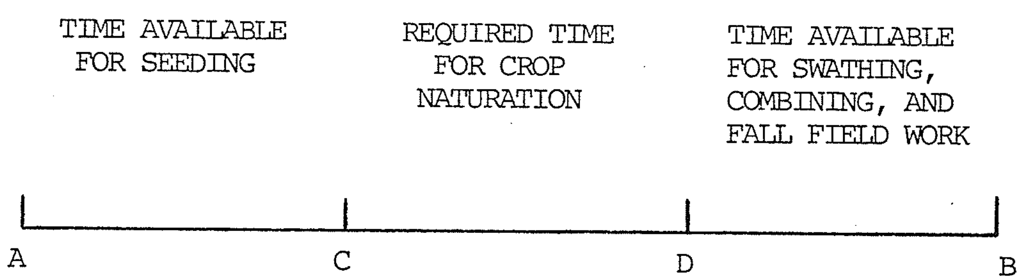

Figure 8: Required Crop Production Time Profile

If line AB of Figure 8 can be assumed to be the total season time available for all operations to be completed at the 90 percent frequency level[24], within this time element is the required time for crop maturation, that portion of AB designated CD. The time period left is available for seeding and swathing as well as combining and fall field work (AC and DB). As the percent frequency level increases the time segment AB gets smaller, leaving less time for field operations.

Due to a technical problem in trying to avoid pre-specifying the time element AC, and therefore the machinery system required, the approach taken was to introduce another time element DE. DE is the time period when the minimum temperature was equal to 27 degrees Fahrenheit (see Figure 9).

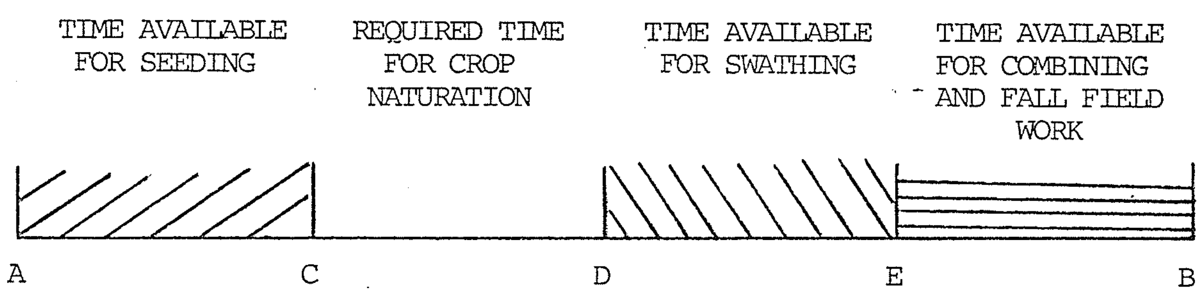

Figure 9[1/]: Definitive Time Profile for Cereal Grain Production

[1/] Temperature and precipitation predetermine AC and DE.

---

[24] This was calculated for each frequency level with the total available time being that time left after days that are too wet, or too cold have been deducted from the time period April to November.

Then the time available for seeding and swathing would be AC plus DE. This would not influence the selection of seeding machinery and swathers other than by the total available time and the amount of acreage being considered.

Table V

Summary of Temperature Frequencies At Occurrence Of Minimum Temperature for Eriksdale, Stonewall and Arborg (Starting Dates)[25]

Date	Eriksdale %	Arborg %	Stonewall %
4th week of April	21	14	36
1st week of May	14	0	7
2nd week of May	36	29	29
3rd week of May	8	29	21
4th week of May	21	21	7
1st week of June	0	7	0
	100	100	100

Earliest average starting date: April 24

Latest average starting date: May 19

Table V indicates the frequency of temperature distribution for Eriksdale, Stonewall and Arborg when the daily minimum temperature was greater than or equal to 32 degrees Fahrenheit for 5 consecutive days. As indicated from the standpoint of temperature, seeding could have begun on April 24th at the earliest and May 19th at the latest.

---

[25]Temperature details in Appendix A.

Table VI

Termination Date for Swathing - Temperature Less Than or Equal to 27 Degrees Fahrenheit (Minimum)[26]

Date	Eriksdale %	Arborg %	Stonewall %
1st week of September	7	0	0
2nd week of September	14	43	0
3rd week of September	29	29	29
4th week of September	50	29	71
	100	100	100

Earliest average termination date: September 8

Latest average termination date: September 31

Table VI indicates the frequency of the first day when the temperature fell to at least 27 degrees Fahrenheit at the minimum. The earliest average freezing date (27 degrees Fahrenheit) for the three locations was September 8; the latest freezing date was September 31. Tables V and VI along with the API levels in Table IV were used in the establishment of the available time periods as indicated in Figure 9.

In Table VII further analysis of the available data indicates that the earliest freezing date in the three areas was November 1 (temperature less than or equal to 10 degrees Fahrenheit). The latest date for freezing was November 26. This tables corresponds to the time period EB in Figure 9.

---

[26]The rational in evaluating comulative frequencies is based on the fact that the latest starting date for seeding was the first week of June. The objective was to determine the earliest starting date. Thus arriving at a series of starting points within the total time available for seeding.

Table VII

Termination Date for Combining and Fall Field Work

Date	Eriksdale %	Arborg %	Stonewall %
November 7	35.7	35.7	28.6
November 15	35.7	42.8	28.6
November 23	28.6	21.5	42.8
	100.0	100.0	100.0

Earliest average termination date: November 1

Latest average termination date: November 26

In order to set a time-precipitation dimension for the simulation program, the days available had to be converted to hours. This was done using two assumptions: (a) The seeding and swathing dimension was assumed to have a 16 hour gross available time during any one day. Time was deducted in the simulation program for repairs, maintenance and field efficiency; (b) Combining and fall field work were restricted to 6 hour days. This was done to account for the effect of humidity levels that would delay combining. The fall field work time dimension was not critical to the outcome, but was assumed equal to the time dimension of combining because of the seasonal factor. These time dimensions, which include precipitation effect are shown in summary form in Table VIII.

Table VIII

90%, 95% and 98% Frequency Levels for Seeding, Swathing, Combining, and Fall Field Work (Available Time)

Operation	90%	95%	98%
Seeding and Swathing	336 hrs.[27] (21 days)	256 hrs.	112 hrs.
Combining and Fall Field Work	312 hrs.[28] (52 days)	300 hrs.	294 hrs.

In summary, what has been presented in this section is the methodology used to calculate the number of hours available to seed, harvest and complete the work required for a crop of wheat relative to temperature and precipitation conditons.

Previously an explanation was presented for Figure 9. It is now possible to insert numerical values into the graphics as shown in Figure 10.

---

[27] The hours used for seeding and swathing are based on 16 hour days.

[28] The hours used for combining and fall field work are based on 6 hour days. As there is no data available to provide a guideline as to the number of hours available in a day to combine a crop, after discussions with University researchers it was felt best to underestimate rather than overestimate the hours available for combining and fall field work. The 6 hour figure is a subjective value, but extremely conservative.

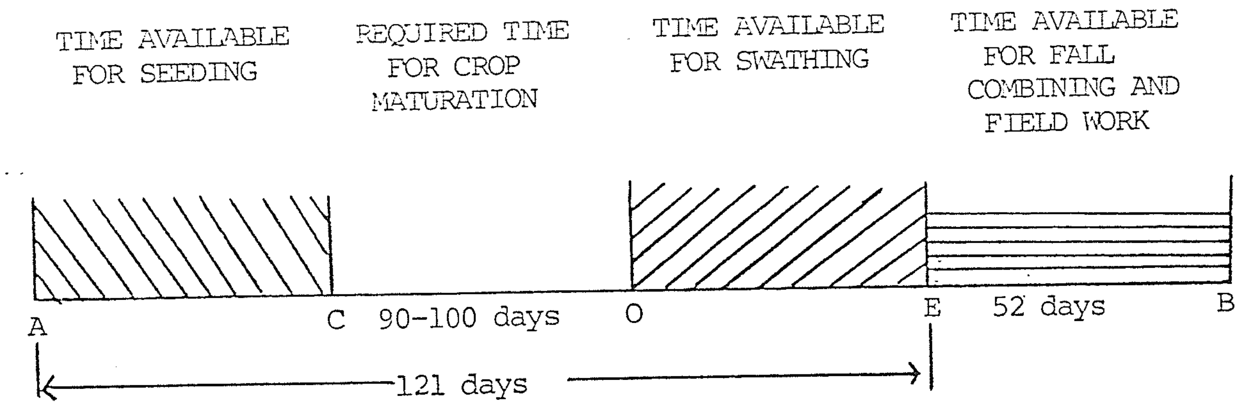

Figure 10: Specified Time Profile for Cereal Grain Production At 90% Probability Level

In total, using the assumptions of time indicated on page 40, there are calculated to be 192 days available for completing the seeding operation, maturation of the crop, swathing and combining the crop and fall field work. Figure 10 indicates the time that is available (173 days) at the 90 percent probability level (9 years out of 10 that time will be available).

The model developed for this study although capable of dealing with a variety of probabilities, different crops and yields, has been constrained to one probability (90 percent), one crop (wheat) and one yield level (48 bushels/acre).* This was assumed to be representative of actual producer practices.

In Figure 10 the line AE indicates that with 90 percent probability there will be 121 days available to seed, mature and swath the crop (wheat is assumed to require 100 days to mature). Combining and fall

---

*As indicated in RACZ (17) 48 bushel yield/acre was the optimum yield achieved.

field work as expressed by the segment EB has approximately 52 days to complete these operations.

The model constructed for this analysis calculates the seeding and swathing requirements simultaneously using a maximum of 21 days (336 hours) as a constraint. In this manner the critical time-frame of when seeding starts, the proper time for the crop to mature and the critical end point for completion of swathing are addressed. In essence, once the seeding requirement is met, crop maturing time (in the model) is assumed to have been completed and the swathing requirement is calculated.

In summary then:

The segment AE of line AB represents the 121 days required and available for seeding, crop maturation and swathing.

The segment EB of line AB represents the 52 days available for combining and fall field work.

4.4 MACHINERY SPECIFICATIONS -- CAPACITY SEEDING AND SWATHING

All machinery sizes that were available in the time period 1968-69 and relevant to the implement types selected for the model being developed were used. These implements are not all implement types available and a more extensive model should include all implement types. However, for the purpose of developing a framework like this, it was felt that as long as the implements selected for this model were representative of the implements actually used it would be sufficient. The following is a listing of the implements and the number of different sizes available for each one (Table IX).

Table IX

Implement Type and Number of Sizes

Implement	Number of Sizes
Disc-Drill	11
PTO Swather	13
Spike Harrows	7
Diesel Tractors (2 and 4 wheel drives)	50
Chisel Plows	16
PTO Combines	8
SP Combines	17

The implements used in this study were considered to be the most logical components of a machinery system. The only option not directly included in the physical considerations was the SP swather. This was only done on the operational calculations as a scrutiny of the size available showed no difference from the PTO swather; therefore, the capacity if powered sufficiently is the same only the cost and perhaps efficiency calculations may be different. It should be emphasized that no bias was introduced as to make of machinery. All major manufacturers of farm machinery were included in the set available in this model.

The capacity of all implements other than the combines and tractors were calculated by the following equation.

$$C = (4 \cdot \text{width} \cdot 0.85) \;/\; 8.25 \qquad (2)$$

where: C = capacity of the machine

Width = width of the implement being considered

0.85 = field efficiency criteria

4 represents an assumed tractor speed of 4 m.p.h. 8.25 represents the result of dividing 43,560 square feet (1 acre) by 5,280 feet (1 mile). The answer from this equation C is expressed in acres/hour.

The calculation of tractor size related to the implement selected is done by equation 3.

$$PTO_{h.p.} = Draft \cdot m.p.h. \ / \ 375 \ (0.96 \cdot 0.75) \qquad (3)$$

Where: $PTO_{h.p.}$ = power take-off horsepower required for the implement being used

m.p.h. = miles per hour of travel time desired (assumed to be 4 m.p.h.)

Draft = total force parallel to the direction of travel required to propel the implement

0.96 = half axle horsepower ratio, typical for most transmissions

0.75 = tractive efficiency ratio related to soil type and condition

375 = conversion of 1 h.p. = 33,000 ft./lb. per minute to m.p.h. (33,000 x 60 / 5,280)

4.4.1 CALCULATION OF TIME REQUIRED FOR EACH ACREAGE SIZE

With time as the restricting variable, it was compared to the time required by each machine system to complete the work required for each acreage specified. Included in the total time required to complete the field operations were equations 4 and 5. These equations estimated the maintenance time for the selected machine system and management time required, if any.[29] It should be noted that with the equations all machinery is assumed to be new, and there is no repurchase consideration.

---

[29] American Society of Agricultural Engineers, 'Agricultural Engineers Yearbook', (ASAE, St. Joseph, Michigan, 1971), pp. 287-294.

$$\text{MAINTENANCE} = (C \cdot ((\text{acres} / \text{disc size} / B) \cdot A)^{D} \quad C \cdot ((\text{acres} / \text{swather} / B) \cdot A)^{D} \quad C \cdot ((\text{acres} / \text{harrow size} / B \cdot A)^{D}) \cdot N \tag{4}$$

Where: C = estimated coefficients for repair and maintenance of individual machines

D = exponential coefficients for repair and maintenance

B = the estimated lifetime hours of the implements used

A = constant conversion factor

N = the number of implements used in case of multiple systems

$$\text{Management Time} = \text{acres} / (\text{equation 2}) \cdot K \cdot N{-}1 \tag{5}$$

Where: K = management time cost per hour of labor; 5 minutes/ 60 minutes of labor

N = number of men required (including management's own labor

The total time required to complete the field work and swathing for each machine system size including maintenance was calculated by equation 6. The total required time for each system of machinery for each and every acreage change was then compared to the available time. The machine system that came closest to the available time was selected to be the system required for that acreage.

$$\text{T.R.T.} = \text{acres} / \text{equation 2 (for each implement)} + \text{maintenance time (for each implement)} + \text{management time (for each implement)} \tag{6}$$

Where: T.R.T. = Total Required Time

At this juncture the calculation of a machine system that is required for seeding and swathing for each acreage and frequency level of temperature and precipitation is complete. It should be noted that the calculation of machinery size required is based strictly on physical capacities with costs not being considered. The discussion of this section corresponds to the operations carried out in the section labeled 'Main' in Figure 7.

4.4.2 COMBINING AND FALL FIELD WORK

As has been indicated in previous sections, the primary concerns in the Combine Selection Model are: (a) the relative humidity level which regulates the amount of time available for combining, and (b) the acreage size relative to combine size.

The capacity of any one combine at any given time is open to question by most authorities. The large variance of performance of any combine is dependent on a number of factors including crop yield variability, amount of straw, speed of combine, and of course moisture levels of the grain and straw[30].

MacHardy[31] developed an equation that calculates combine capacity. This equation has a tendency to overestimate capacity at low yields and underestimate capacity for high yields. However, it does serve as a good indicator of probable levels of performance. The calculated results using this equation were compared to results achieved by tests conducted by the Agricultural Machinery Administration on similar models and under varying conditions[32]. The differences between the actual tests and MacHardy's equation were found not to vary significantly. In addition,

---

[30] Donaldson, Graham F., Ibid.

[31] MacHardy, F.V., 'Economics of Farm Machinery Utilization', Brief to the Royal Commission on Farm Machinery, Edmonton, Alberta, 1967.

[32] Test Reports, Agricultural Machinery Administration, Saskatchewan Department of Agriculture, Regina.

the Agricultural Machinery Administration test results were not conducted under the identical conditions that this model is attempting to fit. After due consultations with knowledgeable individuals, it was concluded that use of the equation would not significantly alter the final decisions in the model.

$$R = 3 \cdot ((W / 192) \quad (BxL^{1.5} / 38.600) \quad (S / 7{,}400)) \qquad (7)$$

Where: R = rate of work in tons per hour

W = cylinder width in inches

B = body length in inches

L = straw walker width in inches

S = combined chaffer and sieve area in square inches

The rate of work derived from the above equation was converted to acres of work per hour. This was achieved by first establishing what the maximum and then optimum yield of crop for this region was. The appropriate optimum yield data for cereal crops in the region of interest was adapted from a study by G.J. Racz of the Soil Science Department of the University of Manitoba[33]. The yield per acre in bushels was then converted to tons per acre and then simply related to acres per hour.

The model used in this study is capable of selecting both pull-type combines and self-propelled combines for each acreage size being analyzed. The final selection of which type of combine to use is made when all costs are compared near the end of the simulation.

---

[33] Racz, C.J., 'Effect of Nitrogen Fertilizer and Water Supply On Yield.... Barley and Wheat', 1975.

The capacity of the chisel plow was estimated by equation 2. The total time required for the combining and fall field work subroutine was estimated by equations 4, 5 and 6. As both the pull-type and self-propelled combines used were estimated in the identical manner, additional consideration had to be given to the horsepower requirements for tractor selection. For the system using the pull-type combine the horsepower required depended on the requirements of the combine. When the self-propelled combine system was estimated, the horsepower requirements selected were dependent only on the requirements of the chisel plow.

All the values from all the equations for each of the acreages examined and for all the alternative machine systems were retained in order to calculate the cost of each machine system.

Chapter V

RESULTS

Nine sets of cost calculations for each of the sixty-two different farm sizes ranging from 160 to 5,040 acres were generated by the model. These are included in the appendix. The following is a summary of these results.

5.1 LONG-RUN MACHINE SYSTEMS COST CURVE

The long-run cost curve produced by the model and displayed in Figure 11 based on data contained in Table XII was as hypothesized earlier and displayed in Figure 4, saw-toothed. It should be noted that, although the long-run cost curve has been drawn such that it would appear tangent to several of the short-run cost curves, the only true tangency point to the industry long-run cost curve is at 1,200 acres, the point of minimum cost. All of the other short-run cost curve tangency points are really the lowest cost alternative for the specific acreages and thus by definition could not be tangent to the 'true' long-run cost curve.

Figure 11 indicates that average cost declines rapidly from \$128.42 per acre at 160 acres to the minimum of \$29.68 per acre at 1,200 acres[34]. The average costs per acre then increase from this minimum to a maximum of \$65.37 per acre at 5,040 acres.

---

[34] All cost figures used in this study are in 1975 dollars.

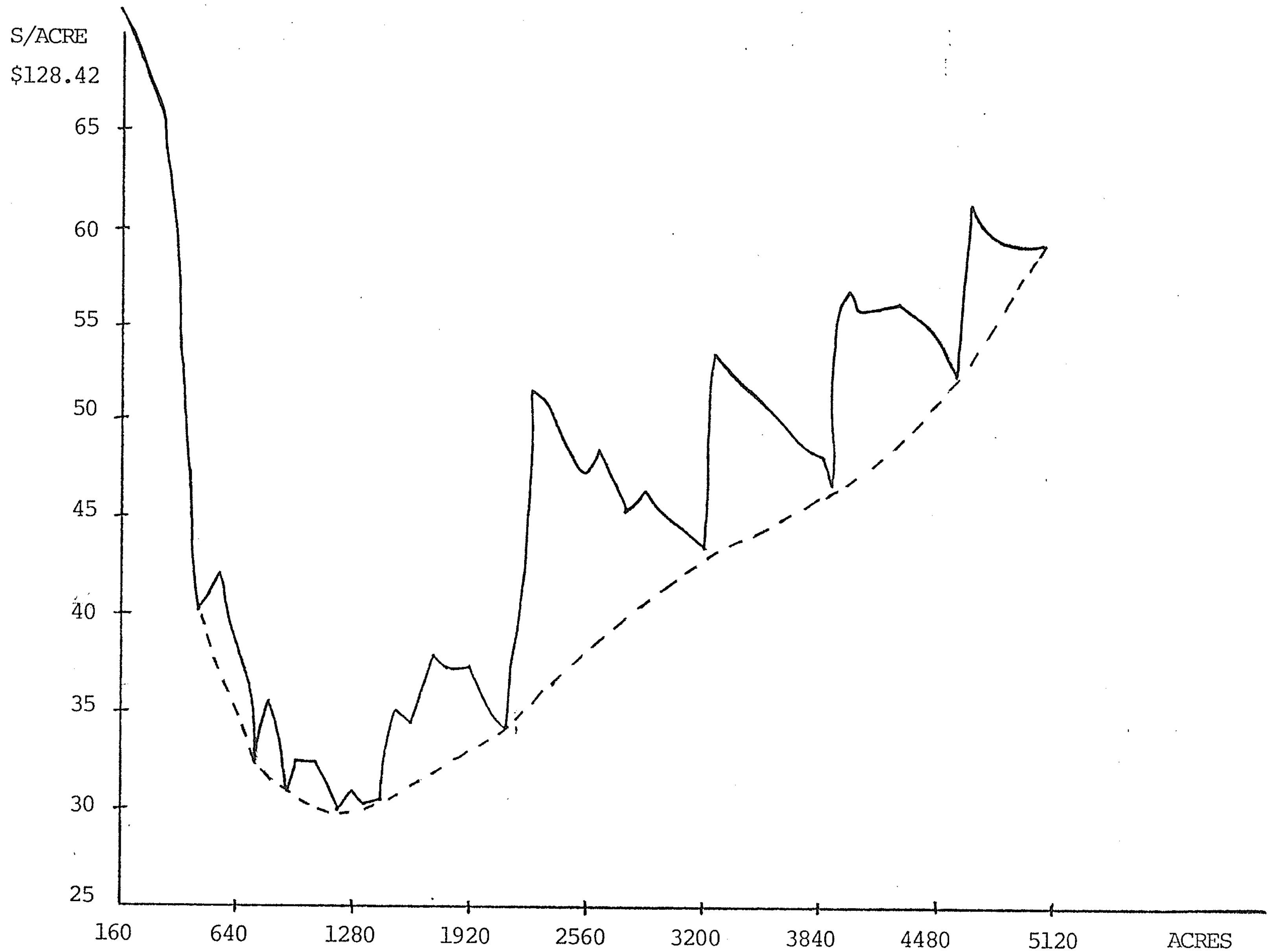

Figure 11: Estimated Long-Run Cost Curve

The average cost curve as indicated in Figure 11 over the range of the land base evaluated was characterized by a very rapid decline at the outset, then a rapid increase (although not as rapid as the rate of decline) as the land base increased.

The rate of these changes varied at the outset as would be expected. However, as the land base increased the rate of change (eg. increasing first at a decreasing then an increasing rate) did not occur with the expected regularity.

Although the rate of increase did show a greater variation than expected, nonetheless costs did increase, and in fact the ranges in costs between the acreages indicated in Table XII were as expected and are presented in Table X.

Table X

Average Cost Ranges Within The Selected Land Base

Range (Acres)	Range (Average Cost/Acre)
560 - 960	\$30.96 - \$83.10
1,040 - 1,440	\$29.68 - \$77.31
1,520 - 1,920	\$36.55 - \$64.58
2,000 - 2,400	\$41.31 - \$61.48
2,480 - 2,880	\$47.07 - \$56.85
2,960 - 3,360	\$50.56 - \$62.73
3,440 - 3,840	\$52.74 - \$63.71
3,920 - 4,320	\$55.77 - \$68.92
4,400 - 4,800	\$60.36 - \$74.66
4,880 - 5,280	\$63.68 - \$76.74

The model selected 382 different machinery systems over the range examined. The distribution of these selected machinery systems over this land base would by and large account for the variability in costs within any one size group.

As can be seen from Figure 12 and from Table XI, the largest number of alternative machinery systems occurred between the acreages of 560 to 1,520 acres. 234 machinery systems or 61.3 percent of the total systems generated by the model were in this range. 20.4 percent of the total systems or 78 machinery systems fell into two specific area; from 160 to 400 acres and 2,240 to 5,040 acres.

There were fewer machinery systems that fit the requirements of the model over the smaller and parts of the larger acreage. In fact as Table XII indicates 63 percent of the observations had two machinery systems. This is a reversal of the range where most of the alternatives in the machinery systems are. This kind of information provides an indication of the flexibility available in machinery selection, at least within the data base utilized in this study.

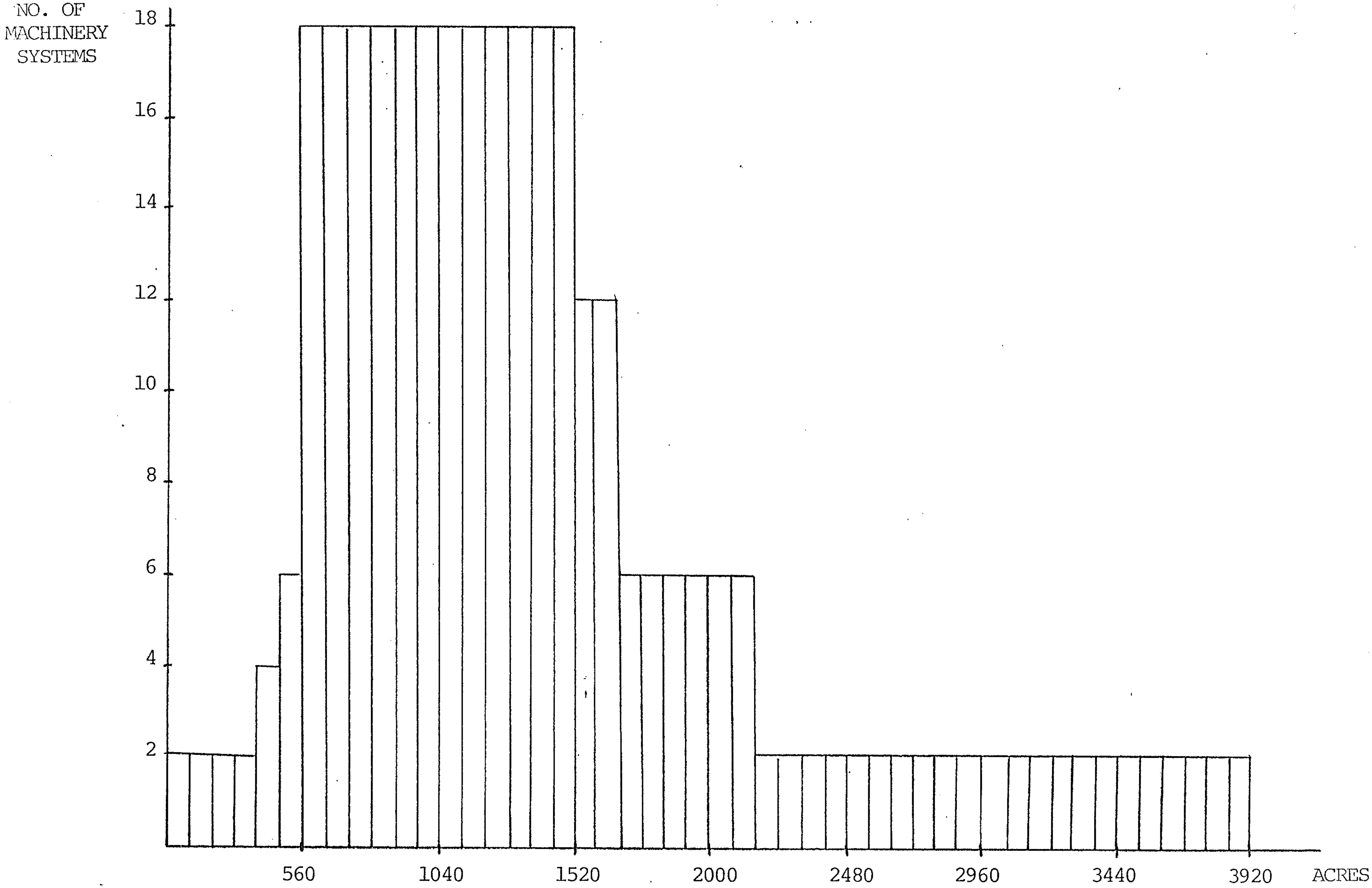

Figure 12: Distribution of Machinery Systems Feasible by Acreages
From 160 - 5,040 Acres

Table XI

Machinery Systems
Statistical Summary of Their Distribution

	Number of Occurrences	%	Total Observations[36]	%
Class 2[35]	39	63.0	78	20.4
Class 4	1	1.6	4	1.0
Class 6	7	11.3	42	11.0
Class 12	2	3.2	24	6.3
Class 18	13	20.9	234	61.3
	62	100.0	382	100.0

5.2 MACHINERY SYSTEMS

The results were also accumulated in order to show the range of acreage over which a one-man system (PTO and SP)[37], one machinery system with two men, and two machinery systems with two men operated in this model and their comparable costs (see Figures 13, 14 and 15). It should be noted that all machinery systems selected were from one data base (see Appendix B for details).

5.2.1 ONE SYSTEM - ONE MAN

The single machinery system with one man was available over a land base of 160 to 1,200 acres. The average cost of this system ranged from a minimum of $36.21 per acre at 1,200 acres to a maximum of $139.01

---

[35]Classes indicate the number of machinery system alternatives available.

[36]Total Observations = number of occurrences x the class number (eg. 2x39=78).

[37]PTO = Power Take-Off, SP = self-propelled.

per acre at 160 acres. However, if the average cost per acre is considered in the range of 480 to 1,200 acres, the range in the average cost per acre was considerably reduced ($36.21-$55.20).

Over the land base of 160 to 1,200 acres as seen in Figure 13., the average cost of a power take-off system ranges from $34.85 to $128.42 per acre, while the average cost of the self-propelled machinery system ranges from $32.71 to $139.01 per acre.

Although average costs were still declining over the range that this system operated, there apparently was not a machinery system available up to 1975 that would allow, relative to the constraints of the model, any further selection of a one man, one machinery system.

5.2.2 ONE MACHINERY SYSTEM - TWO MEN

The average cost per acre of a machinery system utilizing two men is substantially lower, with the self-propelled system, ranging from $34.96 to $61.87 per acre; while the PTO system ranged from $29.68 to $61.87 per acre. The land base over which a single system with two men was operational was from 400 to 1,520 acres. It was with this type of a system (one machinery system, two men) that the lowest point on the long-run average cost curve ($29.68) was reached.

The last system that will be presented is the two men, two machinery system. This system was available on a land base of 400 to 2,240 acres and ranged in cost from $42.10 to $64.48 per acre for the PTO system to $43.63 per acre to $102.43 per acre for the self-propelled system. Figure 15 displays the average cost of these two systems. Note the considerably greater volatility in the average cost per acre compared to the two other systems presented previously.

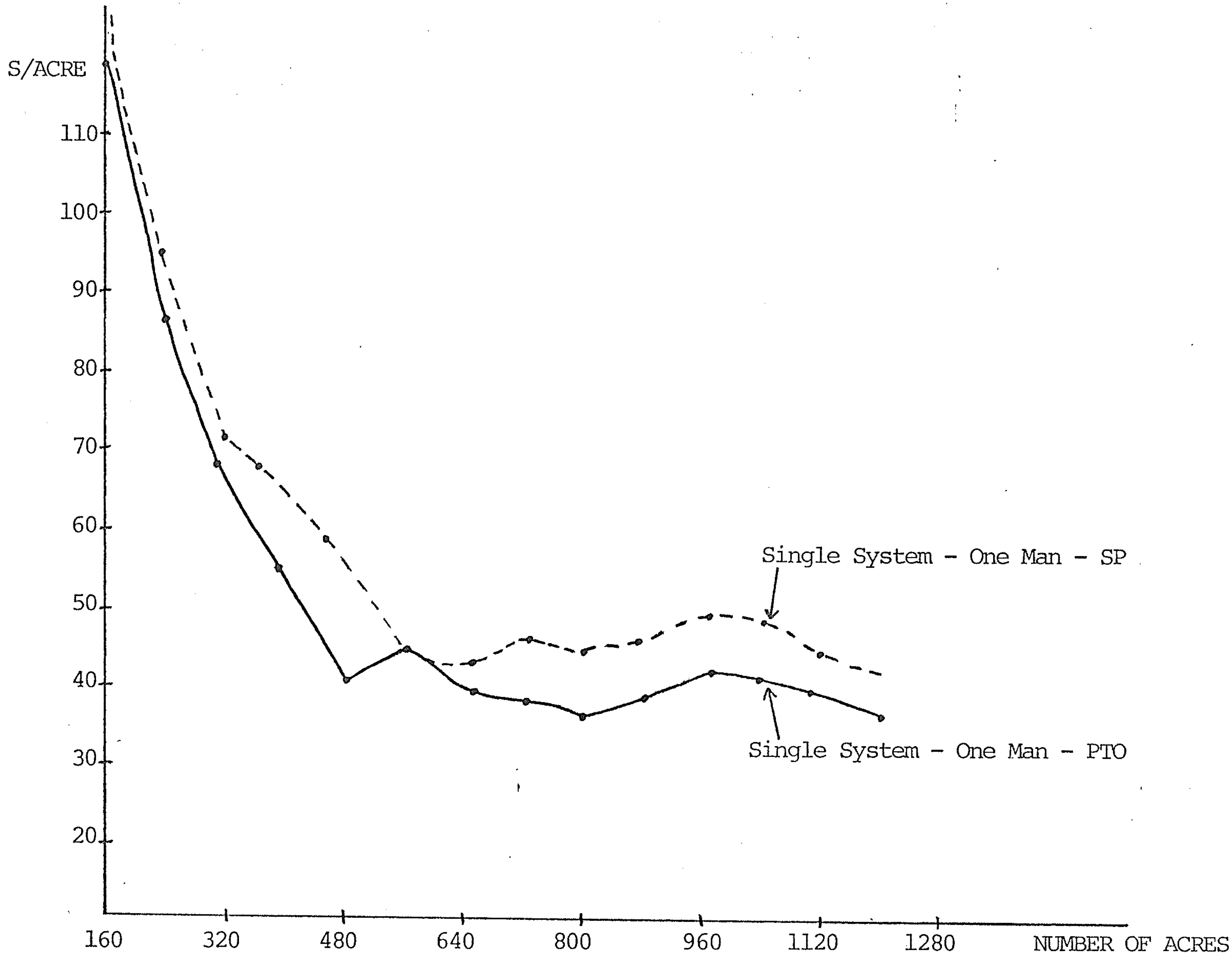

Figure 13: Average Cost Per Acre of a Single Machine System Utilizing One Man

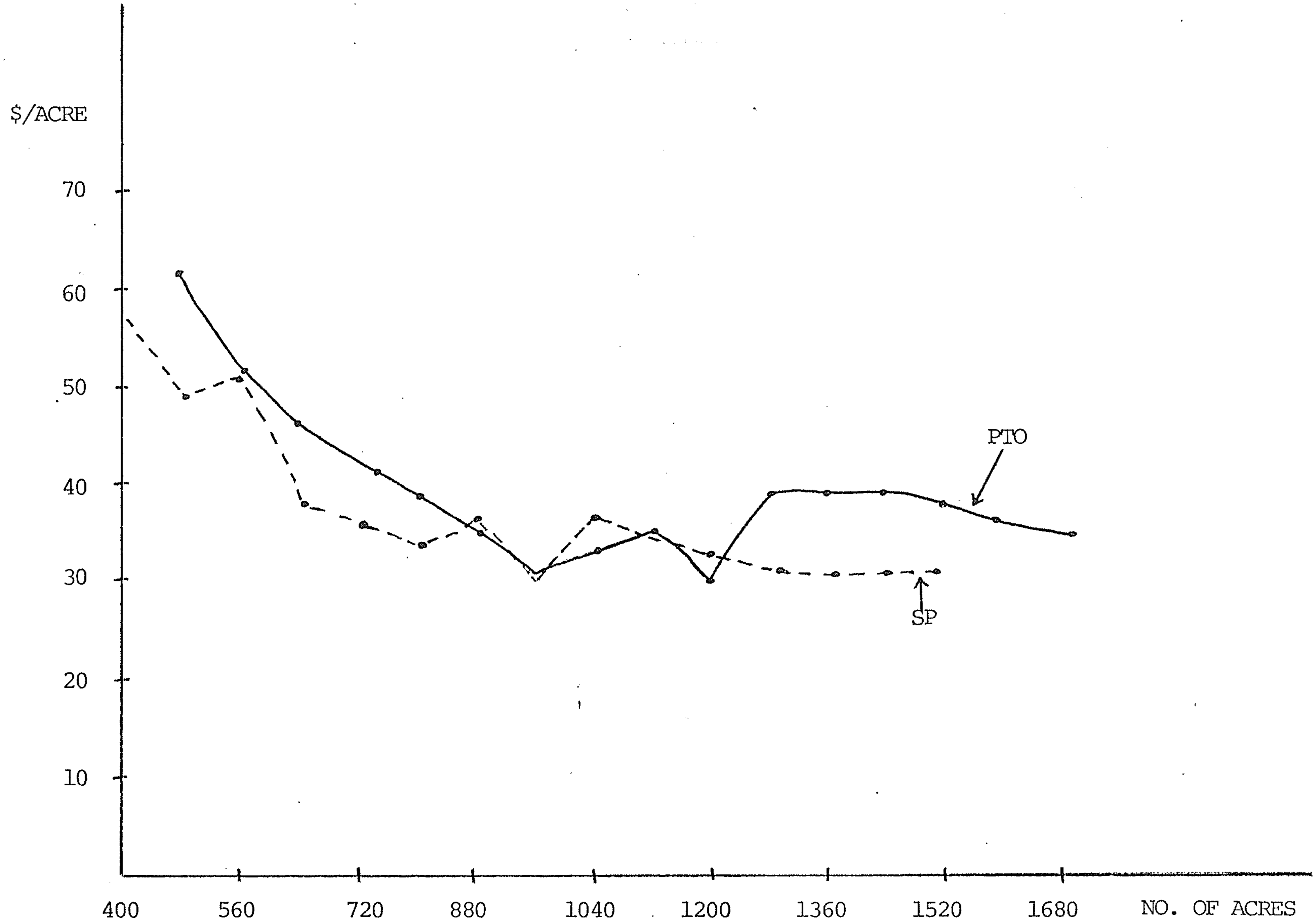

Figure 14: Average Cost Per Acre of a Single Machine System Utilizing Two Men

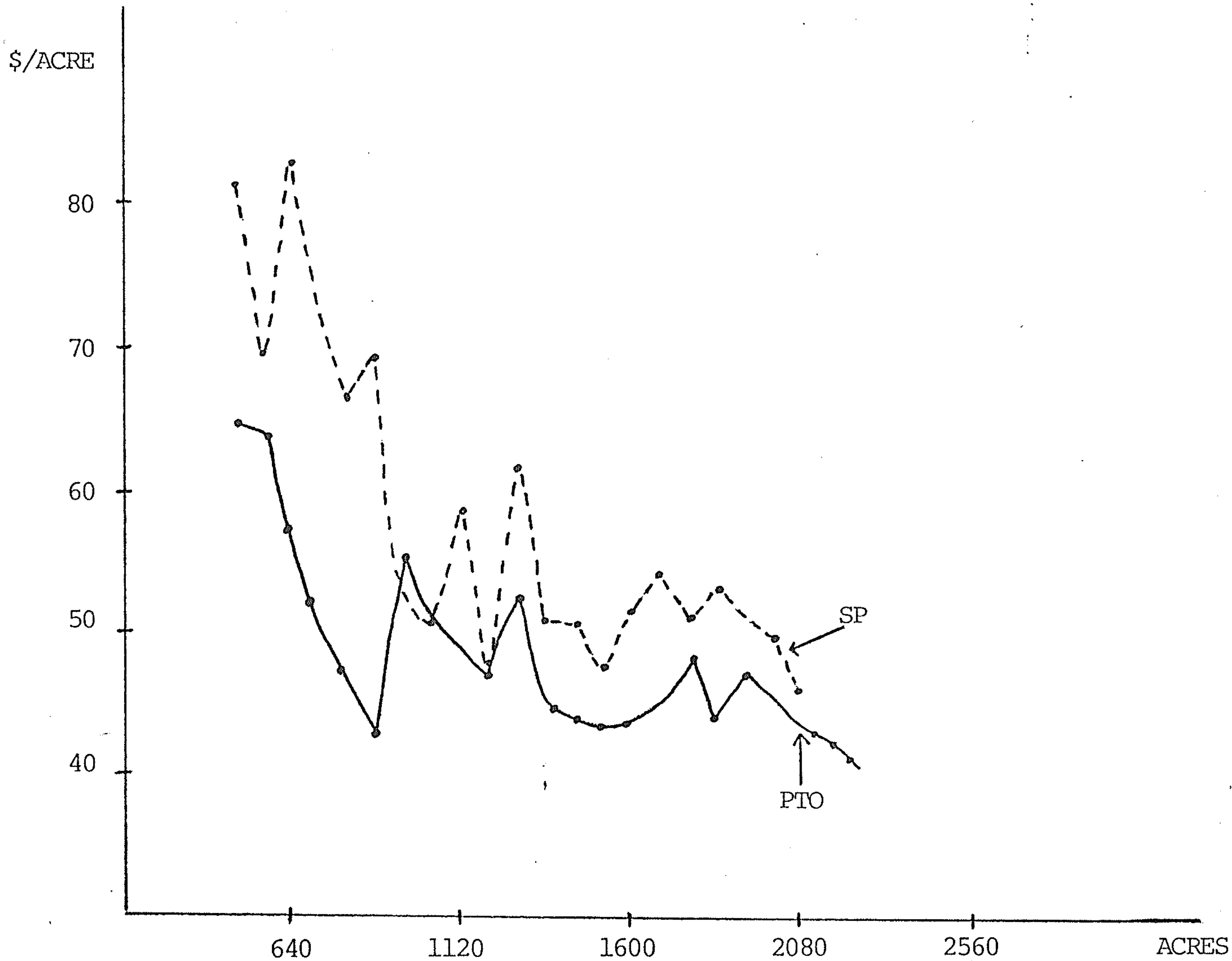

Figure 15: Average Cost/Acre - Two Systems - Two Men

5.3 DISCUSSION OF RESULTS

The constraint of whole machine increments and the 80 acre segments in the model contributed to the 'saw-toothed' type of average cost function. The very rapid decline in average costs particularly over the land base 160 to 480 acres would indicate that there was considerable excess capacity in the system. In turn this can be related to the lack of alternative machinery systems small enough to operate profitably on smaller farms. As this study analyzed only the measurement of physical capacity together with the associated new costs (in 1975), it is understandable why there would be a strong demand for used machinery on a smaller land base.

Table XII provides an indication of the range where the selected machinery systems cost is minimized and the use of capacity maximized. In this case, it would be at 1,200 acres.

Table XII

Changes In Average Cost (Annual)
(Selected Land Base - 1975 Dollars)

Acres	Average Cost Per Acre	Incremental Change[38] In Average Cost
	------------in dollars------------	
560	42.65	-
800	33.91	13.52
960	30.99	14.67
1,200	29.68	18.33
1,520	36.55	32.99
2,160	44.40	45.01
3,200	52.77	54.92
3,920	55.77	57.96
4,640	60.40	62.84

[38] The incremental change was calculated by using 560 acres as a base for the other calculations in the following manner.
ex. Incremental Cost = [(acres (4) x average cost (4)] - (acres (1) x average cost(1))] / acres (4) - acres (1)
$18.33 = [(1,200 x $29.68) - (560 x $42.65)] / (1,200 - 560)

Although the greatest selection of alternative machinery systems occurred over the range of 560 to 1,520 acres, the greatest variability in the average cost for the basis of the lowest costing alternatives occurred when there was a reduction in the number of machinery systems that satisfied the constraints of the model. The primary reason for the greater variability in the average cost can be attributed to excess capacity of the machinery systems. Everytime a change in the machinery system for a selected acreage occurred, there was a large increase in the average cost. Consequently, by implication, as the size and number of machinery systems increase in response to increased land base, the size of the increases in land bases have to increase in order to reduce the increase in average costs. An example of this can be seen in Table XIII.

Table XIII

Selected Average and Incremental Costs
Per Acre For 2,160 - 3,200 Acres

Acres	Average Cost	Incremental Cost
2,160	$44.40	-
2,320	$52.16	$156.92
3,040	$50.89	$ 46.80

Expanding a farm operation (excluding land cost) from 2,160 to 2,320 acres would cause the average cost to increase by $7.76 per acre and the incremental cost to increase by approximately $156.92 per acre. Expanding from 2,320 acres to 3,040 acres would decrease the average cost increase by $1.27 per acre and the incremental cost by $110.12 per acre. If expansion would take place from 2,160 acres to 3,200 acres, average cost would increase $6.49 per acre and the incremental cost would increase by

$66.82 per acre. Consequently, the incentive is to acquire land in larger blocks in order to offset the higher cost of the existing machinery system.

This would indicate that although expansion to these larger sized farm units is feasible, the economic decision framework has changed from minimizing costs to maximizing volume. The worthiness of making decisions in these regions of size is dependent on many variables that cannot be analyzed in this study. However, the major factor contributing to a decision in this size range will have to be the market price for the commodity produced.

5.3.1 ONE SYSTEM - ONE MAN

Although the average cost per acre generally decreased over the range of 160 to 1,200 acres, the greatest change occurred at the point where incremental cost was -$26.57 for the PTO system and -$28.20 for the self-propelled system. The manner in which incremental cost behaved (as indicated by Table XIV), first decreasing, then increasing and then decreasing again, was caused by the capacity of the machinery system. As a new system was required to satisfy the constraints of time, the incremental cost increased rapidly, indicating excess capacity in the system.

It is useful to view some selected changes over the 160 to 1,200 acre range. The first major change occurred at 480 acres when the smallest possible machinery system reached its' capacity. The incremental cost between 160 and 480 acres was -$4.05. The second major shift occurred between 480 and 1,200 acres. From this point onward it was not possible to select a one man, one machinery system. The incremental cost between

480 and 1,200 acres was $42.61 and indicated when comparing to the average cost of $42.32 per acre, costs were near the minimum.

5.3.2 ONE SYSTEM - TWO MEN

This system had a range of 1,280 acres (from 400 to 1,680 acres). Although not much more than the single man system (80 acres), it provided the greatest amount of machinery system selection over all types.

Table XIV

Single Machine System - One Man

--------dollars per acre-------

	PTO		Self-Propelled	
Acres	Average Cost	Incremental Cost	Average Cost	Incremental Cost
160	128.42	-	139.01	-
240	86.74	3.38	93.92	3.74
320	65.92	3.46	71.40	3.83
400	53.44	3.52	65.55	42.17
480	40.11	-26.57	55.20	3.41
560	44.27	69.23	44.57	-28.20
640	38.57	1.17	42.63	8.96
720	38.10	34.34	46.74	88.04
800	36.29	20.07	44.20	23.94
880	37.81	53.09	45.34	64.00
960	41.51	82.18	48.64	84.00
1,040	41.51	41.51	48.15	38.61
1,120	40.36	25.41	46.58	26.17
1,200	42.32	69.76	48.72	78.68

As indicated earlier, there were 382 machinery systems selected by the model. Seventy-seven systems were selected in this 400 to 1,680 acre range. It could be construed that this great flexibility in available machinery systems is directly related to the type and size of farming activity actually on-going.

Table XV provides an indication of the changes in the incremental cost over a selected acreage. With the two man single machinery system the self-propelled combine was most competitive over this range. As time available relative to machine capacity become constraining, it was most economical to utilize the self-propelled system. Although Table XV only provides an indication of the change in incremental cost between the acreages specified, a calculation made of the incremental cost between 480 to 1,200 acres and 480 to 1,520 acres for the self-propelled system showed the difference between the two ($25.87 at 1,200 acres and $40.72 at 1,520 acres). This would indicate a reduction in cost efficiency for this type of system.

The PTO system showed the smallest incremental cost increase between 480 to 1,200 acres at $8.27. The incremental cost to increase from 480 to 1,680 acres was $31.66. In most instances for the PTO as well as the SP systems the incremental cost was below the average cost per acre.

Table XV

Single Machinery System - Two Men

--------dollars per acre---------

	Self-Propelled		PTO	
Acres	Average Cost	Incremental Cost	Average Cost	Incremental Cost
480	48.60	-	61.80	-
640	45.21	35.04	47.06	2.84
800	41.99	29.11	38.65	5.01
960	38.87	23.27	30.99	7.31
1,200	34.96	19.32	29.68	24.44
1,520	43.21	74.15	44.32	99.22
1,680	-	-	40.27	1.80

The major cost differences between the SP and PTO systems can be attributed to the extra tractor required in the PTO system. Otherwise, the costs between these two were very similar.

5.3.3 TWO SYSTEMS - TWO MEN

Two machinery systems with one man each became an alternative machinery system as early as 400 acres. It was not until 1,680 acres that the model selected this type of a system as a reasonable alternative to the other types. Table XVI indicates on a selective basis the changes in average and incremental cost. As with the other examples the average cost and incremental cost decline significantly from the initial availability of the system until the system is no longer available. In this particular system the PTO version was the lower costing.

Table XVI

Two Machinery System - Two Men

-------in dollars per acre-----

	PTO		Self-Propelled	
Acres	Average Cost	Incremental Cost[39]	Average Cost	Incremental Cost[39]
480	64.48	-	86.40	-
960	55.07	45.66	53.10	19.80
1,280	52.28	44.96	69.02	58.59
1,760	48.34	42.29	54.11	42.00
2,240	47.71	43.14	53.09	44.00

---

[39] Incremental cost is calculated in this instance using the change from 480 acres as a basis rather than the incremental changes as in the other tables.

Chapter VI

MODEL LIMITATIONS

6.1 LIMITATIONS - ENVIRONMENTAL CONSTRAINTS IN THE MODEL

As can be seen by the graphs and tables, the results of this study were consistent with the hypotheses presented in the chapter on economic theory.

It has been shown by this study that economies of size (machinery) do exist. Given that all of the machinery used in the study were available for purchase over the time period examined, it is felt that economies of size respecting machine systems not only exist on the basis of the constraints built into this model, but in fact exist in agriculture. It should be noted that the costs and sizes of machinery used in this study were those available in 1975. As technology improves the minimum cost operation may increase in size.

Furthermore, it should be recognized that two other constraints of this model are environmental (temperature and precipitation) and soil type. The soil type used was a fairly heavy clay to clay loan, common through most of the Red River Valley. However, to the west of the valley, soil type changes and will affect the average cost curve. Temperature, precipitation and drainage are other factors that will cause the average cost curve to shift. As only one soil type and one set of environmental constraints were used, the validity in terms of magnitudes are limited to the constraints.

6.2 MACHINERY SELECTION

Although the model has the flexibility to select many alternative machinery systems, it cannot relate the cost of the selected system to the returns from producing the commodity. Furthermore, although the model has the capacity to calculate machinery requirements, it can only select from those machines that are available in the data set. Thus, it is only able to indicate a comparison of requirement and availability if the implement is available. The exception to this is for tractors where an adjustment is made if a tractor size is unavailable. With some minor modification, both technical requirements and available machinery could be printed.

Due to the limitations of machinery size, both the small farm size and the large farm size where the machinery options are limited to less than 18 choices, there will be an overestimation of risk. In other words, the risk of not harvesting the crop will be less than one year out of ten.

6.3 CONSIDERATIONS OF OTHER CROPS AND TIME CONSTRAINTS

The model was only run for a single crop type, wheat. There is consideration built into the model to allow for 'N' number of crops. However, for the purpose of this study, it was felt one crop type would suffice.

The time constraint as indicated by the environmental conditions is flexible in the model as well. The model is capable under continuous operation of evaluation 'N' time elements. It is felt that each change will effect the cost curve.

6.4 VARIABLES

There are several variables that have been constructured on the basis of the 'best information available'. Therefore, one has to consider them as being subjective regardless of how good they may be. Some of these variables are:

(1) Tractor Speed - It was assumed that a reasonable rate of speed was 4 m.p.h. Changing this to 4.5 or 5 m.p.h. would change the minimum point of the cost curve.

(2) Charge for Labor - Management was assessed a cost of 5 minutes for each hour of hired labor thereby restricting the available labor to twelve people. The cost of management time was assumed to be $15 per hour and the cost of hired labor was $2 per hour in this study. There are at least two alternative scenarios that could be created.

(a) Restrict labor more.

(b) If management is not operating machinery, there would not be a loss of available hours charged to the machinery system.

6.5 CROP YIELD AND OTHER INPUTS

The crop yield and other inputs used in this study were not based on actual averages. The yield was based on experimental data and the inputs required for the crop other than the machinery costs, maintenance, and operating costs were not considered. Were they to be considered most certainly the average cost curve would shift upward. However, in measuring the economies of size in machinery systems for cereal grain farming, it was felt that the most significant feature was the determination of the maximum load a machinery system would have to bear rather than the other costs.

Recognition should be given to some of the restrictions put on the model in order to simplify the analysis. As the model nor this thesis was intended to assist in determining producer purchase versus rental or any other machinery option, these were not included in this thesis. Furthermore, there is an implicit assumption of continuous cropping due to the method of evaluation. The implication, therefore, is that machinery costs are allocated to those acres cropped, rather than total acres owned.

6.6 FURTHER RESEARCH REQUIREMENTS

As this model was constrained to specific conditions, it would be of interest to see the extent to which economies of size change with lighter soil types, greater or less degree days, or precipitation.

The costs and machinery used in this model are for 1975. Technology and costs have changed over the last 6 years. It would be useful for decision-makers and economists to assess the changes over the last 6 years if this model were to be updated.

Application of the results generated by this model into a farm cash flow analysis would greatly improve the understanding of the on-going activities in agriculture today, at least in terms of the effect of capital purchases on cash flow.

The concept used to construct this model can be used to evaluate all types of agricultural enterprises. Information on economies of size and scale in Canadian agriculture is extremely limited and studies such as this provide a valuable tool in assessing the social and economic impact of inevitable policy issues.

6.7 IMPLICATIONS AND CONCLUSIONS

The primary objectives of this study were to:

- determine the presence or absence of size economies respecting machinery for cereal grain farms in Manitoba.
- analyze the magnitude of those economies of size that may exist.
- develop a model which may be used in the implementation of research into economies of size in cereal grain farms in other parts of the prairies and in other agricultural enterprises.

The objectives of the study have been accomplished. It has been determined based on 1975 data that in fact economies of size respecting machinery do exist for cereal grain farms in the Manitoba Interlake. The minimum average cost for machinery systems was determined to be $29.68 per acre (1975 dollars) at 1,200 acres (cultivated).

The range in the lowest costing alternatives selected by farm size by the model was from $128.42 per acre at 160 acres to $65.37 per acre at 5,040 acres. Within this broader range there were a multitude of average cost curves for any given size of farming operation. The multitude of alternatives available to the producer, although providing a great deal of flexibility for producer decisions, also adds to the problem of making the best decision.

As this model was developed on the basis of machinery's physical capacity, not cost, it is general enough and suitable for adaption to any region provided the constraints of temperature, precipitation, soil type, and drainage are relative to the region being evaluated.

The implications of the results of this model and the conclusions drawn from it could be far reaching. For the first time there is now an economic basis that can be used as one criteria for developing policy and programs relating to economic efficiency of machine systems and farm size in agriculture.

At the outset it was indicated that farm size from 1966 to 1976 had increased from 404 to 553 acres. Capital to labor ratios were continuing to increase and as shown by this study will increase even more. It is not expected that the average farm size will increase to 1,200 cultivated acres in the immediate future. However, it does indicate that if government programs work against or are unaware of this trend, the result may be costly and lead to ineffective program results.

Financial requirements to operate in the environment that has been presented in this study can be expected to increase more than what has been seen to date. Inadequate preparation today could have disastrous consequences in the future.

It is possible now to separate and evaluate the cost of implementing programs with overriding social considerations such as the 'family farm'. Hopefully, the social versus economic cost of producing agricultural products can be more readily evaluated than at any time in the past, but this is just a beginning, not the end.

BIBLIOGRAPHY

American Society of Agricultural Engineers, Agricultural Engineers Yearbook, (ASAE, St. Joseph, Michigan, 1971).

Bruce, J.P. and Clark, R.H., Introduction to Hydrometeorology, (Pergamon of Canada Ltd., 207 Queen's Quay West, Toronto), 1966.

Donaldson, Graham F., Farm Machinery Capacity, Royal Commission On Farm Machinery, Study No. 10, (Ottawa: Queen's Printer for Canada, 1970).

French, Ben C., Firm Efficiency Analysis, (Paper presented to the Joint Annual Meeting of the American, Canadian, and Western Agricultural Economics Association, August, 1977).

MacHardy, F.V., Economics of Farm Machinery Utilization, Brief to the Royal Commission on Farm Machinery, Edmonton, Alberta, 1967.

Madden, J. Patrick, Economies of Size in Farming, (U.S.D.A. Agricultural Economics Report 107, 1967).

Principles and Practices of Commercial Farming, University of Manitoba.

Racz, G.J., Effect of Nitrogen Fertilizer and Water Supply On Yield, Wheat and Barley, 1975.

Rigaux, L.R. and Singh, R.H., Benefit-Cost Analysis of Agriculture Drainage Expenditures, (A report prepared for the Committee to study drainage policies in Manitoba), March, 1973.

Shaykewich, C.F. and Zwarich, M.A., Relationship Between Soil Physical Constants and Soil Phusical Components of Some Manitoba Soils, (Canadian Journal of Soil Science, Vol. 43, 1968).

Statistics Canada, 1971 Census of Canada, Agriculture - Number and Area of Census Farms, Advance Bulletin No. 96-727 (aa-10), (Ottawa: Information Canada, April, 1972).

Statistics Canada, 1971 Census of Canada, Agriculture - Farm Machinery and Equipment, Advance Bulletin No. 96-720 (aa-3), (Ottawa: Information Canada, August, 1972).

Statistics Canada, 1976 Census of Canada, Agriculture - Number and Area of Census Farms, Farm Machinery and Equipment, (Ottawa: Information Canada, August, 1977).

Tweeten, Luther G., Theories Explaining The Persistence of Low Resource Returns In a Growing Farm Economy, (American Journal of Agricultural Economics, Vol. 51(4), pp. 798-817).

Viner, Jacob, Cost Curves and Supply Curves, (Z. National Okanomie, Vol. 3, Reprinted in Boulding, Kenneth E. and Stiegler, George J. Eds., AEA Readings In Price Theory, Vol. 6, Richard D. Irwin, Chicago, 1952).

Watson, Donald S., Price Theory and Its' Uses, (Houghton Mifflin Company, Boston, Mass., 3rd edition, 1972).

Appendix A

CALCULATION OF PRECIPITATION AND TEMPERATURE VARIABLES

PRECIPITATION

As was indicated in the text (page 33) in order to determine the size and type of machinery systems suitable for existing environmental conditions, an assessment of temperature ranges and soil workability was required. An index called the antecedent precipitation index (API) was used to determine firstly the workability of the soil, and secondly the shear strength of the soil and thus the draft requirements of the implements comprising the various machinery systems.

$$API_t = .84(API_{t-1} + P_{t-1}) - K \quad (1)$$

Where: API_t = index level of day t

API_{t-1} = index level of day t-1

P_{t-1} = precipitation level of day t-1

K = evapotranspiration coefficient for a particular month

In order to start the index it was necessary to assume that the soil was totally saturated. Index values less than or equal to 0.3 were considered to indicate a dry soil. Index values greater than 0.3 but less than or equal to 0.5 indicates a wet but workable soil condition. While index values greater than 0.5 were considered an indication of non-workable conditions.

Table A1 to A3 indicates the average API values by month calculated for the three test stations, Eriksdale, Arborg and Stonewall for the years 1961-1974, inclusive.

Table A1

Average Monthly API Values (1961-1974)

Eriksdale

Year	May	June	July	August
1961	-0.22	-0.27	-0.34	-0.81
1962	-0.04	-0.08	-0.26	+0.73
1963	-0.04	+0.95	-0.01	-0.71
1964	-0.15	-0.01	-0.02	-0.44
1965	+0.20	+0.04	-0.12	-0.52
1966	-0.10	-0.13	-0.12	-0.63
1967	-0.27	-0.02	-0.10	-0.62
1968	+0.19	+0.05	-0.06	-0.27
1969	-0.13	+0.19	-0.14	-0.12
1970	+0.02	+0.11	-0.08	-0.68
1971	-0.27	+0.10	+0.50	-0.55
1972	-0.05	+0.06	-0.30	-0.51
1973	-0.03	+0.67	-0.46	-0.28
1974	+0.32	-0.15	-0.43	-0.45
Monthly Average	-0.04	+0.11	-0.14	-0.42

Source: Derived from data provided by Canada Meteorological Services, Environment Canada, utilizing API formula.

Table A2

Average Monthly API Values (1961-1974)

Arborg

Year	May	June	July	August
1961	-0.29	-0.29	-0.23	-0.72
1962	+0.07	+0.08	-0.08	-0.12
1963	-0.01	+0.65	-0.20	-0.31
1964	-0.09	+0.17	-0.40	-0.42
1965	+0.34	+0.07	-0.13	-0.75
1966	-0.03	+0.05	+0.21	-0.69
1967	-0.27	-0.07	-0.26	-0.46
1968	+0.17	+0.05	+0.55	-0.19
1969	-0.13	+0.36	-0.27	-0.45
1970	-0.03	-0.11	+0.20	-0.68
1971	-0.23	+0.21	+0.35	-0.58
1972	-0.15	0.0	-0.05	-0.70
1973	-0.17	+0.55	-0.25	-0.18
1974	+0.12	-0.04	-0.3	-0.44
Monthly Average	-0.05	+0.12	-0.06	-0.48

Source: Derived from data provided by Canada Meteorological Services, Environment Canada, utilizing API formula.

Table A3

Average Monthly API Values (1963-1974)

Stonewall

Year	May	June	July	August
1963	+0.64	-0.24	-0.13	-0.75
1964	+0.33	+0.17	+0.38	+1.15
1965	+0.08	+0.51	-0.20	-0.45
1966	-0.08	+0.32	+0.02	-0.53
1967	+0.08	+0.09	-0.16	-0.46
1968	0.0	-0.13	-0.18	-0.67
1969	-0.24	-0.16	-0.04	-0.44
1970	+0.19	-0.04	+0.74	+0.56
1971	+0.07	+0.32	+0.21	-0.24
1972	+0.08	+0.33	+0.26	-0.70
1973	-0.06	+0.12	+0.19	-0.59
1974	-0.16	-0.02	-0.17	-0.41
Monthly Average	+0.08	+0.11	+0.08	-0.29

Source: Derived from data provided by Canada Meteorological Services, Environment Canada, utilizing API formula.

As can readily be seen the average monthly values are well within the range indicating a dry soil condition.

The 'K' component of the API reflects the rate of evapotranspiration for a particular month. This is directly related to an estimated vegetative cover. The following table is an indication of the calculations required to obtain the 'K' component.

Table A4

Calculation of Evapotranspiration Coefficients

Items	April	May	June	July	August
1. Potential Evaporation 1/ (total inches/month)	1.56	0.2292	5.61	-1.50	-17.4
2. Average Potential 2/ Daily Evaporation (in.)	0.05	0.007	0.19	-0.05	- 0.56
3. Ratio: Evapotranspiration of soybeans/ open pan evaporation	0.30	0.30	0.34	0.58	0.81
4. Calculated Evapo- 3/ transpiration (inches/ month)	0.468	0.069	1.91	-0.87	-14.1
5. Calculated Average 4/ Daily Evapotranspiration (K)	0.0151	0.002	0.06	-0.03	-0.45

1/ Potential Evaporation = 0.61 + 1.12 API_t + 0.83 AV_{st}; where AV_{st} = average rainfall of stor 's', originating on day 't'.

2/ Average Potential Daily Evaporation = total inches per month/number of days in month.

3/ Calculated Evapotranspiration = total inches per month x ratio, evapotranspiration of soybeans/open pan evaporation.

4/ Calculated Average Daily Evapotranspiration = total inches per month x ratio evapotranspiration of soybeans/open pan evaporation/number of days in month.

From this starting point the data was accumulated into tables which specified the number of days the API indicated workable and non-workable conditions, based on precipitation only.

Table A5

Number of Working Days [API $\leq$ 0.3]
(Days/Total Days Observed)

	Eriksdale	Arborg	Stonewall	Winnipeg
May	365/434	357/434	314/434	2204/2573
June	309/420	309/420	312/420	1659/2490
August	389/434	389/434	345/434	2261/2573
September	388/420	384/420	385/420	2205/2490
October	410/434	403/434	416/434	2443/2573

Table A6

Number of Working Days [API $>$ 0.3 $\leq$ 0.5]

	Eriksdale	Arborg	Stonewall	Winnipeg
May	38/434	46/434	49/434	168/2573
June	45/420	37/420	41/420	261/2490
August	16/434	17/434	26/434	125/2573
September	13/420	12/420	23/420	117/2490
October	14/434	12/434	11/434	49/2573

The above two tables indicate that the average number of field working days at the three Interlake locations in May was 27.8; June, 25.1; August, 28.1; September, 28.7; October, 30.1. For Winnipeg the average number of field working days was: May, 28.6; June, 23.1; August, 28.7; September, 28.0; October, 30.0.

TEMPERATURE

In order to be able to correctly determine the number of days available for seeding, crop maturation and harvesting, both temperature and soil moisture conditions must be acceptable at the same time. Consequently, Tables A7 to A9 were constructed with the following criteria:

(a) Starting Date = minimum daily temperature of at least 32 degrees Fahrenheit for 5 consecutive days and an API of less than or equal to 0.5.

- and -

(b) Killing Frost = minimum daily temperature of 27 degrees Fahrenheit and an API value less than or equal to 0.5.

Table A7

Earliest Starting Dates for Field Operations
(Based On Temperature and API Values)

Year	Eriksdale	Arborg	Stonewall
1961	May 19	May 18	May 4
1962	May 10	May 17	April 24
1963	May 10	May 10	May 7
1964	May 1	May 1	May 1
1965	May 4	May 4	May 10
1966	May 11	May 15	May 10
1967	May 22	May 22	May 22
1968	May 22	May 12	May 12
1969	April 18	May 4	April 17
1970	April 25	May 14	April 25
1971	May 3	June 2	May 3
1972	May 1	April 25	April 26
1973	May 5	May 21	May 17
1974	May 5	May 7	May 7

Source: Derived from data provided by Canada Meteorological Services, Environment Canada, utilizing API formula.

The above information was used to determine the earliest starting date for field operations.

Table A8

Earliest Data For 'Killing' Frost
(Based On Temperature and API Values)

Year	Eriksdale	Arborg	Stonewall
1961	Sept. 11	Sept. 14	Sept. 23
1962	Sept. 1	Sept. 19	Sept. 19
1963	Oct. 11	Oct. 11	Oct. 31
1964	Sept. 15	Sept. 14	Sept. 15
1965	Sept. 24	Sept. 15	Sept. 25
1966	Sept. 25	Oct. 17	Oct. 16
1967	Sept. 27	Sept. 9	Oct. 5
1968	Oct. 4	Oct. 4	Oct. 12
1969	Sept. 17	Sept. 28	Oct. 14
1970	Sept. 13	Sept. 13	Sept. 27
1971	Sept. 22	Sept. 17	Oct. 28
1972	Sept. 23	Sept. 8	Sept. 27
1973	Sept. 16	Sept. 15	Sept. 19
1974	Sept. 21	Sept. 12	Sept. 21

Source: Derived from data provided by Canada Meteorological Services, Environment Canada, utilizing API formula.

From the above table information was obtained that assisted in determining the date by which swathing of the crop had to be completed.

As a result of Tables A7 and A8 the season length could be determined. This is presented in Table A9.

Table A9

Crop Season Length
(In Days)

Year	Eriksdale	Arborg	Stonewall
1961	115	120	131
1962	108	116	120
1963	148	128	153
1964	137	119	118
1965	129	112	121
1966	132	114	155
1967	124	109	137
1968	118	135	146
1969	132	130	134
1970	122	119	128
1971	136	97	168
1972	134	126	146
1973	106	100	106
1974	128	120	123

At this point the information became sufficient in respect of seasonality to enable determination of the frequency of occurrences presented in Tables A5 to A8 (inclusive).

Appendix B

COMPUTER PRINTOUT - EX. 960 ACRES

DATA LISTING

The following is an explanation of the computer printout headings and how they should be read. What is presented in the form of the computer print out is an example of one out of sixty-two different farm sizes ranging from 160 to 5,040 acres.

Further to this there is also provided a data listing and an explanation of how it should be interpreted. The model and its' variables are not included. If more information is required, the author may be contacted.

EXPLANATION OF COMPUTER PRINTOUT - TITLE HEADINGS

1. Acres - the number of acres being evaluated.
2. Available Time - the total time (based on temperature and precipitation) available for seeding and swathing.
3. Required Time - the total required time (including management and maintenance time) to complete the seeding and swathing operations.
4. Maintenance Time - that amount of time lost from operating time.
5. Management Time - that amount of time required to supervise an employee during the seeding and swathing operations.
6. Disc Drill Size - expressed in number of feet.
7. Harrow Size - expressed in number of feet.
8. Swather Size - expressed in number of feet.
9. Men Required - 'N' designates the number of machinery systems. 'K' designates the number of men required. Ex. If 'K' equals O, then the number of men required are equal to 'N'. If 'K' is greater than O, then the number of men required are equal to 'K'.

10. Tractor H.P. Required – the tractor horsepower required for a particular machinery system.

11. Tractor 2 H.P. Required - same as (10), but for a second tractor if required.

12. Cost of Required Time - sum total of operating, depreciation, maintenance and management time.

13. Cost of Maintenance Time - calculated on the basis of machinery life in hours of actual operation and the cost of the machinery.

14. Cost of Management Time - management cost is $15 per hour.

15. Size of Combine Cylinder - expressed in inches.

The other title headings are primarily summations of the ones outlined above. However, there are some elements that comprise total system costs that have not been presented in the tables. Consequently, a direct addition of the individual cost components displayed will not equal the total system costs, or the average cost per acre.

Table B1

Computer Printout 960 Acres

COST OF ALTERNATIVE COMBINATIONS OF SYSTEMS WITH PTO COMBINES AND TRACTORS

ACRES	TOTAL AVAILABLE TIME	TOTAL COST OF REQUIRED TIME	TOTAL CCST OF MAINTENANCE TIME	TOTAL COST OF MANAGEMENT TIME	TRACTOR H.P. REQUIRED	TRACTOR2 H.P. REQUIRED	TRACTOR COST	TRACTOR2 COST	MEN REQUIRED N	K	TOTAL SYSTEM COST	
960	648.	1684.09	505.59	552.94	66.67	62.22	7713.00	7455.00	1.	2.	29751.87	30.99/ACRE
960	648.	1349.93	508.94	94.79	160.00	66.67	16885.00	7713.00	1.	2.	45383.15	47.27/ACRE
960	648.	2158.94	1393.85	429.29	75.00	0.0	8780.00	0.0	2.	2.	48754.37	50.79/ACRE
960	648.	1601.78	508.01	458.15	118.52	62.22	11300.00	7455.00	1.	0.	37222.07	38.77/ACRE
960	648.	1267.62	511.36	0.0	160.00	0.0	16885.00	0.0	1.	0.	39853.27	41.51/ACRE
960	648.	2076.63	1396.27	334.50	118.52	0.0	11300.00	0.0	2.	0.	57703.91	60.11/ACRE
960	648.	2470.75	315.71	824.77	62.22	60.00	7455.00	6235.00	1.	0.	32362.41	33.71/ACRE
960	648.	2136.60	319.06	366.62	160.00	29.63	16885.00	4382.00	1.	0.	45229.23	47.11/ACRE
960	648.	2945.61	1203.97	701.12	75.00	0.0	8780.00	0.0	2.	0.	52869.26	55.07/ACRE

COST OF ALTERNATIVE COMBINATIONS OF SYSTEMS WITH SP COMBINES AND TRACTORS

ACRES	TOTAL AVAILABLE TIME	TOTAL COST OF REQUIRED TIME	TOTAL CCST OF MAINTENANCE TIME	TOTAL COST OF MANAGEMENT TIME	TRACTOR H.P. REQUIRED	TRACTOR2 H.P. REQUIRED	TRACTOR COST	TRACTOR2 COST	MEN REQUIRED N	K	TOTAL SYSTEM COST	
960	648.	1709.87	542.75	552.94	66.67	62.22	7713.00	7455.00	1	2	37314.67	38.87/ACRE
960	648.	1349.90	485.93	94.79	160.00	66.67	16885.00	7713.00	1	2	52277.23	54.46/ACRE
960	648.	2204.53	1353.85	440.14	66.67	0.0	7713.00	0.0	2	2	47372.53	49.35/ACRE
960	648.	1627.56	545.16	458.15	118.52	0.0	11300.00	0.0	1	0	36595.04	38.12/ACRE
960	648.	1267.59	488.34	0.0	160.00	0.0	16885.00	0.0	1	0	46691.94	48.64/ACRE
960	648.	2122.22	1356.26	345.35	118.52	0.0	11300.00	0.0	2	0	58456.06	60.89/ACRE
960	648.	2496.54	352.86	824.77	62.22	29.63	7455.00	4382.00	1	0	38098.55	39.69/ACRE
960	648.	2136.56	296.04	366.62	160.00	29.63	16885.00	4382.00	1	0	53061.12	55.27/ACRE
960	648.	2991.20	1163.96	711.97	62.22	0.0	7455.00	0.0	2	0	50971.41	53.10/ACRE

LOWEST COST ALTERNATIVE FOR THE GIVEN ACREAGE

ACRES	TOTAL SYSTEM COST	MEN REQUIRED N	K	DISC DRILL SIZE	HARROW SIZE	PTO SWATHER SIZE	PTO COMBINE SIZE	SP COMBINE SIZE	TRACTOR H.P. REQUIRED	TRACTOR2 H.P. REQUIRED	CHISEL PLOW SIZE	
960	29751.87	1.	2.	18.	30.	12.	18.X40.	0 X 0	66.67	62.22	7.	30.99/ACRE

ACRES	AVAILABLE TIME	REQUIRED TIME	MAINTENANCE TIME	MANAGEMENT TIME	DISC DRILL SIZE	HARROW SIZE	SWATHER SIZE	MEN REQUIRED N	MEN REQUIRED K	TRACTOR H.P. REQUIRED	TRACTOR2 H.P. REQUIRED
960	336	335.73	29.83	6.32	18	30	12	1	2	66.67	0.0
960	336	335.65	27.10	0.0	32	36	12	1	0	118.52	0.0
960	336	317.86	30.14	24.44	8	24	12	2	0	29.63	0.0

ACRES	AVAILABLE TIME	COST OF REQUIRED TIME	COST OF MAINTENANCE TIME	COST OF MANAGEMENT TIME	DISC DRILL COST	HARROW COST	SWATHER COST
960	336	753.61	348.86	94.79	2595.	711.	1369.
960	336	671.30	351.27	0.0	6134.	799.	1369.
960	336	1540.28	158.97	366.62	1879.	616.	1369.

PTO COMBINE AND FALL WORK, REQUIREMENTS AND COSTS SEQUENCE 2

ACRES	AVAILABLE TIME	REQUIRED TIME	MAINTENANCE TIME	MANAGEMENT TIME	SIZE OF COMBINE CYLINDER	CHISEL PLOW SIZE	TRACTOR H.P. REQUIRED	TRACTOR2 H.P. REQUIRED	MEN REQUIRED N	MEN REQUIRED K
960	312	266.71	9.31	30.54	18.X40	7	62.22	60.00	1	2
960	312	298.16	3.29	0.0	22.X50	18	160.00	0.0	1	0
960	312	290.01	15.29	22.30	22.X50	7	75.00	0.0	2	0

ACRES	AVAILABLE TIME	COST OF REQUIRED TIME	COST OF MAINTENANCE TIME	COST OF MANAGEMENT TIME	PTO COMBINE COST	COST OF CHISEL PLOW
960	312	930.47	156.74	458.15	4480.	704.
960	312	596.32	160.09	0.0	8206.	2038.
960	312	1405.33	1045.00	334.50	8206.	704.

SP COMBINE AND FALL WORK, REQUIREMENTS AND COSTS

ACRES	AVAILABLE TIME	REQUIRED TIME	MAINTENANCE TIME	MANAGEMENT TIME	SIZE OF COMBINE CYLINDER	CHISEL PLOW SIZE	TRACTOR H.P. REQUIRED	MEN REQUIRED N	MEN REQUIRED K
960	312	279.60	8.18	30.54	19.X37	7	62.22	1	2
960	312	298.14	2.52	0.0	22.X50	18	160.00	1	0
960	312	299.42	14.64	23.02	20.X45	7	62.22	2	0

ACRES	AVAILABLE TIME	COST OF REQUIRED TIME	COST OF MAINTENANCE TIME	COST OF MANAGEMENT TIME	SP COMBINE COST	COST OF CHISEL PLOW
960	312	956.26	193.89	458.15	11322.	704.
960	312	596.28	137.07	0.0	13541.	2038.
960	312	1450.92	1004.99	345.35	8322.	704.

EXPLANATION OF DATA LISTING

On the following pages is a listing of the data utilized in this study. An understanding of how this data should be interpreted can be obtained from the following example.

```
ex.  DI08                    1544/1699/1596
     ↑   ↖                          ↑
   Disc   Size In           Cost of Disc Drill
   Drill   Feet
```

The only deviations from this are in the cases of the combines where the numerical description following their code variables indicate one measurement of the cylinder as identification, and tractors where the numerical description refers to the horsepower of the tractor.

MEANING OF CODE NAME DESIGNATIONS

DI - Disc Drill

HA - Harrows

SW - Swather

CP - Chisel Plow

PC - Power Take-Off Combine

SC - Self-Propelled Combine

TR - Tractor

Table B2

Data Listing

```
120.  DI08 154416991596
130.  DI12 2051201821301712215323352027170l
140.  DI15 1970267323702334
150.  DI16 2619
160.  DI18 2207287826432653
170.  DI20 3907
180.  DI24 44704132
190.  DI27 5215
200.  DI28 4936
210.  DI30 4808
220.  DI32 5423
230.  HA12 462477
240.  HA18 547523
250.  HA24 663569
260.  HA26 706
270.  HA30 711
280.  HA36 799
290.  HA37 892
300.  SW12 159812451265
310.  SW15 1607
320.  SW16 2086174913861520
330.  SW18 16061607
340.  SW21 1737
350.  SW28 3342
360.  SW32 397234823640
370.  CP07  704
380.  CP08  716 746
390.  CP10 1012 906 765 849 877
400.  CP12 1180 819 896 940
410.  CP14 12801087 98410011711
420.  CP16 1897104617981780
430.  CP18 1866200120162268
440.  CP20 2115234420892043
450.  CP22 26142289251521292240253l
460.  CP24 2360260722002360
470.  CP25 2830
480.  CP26 245927252505
490.  CP28 28012632
500.  CP30 2704
510.  CP313234
520.  CP32 2848
530.  PC1500 3942
540.  PC1600 3238
550.  PC2000 5232
560.  PC1800 4480
570.  PC2201 5950
580.  PC2202 6300
590.  PC2203 6444
600.  PC2204 8206
610.  SC2200 8095
620.  SC2201 7738
630.  SC2202 9283
```

```
640.  SC220311067
650.  SC1800 8494
660.  SC1925 8232
670.  SC2204 9518
680.  SC2000 8322
690.  SC220513132
700.  SC2001 9810
710.  SC220611734
720.  SC192611322
730.  SC192713608
740.  SC200212699
750.  SC220711560
760.  SC220812868
770.  SC220913541
780.  TR 27  3564
790.  TR 31  4382
800.  TR 32  4696
810.  TR 37  4341
820.  TR 38  4600 5224 5568
830.  TR 39  4485 4949
840.  TR 41  5064 4744 4807
850.  TR 46  6828
860.  TR 48  5248
870.  TR 52  5775
880.  TR 53  6307 7260 6201
890.  TR 54  5788 6904 7771
900.  TR 55  5989
910.  TR 56  6007
920.  TR 61  6235
930.  TR 62  7799 7546
940.  TR 63  7455
950.  TR 64  7284 8254 8280 8287
960.  TR 66  6776
970.  TR 71  7713
980.  TR 72  8351
990.  TR 73  6913
1000. TR 75  8780
1010. TR 77  8850
1020. TR 78  9125
1030. TR 81  9332
1040. TR 84  8419
1050. TR 86  8833
1060. TR 94  980010435
1070. TR 95 10345
1080. TR 96 11163
1090. TR105 10517
1100. TR106  9982
1110. TR108 11180
1120. TR116 11552
1130. TR117 11312
1140. TR121 11300
1150. TR122 1267011642
```

```
TR123 12349
TR126 13155
TR127 13500
TR131 11556
TR133 13453
TR136 136401246416290
TR142 1213514550
TR145 18665
TR146 1492516703
TR163 16885
TR176 1937416650
TR195 19955
/*
```