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A VEGETABLE FARM PLANNING MODEL FOR PRIMARY PRODUCERS

by

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ABSTRACT

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The objective of the thesis was to construct a deterministic, single year, farm planning model that would enable vegetable producers to select an optimal farm plan from among alternative crops and crop production methods so as to maximize farm income consistent with technological and resource constraints and other goals. The model was to be readily adaptable to a wide range of commercial vegetable farmers in Canada but sufficiently flexible to be adaptable to the particular situation of a specific farm. A multiperiod linear programming model was built and validated through its application to a large commercial vegetable farm.

The relevant theory of the firm was reviewed with special attention made to the theory's application to vegetable farms. The structure of a linear programming problem was discussed and related to the theory of the firm and vegetable farms.

Special emphasis was placed on the problem of modeling the machinery used in vegetable production. The work of agricultural engineers was examined to determine the technological relationships involved in machine operation. Other crop budgeting models which involved the construction of similar planning models for a different sector of the agricultural community, especially the

Purdue Crop Budgeting Models were reviewed.

The model constructed was able to deal with machinery constraints by building a number of machine operating activities and tractor transfers so that the time constraint for a particular job would consist of any subset of the predefined set of time periods. Standard coefficients were prepared based on engineering formulae for fuel consumption and repair and maintenance costs for tractors. All inputs in the model except repair and maintenance costs were in physical units. This made it necessary to build several different types of purchasing or renting activities but facilitates the interpretation of data and the use of the model in a large number of different situations.

The model was validated through its application to a large commercial vegetable farm in British Columbia. The model was run in simulation mode by forcing the model to follow the farm's 1974 crop plan and altering yields and prices to yields and prices that actually occured in that year. In this manner the reliability of the cost coefficients of the input data and the relationships between resources could be evaluated and compared with the results recorded in the farm's CANFARM records.

The model was run in optimization mode with expected 1976 prices and yields to demonstrate the use of the model in selecting an optimal farm plan. A total of six plans were prepared based on alternate market and risk constraints and yields. These were compared with the plan selected by the farmer without the aid of the model. A detailed report on one of the farm plans was also prepared.

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CHAPTER 1

INTRODUCTION

1.1 Background Perspective

In 1971 the vegetable industry in British Columbia was of direct concern to more than 1400 farmers and their families who are engaged in the production of vegetables. Relative to such large sectors as dairy, beef, and tree fruits, however, the vegetable industry is a small part of primary agriculture accounting for 2.1% of total cropped acres and 6.0% of the total value of farm production in that year (see Appendix A). Canada follows the British Columbia pattern quite closely except that the vegetable industry is slightly less important in relation to the agricultural industry of the nation.

The vegetable industry itself is very diverse encompassing a large number of very different types of crops, crop production systems, and marketing and other institutional arrangements. With the exception of potatoes, no single vegetable stands out within the industry. In British Columbia potatoes accounted for approximately half the land in vegetables and of the farm value of vegetables produced during the period 1970-74. All other vegetables account for less than 7% of farm income and, with the exception of peas for processing, less than 7% of the land.

There are considerable differences in the performance of the vegetable industry in different parts of Canada and the

United States. If average yields are used as an indicator of performance, Washington State obtains higher yields in general than does British Columbia, British Columbia does better than the United States, and the United States does better than Canada as a whole. To really understand the difference in average yields an examination has to be made of the special circumstances in which each vegetable is produced in each region. Yields may be different because of the different qualities of the crops produced in which case average value of production per acre may provide a better basis for comparison. There may be special economies of scale of which American producers are able to take advantage but the Canadian producers are not, for some institutional reason. It has often been suggested that American producers have a natural advantage owing to climatic and other natural factors. Whatever the cause of the difference in performance, the sphere in which the individual farm family can act to improve its performance is by improving its managerial ability. In this thesis, an attempt is made to improve the managerial environment in which vegetable producers make planning decisions so that they may be better able to achieve farm goals.

1.2 NATURE AND SCOPE OF THE PROBLEM

The framework for planning decisions for the vegetable farm manager is illustrated in Figure 1.1 which has been adapted from Bauer (1972, p. 15). The farm manager has available a number of specific resources which are either acquired on the factor markets or are a flow of specific capital inputs which have been purchased on capital markets. Through the technological relationships of the production process he is able to transform the resources into final products which are sold on the product markets. Decision points where decisions have to be made relating to the acquisition of resources, the use of the resources in the production process, the final products which are to be produced, the disposition of final products, and the managing of the firm's financial resources are indicated.

The diagram illustrates three broad types of decisions which have to be made. First of all, there are the production decisions about what to produce and what method of production to use. It is this type of decision that is the central focus of this study.

1.2.1 Factors Affecting Production Decisions

There are several factors which combine to make this type of decision very complex for the vegetable producer. Vegetables may be perennial, biennial, or annual. Multiple cropping may be feasible but at the same time, some crops may be incompatible so that rotations must also be accurately specified. Furthermore, some vegetable crops produce joint

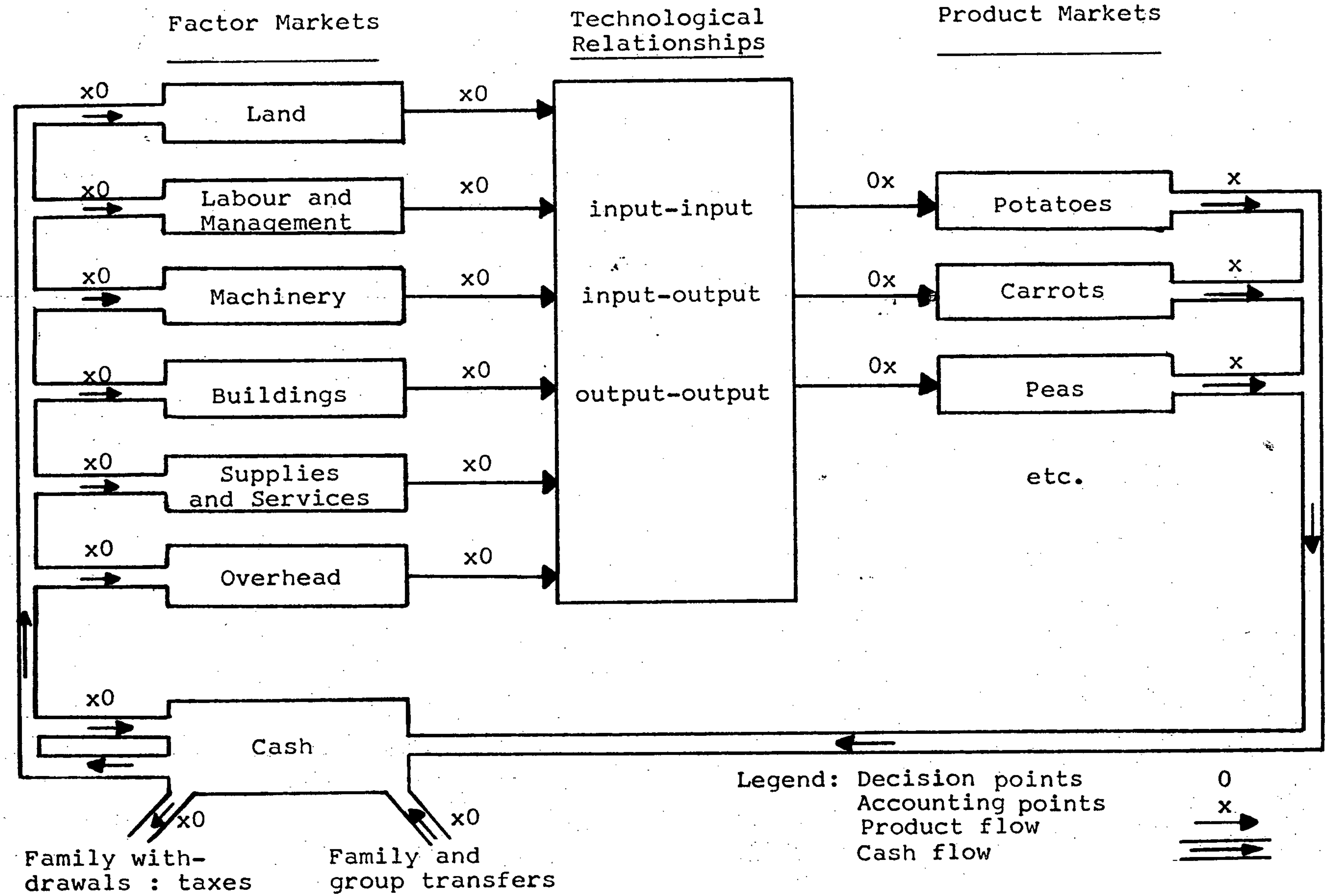

FIGURE 1.1

RESOURCE FLOW IN THE FARM FIRM

products. All of these variables considerably increase the scope of the problem.

Another factor that increases the scope of the problem is the wide range of technological systems that may be used to produce vegetables. These range from greenhouses and market gardens through to large commercial vegetable farms. Each of these systems may be extensively mechanized or rely on large amounts of hired labour in critical time periods. Irrigation and drainage systems may or may not be used. It was not thought possible to examine the special concerns of all possible types of technological systems. This study is relevant to medium and large scale commercial vegetable producers regardless of whether they employ a machine intensive or a labour intensive system. The concentration is in the use of farm machinery in field operations but the study is not specific to farms which employ a particular technological system or degree of machine or labour intensity.

Management decisions on vegetable farms are also made more complex by the wide range of locations in which vegetables may be produced. The particular climatic and soil conditions will have an effect on the decisions made by each farm manager. An effort was made to avoid making the study specific to a region so that it is relevant to vegetable production in all areas of the country.

The diversity of vegetables, technological systems and locations delineate the wide range of situations in which the vegetable producer is making decisions and considerably enlarges the scope of the problem. The actual production relationships which are relevant to a particular farm operator are concerned with the current inputs, such as purchased goods and services and with the flow of services from labour and inputs such as machines, buildings and land. It is essential for rational decision making that the relationships between these inputs are understood and that they are evaluated in terms of relevant constraints on their supply and of the particular operators knowledge and ability. It is necessary to see that the flow of these inputs is measured per unit of time so that the constraints on the resources have to take into account the timeliness of the use of these resources.

1.2.2 Financial and Marketing Decisions

A second broad area of farm management that is evident is in the area of marketing. The farmer is operating on both the factor markets and on the product markets. For the purpose of this study two aspects of his behaviour on these markets are considered: prices that he can expect to obtain or pay, and constraints on his purchasing or selling activities.

The third broad area of concern is in the area of financial management. A necessary implication of financial management is that financial records have to be kept. Accounting points where this type of information should be recorded are indicated in Figure 1.1. The effect of financial withdrawals and transfers must also be taken into consideration. The important area of capital budgeting largely associated with financial management is not included as this is considered beyond the scope of the study. The decisions that are the subject of this thesis are those which optimize decisions in the static sense rather than those that take into account the dynamic growth position of the farm.

1.2.3 The Planning Period

For the purposes of this study the normal planning period is considered to be one year. There are two main reasons for this. Most vegetables are annuals produced over the period of one year. Even in cases where multiple cropping is feasible or perennials and biennials are a factor the period of a year provides a complete set of climatic and biological conditions which can be considered by the farm manager. The institutional setting of the vegetable farm is also based on a year. A complete set of financial records is required every twelve months for taxation purposes. Loan repayments and other dealing with financial intermediaries are also frequently based on the year.

1.3 OBJECTIVES OF THE STUDY

The objective of the study was to develop a computerized farm planning model for those farmers whose resources, technical knowledge, experience and markets limit their choice of what to produce from a finite list of vegetables; who are limited in their options of how to produce to the bundle of capital inputs they presently own and current inputs they can purchase or hire. The model should be readily adaptable to a wide range of commercial vegetable farms producing a wide variety of vegetables in various locations and using either labour intensive or machine intensive technology. The model should realistically cope with the diversity of current inputs and the flow of capital inputs in a framework that reflects the timeliness of the use of these inputs. The model to be built is to be a deterministic, single year, farm planning model that will enable producers to select crops and crop production methods from among alternatives available so as to form an optimal farm plan with the maximum level of income consistent with the farm manager's technological and resource constraints and his other goals.

The objective may be separated into several sub-objectives that are necessary to be able to complete the overall objective:

1. To identify problems encountered by vegetable producers in formulating a farm plan and technological information available that is relevant to rationally making planning decisions;

2. To construct a model that will select optimal farm plans for vegetable producers;
3. To verify the model through its application to a case farm;
4. To demonstrate the use of the model in developing an optimal farm plan for the case farm.

1.4 METHODS ADOPTED FOR ACHIEVING OBJECTIVES

1.4.1 The First Sub-Objective

The first sub-objective involved identifying the problems facing primary producers and the areas of decision making that it would be possible to incorporate into a farm planning model. This sub-objective is the first step in the overall objective of the thesis as indicated in Figure 1.2

The first sub-objective has been satisfied through conversations with growers, university experts, and others interested and informed about the problems of vegetable producers. This sub-objective is naturally an on-going one that is continually being updated throughout the work done towards the completion of the thesis. The major economic problems facing vegetable producers have been identified as a problem of crop selection and resource allocation. How many acres of each crop should be produced and what combination of inputs or resources should be used to produce each crop? Crops are to be selected according to their profitability on the farm subject to technological relationships and resource constraints.

Because of the diversity of vegetables, regions, and individual practices and because the basic 'testing' has not been done to define systematic biological relationships in most cases, it was felt necessary to leave the definition of these relations to the discretion of the farmer. Consequently the direction of research has focused on the relationships that the farmer can be expected to provide. Evaluations of

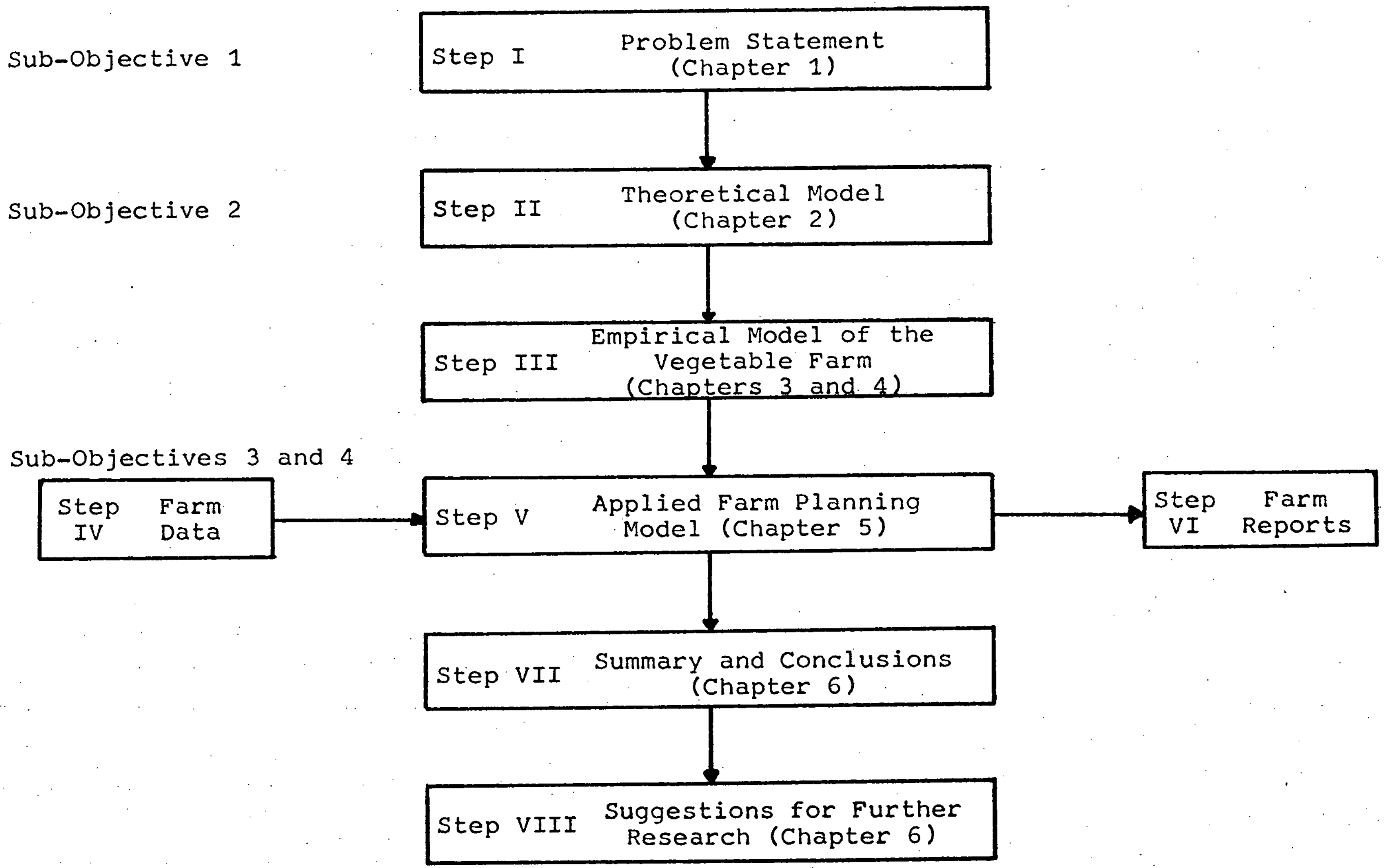

FIGURE 1.2

ORGANIZATIONAL FLOW CHART SHOWING MAJOR STEPS TAKEN TOWARDS SATISFYING THE OBJECTIVES OF THE THESIS resource constraints in a realistic time frame is seen as a major problem about which considerable information may be obtained relevant to the individual grower. The scheduling of machine operations with an accurate evaluation of machine and labour resources available over the time period budgeted for the operation and the prediction of associated costs is the area of central concern. It has been the technological information about machine performance and cost that has been investigated in a most detailed manner. The model has been developed to evaluate these types of constraints and calculate these types of costs in detail. The biological relationships are incidental to the main work done on the model. Intuitively this can be seen as a rational approach; there are such a large number of vegetables and regions each with a great variety of specific biological requirements but the technological relationships between the machinery used to produce them, is common to all.

1.4.2 The Second Sub-Objective

There are two steps that have been identified as necessary for the completion of the second sub-objective: the development of a theoretical model of the vegetable firm and the construction of a quantitative empirical model (steps II and III respectively in Figure 1.2). The theoretical model given is the theory of the firm. The theory of the firm is modified by special considerations of the situation of vegetable farm and of the quantitative model used.

The model built is a multiperiod linear programming model. The model assumes that all coefficients are known with complete certainty and that the farm operator has the single goal of maximizing his gross margins. These last two characterizations of the model can be relaxed to some extent in the specification of limits on resources and activities within the model but these are not explicitly incorporated into the model.

An essential feature of the model is that it is a multiperiod model with limits placed on most resources for a number of segments of the total planning period. The number of segments and the length of each varies according to the demands placed on those resources. A central part of the model allows the length of time in which a specific job must be completed to be specified individually in terms of groups of the basic time segments. This quality of the model enables evaluation of different farm plans in a realistic time constraint framework.

The model incorporates quite detailed machinery data used to determine fuel consumption, repair and maintenance costs, and constraints on machine time. Most of this data, and all data concerning chemical use, cultural practices, and yield response should ideally originate on the farm to which the model is being applied.

Another feature of the model is that it can readily accommodate variations in variable inputs that are known. Considerable work is required to build a crop into the model but when this has been done additional variations in parameters and their consequences for yields can be evaluated by adding a few columns to the matrix.

The model has also been constructed almost completely in terms of physical units. For example, the approach taken to estimate repair and maintenance costs is to build in the hours of use of the machinery and calculate the cost of use on an hourly basis within the model rather than use only a single coefficient in dollars.

1.4.3 The Third Sub-Objective

Three steps have been identified in the completion of the third sub-objective, which are indicated as steps IV, V and VI in Figure 1.2. The first step involved specification of the data required by the empirical model and sources of the data. Once the data had been specified a case farm was selected and the farm data recorded*. The selected case farm was relatively complicated in that a large number of technologically diverse crops are grown. The operators' CANFARM records and information collected on several visits to the farm, and special machine coefficients originating in empirical studies done by agricultural engineers constitute the data base for the case farm.

A farm planning model of the case farm was constructed and constrained to follow the case farm's 1974 farm plan. The solution found with this 'simulation run' of the farm planning model is used to verify the model.

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* Data collected is documented in a separate paper "An Optimal Farm Plan for a Vegetable Farm."

The logic of the model was evaluated by showing that a solution to the model was consistent with resources utilized and costs calculated based on numerical analysis of the empirical model and the data.

The validity of the coefficients used for the case farm and reliability of plans produced by the model were shown by comparing the costs predicted with the farm planning model with those recorded in the CANFARM records of the farm.

1.4.4 The Fourth Sub-Objective

Finally the model was used to produce an optimal 1976 farm plan for the farm. This was done to show that the model can indicate some important changes in the farmer's plan so that he can better satisfy his objectives. Several farm plans were prepared and compared with the farm plan selected by the operator without the additional knowledge he would have had using the farm planning model. Detailed farm reports were prepared for one of the farm plans.

1.5 ORGANIZATION

The organization of the thesis as it relates to the steps taken to achieve objective is summarized in Figure 1.2. The first sub-objective of problem identification is documented in this chapter.

The second sub-objective was separated into two steps. The first step involved an examination of the standard theory of the firm and this is done in the second chapter of the thesis. Attention is also given in Chapter 2 to the quantitative methods that were considered and practical concerns of the nature of vegetable farming and of the quantitative approach used (linear programming) as they affect the theory of the firm.

The specification of the empirical model was such an involved task that it was separated into two chapters. In the third chapter other crop budgeting models, particularly the Purdue Models, are summarized and the machine scheduling system developed for the model is discussed in detail. This is done at this point because the machine scheduling block is really the core of the model and the rest of the model is very straightforward when this section of it is known. The structure of the entire model is introduced, in this chapter, with aid of a flow diagram illustrating source of resources, use of resources and information required by the model.

In the fourth chapter the themes established in the third chapter are expanded. The sources of farm data are specified. A picture of the entire matrix is given and detailed schemata are given of other types of activities not explained in Chapter 3.

The third sub-objective was to verify the model against its application to a specific case farm. The details of the selection of the case farm, the picture of the applied model and results of using the model to simulate the case farm's 1974 farm plan as recorded in the CANFARM records are all given in the first part of Chapter 5.

The model was used to produce six different optimal farm plans based upon alternative constraints and yields which are compared in Chapter 5. One of the plans was used to produce detailed projections of income, costs and resource utilization which are given in Appendix G. This material is presented to satisfy the fourth sub-objective.

Finally the thesis is summarized and conclusions drawn in Chapter 6. Suggestions for further research are also given in Chapter 6.

CHAPTER 2

THEORETICAL MODEL OF THE FIRM

In the previous chapter it was stated that the objective of the thesis was to build a farm planning model applicable to vegetable farms and that linear programming would be the modeling technique employed. In this chapter an attempt is made to indicate the theoretical considerations that underlie the approach taken. The farm planning model will maximize income subject to specific resource, technological and alternative goal constraints. The theory of the firm is summarized in Section 2.1 to point out the relationships that must hold between resources, between resources and products, and between products at the point of maximum profit. The nature of the production process implied by the existence of a maximum profit solution is also indicated.

In Section 2.2, the main potential alternative quantitative modeling techniques are briefly indicated. Modeling methods are divided into the three categories: linear programming, non-linear programming, and simulation. Some major advantages and disadvantages of each are given in table form and the reasons given why linear programming was used for this study.

In the final section, Section 2.3, the formulation of the linear programming problem is explained. An attempt is made to relate the linear programming formulation to the theory of the firm as it is thought to apply to vegetable farms by the author. It is shown that the linear programming model allows an approximation of the necessary conditions for a solution to the maximizing problem, that it implies a production process not unlike that suggested by the theory of the firm as it applies to vegetable farms and that the constraints on the production process for the vegetable farm can be easily handled. Formulation and theoretical justification of the dual linear programming problem is indicated as well as its relationship to the constraints imposed on the production process.

2.1 THE THEORY OF THE FIRM

The firm is the basic unit of production in neo-classical economics. For each firm a relationship is assumed to exist between the resources or inputs that the firm uses and the products which the firm sells. The relationship is called the production function and is expressed in exact terms in equation 2.1.

2.1 $q = f(x_1, x_2, \ldots, x_n)$

where q = maximum possible production,

and x_i = i-th input with $i = 1, 2, \ldots, n$.

The production function is usually described as being continuous, twice differentiable, and concave. This description follows from further assumptions that are made about the relationships between resources and between resources and output. Both inputs and output are assumed continously divisable. There are diminishing returns to the increased use of one input with other inputs held constant. Disposability of resources may or may not be assumed. The market position of the firm is also assumed to approximate perfect competition in which case four additional assumptions have to be made. The firm produces a homogeneous product. Both firms and consumers are numerous and small relative to the size of the markets in which they participate. Both firms and consumers possess perfect knowledge about price and product relationships and both are maximizers. More specifically, the firm is considered to be a profit maximizer. Entry and exit from the market is also assumed free in the long run.

With this description of the firm the conditions under which a firm can achieve its objective of profit maximization can be specified. The firm will obtain the greatest profits at the point where the marginal value products of all inputs are equal (input-input relationship) and where the marginal value product equals the price of output (input-output relationship) rather than at the maximum output. For the solution to exist the production function has to have constant or decreasing returns to scale. If the firm produces several products then the price ratio of any two products must equal the ratio of marginal products of the two products with all inputs.

However, as pointed out by Heady (1971, p 9):

> "All farms have several limited physical resources .... In addition all farms have institutional or subjective restraints."

This may be considered to be the short or medium run position of the firm as with a planning horizon of one year with a fixed capital stock which is the situation being addressed by this study. The profit function for a single product firm in this situation may be represented as in equation 2.2 with a constraint imposed on one input.

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* The description of the firm in long run competitive equilibrium can be found in any standard text, e.g. Henderson and Quandt (1958), Ferguson (1972), etc.

2.2 $\pi = pq - w_1x_1 - w_2x_2 - w_3x_3 - b$

subject to $x_3 \leq c$ or $x_3 + s = c$

where π = profit,

p = the price of the final product,

q = the production function 2.1 where $n = 3$,

w_i = the price of the i-th input,

x_i = the amount of the i-th input,

b = fixed costs,

c = an upper bound on the amount of x available

and s = a slack variable.

The constrained optimization problem in equation 2.2 can be solved by forming the Lagrangian equation 2.3 and taking the partial derivatives.

2.3 $L = pq - w_1x_1 - w_2x_2 - w_3x_3 - b + \lambda(c - x_3 - s)$

The partial derivatives for x_1 and x_2 give the same input-input and input-output relationships as the unconstrained case but for the third input the partial derivative is:

2.4 $L_3 = pf_3 - w_3 - \lambda$.

The marginal value product for the third input is equal to the sum of its wage and the Lagrangian multiplier for the constraint. The term $w_3 + \lambda$ may be called the shadow price for the input x_3 for the solution is as though the price of the input were $w_3 + \lambda$. Another feature of this model is that it does not require an assumption about the returns to scale of the production function.

2.2 QUANTITATIVE MODELING METHODS

An essential feature of all three economic models of the firm is the maximizing behaviour presumed. Criticisms of this assumption usually propose another objective or combination of objectives to be maximized or minimized. Boulding (1960) points out that the first order marginal conditions follow as mathematical tautologies from the fact that optimizing behaviour that is assumed. The objective of developing a mathematical model of the vegetable farm should be restricted to models that are capable of utilizing an optimizing routine to simulate this behaviourial assumption. There is a trade off however between the flexibility and realism that can be incorporated into the model and the availability and reliability of the optimizing routines for the model. In Table 2.1, modeling methods that may be considered for the firm are divided into three main categories and some of the major advantages and disadvantages given for each.

It was decided very early in the undertaking of the thesis to use the technique of linear programming. Simulation was not seriously considered because of the lack of an optimizing procedure. Non-linear programming was considered as a technique necessary for taking account of risk. It was felt however that risk could be accommodated in a linear programming framework and that there are other complex problems in the modeling of the vegetable farm that should be solved first.

There are also a large number of variations on the

TABLE 2.1

MODELING METHODS COMPARED

Linear Programming	Non - linear Programming	Simulation
	Optimizing Method	
Revised Simplex Method readily available in various computer packages	Several methods. Not normally available in packages. Algorithms longer and more expensive	Various search techniques employed but there is no Algorithm which leads to a certain optimum
	Advantages	
Simplest model as all equations linear. Optimizing Method best known because of long history	Equations may be linear or non-linear	Most realistic in that there are no restrictions in the formulation of the model
	Disadvantages	
Lack of realism due to restriction to linearity. Impossible to have even linear approximations of increasing functions	Optimizing Method limits number of non-linear equations. Cost	Lack of guarantee that the solution is optimal

technique of linear programming such as integer programming, parametric programming, multiple goals programming, and stochastic programming. None of these techniques are used in the model. There is considerable room for making the model more realistic by incorporating some of these techniques but the basic problem of crop selection in a framework that accurately computes variable costs and field time constraints is itself a complex linear programming problem that does not require any of these extensions.

2.3 PRACTICAL CONSIDERATIONS THAT MODIFY THE THEORETICAL MODEL

2.3.1 Relationship between the Theory of the Firm and Vegetable Farms

Although it is impossible to say a priori whether there is diminishing returns to any specific resource on a vegetable farm or whether the production function for vegetable farms is continuous and twice differentiable some of the other assumptions may be evaluated intuitively. Divisibility of inputs and outputs is in most cases a reasonable approximation of reality but there may be some variables for which integer values only may be relevant. Perhaps labour has to be hired for a full day or a grower may only be able to get a specific size of marketing contract from processors*. Although returns to scale are difficult to evaluate all farms have both physical and subjective restraints on several resources and the theory of the firm implies that a unique solution to the problem of profit maximization can exist in this case regardless of the returns to scale. A non-unique optimum with constant returns to scale may be assumed without contradicting the theory. Substitutability between resources seems intuitively probable as does the disposability of resources. The vegetable firm for the most part conforms to the description of the firm in the short run with a multiple product output.

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* This type of integer problem is assumed to be unimportant. If it were an important consideration then an integer programming technique would be necessary.

The assumption that the firm is in a perfectly competitive position seems less valid. The assumption of perfect competition implies that the firm has profit maximization as its single goal. The single goal of profit maximization ignores the fact that the owner-operator of a vegetable firm is also a consumer and as a consumer must be making a preference decision between work and leisure. The implication of perfect knowledge is also not satisfied. Because of the time lag between the formulation of the farm plan and the completion of that plan there is bound to be a degree of risk and uncertainty in the prices of inputs and product. Because of the climatic and biological factors involved in crop production there is bound to be a degree of uncertainty concerning yields. Future income has at least two dimensions that should be evaluated: level and variability.

The knowledge criteria is not met in another completely different sense. As pointed out in the first chapter a large number of input-output relationships are unknown. For some resources the grower may be able to point out different expected yields for different levels of inputs. This is the case for example for inputs like different qualities of land. For a great many other alternatives the marginal relationships will remain undefined. It is only that part of the production function that is perceived that can be built into the model. It will have to be assumed that the grower's usual practise satisfies the marginal conditions for an optimum for all other inputs.

2.3.2 The Structure of the Linear Programming Problem and its Implications for the Theory of the Firm

Theory specifies a number of relationships that are supposed to hold for the vegetable firm and deduces from these the conditions necessary for the fulfilment of the maximization assumption. The quantitative model of the firm developed to satisfy the objectives of the thesis should simulate this description of the firm.

The linear programming problem may be represented as in equation 2.4:

2.4 Maximize $c^t x$ subject to $Ax \leq b$ and $x \geq 0$

where c^t is a 1 x n vector of prices,

x is a n x 1 vector of activities,

b is a m x 1 vector of resource constraints,

and A is a m x n matrix.

This system of equations is similar to the system in 2.2 The objective function $c^t x$ may be a type of profit function with the constraint matrix giving the technical relationships of the production function. The elements of the vector x are the variables (or activities or columns) of the linear programming problem. Some of these variables may be inputs with negative coefficients in the objective function which represent levels of purchases of specific resources. Some variables may represent final products and have positive coefficients in the objective function. Other variables may have zeros for coefficients and are called transfer activities. The function of transfer activities is to transform one resource into another or change it into a final product*. Transfer activities are a convenient method of making the technical relationships of the production function explicit.

A main advantage of linear programming is its ease of use. In a sense each different activity is defined by the resources and their relative proportions that the activity requires and produces. The solution of the linear programming problem contains the optimal level of each activity and thus simultaneously answers the questions of what to produce and how to produce it. Each resource can be built into the model as a row and subdivided into as many categories as is thought necessary. In this way the timeliness of the use of each resource can be built into the model in a meaningful way. Divisibility and disposability of resources are automatically assumed. Special restrictions may be placed on specific resources and final products to take into consideration subjective estimates of risk and the personal preferences of the grower.

A final advantage of the linear programming model is that each linear programming problem has an associated dual problem. Equation 2.7 is the dual formulation of equation 2.6.

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* This is not necessarily the only approach that can be taken. Variables could be final products and their prices could be the difference between revenue and variable costs per unit, etc.

2.7 Minimize $b^t y$ subject to $A^t y \geq c$ and $y \geq 0$

where b^t is a 1 x m vector of resource constraints,

c is a n x 1 vector of prices,

A^t ia a n x m matrix,

and y is a m x 1 vector of dual variables.

The dual variables in this case represent the shadow prices of resources. A finite solution to the primal problem, equation 2.6, implies a unique solution to the dual problem and conversely. The shadow prices are the same ones encountered in the solution to the constrained optimizing problem, equation 2.4. In the case of resources which are not constrained, their shadow prices are the same as their purchase or rental price. For constrained resources the value of the shadow price takes into account the change in production that would be possible with one more unit of the resource, They are, as indicated in Section 2.1, what the prices of the resources should be if the resource were not constrained but the solution was optimal.

Shadow prices can be valuable in two ways. Very improbable shadow prices indicate possible errors in coefficients which is useful in validating the model. Believable but high shadow prices indicate directions in which the farm operation may be profitably changed in a longer time horizon than the model encompasses.

As pointed out already the restriction to linear relations affects the realism of the model. This can most easily be seen in comparing how linear programming alters the first order conditions for an optimum. Diminishing returns to a specific resource, for example, has to be approximated in discrete terms with separate activities for production with each different ratio of resources. Restraints have to be placed on each activity with more efficient resource product ratios. The series of these constrained activities approximate the theoretical marginal product curve with a discrete step function (see Figure 1.2).

Similarly separate activities are required to represent input substitution and product substitution. To portray the theoretical isoquant or product substitution curve would require an infinite number of activities although both may be approximated by a finite number of points with a linear segment joining the points. Exact tangency between the price ratio and any point is impossible. There is no first derivative at a point. Tangency between the price ratio and the line segment joining the points may be possible in which case the tangency covers a whole range of solutions.

A final consideration is that a linear programming model must, because of its linearity, imply a production function with constant returns to scale. Without this assumption one must admit that there is a systematic bias in the coefficients used in the model depending on whether the optimal solution contains an activity at a level greater or smaller than at the level from which the coefficients were estimated and whether the production function actually has increasing or decreasing returns in this area.

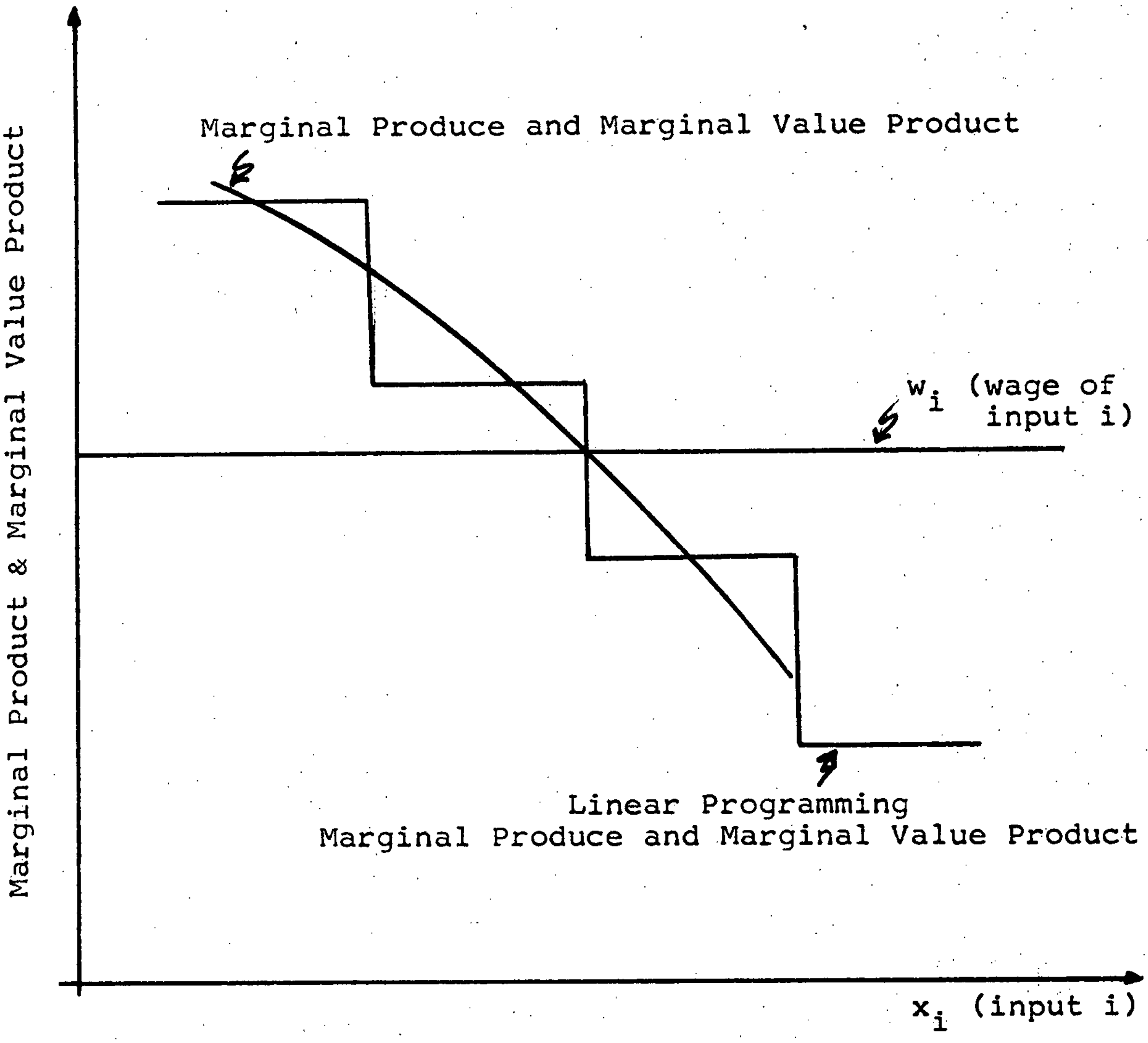

FIGURE 1.2

A COMPARISON OF THE THEORETICAL INPUT-OUTPUT RELATION AND THE LINEAR PROGRAMMING APPROXIMATION

To summarize, the underlying economic theory on which the farm planning model rests has been given in this chapter. The structure of the quantitative method employed and its relationship to economic theory have also been given. In the next two chapters, the specifics of how the method was used, and the exact formulation of the empirical model are detailed.

CHAPTER 3

THE DEVELOPMENT OF THE EMPIRICAL MODEL

The purpose of this chapter is to present the method adopted for programming the machinery and handling the variable time constraints and to introduce the structure of the entire model illustrating the flow of resources and the types of activities implied by the machinery section.

In the first section of the chapter a brief review is given of other empirical models. The structure of the Purdue Crop Budgeting Models are explained in detail with special reference to the method used to handle time constraints.

In Section 3.2 three alternative methods of programming the machinery are explained and illustrated with the aid of schemata of the structure of a linear programming tableau. Each of the methods involved the construction of machine operating activities and in one case a number of tractor transfers. This section explains the relationships between resources and machinery in the theoretical model and how the variable machine time constraints on crop production are realized.

In the third section of the chapter the special advantages of the method eventually selected are indicated and related to the problems encountered in programming the machinery. The method used allows greater flexibility than the Purdue models but will in the end require a substantially larger model.

In the final section of the chapter the entire farm planning model including the machine operating activities and tractor transfers is illustrated with a flow diagram analogous to Figure 1.1. In this diagram the major classifications of resources used in the theoretical model and the number of time periods used for each are given. The origin and use resources by the major classifications of activities are indicated together with units that are used for each resource and activity.

3.1 CROP BUDGETING: THE PURDUE MODELS

Most farm planning models necessarily have to deal with crop activities at least in part. In a model of a beet farm (Graham and Lopez, 1975; IBM, 1965) for example, it may be that crop activities are looked on as an alternative demand for labour and crops may be selected in the model on the basis of gross or net margins. Alternatively, the various possible machinery and time constraints may be brought into the model (Kizer, 1974; McHardy, 1966; Donaldson, 1970; Barlow, 1974) if the crop activities are thought to be more important to the whole enterprise. In a commercial vegetable farm the only important productive activities are the crops and the treatment of field operations becomes of major importance in the model.

Models have been developed in the past on farms where the crop decisions are critical to the successful management of the farm. The Purdue Corn Enterprise Budget Model A (Purdue Agricultural Research Station, 1969) was a model designed to select optimal planting and harvesting times for mid-West American corn farms. Fourteen separate time periods were used in the Purdue model. Four abstract types of field operations are evident: those operations which may occur at any time before a certain time period, those operations that can only be done at a specific time, those operations which may be done in a range of possible intermediate time periods, and those operations which may be done at any time after a certain date. Each of these types of operations is programmed differently.

Land may be prepared in any one of the first 8 periods. Land preparation requires labour and machinery time and one acre of land to produce one acre of prepared land. The prepared land is used by various permutations of all of the succeeding operations to produce corn. This process is illustrated in Figure 3.1

The plant-harvest activities require land from the land preparation activities that occur in the preceding time periods. The vectors of ones and minus ones control this transfer of land. Land can be planted in six of the spring periods and harvested in three different periods in the fall. The first three activities in the plant-harvest block consist of planting in the first planting period and harvesting in the three different harvest periods. There are 18 of these plant-harvest activities needed to program all the alternatives in planting and harvesting dates that are feasible, each with the appropriate yield. The 18 plant-harvest activities illustrate the necessity of building a separate activity for each alternative that may be done in an intermediate time range.

An operation that has to be done in a specific time frame is programmed into each plant harvest activity in that time period and does not require any special control rows or extra activities. Using equality constraints the model forces in land preparation in any of the periods following the harvest with a system of land accounting rows similar to those in the control section in Figure 3.1 Fertilizer and available costs associated with machine operation were added as necessary to each of the plant-harvest activities.

Resource (period)	Prepare Land in Period					Plant-Harvest Combinations							
	(1)	(2)	(3)	...	(8)	(1)	(2)	(3)	(4)	(5)	(6)	...	(18)
Objective													
Land	1.0	1.0	1.0		1.0								
Labour: (1)	.98												
(2)		.98											
(3)			.98										
.													
.													
.													
(14)					.98								
Machine: (1)	.30												
(2)		.30											
(3)			.30										
.													
.													
.													
(14)					.98								
Plant-Harvest Prepare Control: (1)	-1.0	-1.0				1.0	1.0	1.0					
(2)	-1.0	-1.0	-1.0			1.0	1.0	1.0	1.0	1.0	1.0		
(3)	-1.0	-1.0	-1.0	-1.0		1.0	1.0	1.0	1.0	1.0	1.0	...	
(4)	-1.0	-1.0	-1.0	...		1.0	1.0	1.0	1.0	1.0	1.0	...	
(5)	-1.0	-1.0	-1.0	...		1.0	1.0	1.0	1.0	1.0	1.0	...	
(6)	-1.0	-1.0	-1.0	...	-1.0	1.0	1.0	1.0	1.0	1.0	1.0	...	1.0

FIGURE 3.1

LAND PREPARATION IN THE PURDUE MODELS

The main function of the Purdue Model is to select between different planting and harvesting dates based on yield response and subject to machinery and labour time constraints. There are four well defined jobs each of which may consist of more than one field operation with different tractors and implements. This sequence of operations is the same for all alternatives since only one crop is considered. The model is thus oriented to very large farms that are growing a single crop,* about which detailed yield response data to various planting and harvesting dates is known.

It should be kept in mind when evaluating the model for a vegetable farm that there are a large number of different vegetables each with different sequences of machine operations any combination of which may be grown on an individual vegetable farm. There is also very limited information available on the yield response of even the important vegetables to planting and harvest dates. For this reason a system similar to the Purdue approach is unsuitable for our purposes.

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* The Model has been extended to other similar crops (Bruck et.al., forthcoming publication).

3.2 ALTERNATIVE MACHINE SCHEDULING MODELS

The most simple method proposed for machine scheduling involves programming each machine operation with each tractor and the rate at which it can be performed as activities. Each hour of machine operation requires one hour of machine time, one hour of tractor time and supplies machine capacity in acres per hour. The sum of the repair and maintenance costs for tractor and implement and the cost of fuel are the coefficients for the objective function and cash rows. Figure 3.2 illustrates this method in the case where two implements and two tractors are considered as possibly limiting production and either tractor can be used with either implement. Presence of positives in the constraint rows indicate the use of resources and negatives represent the receipt of resources. In the objective function negatives represent costs and positives and receipt of income. In the right hand side positives stand for limited owned resources or resource endowments. Blank spaces are necessarily zero while all other coefficients may be zero in particular instances.

Using Method One as in Figure 3.2 the same machine operating activities can be used by any number of different crops. This is because the alternative methods of doing the same job feed into the same accounting row which connects the machine operating activities with the crop growing activities. The machine coefficients for the crop growing activities are integers for the number of times an operation is done in the same time period.

		Borrow Cash	Lend Cash	Rent Land	Purchased Inputs	Hire Labour	Machine A Transfer 1	Machine A Transfer 2	Machine B Transfer 1	Machine B Transfer 2	Hire Labour	Machine A	Machine B	Grow Crop	Sell Crop	Maximum
						Time Period I					Time Period II					
	Objective	−	+	−	−	−	−	−	−	−	−	−	−	−	+	
	Cash	±	±											+	−	≤ +
	Land			−										+		≤ +
	Purchasing Inputs				−									+		≤ 0
Time Period I	Labour					−	+	+	+	+				+		≤ +
	Tractor A						+		+							≤ +
	Tractor B							+		+						≤ +
	Machine A						+	+								≤ +
	Machine B								+	+						≤ +
Time Period II	Labour										−	+	+	+		≤ +
	Tractor A											+				≤ +
	Tractor B												+			≤ +
	Machine A											+	+			≤ +
	Machine A Acc.					−	−					−	−	+		≤ 0
	Machine B Acc.								−	−				+		≤ 0
	Yields													−	+	≤ 0

FIGURE 3.2

METHOD ONE OF PROGRAMMING THE MACHINERY

The most powerful feature of this approach relies on a flexible definition of the accounting rows. The time constraint for the job is defined by the combination of the time constraints on each operation activity that is connected to the same accounting row. The job defined by "Machine A Acc." in Figure 3.2, for example, shows that the operation may be performed in either time period I and time period II. The job defined by "Machine B Acc." in Figure 3.2, on the other hand, may be performed only in time period I. This most important feature is maintained in the other two models that are proposed. The other models are proposed as possible methods of improving upon the manner tractors are handled.

It is possible to eliminate one of the causes of the uplication of machine operating activities by converting the resource tractor into the resource horsepower hours. In situations where the nature of the implement or the job being performed limits the capacity of the tractor implement combination, larger tractors can substitute for smaller tractors without any change in any of the time coefficients. The assumption may be made that the tractors which could be used depends only on tractor horsepower. By converting tractor hours into horsepower hours, the number of tractors available to do a job can be reflected in the right hand side. Figure 3.3 illustrates this method of building the machine transfers. Analogously to the plant-harvest activities in the Purdue Model (Figure 3.1) it is necessary in this approach to have an entry in the maximum horsepower that the implement uses and all lower levels of horsepower.

	Borrow Cash	Lend Cash	Rent Land	Hire Labour	Purchase Inputs	Machine A Operation	Machine B Operation	Grow Crop	Sell Crop	Maximum
Objective	−	+	−	−	−	−	−	−	+	
Cash	±	±	+	+	+	+	+	+	−	≤+
Land			−					+		≤+
Labour				−		+	+	+		≤+
Purchased Inputs					−			+		≤0
0 Horsepower						+	+			≤+
40 Horsepower						+	+			≤+
60 Horsepower						+				≤+
Machine A						+				≤+
Machine B							+			≤+
Machine A Acc.						−		+		≤0
Machine B Acc.							−	+		≤0
Yields								−	+	≤0

FIGURE 3.3

METHOD TWO OF BUILDING MACHINE TRANSFERS

A disadvantage of this method is that repair and maintenance costs and fuel costs have to be an average of what they would be with each tractor implement combination. Another disadvantage is that the method may not be applicable for some implements such as those limited to a specific tractor by hitch, wheel base or some other feature of the tractor. Implements that may be operated at more than one capacity and are in fact limited by the power of the tractor would still have to be duplicated.

It was thought that it might be possible to further disaggregate machine operating activities so that tractor fuel and repair and maintenance costs are separated and still have the capacity to include the advantages of both the first and second method by building a tractor selection block. In Figure 3.4 an hour of tractor time is transferred into an hour of tractor time at a certain horsepower which is used in the machine transfers as in Figure 3.3. Tractor time for repair and maintenance cost calculation and fuel consumption are also built into the tractor transfers. Implements which require specific tractors can have machine transfers as in Figure 3.2.

This is in fact the procedure used in the farm planning model that was built. All machine operations for all crops were handled as in Figure 3.2 or Figure 3.4. The crop growing activities consist of coefficients for land, manual labour, purchased inputs and integers for the frequency of each machine operation performed on an acre of the crop.

	Borrow Cash	Lend Cash	Rent Land	Hire Labour	Purchase Inputs	Tractor A 60 HP	Tractor A 40 HP	Tractor A 20 HP	Tractor B 40 HP	Tractor B 20 HP	Machine A	Machine B	Machine C	Grow Crop	Sell Crop	Maximum
Objective	−	+	−	−	−	−	−	−	−	−	−	−	−	−	+	
Cash	±	±	+	+	+						+	+	+	+	−	≤+
Land			−											+		≤+
Labour				−							+	+	+	+		≤+
Purchased Inputs					−									+		≤0
Fuel					−	+	+	+	+	+			+			≤0
Tractor Repair						+	+	+	+	+						≤+
Tractor A						+	+	+								≤+
Tractor B									+	+			+			≤+
20 Horsepower								−		−						≤0
40 Horsepower							−		−			+				≤0
60 Horsepower						−					+					≤0
Machine A											+					≤+
Machine B												+				≤+
Machine C													+			≤+
Machine A Acc.											−			+		≤0
Machine B Acc.												−		+		≤0
Machine C Acc.													−	+		≤0
Yields														−	+	≤0

FIGURE 3.4

METHOD THREE OF PROGRAMMING THE MACHINERY

3.3 SPECIAL FEATURES OF MACHINE SCHEDULING BLOCK SELECTED

The technique of programming each machine operation using either method one or method three was initially attempted to reduce the confusion of aggregation and to simplify the scheduling of the crops. There are three aspects of the technique that contribute to this desirable result:

1. Explicit use of the basic parameters of machine use, i.e. Capacity, Horsepower, Fuel Consumption and Repair and Maintenance Costs per Hour.
2. Each crop is a sequence of crop operations denoted by integers which reflect the number of times each operation is done in each time period.
3. The problem of the variation in the length of feasible time periods by operation can be easily handled for a large number of different crops by the appropriate definition of the machine operation accounting rows.

The first of these points is concerned with the problem of aggregation. The fact that all the machine parameters are explicit, facilitates changing them when applying the model in a wide range of farms. The schedule of a particular crop on the case farm can be used and easily adapted to another farm with a different line of machinery in a framework that actually reflects the characteristics and costs of that different line of machinery. Similarly, changes in the machinery available on a single farm can be evaluated in a realistic manner. The explicit use of the parameters for machinery performance may also have some potential educational value.

The second point concerns the simplification in scheduling. The crop activities are fairly easy to program because they now consist of a sequence of integers which represent the frequency of performing the machine operations. To a great extent the difficult aspects of programming the crop activities have been transferred to the tractor selection block and the machine operating activities. Once established though, the tractor selection block and the machine activities may be used in other crops.

Finally there is the problem of the variable length of feasible time periods between operations. The Purdue Corn Budget model developed a method of dealing with this problem directly for a specific crop. By properly defining the accounting rows for each machine operation, the problem can be effectively handled by the technique herein developed. The smallest unit in which work done can be constrained is in one of the basic work periods in the model. Larger units consisting of combinations of one or more of the basic work periods can be assembled by feeding the machine operating activities into a single accounting row for the longer period. For instance, an operation like plowing that may be done in the first four of the work periods perhaps, would have the first four machine operations for this implement supply in single accounting row. Similarly an operation that may be done in two intermediate time periods would connect the two machine operating activities into a single accounting row. In the Purdue model the different planting harvest combinations are also distinguished by different yields. The model that has been developed does not presently have the capacity to accommodate different yields except by separate crop activities. However, crop scientists and engineers have not quantified the effect of the timeliness of the machine operations on any of the vegetable crops.

The technique is, as far as known by the author, a completely new method for handling crop programming. The three aspects highlighted above show that there are several advantages to the technique. The main disadvantage is the theoretically huge size of the matrix and the substantial size of the matrix in practise.

3.4 SUMMARY OF THE COMPLETE FARM PLANNING MODEL INCORPORATING THE MACHINE SELECTION BLOCK

The model is summarized in Figure 3.5. The diagram is a further refinement of Figure 1.1 in which the technological relationships and the resources used in crop production are more clearly identified. The first two columns of the diagram represent resource acquisition. It can be seen that there are five categories of 'owned resources' and five categories of 'hired resources'. Although tractors and implements are not acquired directly, custom operations can be included as purchased inputs. It is assumed that stocks in inventory of purchased inputs and fuel are zero. This may not be true strictly speaking, in which case the rows for fuel and for purchased inputs can be looked upon as a valuation of the change in inventory as a result of the crop production activities.

The time period in which each resource may conceivably be considered constraining is also given here in parenthesis. The decision on the number of time periods and their breakdown is somewhat arbitrary. Land may be broken into as many time periods as consecutive crops that may be produced. The maximum for B.C. farms would, therefore, be five although only one may be needed for most vegetable farms. Only one time period is needed for each purchased input. Fuel is divided into 12 time periods so that its use in each month can be predicted. A distinction is made between fuel and the other purchased inputs because fuel is an input used by all crops in all times

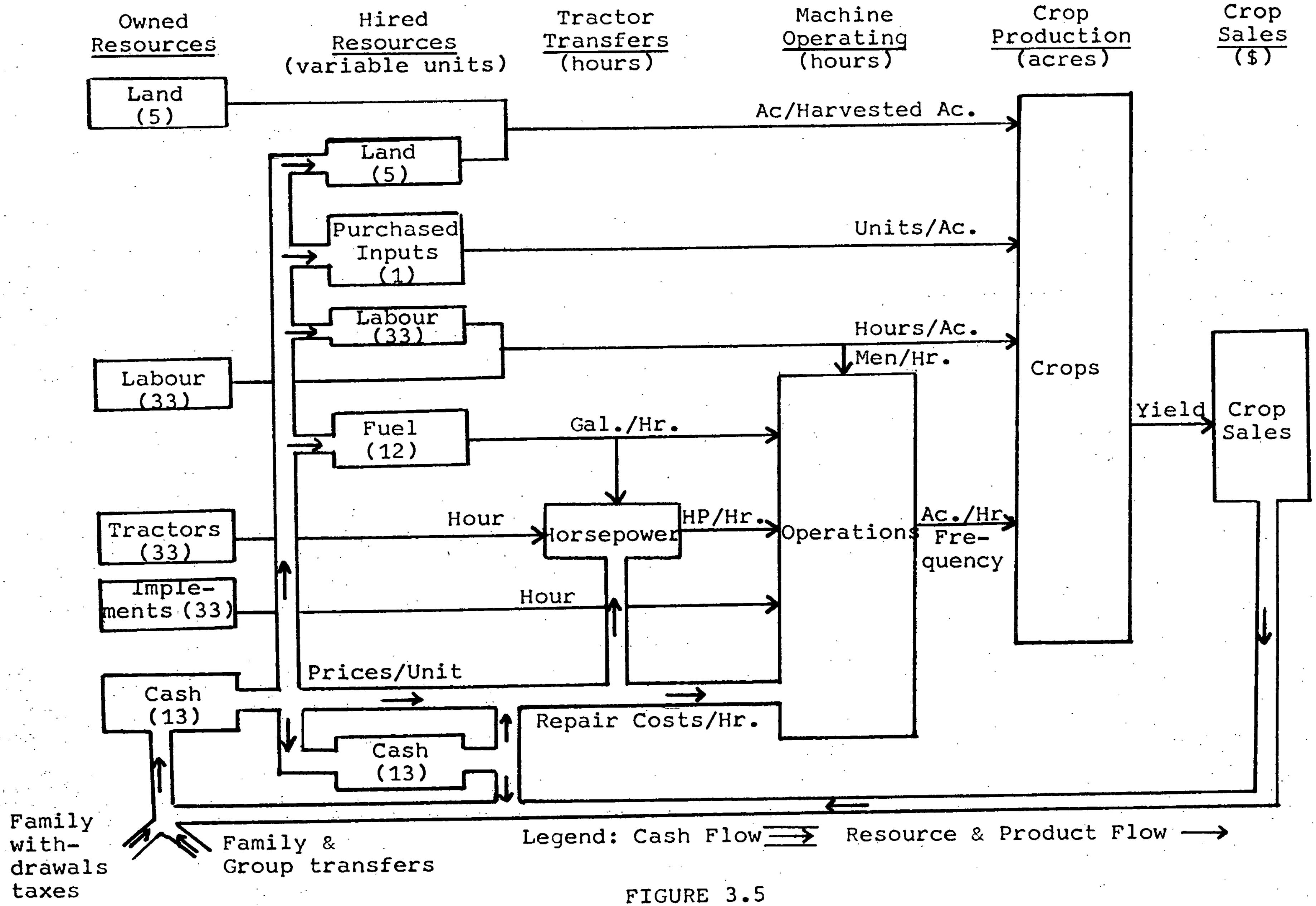

FIGURE 3.5

RESOURCE FLOW IN THE THEORETICAL MODEL

of the year whereas other inputs may only be purchased once or twice during the year. Thirteen periods are needed for cash. Twelve periods are needed for the cash flow predictions throughout the year and a 'thirteenth month' is required to account for cash that will be held at the end of the year. Labour is arbitrarily divided into 33 periods. 5 periods are used to represent labour in the months January, February, March, November and December. The rest of the months are divided into 4 roughly equal periods chosen so as to make the number of work days in each period as equal as possible. More specific work periods could be defined for a more narrow range of crops but it is felt that time may be critical in any of these weeks for some vegetable farms. Tractor and implement time is divided into the same number of periods.

The production activities are separated into three types in the diagram: tractor transfers, machine operating activities, and crop production activities. The interaction between the activities and inputs have already been illustrated in Figure 3.4. The arrows in Figure 3.5 indicating factor and product flow are another way of illustrating this interaction. The units of each input that each activity requires are also given in Figure 3.5. In addition, prices for all products and hired inputs and possible constraints on resource purchases and crop production and sales have to be specified.

In the next chapter the sources of the data and the relationships between different sections of the model are given in detail. A picture of the complete farm planning model in matrix is given in Figure 4.1. Figure 4.2 provides a key illustrating where the machine operating activities of Figure 3.4 or 3.2 fit into the structure of the entire matrix. After the presentation of the entire matrix schemata are given to illustrate the purchasing activities and other sub-sections of the entire model.

CHAPTER 4

DETAILED PRESENTATION OF THE MODEL

The method of scheduling machine activities and the structure of the entire model has been explained in Chapter 3. In Chapter 4, these two themes will be enlarged upon in detail considering the practical problems of data sources and the manner in which all the elements of the model can be brought together in a single matrix.

The data required by the model has already been indicated in Figure 3.5. Almost all of this data may be obtained directly from the farmer or his CANFARM records. The data required by the model is summarized in tables presented in Section 4.1. The use of engineering formulae to provide a data base for some machine operating parameters that may not be known by the farmer is discussed in the Appendices.

A picture of the entire model in matrix form is given in Figure 4.1 followed by an explanation of the objective function and the resources and constraints in the model. The most important activities in the model (the tractor transfers, the machine operating activities, and crop production and selling activities) have already been discussed in Chapter 3 and are illustrated in Figure 3.4. The labour hiring activities and labour transfers, the resource purchasing activities and the fixed cost activities are explained in detail in Section 3.3 Perhaps the most important part of the chapter is the tying together of the disparate parts of the matrix in Figure 3.2

which shows how the activities shown in detail in Figures 3.4 and 4.3 - 4.9 are all brought together to make the complete matrix of the farm planning model in Figure 3.1.

4.1 SOURCES OF DATA

The information required by the model can be classified into three general categories: cost information, internal and external constraints, and physical input-output parameters. By cost information is meant the prices that a farmer faces as well as the overhead and fixed costs of his business. Some cost information may be obtained from CANFARM or other accounting records. The type of information most reliably available from this source would be overhead costs. For variable costs it is necessary to know the unit prices of inputs and outputs which may not be available at all from CANFARM records. It is necessary therefore to have all input prices evaluated by farmer.

Internal constraints are directly related to the farmer's goals so it is only he who can specify these constraints. The farmer himself will also be the best source of information for external constraints. Thus all resource and activity constraints must be specified directly by the farmer.

For information about input-output coefficients such as machine capacity, yields, fertilizer use and so on the farmer himself is still the most important source. The CANFARM records may provide some help but it will be the physical record system that will be most valuable here. In some instances the parameters may be too technical to be known by the farmer, or they may be concerned with activities with which he does not have any experience. This might apply in situations where information such as'horsepower required to operate his seeder' is required or when the farmer is considering growing a new crop. In this case standard package data will have to be supplied.

It should be noted that in all situations the farmer himself should evaluate the coefficients and as many of the coefficients as possible should be specific to the farm. The data required according to type is summarized in Table 4.1. In Table 4.2 it can be seen that all the parameters in the resource renting, cropping and crop selling activities are farm specific. Some of the parameters in the tractor transfers and in the machine operating activities may require the use of various formulae in one of the following calculations:

1. Repair and maintenance costs for tractors and implements.
2. Fuel required to operate the tractors.
3. Horsepower required to operate the implements.

The use of these formulae and the information they require is dealt with in details in Appendices B, C and D.

TABLE 4.1

SUMMARY OF DATA REQUIRED BY TYPE AND SOURCE

Data Required	Farmer	CANFARM Records	Physical Records	Package Data
Cost Information				
a. Variable Costs, Prices	X	X		
b. Fixed Costs	X	X		
Constraints				
a. Internal	X			
b. External	X			
Physical Parameters	X	X	X	X

TABLE 4.2

SUMMARY OF DATA REQUIRED AND SOURCES BY SECTION OF THE MODEL

Section of Model	Date Required	Units	Source
Own Resources (Land, Labour, Tractors, Implements, and Cash)	Maximum Amount Available by Time Period	units	Farm Specific
Rented, Resources (Land, Labour, Fuel, Cash and Purchased Inputs)	Limits on Renting Activities	units	Farm Specific
	Prices	$/unit	Farm Specific
Horsepower Transfers	Fuel Required	gal/hour	Hunt's Fuel Formulae
	Repair Costs	$/hour	ASAE Repair Formulae
Machine Operating Activities	Fuel Required	gal/hour	Farm Specific
	Repair Costs	$/hour	Implement Standards
	Horsepower Req'd	HP/hour	Hunt's Power Formulae
	Implements Req'd		Farm Specific
	Labour Required	men/hour	Farm Specific
	Capacity	acres/hr	ASAE Capacity Formula
Cropping Activities	Limits on Cropping Activities	acres	Farm Specific
	Land	acres	Farm Specific
	Purchased Inputs	units/acre	Farm Specific
	Labour	hr/acre	Farm Specific
	Machine Operations	Frequency	Farm Specific
	Yield	tons/acre	Farm Specific
Crop Selling Activities	Limits on Selling Activities	tons/acre	Farm Specific
	Prices	$/ton	Farm Specific

4.2 PRESENTATION OF THE MODEL

The complete model in matrix form is illustrated in Figure 4.1. Figure 4.2 is a key showing how specific sub-matrices shown in Figure 4.1 and in Figures 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9 fit into the entire picture. All activities are discussed in the context of these sub-matrices. The objective function and resources and constraints in the model are discussed in detail below.

4.2.1 The Objective Function

The objective function consists solely of the difference between the value of purchases and the value of sales. Capital purchases or sales are not included in the model. Beginning inventories and accounts due or receivable at the beginning of the planning period are either assumed to be zero or can be expressed in monetary value and used to increase the original endowment of cash in January. Ending inventories and accounts due and accounts receivable are used to increase the cash received in the 'thirteenth' month.

The objective function is similar to 2.2:

4.1
$$\text{Objective} = \Pi = \sum_{i=1}^{n} p_i q_i - \sum_{j=1}^{m} w_j x_j$$

where Π = profit (income above variable and fixed expenses)

p_i = price of product i,

q_i = amount of produce i sold,

w_j = price of input j,

and w_j = amount ofinput j purchased.

	Borrow Cash (12)	Lend Cash (12)	Fixed Costs (1)	Rent Land (1)	Buy Fuel (12)	Buy Input (1)	Hire Labour (33)	Hired Labour Transfer (33)	Own Labour Transfer (33)	Tractor Repair Costs (12)
OBJECTIVE	$-A_{1,1}$	$A_{1,2}$	$-A_{1,3}$	$-A_{1,4}$	$-A_{1,5}$	$-A_{1,6}$	$-A_{1,7}$			$-A_{1,10}$
Cash (13)	$\pm A_{2,1}$	$\pm A_{2,2}$	$A_{2,3}$	$A_{2,4}$	$A_{2,5}$	$A_{2,6}$	$A_{2,7}$			$A_{2,10}$
Fixed Costs Control			$-A_{3,3}$							
Own Land (5)										
Rented Land (5)				$-A_{5,4}$						
Fuel (12)					$-A_{6,5}$					
Purchased Inputs (1)						$-A_{7,6}$				
Own Labour (33)									$A_{8,9}$	
Hired Labour (33)							$-A_{9,7}$	$A_{9,8}$		
Labour (33)								$-A_{10,8}$	$-A_{10,9}$	
Total Repair Percent (12)										$-A_{11,10}$
Repair Hours (12)										
Control Repair Hours (12)										
Tractor Hours (33)										
Horsepower (33)										
Implement Hours (33)										
Labour-Machine Control										
Operations Account										
Crop Control										
Yields										

FIGURE 4.1

PICTURE OF THE EMPIRICAL MATRIX

Repair Transfer One (12)	Repair Transfer Two (12)	Repair Transfer Three (12)	Tractor Transfer 0-10HP (33)	Tractor Transfer 10-20HP (33)	...	Tractor Transfer 130-140HP (33)	Machine Operating (33)	Labour-Machine Supply	Grow Crop	Sell Crop	RIGHT HAND SIDE
							$-A_{1,28}$			$A_{1,31}$	
							$A_{2,28}$			$-A_{2,31}$	$\leq b_2$
											$=b_3$
									$A_{4,30}$		$\leq b_4$
									$A_{5,30}$		$\leq b_5$
			$A_{6,14}$	$A_{6,15}$		$A_{6,27}$	$A_{6,28}$				
									$A_{7,30}$		
							$A_{8,28}$	$-A_{8,29}$	$A_{8,30}$		
							$A_{9,28}$		$A_{9,30}$		
							$A_{10,28}$		$A_{10,30}$		
$A_{11,11}$	$A_{11,12}$	$A_{11,13}$									
$-A_{12,11}$	$-A_{12,12}$	$-A_{12,13}$	$A_{12,14}$	$A_{12,15}$		$A_{12,27}$					
$A_{13,11}$	$A_{13,12}$	$A_{13,13}$									$\leq b_{13}$
			$A_{14,14}$	$A_{14,15}$		$A_{14,27}$		$-A_{14,29}$			
			$-A_{15,14}$	$-A_{15,15}$		$-A_{15,27}$	$A_{15,28}$				
							$A_{16,28}$	$-A_{16,29}$			
								$A_{17,29}$			$\leq b_{17}$
							$-A_{18,28}$		$A_{18,30}$		
									$A_{19,30}$	$A_{19,31}$	$\leq b_{19}$
									$A_{19,31}$	$A_{20,31}$	

FIGURE 4.1 continued

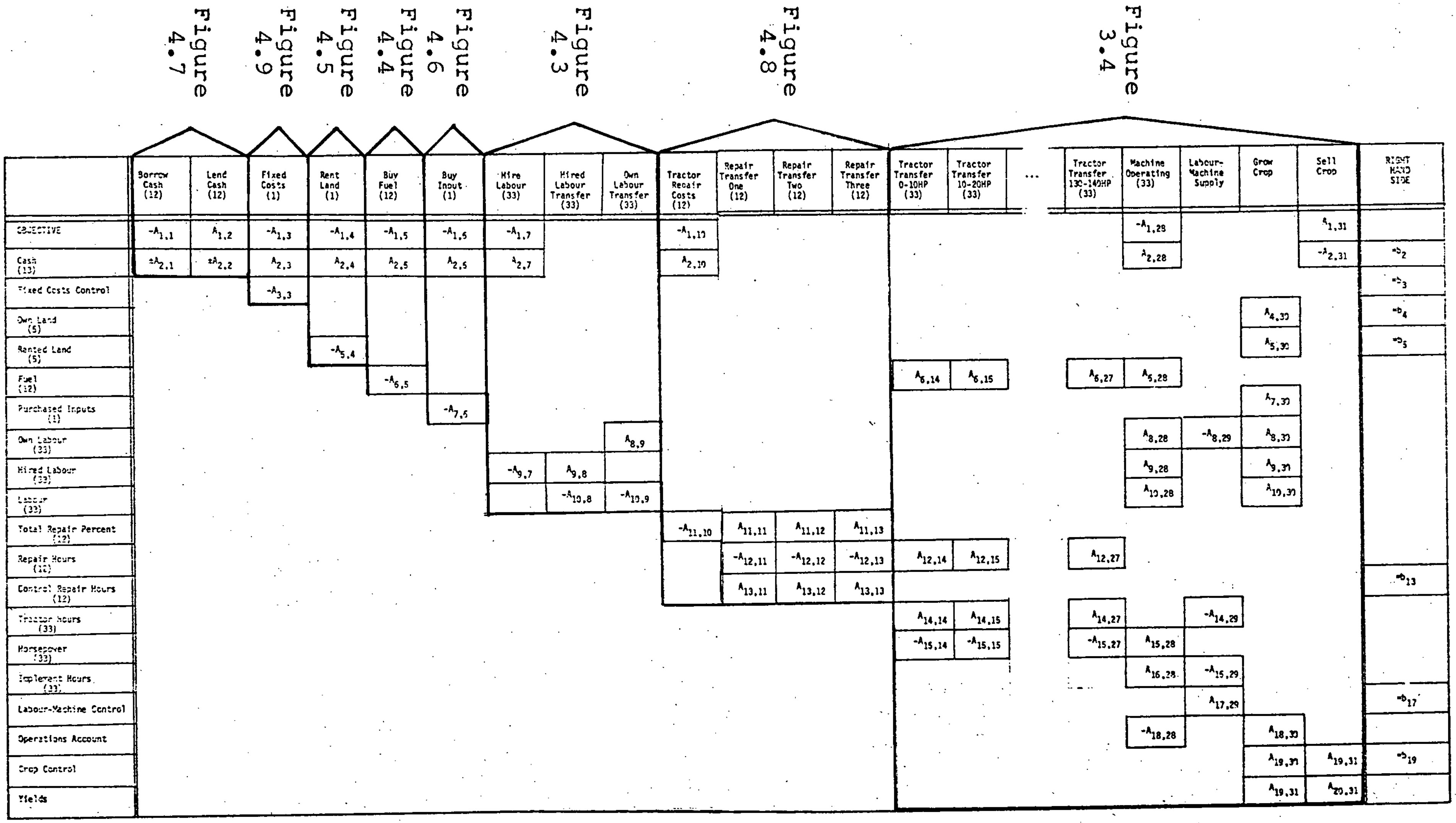

FIGURE 4.2

KEY TO FIGURES ILLUSTRATING SECTIONS OF THE COMPLETE MATRIX

The variables in the objective function are the products sold and inputs purchased. The prices are the coefficients which appear in the objective function.

The major items purchased or sold can be readily identified from Figure 3.1. The items sold consists of crop sales and interest on unused cash. As the model is set up to maximize these will have positive coefficients. The items purchased are interest on borrowed cash land rental, fuel and other 'purchased inputs', hired labour, tractor repair and maintenance costs, and implement repair and maintenance costs. The items purchased all have negative coefficients in the objective function.

4.2.2 Resources and Constraints

The major resources in the model are cash, fuel, purchased inputs, labour, tractors and implements. Cash may be constrained with upper bounds and there is an interest charge for cash and an original endowment of cash in the cash period for January. Fuel, purchased-inputs and hired labour are similar to cash in that they are unconstrained but may only be acquired through purchasing activities. Labour is divided into three classifications: own labour which is the labour supplied by the farm operator and his family without charge but with an upper limit, the unconstrained hired labour and a third classification which is either own labour or hired labour. There may be any number of tractors or implements in the model each of which constitutes a separate resource measured in machine time per work period. Each piece of machinery is constrained and although the farmer may define substitutes for a specific machine by assigning its use in an adjacent time period, by defining another crop production activity that does not use the machine but uses more labour or custom work obtained as a purchased input as a substitute. The level of any activity which supplies resources may be easily constrained introducing bounds on these activities although this is not illustrated in Figure 3.1 and was not done on the applied model that is discussed in the sixth chapter.

All other rows in the model are either accounting rows or are rows introduced to control the level of specific activities or groups of activities. The most important accounting rows are used for horsepower, machine jobs, and yields. Control rows are introduced to fix the level of fixed costs, and of the hours available per day for labour, tractors and implements. Special control rows may be used on crops or groups of crops and crop sales to take account of specific marketing, risk, and/or rotation constraints.

4.3 MAJOR ACTIVITIES IN THE MODEL

The most important activities in the model have been explained and illustrated in Chapter 3. Other activities are classified into major types and are illustrated in this section. These include the labour hiring activities and labour transfers and resource purchasing activities and the fixed costs activity. With this section the picture of the entire empirical model is complete.

4.3.1 Labour Hiring and Labour Transfers

There are two aspects of the labour block which require comment. The first aspect is the manner in which the own labour constraints in the different time periods are made (see Figure 4.3). A vector of work days per period is introduced. This vector is bounded by a constraint for the number of hours per day that the farm family is able to provide. The advantage of using this approach is that only one coefficient in the right hand side has to be altered to change the amount of time available in all thirty three time periods. The same method is used to constrain all implement and tractor time constraints.

The second notable feature is the three classifications of labour included in the model: own labour, hired labour, and a third classification for either owned labour or hired labour. To accomplish this, transfer columns which transfer own and hired labour into 'either' labour are utilized. All three classifications are felt to be needed. Certain supervisory jobs can only be performed by the farm

	Own Labour Supply	Own Labour Transfer 01	Own Labour Transfer 02	Own Labour Transfer 03	…	Hire Labour 01	Hire Labour 02	Hire Labour 03	…	Hire Labour Transfer 01	Hire Labour Transfer 02	Hire Labour Transfer 03	Machine Operating Activity	Maximum
Objective						−	−	−						
Cash						+	+	+						≤+
Own Labour Period 01	−	+											+	≤0
Own Labour Period 02	−		+										+	≤0
Own Labour Period 03	−			+									+	≤0
Own Labour Control	+													≤+
…														
Hired Labour Period 01						−				+			+	≤0
Hired Labour Period 02							−				+		+	≤0
Hired Labour Period 03								−				+	+	≤0
…														
Either Labour Period 01		−								−			+	≤0
Either Labour Period 02			−								−		+	≤0
Either Labour Period 03				−								−	+	≤0

FIGURE 4.3

THE LABOUR SECTION OF THE MODEL

operator. The farm operator may also want to restrict himself to family labour for certain jobs and time periods in the year. For other jobs, in harvesting for example, it may be necessary to hire labour. In most cases the classification of either labour may be most useful so that labour is not a constraint.

The labour hiring activities simulate the hiring of hourly labour. The cost per hour for the labour is entered in the objective function and in the cash section in the appropriate month. Each activity supplies one hour of labour in a specific work period in the hired labour rows. A labour hiring activity is built for each of the thirty three work periods.

4.3.2 Resource Purchasing and Hiring Activities

There are six classifications of resources in the model that may be purchased or hired: fuel, land, purchased inputs, cash, repair and maintenance, and labour. Labour hiring is explained in Section 4.3.1. The other five types are explained here. Each fuel purchasing activity supplies a particular type of fuel in a specific month that may be used by the tractors in the tractor selection block or by the machine tractor combinations in the machinery activities. The fuel buying activities are illustrated in Figure 4.4. The entries in the objective function and cash rows are the cost per gallon for the fuel. The entries in the fuel rows would normally be ones but these entries are adjusted to allow for the difference of 15% between theoretical fuel use and actual

	Buy Fuel A Jan.	Buy Fuel A Feb.	Buy Fuel A Mar.	. . .	Buy Fuel B Jan.	. . .	Tractor Transfers	Machine Operating Activity	Maximum
Objective	−	−	−		−				
Cash	+	+	+		+				≤+
Fuel A January	−						+	+	≤0
Fuel A February		−					+	+	≤0
Fuel A March			−				+	+	≤0
.									
.									
.									
Fuel B January					−		+	+	≤0

FIGURE 4.4

THE FUEL PURCHASING ACTIVITIES OF THE MODEL

	Rent Land A	. . .	Grow Crop	Maximum
Objective	−			
Cash	+			≤+
Land A Period I	−		+	≤0
Land A Period II	−		+	≤0
Land A Period III	−		+	≤0
Land A Control	+			≤+

FIGURE 4.5

THE LAND RENTAL ACTIVITIES OF THE MODEL

fuel use. The entries are therefore - 0.86.

Rented land requires a payment in one or two months which are to be specified by the farmer and supply land in each of the land periods that are defined for use (see Figure 4.5). The coefficients for the rented land is a vector of ones except for the entries in the objective and cash rows. A constraint is provided to limit the amount of land that may be rented.

Except for labour and cash all other purchased inputs are treated the same in the purchased input section of the model. Purchased inputs include such things as fertilizer, sprays, soil tests, custom work, twine and so on. Each of these inputs are included by the construction of a purchasing activity requiring cash in one or more months similar to the land rental activities and supply the input in a single row (see Figure 4.6). The entries in the cash rows are proportional to the amount of the input that is purchased in that month. The sum of the cash entries is the purchase price per unit of the input and appears in the objective function. The entries in the input rows are either negative ones or are a conversion factor to convert the input from the units it is normally purchased into those that it is used.

The cash row for January has an original endowment of cash in the right hand side. More cash may be acquired either through the cash borrowing activities or through the sale of crops. The model has to generate enough cash in the next month to repay any cash borrowed in the previous month plus interest charges. Any cash not used is collected in the transfer cash columns which add to the objective function the interest that would be earned by the money in a savings account. The money in the transfers are the cash endowments for the succeeding months and at the end of the year (see Figure 4.7).

For tractors the model calculates repair and maintenance costs as follows. The model selects a repair and maintenance cost coefficient for each tractor based upon the tractor's age in accumulated hours of use. Three coefficients from Table B.4 in Appendix B are used for three 1,000 hour intervals of tractor use for each tractor. These coefficients are used in the row "Tractor Repair %' in Figure 4.8. The product of these coefficients times the accumulated hours of use is multiplied with the list price of the tractor which appears in the objective function to come up with the repair and maintenance costs for a particular tractor in a particular month.

This cost accounting system was thought to be too large to use for each of the implements so it was decided to use single coefficients for each implement. These coefficients are the hourly repair and maintenance costs in dollars per hour which can be determined by multiplying the appropriate coefficient from Table B.3 in Appendix B against the list price for any particular implement. These coefficients are used in the machine operating activities as entries in the objective function and the relevant cash row.

	Buy Input 01	Buy Input 02	Buy Input 03	. . .	Grow Crop	Maximum
Objective	-	-	-			
Cash	+	+	+			≤+
Input 01	-				+	≤0
Input 02		-			+	≤0
Input 03			-		+	≤0

FIGURE 4.6

THE PURCHASED INPUT BUYING ACTIVITIES

	Borrow Cash January	Borrow Cash February	. . .	Lend Cash January	Lend Cash February	Maximum
Objective	-	-		+	+	
Cash January	-			+		≤+
Cash February	+	-		-	+	≤0
Cash March		+			-	≤0

FIGURE 4.7

THE CASH BLOCK OF THE MODEL

	0 HP Transfer	10 HP Transfer	20 HP Transfer	. . .	Repair Transfer One	Repair Transfer Two	Repair Transfer Three	Repair Costs	Maximum
Objective								-	
Cash									≤+
Fuel	+	+	+						≤0
Repair Hours	+	+	+		-	-	-		≤0
Control One					+				≤+
Control Two						+			≤+
Control Three							+		≤+
Total Repair %					+	+	+	-	≤0
Tractor Hours	+	+	+						≤+
0 Horsepower	-								≤0
10 Horsepower		-							≤0
20 Horsepower			-						≤0

FIGURE 4.8

THE TRACTER TRANSFER BLOCK TOGETHER WITH ROWS AND COLUMNS FOR REPAIR AND MAINTENANCE COST CALCULATIONS

4.3.3 Fixed Costs

Fixed Costs have to be forced into the model so that cash flow prediction is accurate and limitations on available cash are recognized realistically. Fixed costs are aggregated by month and a vector of monthly fixed costs are forced into the model with an equality constraint, as in Figure 4.9. The entry in the objective function is the sum of the fixed costs of the twelve months. The entry for each month is the sum of fixed costs incurred from all sources for that month. The fixed costs control row is an equality with ones in the fixed cost column and in the right hand side.

	Fixed Costs	Maximum
Objective	-	
Cash January	+	≤+
Cash February	+	≤0
Cash March	+	≤0
.	.	.
.	.	.
.	.	.
Fixed Costs Control	1.0	=1.0

FIGURE 4.9

SCHEMATA OF THE METHOD USED FOR FIXED COSTS

4.4 SUMMARY

In this chapter the practical considerations of the empirical model put forth in the previous chapter have been explained in detail.

The empirical model documented in this chapter is proposed as a model which satisfies the requirements of the second sub-objective ofthe thesis. The model may be examined in light of the characteristics that were deemed desirable in the statement of objectives. The data required by the model can nearly all be determined directly from a farm manager so that the model should be able to reflect the specific technological relationships and constraints of that farm. The model is completely general with respect to input-output coefficients and time periods. This means that the model is able to incorporate flexible time constraints and thus overcome the critical problem of the timeliness of the use of capital inputs. Neglecting the problem of converting data supplied by a farmer into a format usable by a linear programming solver, the model is, therefore, adaptable to a wide range of farms. Furthermore, the model functions to select a crop plan and production techniques that can be defined by varying the schedule of crop inputs in the crop production activities.

Logically the model is sound. This is shown in Appendix F in which the production, sales, resource use, and costs shown in the solution of a particular farm plan for a specific farm are compared with the production, sales, resource use, and costs calculated arithmetically from the crop plan selected by the model and using the interrelationships proposed in Chapter 3 and Chapter 4. The real evaluation of the model comes in the application of the model to a real farm (third objective) which is the subject of the next chapter.

CHAPTER 5

APPLICATIONS OF THE EMPIRICAL MODEL TO A CASE FARM

The subject matter of this chapter is presented to satisfy the third objective of the thesis which was to verify the model through its application to a specific farm. The verification of the model should provide answers to at least the following three questions: Can the model accurately simulate the production of vegetables on a real farm, Can the model be used to produce an optimal farm plan that is useful to the decision-maker on the farm? What sort of records can be projected with the model?

Before addressing these questions the special characteristics of the case farm are discussed in the context of how typical of vegetable farms is the case farm. This is necessary as the special circumstances of the case farm may provide different answers to the three questions than would normally be obtained so an effort is made to relate the types of situations that may be found and which it would be difficult to cope with using the model as it is applied to the case farm. In the second section of the chapter the model as it was built for the case farm is described.

In the third section an attempt is made to provide an answer to the first question. The procedure used to simulate the 1974 farm plan is given. The results of comparing the 1974 CANFARM records with similar records produced from the solution of the farm planning model used in simulation mode is provided although an evaluation of the comparison is necessarily subjective.

In the final section of the chapter the results of using the model to produce five optimal farm plans for varying market conditions and yields are summarized and compared with the plan selected without using the model. This is an attempt to show how the model may be used and the value of the information available from the model. An appropriate form for the farm report and the type of records that should be given is discussed with a complete set of records for one of the farm plans in Appendix G.

5.1 SELECTION OF THE CASE FARM

The case farm was selected soon after work on the thesis was initiated. The particular problems and structure of the case farm has been kept in mind throughout the processes of problem identification and the development of the empirical model. Knowledge of the problems of vegetable farms was acquired through meetings with other farmers and persons directly involved with vegetable production at seminars and field trips. The problems of other farms have modified the approach taken to the case farm but the case farm has been critical to the perception of many parts of the empirical model. To a large extent this can be justified by the special characteristics of the case farm. At the same time, an understanding of the special features of the case farm is necessary to appreciate difficulties that may be encountered in an attempt to apply the model to a second farm. The following is a discussion of the critical features of the case farm and how they have influenced the empirical model. A detailed account of the actual resources available, the activities considered and the technical coefficients used in the empirical model is given in a paper produced separately.

The special characteristics* of the case farm that have influenced the model in a positive manner are associated with the size and complexity of the case farm, the large number of crops of several types that are considered, the wide range of machinery used, the detailed CANFARM records that have been maintained over the years, and the experience and influence of

* These are documented separately in "An Optimal Farm Plan for a Vegetable Farm."

of the farm operator within the vegetable industry as well as on his own farm.

The complexity of the case farm is mainly due to the large number of different crops grown. At present, the farm is producing both early and late potatoes, the processing crops of beans and early and late peas, the biennial seed crops, cabbage, turnips and sugar beets, barley and two annual berry crops. The large range of crops involve the model in the most important vegetable, potatoes, in annuals, biennial and perennials, in marketing contracts, quotas and unrestricted sales, in crops requiring vastly different relative levels of such important inputs as labour, machinery, and purchased inputs and in various degrees of complexity in the manner in which each input is utilized. The usual vegetable farm characteristically produces only two or three different vegetables. There are some elements of other farms missing of course. Only one planting date is considered for each crop. The farm is completely made up of a mineral soil so cultural practices necessitated by muck soils are not attempted. The perennial crops are still at the experimental stage so they are treated as annuals in many respects. Finally, despite the large number of crops produced, many important vegetables are not produced on the case farm such as lettuce, onions, carrots and tomatoes.

The size of the case farm and the number of crops that are produced make it necessary for the operator to maintain and operate a large and varied complement of machinery. Seven tractors are operated which range in size from 30 HP to 140 HP and in age from 28 years to 1 year. The farm operates several trucks, two combines one of which is for potatoes the other for seed crops, several cultivators and various other types of tillage implements, sprayers, fertilizer spreaders, seeders and so on. Two of the implements are self powered and all vary greatly in the demands they make on power, labour and with respect to field efficiency, capacity and other machine characteristics.

A shortcoming of the case farm in this area is the dearth of physical records maintained. The extensive use of the CANFARM records perhaps has induced the operator to not worry about a physical record system. In the CANFARM records much of the information is given in the form of cost so prices and units used are concealed making it difficult to make even inter-year comparisons based solely on the records available.

The case farm does not have a cash constraint although it would be easy to introduce such a constraint by bounding the cash borrowing activities. The case farmer does not do custom operations so this type of alternative activity has not been built. The farm family is the source of most of the labour required. Although temporary labour is a factor, permanent hired labour is not, so a hiring activity for labour on a weekly or monthly basis is not included. To some extent the three classes of labour included in the theoretical model are not really needed on the case farm and the inclusion of the three classes is a concession to the needs of other farms.

The case farm also does not have an animal production enterprise competing for the resources used on the crops so this type of operation has not been built. Some vegetable producers produce only one vegetable and the special trade-offs they encounter has not been evaluated.

5.2 PICTURE OF THE EMPIRICAL MODEL

In this section of the thesis an attempt is made to summarize the salient parts of the input data and show how it was used to make the empirical model.

Family and hired labour is available in all periods with additional family labour being available in certain periods of the year. Labour hiring activities were included for all work periods. Labour utilized by the machine operating activities and by the crop activities is the labour type 'either labour' in every case. This was done to ensure that labour would not be a constraint.

Three types of land in two time periods for each were included in the model. This was to keep track of the crops planted on two separate fields and a section of rented land, although different yields are recognized only on the rented land. Two time periods are needed to accommodate the possibility of double cropping.

There are a total of 22 purchased inputs all of which were paid for in one period only. Interest rates for the opportunity cost of operating cash are approximately 10% and 8.75%. annually for borrowed cash and transferred cash respectively. It was presumed that borrowed cash would be withdrawn from term deposits in banks and transferred cash would be put into a savings account. Fixed costs for the model are calculated directly from the 1974 CANFARM records.

One of the most important sections of the model is the tractor selection block. There are seven tractors on the farm.

The two largest tractors are too heavy to do a lot of the operations done by the smaller tractors so tractor transfers for these tractors are not built for the lower levels of horsepower output.

A total of 294 separate machine operating activities were built for the operation of 29 pieces of machinery. Many of these activities are built for more than one job time constraint and each job may require several columns. For three operations specific tractors are required so method one in Figure 3.2 was used. This was necessitated by considerations of wheel width and the special operating circumstances of the potato combine and the rotovator. For all the other implements the tractor selection block (method three in Figure 3.4) was used.

Separate activities were made for the growing of each crop on each land classification except for seed crops and the berry crops which were produced on only one land classification. Separate selling activities were built for the sales of each crop on each market. Constraints are imposed on selling activities to represent market constraints.

All the coefficients of the model were either supplied directly by the farm operator from memory with the aid of his CANFARM records and bills of sale or they were reviewed by him. The parameters for machine costs and power requirements which he disagreed with were altered to accord with his experience. Parameters for fuel consumption and tractor repair costs were not altered.

The tractor selection part of the model occupies 320 rows and 351 columns. 162 rows and 287 columns are used to calculate tractor repair and maintenance costs. The entire size of the matrix is 963 rows by 1,150 columns. The matrix was solved using IBM's linear programming package MPSX using the 'macro' command 'primal'. Solving the problem required 678 pages of temporary files and 98 seconds of computer time. The matrix was modified to run in simulation mode so that the farm's 1974 farm records could be used to verify the model. Solution to the revised problem required essentially the same computer parameters.

Figure 5.1 gives a revised version of Figure 3.5. The case farm is depicted as a flow diagram with numbers in brackets to indicate the number of rows and columns respectively required to simulate each section of the farm.

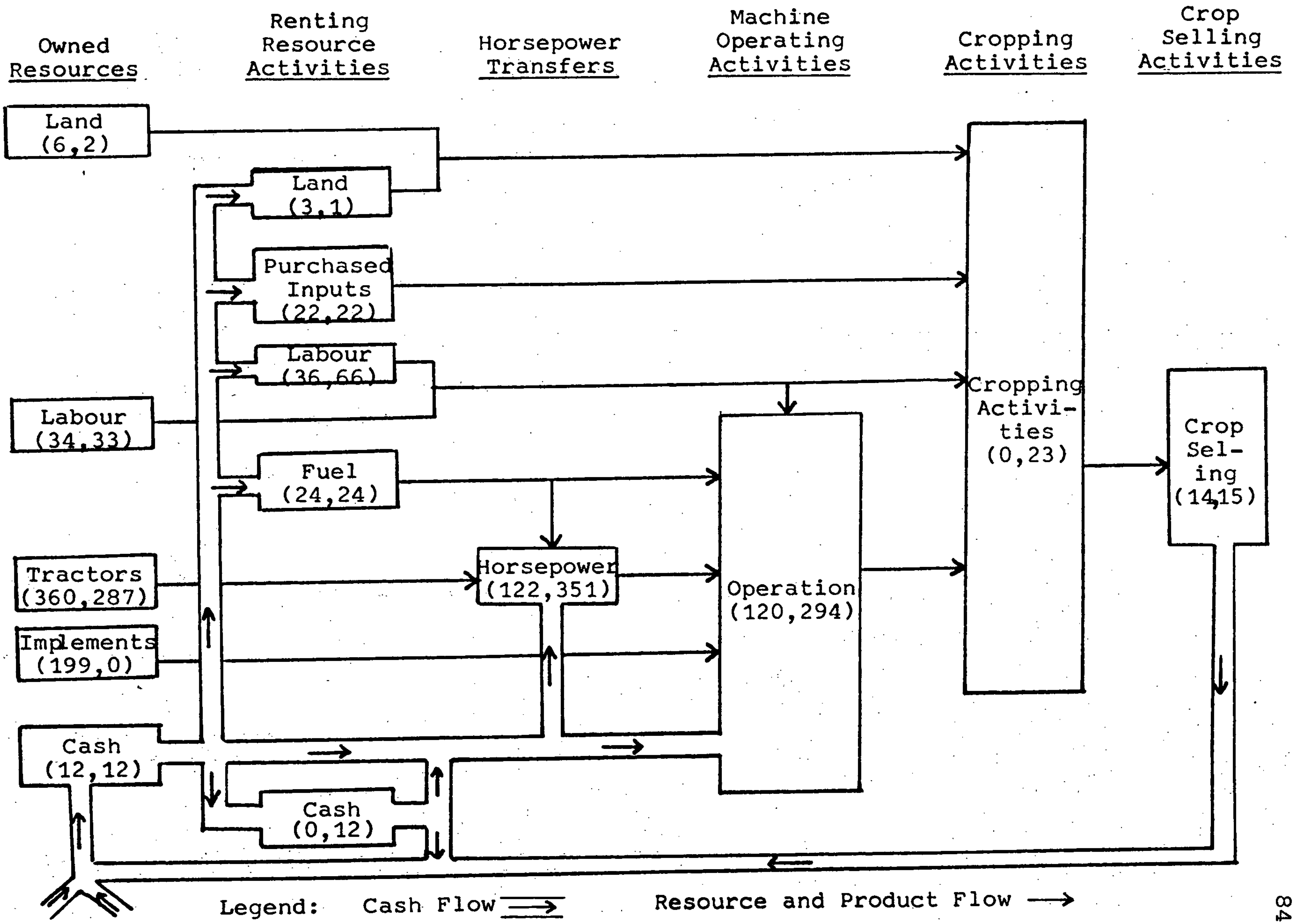

FIGURE 5.1

FLOW DIAGRAM SHOWING THE CLASSIFICATION OF RESOURCES AND TIME PERIODS FOR EACH RESOURCE AND USE OF RESOURCES ON THE CASE FARM

5.3 EMPIRICAL RESULTS OF MODEL VERIFICATION

5.3.1 Procedure for Simulation 1974 Farm Plan

To verify the coefficients and reliability of the model it was necessary to attempt to simulate the actual farm operations and results obtained in 1974 which are summarized in Table 5.1 To do this several major modifications of the model were made. Actual prices and yields achieved in 1974 were calculated from the 1974 income statement. The yields obtained were altered for each crop grown. Crops not produced were dropped as was the resource 'rented land'. Where market and risk constraints were violated in 1974 due to the different situation and markets, the constraints were dropped. A single selling activity was constructed for each product at the average price per unit of the crop that was received in that year. The price of the products were proportioned into the months in which the cash for the sales of those crops were actually received with crops in inventory increasing the value of the cash row for the 'thirteenth' month. Constraints were introduced to bound each crop production activity to the level of acres that were produced in 1974 with equality constraints. In this way crop production, crop sales and inventory changes should be almost exactly simulated. The difference between actual results and the CANFARM records should be due entirely to the opportunity cost of cash that the model calculates and rounding errors in the computer. The first of these sources of difference was eliminated by reducing the interest rate to zero for borrowed cash and eliminating the transfer cash columns altogether.

TABLE 5.1

INCOME STATEMENT
ACTUAL 1974 FARM PLAN

	Cash $	Accrual $
Crop Sales		
Barley	7,769	7,643
Field Beans	28,238	28,238
Field Peas	13,287	13,287
Potatoes	16,496	58,800
Strawberries	500	500
Sugar Beet Seed	6,755	6,815
Leaf/Fruit Vegetable Seed (Turnip)	405	3,522
Cabbage Seed	3,529	6,434
Pea Vines	2,370	2,370
Total	79,348	127,735
Expenses		
Seed		
Grain Corn	41	41
Field Beans	105	105
Roots & Tubers	28	28
Potatoes	6,612	6,612
Fruit Bushes	900	
Herbicides	4,170	4,170
Chemical Fertilizer	13,907	13,907
Lime	388	388
Gen.Crop S & S	221	221
Seed Treating	106	106
Baler Twine	1,044	1,044
Binder Twine	2	2
Purple Gasoline	980	980
*Car Gas	1,058	1,058
Diesel Fuel	382	382
*Oxygen	90	90
Tractor R & M	662	662
*Truck R & M	504	504
*Automobile R & M	1,364	1,364
Harvest Equip. R & M	7	7
Gen. Farm Equip. R & M	2,438	2,438
*Building R & M	4,528	4,528
*Yard R & M	114	114
*Structures R & M	367	367
*Tools	1	1
Part Time Labour	3,346	3,346
*Custom Work	63	63
*General Expenses	99	99
*Handling Charge	120	120

TABLE 5.1 continued

	Cash $	Accrual $
Expenses continued		
*Freight & Trucking	288	288
*Interest	111	111
*Insurance	857	857
*Equip. & Machine Insurance	22	22
*Car Insurance	406	406
*Truck Insurance	691	691
*Telephone	118	118
*Hydro/Electricity	692	692
*Property Tax	6,119	6,119
*Administration Costs	45	45
*Fees & Subscriptions	45	45
*Legal Service	55	55
*Other Prof. Services	105	105
*Office Supplies	18	18
*Miscellaneous Expense	78	78
Total	53,295	52,395

*Considered a Fixed Expense, i.e. independent of the level of crop production for each crop.

Source: 1974 version 1 CANFARM records.

5.3.2 Results for Verification

The model run in simulation mode was feasible; machinery and tractor time was in slack in all time periods. Labour was only fully utilized in the fourth period in May and in the last three periods in September in which hired labour was required. The feasibility of the farm plan does not imply that the time coefficients and constraints are correct but it does imply that matrix time coefficients are not exceptionally larger in the model than in fact and that time constraints are not exceptionally smaller.

The income statement for the simulated 1974 farm plan is given in Table 5.2 Total variable costs were underestimated by 4.84% (see Table 5.3). This number is due in part to a great many differences between actual 1974 costs and predicted costs by the model cancelling each other out. The extent to which the underestimation is acceptable must be judged comparing how the value for total variable costs originates both in the model and in the CANFARM records.

Purchased inputs costs were overestimated by 6.34%. There are several sources of the difference. The model spends almost $2,000 more on fertilizer, $900 less on herbicide, $2,000 more on other chemicals. Other chemicals is one of several items for which it is difficult to match the CANFARM names with those used in the model. The CANFARM record system uses a large number of package names. In entering a purchased input in the record system the user has to identify the items by the CANFARM names. It may be more convenient to enter most pesticides under

TABLE 5.2

INCOME STATEMENT
1974 SIMULATED FARM PLAN

	Cash	Accrual
Crops Sales		
Barley	7,769	7,643
Field Beans	28,238	28,238
Field Peas	13,287	13,287
Potatoes	16,496	58,800
Strawberries	500	500
Sugar Beet Seed	6,755	6,815
Leaf/Fruit Vegetable Seed (Turnip)	-	3,522
Cabbage Seed	3,529	6,434
Pea Vines	2,370	2,370
Total	78,944	127,609
Expenses		
Purchased Inputs		
Twine	87	87
Premerge	1,021	1,021
Pea Fertilizer	675	675
Potash	1,741	1,741
Eptam	2,216	2,216
Fertilizer 0-0-22	489	489
Fertilizer 11-55-0	3,315	3,315
Benlate	461	461
Beet Fertilizer	2,000	2,000
Turnip Fertilizer	459	459
Bees	230	230
Cabbage Fertilizer	726	726
Raspberry Fertilizer	-	-
Strawberry Fertilizer	297	297
Barley Seed	266	266
Barley Fertilizer	570	570
Early Potato Seed	-	-
Potato Fertilizer	5,610	5,610
Late Potato Seed	6,500	6,500
Blight	42	42
Sprout Inhibitor	1,050	1,050
Monitor Insecticide	556	556
Total Purchased Inputs	28,312	28,312
Purple Gasoline	504	504
Diesel Fuel	525	525
Tractor R & M	441	441
Gen. Farm Equip. R & M	1,185	1,185
Part Time Labour	2,057	2,057
Interest on Operating Capital	-	-
Total Variable Inputs	33,023	33,023

TABLE 5.2 continued

	Cash	Accrual
Fixed Expenses		
Car Gas	1,058	1,058
Oxygen	90	90
Truck R & M	504	504
Automobile R & M	1,364	1,364
Building R & M	4,528	4,528
Yard R & M	114	114
Structures R & M	367	367
Tools	1	1
Custom Work	63	63
General Expenses	99	99
Handling Charge	120	120
Freight & Trucking	288	288
Interest	111	111
Insurance	857	857
Equip. & Machine Insurance	22	22
Car Insurance	406	406
Truck Insurance	691	691
Telephone	118	118
Hydro/Electricity	695	695
Property Tax	6,119	6,119
Administration Costs	45	45
Fees & Subscriptions	45	45
Legal Services	55	55
Other Prof. Services	105	105
Office Supplies	18	18
Miscellaneous Expense	78	78
Total Fixed Expenses	17,961	17,961
Total Expenses	50,984	50,984
Income less Expenses	27,960	76,625

Source: Solution to farm planning model in simulation mode and CANFARM records.

TABLE 5.3

A COMPARISON OF ACTUAL 1974 COSTS WITH MAJOR ITEMS OF VARIABLE COSTS IN THE SIMULATED FARM PLAN

Item	Model $	CANFARM Records $	Difference $	Difference as % of CANFARM Records %
Total Variable Costs	33,023	34,439	1,415	- 4.10
Purchased Inputs	28,312	26,624	1,688	6.34
Chemical Fertilizer	15,883	13,907	1,976	14.21
Herbicide	3,237	4,170	- 933	- 22.37
*Other Pesticide	2,109	-	2,109	
Seed	6,766	6,786	- 20	- 0.29
*Bees	230	-	230	
Baler Twine	87	1,046	- 959	- 91.68
**Lime	-	388	- 388	
**Gen. Crop S & S	-	221	- 221	
**Seed Treating	-	106	- 106	
Fuel	1,029	1,362	- 333	- 24.38
Purple Gasoline	504	980		
Diesel Fuel	525	382		
Repair & Maintenance Costs				
Tractors	441	662	- 221	- 33.38
Gen. Equip. R & M	1,185	2,445	-1,250	- 51.49
Part Time Labour				
Potato Harvest	2,057	2,027	- 30	1.48
Other	-	1,319	-1,319	-100.00

*Items which are in the model but do not obviously correspond to items in CANFARM records.

**Items which are in the CANFARM records but do not obviously correspond to elements in the model

Source: CANFARM records (Appendix G) and farm records created from solution to the matrix (Appendix I).

the name 'herbicide' for example. Some of the names used are also simply different from those that the farmer would normally use to discuss the input. For example, it appears to probably be the case that bees are entered under the heading 'Gen. Crop S & S'. Inventories also account for some of the difference as the CANFARM records are recorded on a cash basis. The farm operator reported that he did in fact carry an inventory of fertilizer and chemicals over from 1973 worth around $2,000 but did not carry any inventory into 1975. Lime, on the other hand, is a purchased input that was left out through an oversight. In general then although there are several differences the most major differences can be accounted for and it is felt that the models input purchases are probably more accurate on an accrual basis than those reflected in the farm records.

Fuel consumption was underestimated by 24%. There are several reasons to expect that the model may underestimate the total fuel bill. The tractor selection block of the model was working so that the tractors are scheduled to minimize fuel and repair and maintenance costs given the level of crops selected. The model was able to perform almost all operations with only three of the seven tractors. The farm plan represents the usual utilization of machinery providing events follow their normal course. It is to be expected however that over the course of the year something is bound to happen to cause a deviation from the normal course of events in some part of the farm operation. It seems likely that such a situation would likely cause more fuel to be used rather than less. Fuel consumed during transporting implements to the field and in the trucks on farm business is also not accounted for.

The results for tractor repair and maintenance costs are quite similar. The model underestimates tractor repair and maintenance costs by 33%. Part of the reason for the difference must lie in the fact that the tractor selection part of the model was operating and part of the answer must be that it is not possible to follow the farm plan at least part of the year. The lumpiness of repair and maintenance costs must also be kept in mind. 1974 was in fact an exceptionally high year for repair and maintenance costs. Tractors and implements together in 1974 required $3,000 to repair and maintain but only $1,428 in the preceding year. In 1974 implement repair and maintenance costs were $2,445 but they only amounted to $1,853 in 1975. The estimate made is therefore probably an underestimate over the long term for implements and tractors but not of the magnitude 33%. The estimate for implements is probably more of an underestimate than the estimate for tractors because the age of the operator's equipment has not been taken into account. The comparison with the CANFARM results probably overstates the difference in the long term between the actual repair and maintenance costs and predicted costs.

The final variable cost is part time labour and results for part time labour are the most interesting. In the actual farm plan part time labour was used in the potato, peas, beans, berry and barley crops as well as in general farm maintenance. In the model on the other hand hired labour was only required for the potato harvest. The difference between the predicted and the actual amount for the potato harvest. The difference between the predicted and the actual amount for the potato enterprise is less than 1½%. This result suggests very strongly that not only is the labour hiring activities accurate but the time coefficients for labour and machinery and the constraints on these resources are very accurate at least in the month of September. The fact that part time labour was also required on several other crops is also interesting. When asked about this labour the farm operator stated that it was necessary to hire part time labour for harvest operations on these crops in 1974 although this would not normally be the case. Part of the reason the fuel and repair and maintenance bill was underestimated might be due to the unusual harvest circumstances.

By the nature of the validation the results could not in any circumstances be described as final but they are very positive on the whole. Several anomolies appeared in the purchased inputs which could, for the most part, be explained in terms of inventories and the problem of identifying items recorded in the CANFARM records with those used by the farm operator. Labour costs were predicted within 1½% in the month of September which together with the feasibility of the farm plan suggests that time coefficients are reasonably accurate. Fuel and repair and maintenance costs were underestimated by up to 50% but there are several reasons for thinking the model would underestimate these costs. It is probably the case that these cost estimates are systematically lower than should be but not by an amount sufficiently large to influence crop selection. Based on the results it is felt that the model is sufficiently accurate to use it to suggest an optimal farm plan which is the subject of the next section of this chapter.

5.4 RESULTS OF USING THE MODEL TO SERVE THE OPTIMAL FARM PLAN

Because of the changing market conditions some crop plans that were feasible in 1974 are no longer possible. The farm operator feels that he may wish to reduce the amount of land in potatoes and peas because of the possibility of lower prices for those crops. In effect he feels the demand and/or supply curves for these crops may have shifted. At the same time he feels that he may be able to obtain higher yields for beans, barley and sugar beets. The farm operator is also considering the renting of 100 acres for the production of barley. It was thought initially that three different optimal plans might be prepared with increasing yields for beans, sugar beet seed and barley. This course of action was changed after seeing the first optimal farm plan (see Table 5.4 and Appendix G). In the optimal plan 86 acres of land was rented. All crops with exception of barley came in at the upper limit of their respective market, risk or rotation constraint. Barley, the only crop without an upper limit because of the market risk or rotation constraint, was selected at a level of 108 acres where a machine constraint came into effect.

For all other implements machine time was not an important constraint. Several implements were fully utilized in some time periods but possibilities existed to substitute implement time in an adjacent time period so the model was not forced to alter the farm plan. The implements which were fully utilized

TABLE 5.4

INCOME STATEMENT
1976 OPTIMAL 'PLAN A'

	Accrual $
Crop Sales	
Straw	10,800
Barley	23,760
Field Beans	16,200
Field Peas	25,920
Potatoes	110,380
Strawberries	6,000
Sugar Beet Seed	18,240
Leaf/Fruit Vegetable Seed (Turnip)	4,500
Cabbage Seed	34,000
Pea Vines	2,925
Raspberries	2,800
Total	255,525
Expenses	
Rent	7,740
Purchased Inputs	
Twine	87
Premerge	747
Pea Fertilizer	675
Potash	2,348
Eptam	2,274
Fertilizer 0-0-22	463
Fertilizer 11-55-0	1,912
Benlate	266
Beet Fertilizer	2,000
Turnip Fertilizer	573
Bees	400
Cabbage Fertilizer	1,453
Raspberry Fertilizer	124
Strawberry Fertilizer	297
Barley Seed	756
Barley Fertilizer	1,620
Early Potato Seed	2,240
Potato Fertilizer	9,312
Late Potato Seed	8,190
Blight	53
Sprout Inhibitor	1,323
Monitor Insecticide	700
Total Purchased Inputs	37,814

TABLE 5.4 continued

	Accrual $
Expenses continued	
Purple Gasoline	977
Diesel Fuel	934
Tractor R & M	678
Gen. Farm Equip. R & M	1,906
Part Time Labour	4,478
Interest on Operating Capital	- 662
Total Variable Inputs	53,864
Fixed Expenses	
Car Gas	1,058
Oxygen	90
Truck R & M	504
Automobile R & M	1,364
Building R & M	4,528
Yard R & M	114
Structures R & M	367
Tools	1
Custom Work	63
General Expenses	99
Handling Charge	120
Freight & Trucking	288
Interest	111
Insurance	857
Equip. & Machine Insurance	22
Car Insurance	406
Truck Insurance	691
Telephone	118
Hydro.Electricity	695
Property Tax	6,119
Administration Costs	45
Fees & Subscription	45
Legal Services	55
Other Prof. Services	105
Office Supplies	18
Miscellaneous Expense	78
Total Fixed Expenses	17,761
Total Expenses	71,825
Income less Expenses	183,700

Source: Solution to farm planning model in optimization mode and CANFARM records.

in some time periods were the pulvi-mulcher throughout April, the power mulcher in March, the plow in the third week of April, the potato combine in two weeks in September, and the disc in two weeks in April.

Tractor time was not a limiting factor at any power level because of the possibilities for substitution. Tractor time was fully utilized for the 1370 Case throughout April and for the smaller tractors at odd periods in the year. The shadow price on these resources remained very low.

Labour was not critical in any time period because of the possibility of substituting hired labour. Hired labour was required in May, the first week in August, and with potato harvest in September.

Consideration was next given to which crops it would be most profitable to expand above the risk and/or market constraint. This was really an attempt to deal with the question brought up by the farmer about which crops it would be most profitable to substitute for peas and potatoes for which market conditions were becoming more uncertain. The market and/or risk constraint for beans and sugar beets was eased so the effect of incorporating more of these crops could be evaluated. The results are summarized in Table 5.7 in Plans B, C and D. Plan A, or the 'base plan', is the first optimal plan prepared without easing risk and/or market constraints

The effect of the easing of the risk and/or marketing constraint was to substitute these crops for barley. There was no effect on the acreages of peas and potatoes. An upper bound on the level of the sugar beet crop also appears as this crop competes for land with potatoes. It is interesting to note that with reduction of the level of barley production none of the resources for tractor or implement time is critical; machinery is not a constraint. The five acres of turnips are dropped from the farm plan however.

To finally get at the question of whether increased yields might lead to a substitution for potatoes or peas, two more plans were prepared with the yields increased by 12.5% and 25% for barley, beans and sugar beet seed. Risk and market constraints were set at the level of those in Plan C to give the computer considerable space to bring in more barley and possibly sugar beets at the expense of pease and/or potatoes. The results of these changes are Plan E and Plan F in Table 5.5.

It can be seen that even in this case no substitution is made for potatoes or peas. The conclusion is, therefore, that in the circumstances considered no substituion should take place involving either barley, beans or sugar beet seed for either potatoes or peas. There is some conflict between the seed crops and late potatoes when both of these are at their upper limits imposed by the marketing, risk and rotation constraints on 'Land A' but this is resolved in favour of potatoes even at 25% higher yields for sugar beet seed or any equivalent change in prices and yields for sugar beets and potatoes. If it is possible to increase the acreage of any of the crops above the levels in Plan A in Table 5.5 then conflicts

TABLE 5.5

A COMPARISON OF ALTERNATIVE 'OPTIMAL' PLANS

Crop	Base Plan A acres	Relaxed Risk and Market Constraints B acres	C acres	D acres	Increased Yields E acres	F acres	Simulation of Plan Selected (Without Model) G acres
Bean Constraint	30	45	60	75	60	60	N.A.
Sugar Beet Constraint	20	30	40	50	40	40	N.A.
Yield Index	100%	100%	100%	100%	112.5%	125%	100%
Late Potatoes	63	63	63	63	63	63	50
Early Potatoes	20	20	20	20	20	20	15
Late Peas	15	15	15	15	15	15	30
Early Peas	30	30	30	30	30	30	
Beans	30	45	60	75	60	60	30
Barley	108	97	78	63	78	78	40
Sugar Beets	20	30	39	39	39	39	30
Turnip	5	5	0	0	0	0	4
Cabbage	20	20	20	20	20	20	20
Raspberries	2	2	2	2	2	2	2
Strawberries	5	5	5	5	5	5	5
Total Harvested	318	332	332	332	332	332	226
Net Income	$ 183,700	189,184	192,025	193,072	203,058	214,524	157,788
Net Income as % of Base Plan	100%	103%	104.5%	105.1%	N.A.	N.A.	86%

Source: Solutions to the farm planning model in optimal mode.

should be resolved in the direction of a decrease in the production of barley.

Some conclusions can also be made in comparing the optimal farm plans with the plan that the operator selected for 1976 without the use of the model (Plan G in Table 5.5). The level of income in Plan G is 86% the level of income in Plan A. Some discretion is required in comparing these two plans as both involve the use of the farm planning model. The question arises whether the difference between the optimal 1976 farm plan and the 1976 farm plan selected without the model are significant enough to justify the construction and use of a linear programming model. Providing the reliability of the model is acceptable I believe the answer is yes. The difference in net income between Plan A and Plan G is $25,712. Furthermore, the model definitely shows a course of action on two alternatives the farm operator is considering: it would be profitable to rent the land available and produce barley but it would not be profitable to reduce his production of potatoes or peas.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

6.1 SUMMARY OF THE THESIS

The overall objective of the thesis was to construct a farm planning model that would be of value to vegetable producers in making planning decisions. More specifically, the objective was to build a model that would indicate the most appropriate selection of crops and production methods. This objective was subdivided into four sections: identify the special problems of vegetable producers that have to be incorporated into the model, construct the model, validate the model through its application to a case farm, and use the model to produce an optimal farm plan.

It was pointed out that the vegetable industry is extremely diverse. The large variety of vegetables produced, methods of production and regions in Canada meant that the model had to be a very general crop budgeting model. The diversity of the industry also is probably responsible for the lack of basic 'testing' to demonstrate the affect of changes in the use of various inputs on yields. A further result of the diversity of the industry is that a great many vegetable producers become specialists part of whose income derives from their very specific experience, ability and resource base.

These aspects of the industry have influenced the model. It was felt that it would be impossible to develop general principles for varying yields with inputs but that it is necessary to have the capability to easily include various alternatives in the use of variable inputs and their effect on yields in so far as they can be quantified by the individual farmer. To select crops on a particular farm the specific resource base and production relations of that farm have to be included in the model so that variable costs and resource constraints accurately reflect the real marginal relationships in the farms production function.

The variable inputs, purchased inputs such as fertilizer and other chemicals were seen as fairly straightforward given the degree of 'testing' that has been done; to achieve an expected yield a prescribed amount of each chemical has to be purchased. In all cases there would not be constraints on the amount that can be acquired at a constant price and for most cases the affect of marginal changes in the amount used would not be known. The scheduling of machine operations on the other hand was seen as the main difficulty. Each machine operation uses labour, tractor and implement time. The constraints on the amount of time available of each of these resources in the section of the total year in which a job has to be completed and the amount of time required to complete the job was seen as a very complicated and possibly very critical consideration if the farm plan that is recommended is to be truly feasible.

Consequently, the characteristics of machine operation were studied in detail for the dual purpose of developing a method of machine scheduling and of predicting costs of use specific to the farm. Although the specific farm was envisaged as the final source of all data engineering principles were used as a source of 'standard' data for repair and maintenance cost ratios and fuel consumption. ASAE repair and maintenance formulae and Donnell Hunt's fuel formulae are used for data that may not be known by the farmer. These include ASAE field capacity formulae and Hunt's power formula. Engineering principles were incorporated into the structure of the matrix to specify the interrelationships between resources.

The core of the theoretical model developed involved the construction of machine operating activities for each job that has to be performed on each crop. The advantage of this method was that the time constraints for each job could be specified in a flexible manner and the particular parameters of each job could be used explicitly in the model. A tractor selection block was built to explicitly incorporate the tractors actually available for a particular operation in terms of power. The schedule of machine activities for each crop becomes a column of integers in the crop activities.

The complete theoretical model also included various resource purchasing activities. A slightly different method was used to include each class of resources: land, labour, fuel, purchased inputs, borrowed cash, tractor repair and maintenance, and implement repair and maintenance. A vector of fixed costs was forced into the model to accurately reflect the farm's cash flow position. Rotation and marketing constraints were to be added as required to crop and crop selling activities.

The model was applied to a large commercial vegetable farm in British Columbia. Eleven crops were evaluated on three different classes of land. The prices, yields and acreages of each crop were fixed at levels actually obtained in 1974. The logic of the model was validated by calculating by hand the resources and costs required by the solution and comparing these with those obtained by solving the model on the computer. The results were exactly the same in all cases except for difference readily attributable to rounding errors.

The cost predictions of the computer solution were also compared with CANFARM records for 1974 to evaluate the parameters of the empirical model and the methods proposed to predict variable costs in the theoretical model. Although these results were more ambiguous they were for the most part very positive. Several significant differences did appear between actual costs and predicted costs but they could be attributed to peculiarities of the farm operation in 1974 and to the optimization routine in the tractor selection block of the model.

6.2 CONCLUSIONS

The hypothesis implied by the objectives of the thesis was that it was possible to build a farm planning model that would be useful to vegetable producers in making planning decisions. The testing of this hypothesis is necessarily a subjective valuation of the usefulness of the model. The model built is essentially a crop budgeting model whose main function is to select crops based on gross margins and constraints on labour, machinery, land, operating cash, and considerations for risk and rotations. The usefulness of such a model that can successfully make an efficient selection is obvious. By making a modification in his farm plan based on the results of the model the grower should be able to receive a higher farm income than he would otherwise using a very similar combination of resources. The model also provides information on which tractors are the most economical to operate although this information is available through arithmetic calculations outside the framework of the model. This last point is illustrative of the educational value of the model. By working out the input data that the model requires for a solution the farm operator is made aware of the great deal of information that he has to deal with in making efficient decisions. The shadow prices of the resources of the model also indicate directions in which the farm business may be altered in the future to improve the profitability of the operation. The model also gives the farmer a valuation of the cost to him in following a slightly different plan.

Whether the model successfully performs all these functions depends upon its reliability. The logic of the model has proven to be sound. Given that the logic is sound, the reliability depends upon the validity and completeness of the input data. For the case farm it has been possible to very closely simulate 1974 costs using the model. Although some reservations about the reliability of the predictions for some parts of the model must be held, most especially concerning the estimate of implement repair and maintenance costs, the predictions are for the most part quite accurate. The conclusion is that for the case farm at least the model does achieve its objectives.

It is also apparent that the model is readily applicable to any similar vegetable farm, i.e. large commercial vegetable farms that produce a range of crops. Indeed the model would be useful in making crop selections on any type of farm although the large number of time periods is more directly related to the vegetable industry. It is not obvious how the model would be used on farms which are organized in a very different manner. One situation in which it would be most difficult to adapt the model is the case where there is only one crop considered unless a great deal more information can be supplied about alternative production methods than was available on the case farm. The reason why the model is of little value in this situation is that with one crop and one production method the farm plan is pretty well predetermined. The other case is where there is an alternative animal enterprise for which the model has not really means to evaluate. Other than these two situations it would not be difficult to adapt the model to any farm where crop selection is an important problem. Whether the model can be reliably used on these other farms is still an open question. The reliability of the model can only really be evaluated through extensive testing of the model on a large number of farms.

6.3 SUGGESTIONS FOR FURTHER STUDY

As with any study the final result is to indicate the wide range of extensions and associated problems that may be profitably investigated. To facilitate the presentation of topics for further research the topics have been divided into three classifications: further developments of the present model, technical subjects, and extensions of the present model to include more complex farm planning problems.

6.3.1 Further Developments of the Present Model

The original plan as conceived by CANFARM called for the development of software packages to aid in the application of the model. It is reasonable to ask at this stage whether the model should be applied to several more farms or whether the software packages should be built now. I feel the software packages should wait until further evaluation of the model has been made. Questions should first be asked about the suitability of the time periods and the reliability of the cost predictions that are in the model. Work should be done to develop an adequate and complete set of input and output forms. The usefulness of these forms in extension should be a major consideration. The farm plans (see Appendix G) for the case farm with the model in optimization mode are an attempt to provide the output forms. The experience with the Purdue crop budgeting models would be extremely useful as a reference here. Finally, it may be useful to make minor adjustments in the linear programming problem to provide the software packages with useful information and vice versa. To summarize, the software packages should be constructed in conjunction with a thorough review of the linear programming model and with a great deal of thought going into the input and output forms.

Concurrent with the development of the software package a decision has to be made on the manner in which CANFARM is to service the large number of vegetable farms in the country. The direction of development can take the form of using a large number of very specific models for specific producers in specific regions or a single more complex and general model. The problems of other vegetable farms that have not been incorporated into the model may have to be dealt with in this context. For example, should the possibility of custom hiring in and out of the farm operation be built into the theoretical model or should there be two models one of which includes custom hiring and one which does not? The model may have to be adapted one way or the other to farms which produce only one crop and farms with an animal enterprise making demands on resources. When these type policy decisions have been made it will be possible to go on to the next stage of model development.

6.3.2 Technological Studies Needed

The type of technical information that it would be worthwhile to investigate more thoroughly falls into several classifications. There is a great deal of work that can be done on machinery repair and maintenance costs. The coefficients used for the tractors in the model could be re-estimated at smaller intervals. Four or five hundred hour intervals might be more accurate than the present thousand hour intervals. The repair and maintenance coefficients used for the other implements could be revised to take account of age of the implement. This may be done by using the other ASAE formulae for repair and maintenance costs and developing tables of coefficients for each class of machinery. A single coefficient should still be used for each implement however. It may be that the formulae should be revised upwards altogether to take account of Canadian conditions and inflation. This can only really be determined by the further application of the model to several farms.

Hunt's fuel formulae may also be revised. It would not be difficult to re-estimate the formulae based on the Nebraska tests using either the same or a different functional form from that developed by Hunt. A formula that used one of the summary statistics of the Nebraska Tests might be especially valuable in providing a tractor specific estimation of fuel consumption at various loads. Some evaluation of the formula may also be made in actual farm use. If this course were taken then it might be possible to include the use of fuel for reasons other than directly in field operations so that the estimate may be rationally revised upwards.

Perhaps the most important technical information that is required is some method to relate yields and production methods in a systematic fashion with formulae similar to the engineering formulae. It is already pointed out in several places that it is left to the grower to define a set of best production practises. However, it is necessary to be able to deal with the effect of a deviation from these best practises in a quantitative manner. An example of the type of information needed can be seen in the Purdue Crop Budgeting Model B-9. In the model corn yields are reduced by 1/Bu./day for alternative planting periods between May 10 and May 23 and by 2/Bu./day for planting periods between May 24 and June 10. Data expressed in this manner or perhaps in percentage yield reductions are needed for the timeliness of operations w.r.t. planting dates, harvesting dates and on weed control. Similar data is also needed for such factors as fertilizer use, pesticides and water. Ideally the information would be based on actual farm results rather than crop tests but whatever the source systematic relationships are needed for each vegetable or class of vegetable.

A final area for technical investigation is in the effect of weather. Weather is a subject area which really cuts across all three classifications of areas for further study. The effect of weather on machine time is implicitly incorporated into the data as it is collected on machine constraints and on crop production activities in the schedule of machine activities for each crop. It may be that it would be useful to make the effect of weather explicit. This would necessitate the investigation of how weather variable can be used explicitly in the model. Weather may provide for a systematic method for dealing with alternative planing and harvesting dates for example.

6.3.3 Expanding the Model to More Complex Farm Planning Problems

The third classification of areas for further research in extending the complexity of the present model. At present the model is a single year linear programming model assuming a fixed capital stock and certainty. The assumptions of fixed capital stock and certainty is a strict description of the model and is not to say that risk is ignored completely and the model has nothing to say about capital purchases. Both of these topics are handled indirectly. Risk is evaluated subjectively by the farmer when he specifies upper and lower bounds he will consider on the crops in his farm plan. Similarly although capital budgeting is not handled explicitly, the shadow prices on resources in the final farm plan give an indication of the machinery that may be profitably replaced. The subjects of risk and capital budgeting are both very important topics of farm management and a reformulation of the crop budgeting problem from the point of view of the economist should probably be in this direction.

CANFARM already has a few small farm planning packages used to make capital budgeting decisions. These packages work outside the context of the whole farm plan in a manner analogous to a partial budget and thus do not really take into consideration the effect of machine purchases on constraints and the resultant change in crop plan that may become feasible. Programs are also being developed to explicitly incorporate risk into farm planning models in other sectors of agriculture.

The question arises, however, in the context of the present model as to which of these subjects it would be the most profitable to investigate next. The question may be divided into three aspects: the relative importance of risk and capital budgeting to the farmer, the improvement over the present capability of the model, and the ease with which the model can be revised.

The importance to the farmer of having more information about risk or more information for his capital purchases is really impossible to evaluate. For each farmer the relative importance of the two types of information may change from time to time. The solution to the optimization problem in Chapter 5.5 illustrates how the model may be used to take account of risk and uncertainty. The farmer specified risk constraints on his crop plan and five different plans were prepared based on different possible outcomes based on yield. The farmer is left to select a farm plan for himself based on the additional information provided by the model. The real value of incorporating risk in a more explicit fashion must either be in the ability of the model to include more information in the evaluation of risk or to be able to express the farmer's valuation of risk in more precise mathematical terms so that the exact trade-off between risk and other factors may be more exactly calculated. I doubt if more information can be incorporated. If the farm management specialist had special information on future prices and yields he would not have to work for a living. Most risk models rely heavily on past prices and yields. There are such a great many dimensions to risk, however, that it is difficult to incorporate all of them in a simple prediction model. Growers may sometimes have fairly strong reasons to suspect the prices of a crop will be good or bad based on a complex perception of changes in supply or demand which it is really impossible to incorporate in a prediction model. This being the case, it is really questionable whether there is a great deal to be gained in trying to build in risk.

I feel on the other hand that including capital budgeting would dramatically increase the scope of the problem. The shadow prices of machinery is only an indication of where machinery might be a problem. The inclusion of capital budgeting would enable the model to aid in these type of decisions in a much more realistic fashion. New pieces of machinery are acquired nearly every year on the case farm. Capital budgeting would be a useful guide as to which machines should be replaced. McHardy's model demonstrates relationships that may be used in a machine budgeting section of the model that not only give a yes or no decision on machine purchases but can be used to select appropriate size of machinery. The inclusion of capital budgeting would also allow the expansion of the plan to include several years and the growth rate of the firm.

Finally, consideration must be given to the formulation of the objective function. The farm planning model maximizes income above variable costs but it ignores inventories and the effect of taxes. Some consideration should be given to these variables so that it is really net farm income after taxes that is maximized.

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APPENDICES

APPENDIX A

THE IMPORTANCE AND PERFORMANCE OF THE VEGETABLE INDUSTRY IN BRITISH COLUMBIA AND CANADA

TABLE A.1

IMPORTANCE OF THE VEGETABLE INDUSTRY IN CANADA AND BRITISH COLUMBIA: AREA 1970-74

	Area under Vegetables		Vegetable Acres as Per Cent of Total 1971 Cropped Acres	
	B.C. (acres)	Can. (acres)	B.C. %	Can. %
1970	22,900	554,610	2.10	0.81
1971	22,610	470,580	2.07	0.68
1972	22,740	467,360	2.45	0.68
1973	27,550	511,790	2.52	0.74
1974	25,270	536,810	2.31	0.78

Source: "Quarterly Bulletin of Agricultural Statistics", Statistics Canada, 21-003, Agricultural Division, Ottawa, July-September, 1975, 1973, 1971.

"1971 Census of Agriculture Canada", Statistics Canada, 96-701, Vol. 4, Part 1, Census Branch, Ottawa, July, 1973.

TABLE A.2

IMPORTANCE OF THE VEGETABLE INDUSTRY IN CANADA AND BRITISH COLUMBIA: FARM VALUE OF PRODUCTION 1970-74

	Farm Value of Vegetable Production		Per Cent of Total Value of Production	
	B.C. $000's	Can. $000's	B.C. %	Can. %
1970	14,481	144,021	6.48	4.63
1971	13,412	168,779	5.98	3.71
1972	17,468	243,480	7.03	4.48
1973	29,977	355,282	8.99	5.20
1974	n.a.	n.a.	n.a.	n.a.

Source: "Quarterly Bulletin of Agricultural Statistics", Statistics Canada, 21-003, Agricultural Division, Ottawa, July-September, 1975, 1973, 1971.

"1971 Census of Agriculture Canada", Statistics Canada, 96-701, Table 1, Vol. 4, Part 1, Census Branch, Ottawa, July, 1973.

TABLE A.3

IMPORTANCE OF THE VEGETABLE INDUSTRY IN CANADA AND BRITISH COLUMBIA: THE NUMBER OF FARMS REPORTING VEGETABLE PRODUCTION 1961, 1966 AND 1971

	The Number of Farms Reporting Vegetable Production (Potatoes in Parenthesis)		Per Cent of Total Number of Farms	
	B.C. No.	Can. No.	B.C. %	Can. %
1961	1,191	22,874	5.97	4.76
1966	1,146	17,420	6.00	4.04
1971	1,144 (707)	16,120 (23,311)	6.22	4.40

Source: "1971 Census of Canada Agriculture Canada", Statistics Canada, 21-701, Census Branch, Vol. 4, Part 1, Ottawa, July, 1971, 1966, 1961.

TABLE A.4

RELATIVE IMPORTANCE OF SELECTED VEGETABLES IN THE BRITISH COLUMBIA AGRICULTURE INDUSTRY: AVERAGE 1970-74

Vegetable	Farm Income	Per cent of Total Vegetable Farm Income	Acres Harvested	Per cent of Total Vegetable Acres Harvested
	$000's	%	acres	%
Potatoes	10,736*	54.5	11,920	47.3
Cucumbers	324	2.0	356	1.5
Lettuce	1,165	6.1	614	2.5
Onions	1,036	5.5	644	2.6
Tomatoes**	439	3.0	240	1.0
Cabbage	818	4.2	802	3.2
Carrots	695	3.6	460	1.8
Processed Peas	1,281	6.0	4,648	18.5
Processed Beans	562	2.8	1,660	6.9
Residual	1,779	12.3	3,730	14.7
Total	18,835	100.0	25,074	100.0

* Average for the years 1970-73 only.
** Average for the years 1971-72 only.

Source: "Quarterly Bulletin of Agricultural Statistics." Statistics Canada, 21-003, Agricultural Division, Ottawa: Sept.-Dec., 1972, 1973, 1974, 1975.

TABLE A.5

YIELD PER ACRE COMPARED FOR SELECTED CROPS IN BRITISH COLUMBIA, CANADA, UNITED STATES, AND WASHINGTON STATE: AVERAGES 1970-74

Vegetable	British Columbia	Canada	Washington	United States
	. . . .	tons per	acre . . .	. .
Potatoes	11.18	9.1	19.10	11.65
Carrots	11.57	11.57	21.47	12.64
Onions	12.52	11.78	18.92	14.80
Peas	2.05	1.29	1.66	1.29
Beans	3.05	2.00	3.21	2.48
Corn	5.60	4.01	5.80	4.78
Lettuce	14.45	6.39	8.57	10.80
Cabbage	7.42	9.84	10.88	10.70
Cucumbers	6.28	6.63	n.a.	n.a.

Source: "Quarterly Bulletin of Agricultural Statistics." Statistics Canada, 21-003, Agriculture Division, Ottawa: July-Sept., 1971, 1973, 1975 and 1971, 1973, 1975.

"Agricultural Statistics 1974." United States Department of Agriculture, Chapter IV, pages 149-203, Washington.

TABLE A.6

A COMPARISON* OF FARM SIZE IN CANADA, BRITISH COLUMBIA AND WASHINGTON STATE MEASURED IN ACRES AND VALUE OF PRODUCTS SOLD

	Average Size (acres)			Value of Sales ($/year)		
Year	1971	1966	1961	1971	1966	1961
Canada						
All Farms	463	404	359	11,328	7,752	4,880
Vegetable Enterprise	15.8	13.7	9.5	5,749	3,791	2,390
Potato Enterprise	21.7	1.9	1.4	10,090	5,056	3,560
Year	1971	1966	1961	1971	1966	1961
B.C.						
All Farms	316	277	226	11,386	7,326	5,222
Vegetable Enterprise	15.7	13.8	8.3	8,432	5,481	2,951
Potato Enterprise	16.1	2.5	2.6	7,478	4,748	3,481
Year	1959	1964	1969	1959	1964	1969
Washington						
All Farms	516	418	363	22,661	13,979	11,042
Vegetable Enterprise	70	58	39	18,211	9,887	6,732
Potato Enterprise	779	n.a.	n.a.	43,857	n.a.	n.a.

* Numbers are not really comparable as they were collected from many diverse sources with different definitions of what is here called 'potato enterprise'. This is especially evident if you use the numbers to calculate the revenue per acre for potato farms in Canada and British Columbia. The terms 'potato enterprise' and 'vegetable enterprise' are used here as there was no way of assuring that a farm not be counted twice.

Source: "Census of Canada Agriculture Canada", Statistics Canada, Ottawa, Canada; Queens Printer, 1971, 1966, 1961.

"1969 Census of Agriculture Washington", U.S. Dept. of Commerce, Bureau of Census, Vol. 1, Part 46, Washington, D.C.; U.S. Government Printer, 1972.

TABLE A.7

FARM VALUE PER ACRE
A COMPARISON OF FIVE YEAR AVERAGES FOR
BRITISH COLUMBIA, CANADA, WASHINGTON AND UNITED STATES
AVERAGES 1970-74

	B.C.[1]	Can.[1]	Wash.	U.S.
Potatoes[2]	900*	342	665	653
Carrots	1,510*	619	868	1,212
Onions	1,687	1,056	1,926*	1,571
Peas	213*	150	186	144
Beans	271	173	326*	243
Corn	170	141	171*	123
Lettuce	1,889*	837	962	1,300
Cabbage	1,004*	1,706	850	827
Cucumbers	940*	649	n.a.	n.a.

1 "Quarterly Bulletin of Agricultural Statistics", July-September, 1971, 1973, 1975.

2 "Quarterly Bulletin of Agricultural Statistics", July-September, 1971, 1973, 1975, Average 1970-73 only.

3 "Agricultural Statics 1974", U.S. Department of Agriculture, Chapter IV, Statistics for Vegetables & Mellons, Average 1970-73 only.

APPENDIX B

THE CALCULATION OF REPAIR AND MAINTENANCE COSTS

B.1 REPAIR AND MAINTENANCE COSTS

Repair and maintenance costs may be predicted using formulae developed by the ASAE and reproduced annually in their yearbook. There are seven basic formulae which all have the same structure although they differ in the value of the parameters used. The formulae applicable depends upon the type of machine being used. For instance, for a two wheel drive tractor formula number two in Table B.1 should be used. The formulae gives the total accumulated repair cost in per cent of the purchase price as a function of the hours of use of the machine. A graph of formulae 2 is shown in Figure B.1. It can be seen that repair and maintenance costs are an increasing function of age.

To calculate the average hourly repair costs in the next time period the formulae have to be modified as in B.1.

$$B.1 \quad R = \frac{TAR\%_{n+1} - TAR\%_{n}}{H}$$

where R = repair and maintenance costs per hour,

$TAR\%$ = total accumulated repair costs at the end of period n,

and H = total hours of use in the time period.

CANFARM (1975) use these formulae in their various machine packages in this form as does Hunt (1966). However, CANFARM has divided all the A coefficients by two. (CANFARM coefficients are also given in Table B.1).

Approximations of these formulae have often been suggested. For example, United Grain Growers determine repair and maintenance costs as a per cent of purchase price for four

TABLE B.1

ASAE FORMULAE FOR REPAIR AND MAINTENANCE COSTS

Formulae	Coefficients ASAE a	Coefficients ASAE b	Coefficients CANFARM a	Coefficients CANFARM b	Machinery Applicable
1. TAR% $a(X/Y)^b$	0.100	1.5	0.0500	1.5	4 wheel drive tractors, tractor crawlers.
2. TAR% $a(X/Y)^b$	0.120	1.4	0.0600	1.4	2 wheel drive tractors, statinary power units.
3. TAR% $a(X/Y)^b$	0.096	1.4	0.0480	1.4	s.p. combines and forage harvestors, front end loader, pick-up truck, manure spreader, baler with engine floats, rotary cutters.
4. TAR% $a(X/Y)^b$	0.127	1.4	0.0635	1.4	Sprayer, pull type harvestor, baler, potato harvestor, truck, corn picker, beet harvestor.
5. TAR% $a(X/Y)^b$	0.159	1.4	0.0795	1.4	PTO combine, s.p. swather, wagon, hay conditioner, rake, seeding equipment, mounted sprayers.
6. TAR% $a(X/Y)^b$	0.191	1.4	0.0955	1.4	Fertilizer equipment.
7. TAR% $a(X/Y)^b$	0.301	1.3	0.1500	1.3	Mower, tillage equipment such as plows, planters, cultivators, harrows, etc.

Source: 1974 Agricultural Engineers' Yearbook, section 0230.2, page 299 and page 303 Table 2.
"Machinery Planning Replacement." CANFARM publication. According to correspondence with CANFARM the 'a' coefficients were simply divided by two as engineers working on the CANFARM package thought the formulae gave results that were too high.

Note: TAR% is total accumulated repair and maintenance costs to date as a per cent of purchase price. X is 100 times accumulated hours of use, and Y is the wearout life of the machine. See Table B.3 for typical values for wearout life.

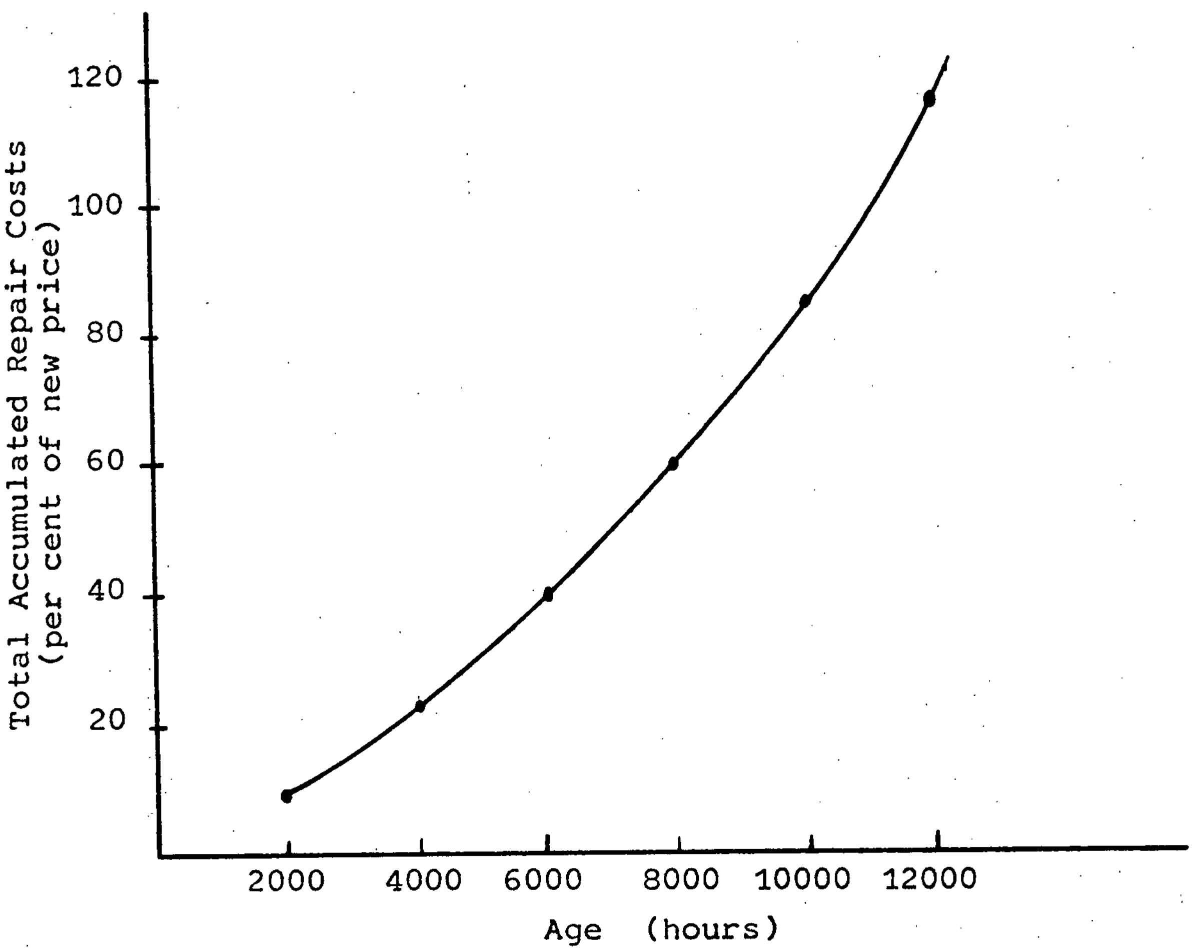

FIGURE B.1

TOTAL ACCUMULATED REPAIR AND MAINTENANCE COSTS IN PER CENT OF PURCHASE PRICE AS A FUNCTION OF AGE FOR A TWO WHEEL DRIVE TRACTOR broad classifications of machinery regardless of age (see Table B.2). Lubricants are in this case considered separately at 15% of fuel costs. Kepner, Bauer and Barger (1972) use a similar approach but give their results for more specific classifications of machinery (see Table B.3). Such systems are necessarily an average over the life of the machine and overestimate when the machine is relatively new and underestimate when the machine is older. This can easily be seen in Figure B.2 in which average hourly repair costs for a two wheel drive tractor is determined by using equation B.1 with TAR% calculated with formulae two in Table B.1. The average repair costs over the life of the tractor is .01%/hour as reported in Kepner, Bauer and Barger (Table B.3) and this figure is represented by the horizontal line. When comparing the two methods however it should be kept in mind that there is a large stochastic element in estimating repair and maintenance costs and they tend to be lumpy so that any estimate may well be quite wide of the mark.

TABLE B.2

REPAIR AND MAINTENANCE COSTS PER HOUR AS A PER CENT OF LIST PRICE ACCORDING TO BROAD IMPLEMENT CLASSIFICATION

Machine Type	Cost/Hour %
Tractor	0.012
Tillage	0.060
Harvesting	0.030
Planting	0.075

Source: United Grain Growers, " How to Pin Down Your Machinery Operating Costs".

TABLE B.3

REPAIR AND MAINTENANCE COSTS PER HOUR AS A PER CENT OF LIST PRICE ACCORDING TO MACHINE TYPE

Machine	Years Until Obsolete	Wear-out Life Hours	Hrs per Year for Wear-out Life to Equal Obsolescence Life	Repair Costs, Per cent of New Cost	
				Average per Hour	Total During Wear-out Life
Tractors					
Wheel-type	12*	12,000	1,000	0.010	120
Track-type	12*	12,000	1,000	0.0065	78
Tillage implements					
Cultivator	12	2,500	208	0.060	150
Disk harrow	15	2,500	167	0.048	120**
Disk plow	15	2,500	167	0.045	113
Moldboard plow	15	2,500	167	0.080	200**
Spike-tooth harrow	15*	2,500	167	0.040	100
Spring-tooth harrow	15*	2,000	133	0.060	120
Seeder					
Grain drill	15*	1,200	80	0.080	96
Row-crop planter	15	1,200	80	0.070	84
Harvesting equipment					
Combine, self-propelled	10	2,000	200	0.027	54
Corn picker	10	2,000	200	0.032##	64
Cotton picker	10*	2,000	200	0.026##	52
Cotton stripper	10	2,000	200	0.020##	40
Field chopper, pull-type	10	2,000	200	0.040	80**
Hay baler, aux. eng.	10	2,000**	200	0.022	55
Hay baler, PTO	10	2,000**	200	0.031	78
Hay conditioner	10	2,500	250	0.040	100
Mower	10*	2,000	200	0.120	240
Rake, side delivery	10*	2,500	250	0.070	175
Sugar beet harvester	10	2,500	250	0.025##	63
Windrower, self-propelled	10*	2,500	250	0.040	100
Miscellaneous					
Forage blower	12	2,000	167	0.025	50
Wagon (rubber tired)	15	5,000	333	0.018	90

From 1963 Agricultural Engineers Yearbook, p.232. ASAE, St. Joseph, Mich.

* Changed by authors.

** Changed by authors, based on references 4 and 7.

When average annual use exceeds this number of hours, machine will wear out before it becomes obsolete.

If machine is mounted type, add total of 1% of new cost for each time machine is mounted and dismounted (normally once a year).

Source: R.A. Kepner, Roy Bauer, and E.L. Barger in Principles of Farm Machinery, 2nd Ed., 1972.

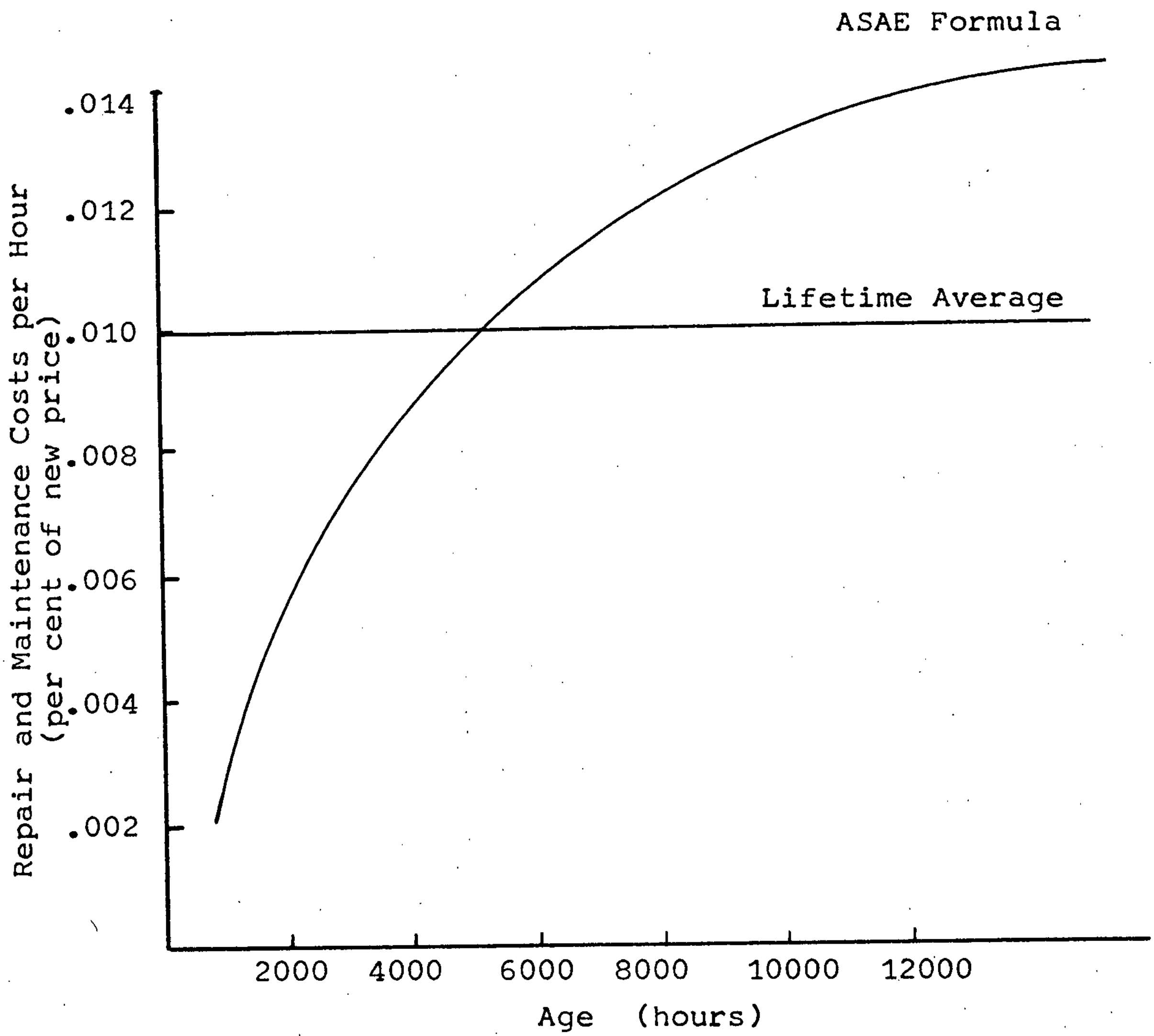

FIGURE B.2

REPAIR AND MAINTENANCE COSTS PER HOUR IN PER CENT OF LIST PRICE AS A FUNCTION OF AGE: ASAE FORMULA COMPARED WITH LIFETIME AVERAGE AS AN APPROXIMATION

B.2 REPAIR AND MAINTENANCE COST COEFFICIENTS IN THE MODEL

Two different approaches are used for repair and maintenance costs in the model. For tractors, repair and maintenance costs coefficients are estimated using linear approximations of Formula B.1. Average repair and maintenance costs per hour as a per cent of list price for each 1000 hour period from when a tractor is new until it is worn out at 12000 hours were calculated. Formula 2 in Table B.1 was used to calculate TAR%. The results are given in Table B.4. The coefficients in Table B.4 are utilized in the model to calculate repair and maintenance costs for tractors. It can be seen in Figure B.3 that the coefficients overestimate repair and maintenance costs in the first part of the 1000 hour interval and underestimate in the rest of the interval. However, the coefficients do follow the curve much more closely than the single coefficient method, illustrated in Figure B.2

TABLE B.4

AVERAGE REPAIR AND MAINTENANCE COSTS PER HOUR AS A PER CENT OF LIST PRICE FOR TWO WHEEL DRIVE TRACTORS

Hours of Use	0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000
Repair Costs as a per cent of New Price (thousandths)	2.89	5.28	6.84	8.09	9.18	10.15
Hours of Use	6000-7000	7000-8000	8000-9000	9000-10000	10000-11000	11000-12000
Repair Costs as a per cent of New Price (thousandths)	11.04	11.86	12.61	13.34	14.03	14.68

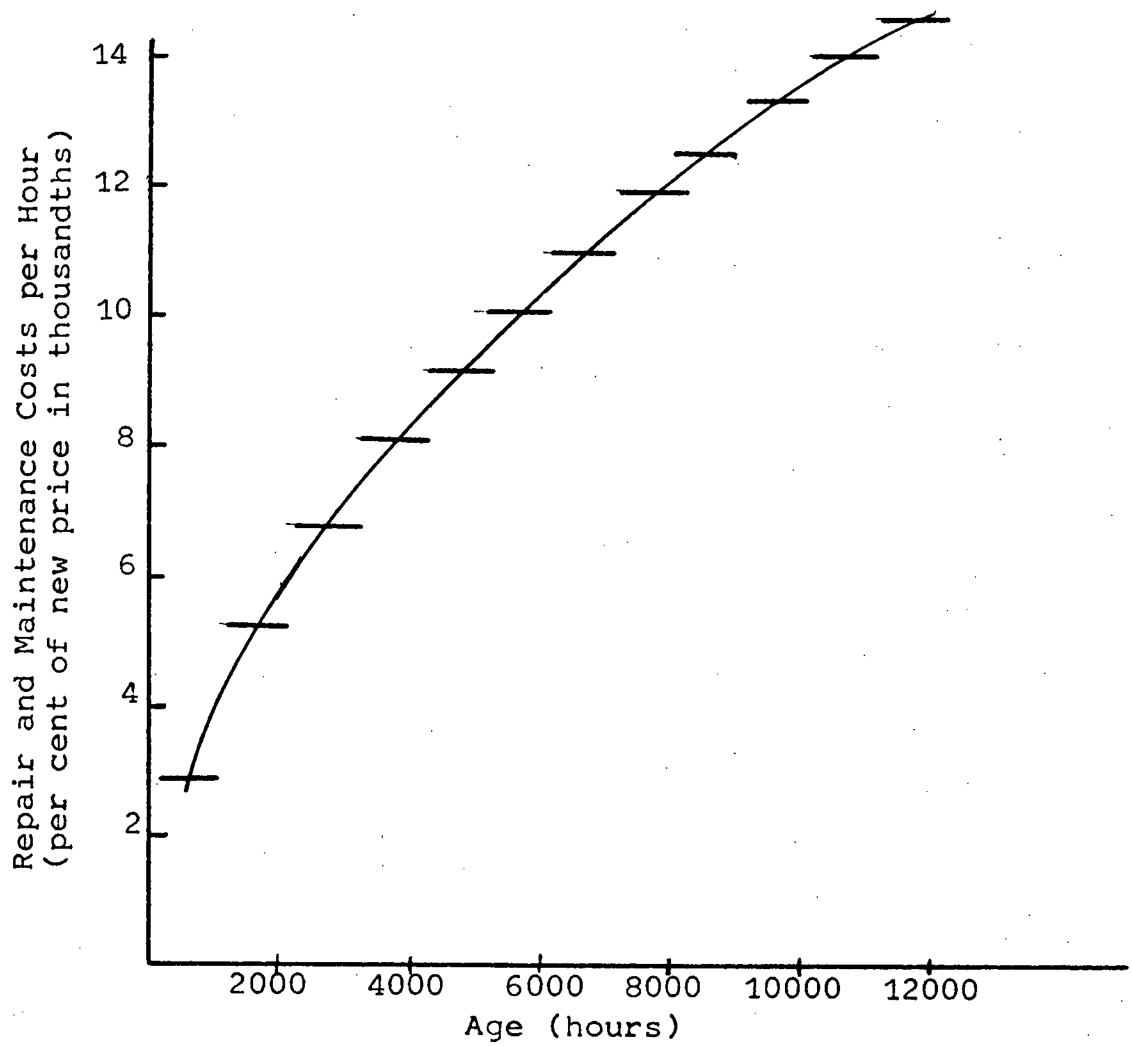

FIGURE B.3

REPAIR AND MAINTENANCE COSTS PER HOUR IN PER CENT OF LIST PRICE AS A FUNCTION OF AGE: ASAE FORMULA FOR TWO WHEEL DRIVE TRACTORS COMPARED WITH APPROXIMATIONS OF THE FORMULA USED IN THE MODEL

The model computes the total hours of use of each tractor in each month and then calculate repair and maintenance costs as the product of the coefficients in Table B.3, accumulated hours of use, and new price. The data that has to be supplied by the farmer are new price and the age of the tractor in accumulated hours of use at the start of the planning period.

The coefficients required for the implements will be obtained from Table B.3. The only information required from the farmer for repair and maintenance costs for implements will be the list price of his implements and the implement type so the proper coefficient can be selected. The matrix parameter will be the product of these two numbers.

APPENDIX C

FUEL CONSUMPTION COEFFICIENTS

Some authors have suggested using average fuel consumption in gallons per hour at 75% of maximum load as determined by the Nebraska tests for each specific tractor. This method does take into account the size and peculiarities of the particular tractor being used but completely ignores the amount of horsepower required by the specific job.* Figure C.1 illustrates the variation in fuel consumed according to the variable load fuel consumption tests for two specific tractors tested at the Nebraska Tests.

Another method proposed has been to use an average figure for horsepower hours per gallon and multiply this by the horsepower required to do the specific job. In this method an average figure for all tractors is usually used in which case the size of the tractor being used is ignored. Tractors are made in a complete range of sizes measured in maximum PTO HP within limits which depend on the type of fuel the tractor uses (see Table C.1). Even if a specific figure for horsepower hours per gallon is used for each specific tractor, there is a systematic bias in the estimate as the origin is implied as a point on the curves in Figure C.1

Hung (1966) developed formulae to predict fuel consumption as a function of per cent load on the tractor and so take into account the size of the tractor and the load. When the

* Hunt (1973, p. 41) reports that only 16.8% of time is spent in the top range in actual farm conditions.

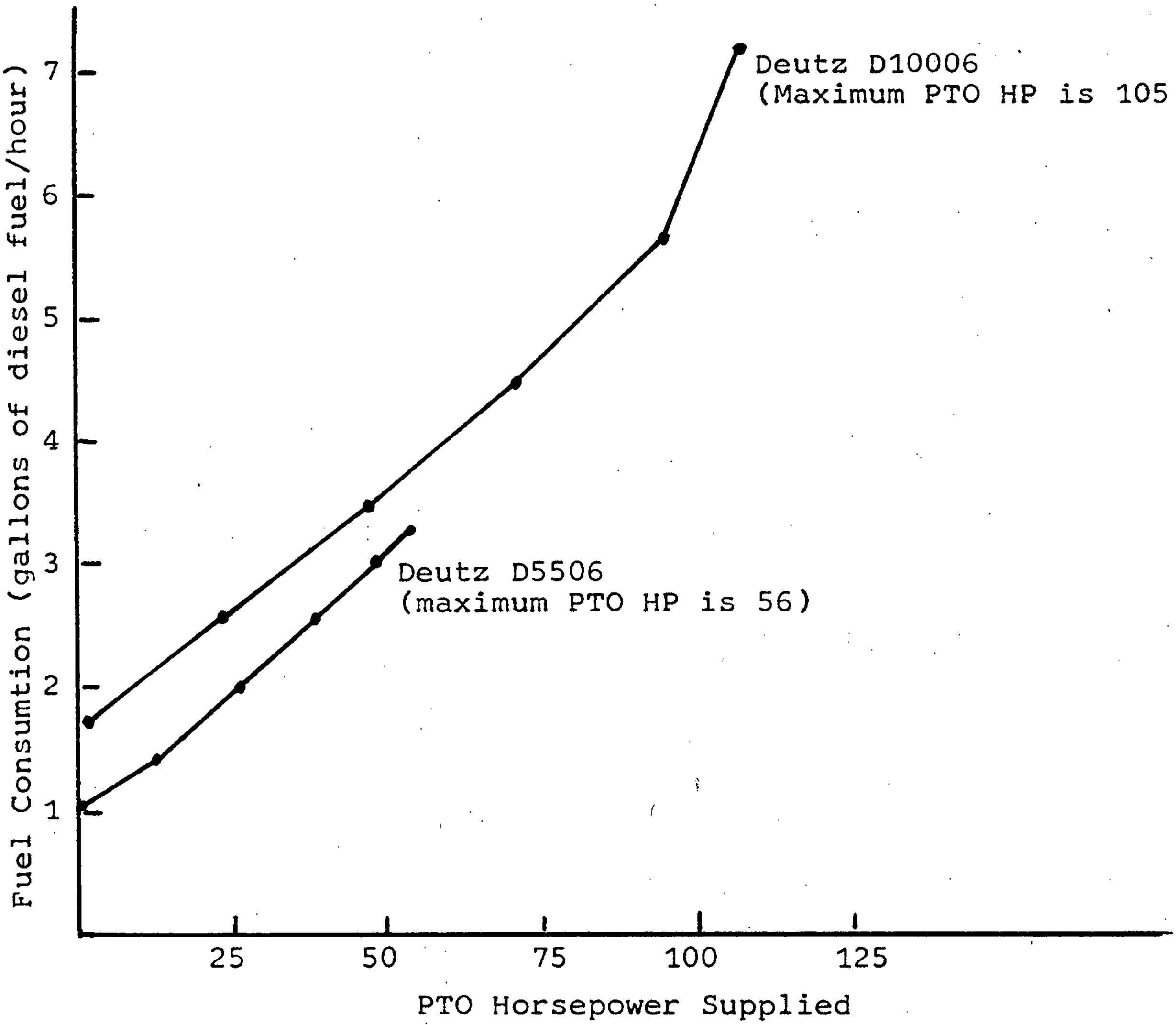

FIGURE C.1

FUEL EFFICIENCY OF A DEUTZ D10006 AND
A DEUTZ D5506 TRACTOR FROM NEBRASKA TESTS REPORTS

TABLE C.1

FREQUENCY DISTRIBUTION OF TRACTOR SIZE IN MAXIMUM PTO HORSEPOWER AT RATED ENGINE SPEED OF TRACTORS TESTED IN THE NEBRASKA TESTS

Maximum PTO HP at Rated Engine RPM		1958 - 1968			1964 - 1973		
more than	not more than	gaso-line	diesel	LP gas	gaso-line	diesel	LP gas
15	20				1		
20	25		1		3	1	
25	30	2	1			2	
30	35	14	15	1	4	4	
35	40	16	24	1	12	13	
40	45	4	5	3	1	9	
45	50	10	12	1	7	5	
50	55	9	15	1	11	16	
55	60	7	7	5	5	8	1
60	65	7	10	5	7	11	1
65	70	9	11	2	9	11	
70	75	4	4	6	5	7	2
75	80	2	6	3	3	4	1
80	85	5	3	3	1	8	
85	90	3	1	2	5	6	2
90	95	4	7	3	3	9	1
95	100	2	2	1	4	7	1
100	105		8	4		9	
105	110		5			10	
110	115		3	2		6	2
115	120		3			6	
120	125		2			6	
125	130		1			7	
130	135		2			5	
135	140					5	
140	145					9	
145	150					5	
150	155					3	
155	160					2	
160	165						
165	170					2	
170	175					1	
175	180					3	

horsepower to operate an implement is known the fuel required to power that implement can be calculated for a specific tractor using one of the formulae developed by Hunt:

C.1 $Y = 0.54A + 0.62 - 0.04 \quad 697.0A$

C.2 $Y = 0.52A + 0.768 - 0.04 \quad 738.5A + 173.0$

C.3 $Y = 0.289A + 0.386 - 0.04 \quad 213.9A - 25.7$

where A = HP required/maximum PTO HP.

Y = gal./hr. of fuel consumption.

The formulae are parabolic curves fitted to the results for the variable fuel efficiency tests of 118 tractors in the Nebraska tests. The formulae are for gasoline, diesel and LP gas tractors respectively. In practice at lease a 15% increase should be made to allow for differences between field conditions as opposed to the ideal conditions during theNebraska tests according to Hunt (1973, p. 37).

These formulae have been used to calculate fuel consumption for fourteen horsepower levels for the tractor transfer section of the model. Fuel consumption has been calculated using Hunt's formulae for the entire range of tractor size for gasoline and diesel fuel tractors with maximum PTO HP increasing in 5 HP increments. Loads are set at the median levels for the fourteen intervals 0-10 HP, 10-20 HP, ..., 130-140 HP. Results are given in Tables C.2 and C.3 for gasoline and diesel tractors respectively. The coefficients in these tables are used for the fuel entries in the tractor transfer activities in the model (see Figure 3.4).

A fortran program was used to produce the fuel parameters in Table C.2 as given in Figure C.2. The output from this program is deposited in a file named 'FUEL' starting at line 190. A header for the table can then be inserted in the file just before the output. Table C.3 was created by replacing line 0013 the fortran program with:

```
Z = 0.289*R*0.386-0.04*(213.9*R-25.7)**0.5
```

The formula on line 0013 estimates the solution for gasoline tractors. The other two formulae are for liquid propane and diesel tractors respectively.

The variables in the fortran program are:

X = maximum PTO HP,

Y = load in HP,

Z = fuel consumption in gal. per HP per hour,

and GAL = fuel consumption in gallons per hour.

TABLE C.2

FUEL CONSUMPTION FOR GASOLINE TRACTORS
ACCORDING TO TRACTOR SIZE AND LOAD

Maximum	LOAD (PTO Horsepower)													
PTO HP	5	15	25	35	45	55	65	75	85	95	105	115	125	135
25	1.1	1.6	2.2											
30	1.2	1.8	2.2											
35	1.2	2.0	2.4	3.0										
40	1.3	2.2	2.6	3.1										
45	1.4	2.4	2.8	3.2	3.9									
50	1.4	2.5	3.0	3.3	3.9									
55	1.5	2.7	3.2	3.5	4.0	4.8								
60	1.5	2.8	3.4	3.7	4.1	4.8								
65	1.5	3.0	3.6	4.0	4.3	4.8	5.6							
70	1.6	3.1	3.8	4.2	4.5	5.0	5.6							
75	1.6	3.2	4.0	4.4	4.7	5.1	5.7	6.5						
80	1.6	3.3	4.1	4.6	4.9	5.3	5.8	6.5						
85	1.6	3.4	4.3	4.8	5.2	5.5	5.9	6.5	7.4					
90	1.7	3.5	4.4	5.0	5.4	5.7	6.1	6.6	7.3					
95	1.7	3.6	4.6	5.2	5.6	5.9	6.3	6.7	7.4	8.2				
100	1.7	3.6	4.7	5.4	5.8	6.1	6.5	6.9	7.5	8.2				
105	1.7	3.7	4.9	5.5	6.0	6.3	6.7	7.1	7.6	8.2	9.1			
110	1.7	3.8	5.0	5.7	6.2	6.6	6.9	7.3	7.7	8.3	9.1			
115	1.8	3.9	5.1	5.9	6.4	6.8	7.1	7.5	7.9	8.4	9.1	10.0		
120	1.8	3.9	5.2	6.0	6.6	7.0	7.3	7.7	8.0	8.5	9.2	9.9		
125	1.8	4.0	5.3	6.2	6.8	7.2	7.5	7.9	8.2	8.7	9.2	9.9	10.8	
130	1.8	4.0	5.4	6.3	7.0	7.4	7.8	8.1	8.4	8.8	9.4	10.0	10.8	
135	1.8	4.1	5.5	6.5	7.1	7.6	8.0	8.3	8.6	9.0	9.5	10.1	10.8	11.7
140	1.8	4.1	5.6	6.6	7.3	7.8	8.2	8.5	8.8	9.2	9.7	10.2	10.9	11.7

TABLE C.3

FUEL CONSUMPTION BY DIESEL TRACTORS
ACCORDING TO TRACTOR SIZE AND LOAD

Maximum	LOAD (PTO Horsepower)													
PTO HP	5	15	25	35	45	55	65	75	85	95	105	115	125	135
25	0.6	1.1	1.7											
30	0.7	1.2	1.6											
35	0.7	1.3	1.7	2.3										
40	0.8	1.4	1.8	2.3										
45	0.8	1.5	1.9	2.3	3.0									
50	0.8	1.6	2.0	2.4	2.9									
55	0.8	1.7	2.1	2.5	2.9	3.7								
60	0.8	1.8	2.2	2.6	3.0	3.6								
65	0.8	1.8	2.3	2.7	3.1	3.6	4.3							
70	0.8	1.9	2.5	2.8	3.2	3.6	4.3							
75	0.9	1.9	2.5	2.9	3.3	3.7	4.2	5.0						
80	0.9	2.0	2.6	3.0	3.4	3.7	4.2	4.9						
85	0.9	2.0	2.7	3.2	3.5	3.8	4.3	4.9	5.7					
90	0.9	2.1	2.8	3.3	3.6	4.0	4.4	4.9	5.6					
95	0.9	2.1	2.9	3.4	3.7	4.1	4.4	4.9	5.5	6.4				
100	0.9	2.2	2.9	3.5	3.9	4.2	4.5	5.0	5.5	6.3				
105	0.9	2.2	3.0	3.6	4.0	4.3	4.6	5.0	5.5	6.2	7.0			
110	0.9	2.2	3.1	3.7	4.1	4.4	4.8	5.1	5.6	6.2	6.9			
115	0.9	2.2	3.1	3.7	4.2	4.5	4.9	5.2	5.7	6.2	6.9	7.7		
120	0.9	2.3	3.2	3.8	4.3	4.7	5.0	5.3	5.7	6.2	6.8	7.6		
125	0.9	2.3	3.2	3.9	4.4	4.8	5.1	5.4	5.8	6.3	6.8	7.5	8.4	
130	0.9	2.3	3.3	4.0	4.5	4.9	5.2	5.6	5.9	6.3	6.9	7.5	8.3	
135	0.9	2.3	3.3	4.1	4.6	5.0	5.3	5.7	6.0	6.4	6.9	7.5	8.2	9.0
140	0.9	2.4	3.4	4.1	4.7	5.1	5.5	5.8	6.1	6.5	7.0	7.5	8.1	8.9

```
                DIMENSION A(14,25)
                X=20.0
                DO 2 1=1,25
                DO 2 J=1,14
      2         A(J,I)=0.0
                CALL FTNCMD('SET ZEROSUPPRESS=ON',19)
                DO 21 I=1,25
                Y=5.0
                DO 22 J=1,14
                1F(X.EQ.20.0) GOTO 10
                R=Y/X
                1F(R.GT.1.0) GOTO 30
                Z=0.540*r+0.620-0.04*(697.0*R-00.0)**0.5
                GAL=Z*Y*231/277.42
                GOTO 12
     10         GAL=Y
     12         A(J,I)=GAL
                Y=Y+10.0
     22         CONTINUE
     30         X=X+5.0
     21         CONTINUE
                WRITE (6,1)((A(J,1),J=1,14),I=1,25)
      1         FORMAT (8X,14F5.1)
                STOP
                END
Execution terminated

$ run - load 6 = fuel (190)
Execution begins
Execution terminated
```

FIGURE C.2

FORTRAN PROGRAM USED TO PRODUCE TABLE C.2 AND TABLE C.3

APPENDIX D

FIELD CAPACITY AND POWER REQUIREMENTS

Field capacity can normally expect to be known by the farmer. In cases where it is not known, field capacity can be estimated using D.1.

$$\text{D.1} \quad \text{Field Capacity} = \frac{\text{Width} \quad \text{Speed} \quad \text{Efficiency}}{8.25}$$

where Field Capacity = the acres per hour of work done,

Width = the width of the implement's operating edge,

Speed = the speed in miles per hour,

and Efficiency = the per cent of the theoretical capacity for the specific operating condition.

Typical values for speed and efficiency are given in Table D.1. The particular conditions under which an implement is operated will normally determine capacity through setting limits on speed and efficiency.

The amount of fuel required to operate an implement is a function of the power required to operate the implement and thus indirectly on field capacity and the characteristics of the implement and field conditions as well as the fuel economy of the power source being used. The power required by an implement also determines which tractors of those available are capable of operating the implement although there are several other factors that have to be considered. It could normally be expected that the farmer will be able to estimate the power required in the field operations he performs. Where this is not the case, engineering formulae have been developed by Hunt (1963 and 1966) and refined by Schmeidler et al (1973)

TABLE D.1

MACHINERY PERFORMANCE DATA

Machine	Typical Energy, Power or Requirement	Speed or Performance Rate	Typical Range for Field Efficiency Per Cent
Tillage			
Moldboard or disk plow	See Fig. 2	3.5-6 mph	70-90
Chisel plow	200-800 lb per ft	4-6.5 mph	70-90
Lister	400-800 lb per bottom	3-5.5 mph	70-90
One-way disk, 3-5 in. depth	180-400 lb per ft	4-7 mph	70-90
Subsoiler	70-110, 100-160 lb per in. depth*	3-5 mph	70-90
Land plane	300-800 lb per ft	-	-
Powered rotary tiller, 3-4 in. increment of cut	5-10 PTO HP per ft	1-5 mph	70-90
Harrow			
Single disk	50-100 lb per ft	3-6 mph	70-90
Tandem disk	100-280 lb per ft	3-6 mph	70-90
Offset or heavy tandem disk	250-400 lb per ft	3-6 mph	70-90
Spring tooth	75-310 lb per ft	3-6 mph	70-90
Spike tooth	20-60 lb per ft	3-6 mph	70-90
Roller or packer (cultipacker)	20-150 lb per ft	4.5-7.5 mph	70-90
Rotary hoe	30-100 lb per ft	5-10 mph	70-85
Rod weeder	60-120 lb per ft	4-6 mph	70-90
Field cultivator	150-500, 340-650 lb per ft#	3-8 mph	70-90
Row crop cultivator			
Shallow	40-80 lb per ft	2.5-5 mph	70-90
Deep	20-40 lb per ft per in. depth	1.5-3 mph	70-90
Bed sled or shaper	15 HP per row	2-4 mph	70-90
Unpowered rotary cultivator	-	3-7 mph	70-90

TABLE D.1 continued

Fertilizer and Chemical Application			
Fertilizer spreader, pull-type	-	3-5 mph	60-75
Anhydrous ammonia applicator	420 lb per knife	3-5 mph	60-75
Sprayer	-	3-5 mph	50-80
Planting			
Corn, soybeans, or cotton, drilling seed only	100-180 lb per row	3-6 mph	50-85
Corn, soybeans, or cotton, drilling, all attach.	250-450 lb per row	3-6 mph	50-85
Grain drill	30-100 lb per ft	2.5-6 mph	65-85
Harvesting/			
Mower only	1 DB HP per ft, 0.5 PTO HP per ft	5-7 mph	75-85
Mower-conditioner, cutterbar-type	1-1.5 DB HP per ft, 2-2.5 PTO HP per ft	4-6 mph	60-85
Mower-conditioner, flail type	10-17 PTO HP	4-6 mph	60-85
Self-propelled mower-conditioner-windrower	2-2.5 DB HP per ft, 2-2.5 PTO HP per ft	3-6 mph	55-85
Conditioner only	2 PTO HP per ft	5-7 mph	75-85
Rake	-	4-5 mph	60-85
Baler	1.5-2.5 HP hr per ton	3-10 tons per hr	60-85
Hay cuber	15-20 HP hr per ton	3-5 tons per hr	60-85
Loose hay sweep	-	7-24 tons per hr	-
Hay stacker, separate bucking operation	-	24-38 tons per hr	-
Bale loader-stacker, loading only	-	9-15 tons per hr	-
Forage harvester, flywheel or cylinder knife			
Green forage	1-2.5 HP hr per ton	Performance rate is generally a direct function of the PTO horsepower available	
Wilted forage	1.5-5 HP hr per ton		
Day hay or straw	2-5 HP hr per ton		
Corn silage	1-2.5 HP hr per ton		

TABLE D.1 concluded

Harvesting (contd)			
Forage harvester, fly-wheel or cylinder knife		from the power source.	
Corn silage recutter attachment	0-100 per cent increase in above figures	Usual travel speeds are 1.5 to 4 mph.	
Windrower, small grain	1.5-2 HP per ft cut	5-7 mph	75-85
Combine			
Small grain	1 PTO HP per in. cylinder width	2-4 mph	65-80
Corn	-	2-4 mph	65-80
Corn picker			
1 row, trailed	8-10 HP	2-4 mph	60-80
2 row, trailed	12-20 HP	2-4 mph	60-80
2 row, mounted	12-18 HP	2-4 mph	60-80
Cotton picker			
1 row, mounted	-	0.6-0.8 acres per hour	60-75
2 row, self-propelled	-	0.9-1.2 acres per hour	60-75
Cotton stripper, 2 row	-	1-2 acres per hour	60-75
Beet topper	6-8 HP per row	2-3 mph	60-80
Beet harvester	30-45 HP per row	3-5 mph	60-80
Rotary mower, hori-zontal blade			
Open field	3-8 HP per ft cut	3-8 mph	75-85
Row crop	9-18 HP per ft cut	3-6 mph	75-85
Forage blower			
Wilted forage	1-2 HP hr per ton	20-30 tons per hour	-
Corn or grass silage	1-1.5 HP hr per ton	20-50 tons per hour	-

* Ranges shown are for sandy loam and medium or clay loam, respectively.

Second range shown is for heavy clay soils.

≠ For trailed harvesting equipment, add power required to overcome rolling resistance to the listed soil or crop power requirements.

§ Energy requirements per ton are lowest with high feed rates, low cutterhead speeds, and long cuts.

may be used to predict power requirements.

Hunt's calculation of the power required to operate an 'implement' is based on what he terms 'force factors'. A force factor is the pounds of force needed to power a foot of width of an implement. Typical ranges for the force factors of various implements are given in Table D.1. When the force factor is known or can be estimated from engineering tables, the drawbar horsepower required to operate the implement can be calculated as in 3.4.

$$\text{D.2} \quad \text{Drawbar Horsepower} = \frac{\text{force factor x width x speed}}{375}$$

where width is in feet,

speed in miles per hour,
force factor in lbs./feet,

and 1/375 is a conversion factor.

Schmeidler et al noted that tractor horsepower is normally rated in PTO horsepower rather than Drawbar horsepower so they provided a method to convert drawbar into an equivalent PTO HP using formula D.3

$$\text{D.3} \quad \begin{matrix}\text{Drawbar Horsepower} \\ \text{(PTO equivalent)}\end{matrix} = \frac{\text{Drawbar Horsepower}}{0.96 \text{ x TER}}$$

Where TER = the "tractive efficiency ratio" or ratio of drawbar horsepower to axle horsepower.

and 0.96 = the ratio of axle horsepower to PTO horsepower.

The ratio 0.96 is taken as a constant. The value of TER is a function of soil type and per cent slip of the drive wheels which in turn depends on rear tractor weight, method of implement attachment and tire characteristics. Schmeidler et al takes the optimum value of TER for each soil type.

A certain percentage (optimum) slip of the drive wheels give the maximum (or optimum) TER for each soil type. Variation from the optimum wheel slip does not bring about a great change in the TER though the value of TER varies considerably from one soil type to another (see Table D.2). The main change in the TER comes when the wheel slip declines from the optimum.

TABLE D.2

EFFECT OF SOIL TYPE ON TRACTIVE EFFICIENCY RATIO

Soil Type	Optimum		Non-Optimal Per Cent Wheel Slip			
			Optimal Wheel Slip Plus 5%		Optimal Wheel Slip Minus 5%	
	% Wheel Slip	TER	% Wheel Slip	TER	% Wheel Slip	TER
Concrete	6.0	.92	11.0	.90	1.0	.80
Firm Soil	9.0	.78	14.0	.75	4.0	.68
Tilled Soil	11.5	.64	16.5	.62	6.5	.60
Soft or Sandy	12.5	.53	17.5	.51	7.5	.49

This method is suitable for machines whose main demand on the tractor is drawbar horsepower. For machines whose main demand is for PTO horsepower (called processing machines), the calculation of HP required is somewhat different. Examples of this type of machine are balers, combines, and other harvesting machines. The HP required to operate these machines is rated in HP per ton and their capacity is measured in tons/hour. The HP required to operate this type of machine is given by D.4.

D.4 PTO HP = Processing Capacity x PTO Energy,

where PTO Energy = coefficient in HP/ton from standard tables,

and Processing Capacity = Field Capacity x Yield.

APPENDIX E

GLOSSARY OF ENGINEERING TERMS

Axel Horsepower: The amount of horsepower a tractor delivers at the rear wheel axels.

ASAE: The American Society of Agricultural Engineers. Organization which sets standards for agricultural machinery and publishes many engineering research papers.

Capacity: The rate of work done for field operations measured in acres per hour. Capacity is a function of the width of the implement, field speed and field efficiency.

Drawbar Horsepower: The amount of horsepower the tractor makes available to pull an implement at the drawbar. For operations that do not require the power take off this is the total amount of power which is being used by the implement. The amount of drawbar horsepower a tractor can develop depends on the weight on the rear wheels, wheel characteristics, the surface and the design of the tractor.

Efficiency: Efficiency is a measure of the amount of time lost due to the characteristics of the implement being used and the shape of the field in per cent. 100% is defined as the capacity of the implement operating on an ideal field the width of the implement (so turning is unnecessary) and without having to deviate from normal operating speed to adjust the implement, etc. Typical values range from 50% to nearly 100%.

Force Factor: Term invented by Donnell Hunt to represent the amount of force required to operate one foot of an implement measured in lbs. per foot.

Horsepower: Unit used to measure power. Power is the rate of doing work. Work is merely the use of energy to accomplish certain goals. For tractors energy in the form of fuel is converted into the physical motion of an implement.

Implement: Three terms are used to describe the machinery in this thesis. Implements are used to describe machinery other than tractors. Machine is a general term which includes both implements and tractors. Implement is used interchangeably with equipment.

Job: Two terms are used to describe the use of machinery in this thesis: job, and operations. Jobs are the task which machinery is used to accomplish. Plow an acre in a certain time of the year for example. An operation on the other hand is the use of specific implements in a specified manner (power, speed, etc.) to perform a job.

Machine: See implement.

Operation: See job.

Power Take Off: Also called PTO. Some implements operate through the action of being pulled across the surface of a field. Others require a source of rotary power from the tractor, mowers and balers for example. This rotary power is delivered by the PTO. An archaic term is belt power. Tractor size is usually rated in terms of the maximum PTO power the tractor can produce. The maximum PTO power of a tractor is usually more than the maximum drawbar because less power is lost in operating the PTO than in moving the tractor.

Tractor Efficiency Ratio: The ratio of drawbar horsepower to axel horsepower which would be equal to one in the ideal world. Some power is loss because of wheel slip so this figure is less than one in real life.

Tractor Size: Usually measured in maximum PTO horsepower. See power take off.

Speed: Speed at which an implement or tractor moves is measured in miles per hour relative to the ground when the machine is operating normally and travelling in a straight line.

Wheel Slip The slight spinning of the drive wheels of a tractor that normally takes place. Wheel slip is measured in the percentage reduction in travel speed from what the speed would be were there no wheel slip. A certain amount of wheel slip is best (optimal) for converting the energy expanded in the drive wheels into forward motion.

Width: The width of an implement is usually the theoretical width which can be determined by a simple measurement with a yardstick. The actual width in use is typically less than the theoretical width because of the slight overlap of the machine's operations which will be reflected in the efficiency figure for the implement.

APPENDIX F

VALIDATION OF THE LOGIC OF THE MODEL

The central section of the model is the machine operating activities. Consequently the level of machine operations was taken as a starting point from which the arithmatic of a solution of the model could be worked through by hand to validate the logic of the model. The level of machine activity was compared with that required by the crop plan in the solution to see if exactly the right amount was available (see Table I.1). The crop plan was used to calculate the land and purchased inputs used which in turn was compared with the amount of these resources selected by the model. The results of this calculation are given in Tables F.2 and F.3. The crop plan and the record of machine operating activity together were used to calculate the labour required by the plan. The results of this calculation are given in Table F.4. The record of machine operating activity only was used to calculate the amount of tractor time required at various loads. The calculated time is compared with the time selected by the model in Table F.5. Repair and maintenance costs were calculated based on tractor time while fuel costs were calculated based on hours of tractor use at each horsepower level. These results are given in Tables F.5 and F.3 respectively together with model results for comparison.

Errors of difference between calculated results and model results are very small in all cases. Usually differences can be found in conjunction with a point where it is necessary to divide by a three or a seven or some such similar number. Differences are slightly larger for production and value of production because yields were only put in correct to one decimal place.

TABLE F.1

VERIFICATION OF FEASIBILITY OF FARM PLAN

Operation	Hours	Model Acres of Work	Calc. Acres in Farm Plan	Machine Costs
OA	46.5	372.	372.	31.6665
OB	73.125	585.	585.	
OC		0.	0.	
OD	16.14286	113.	113.	5.9728582
OE		0.	0.	
OF	17.0	34.	34.	10.2
OG	35.83333	214.99998	215.	22.933312
OH		0.	0.	
OI		0.	0.	
OJ	2.0	14.	14.	0.6
OK	20.0	10.	10.	28.0
OL	16.0	24.	24.	22.4
OM	7.6	38.	38.	10.64
ON	39.0	34.	34.	153.306
OO	12.66667	38.00001	38.	57.114015
OP	61.66667	185.00001	185.	123.33333
OQ				
OR				
OS	41.5	83.	83.	13.28
OT	27.66667	83.00001	83.	25.0106696
OU	50.0	50.	50.	32.4
OV	16.66667	50.00001	50.	11.6
OW	10.0	50.	50.	0.24
OX	33.33333	49.999995	50.	1.199999
OY	33.33333	49.999995	50.	1.199999
OZ	100.0	50.	50.	320.0
QA	26.4	132.	132.	10.1376
QB	5.0	10.	10.	2.88
QC				
QD	17.0	34.	34.	5.1
QE	29.0	116.	116.	4.35
QF	10.4	52.	52.	1.248
QG	10.000002	30.00006	30.	3.0
QH	6.0	24.	24.	1.62
QI	25.5	102.	102.	24.99
QJ	62.5	375.	375.	30.0
QK	2.14286	15.000002	15.	0.642858
QL				
QM	92.4	462.	462.	55.44
QN	46.5	279.	279.	22.785
QO	52.00001	156.00003	156.	48.308000
QP	12.4994	12.49940	12.49940	12.49940

Source: Solution to linear programming problem and calculated from crop plan and input data.

TABLE F.2

VERIFICATION OF THE PRODUCTION AND SALES IN THE MODEL

Crop	Crop Harvested	Product	Production		Value of Production	
			Model	Calculated	Model	Calcu-lated
Late Potatoes	50	Potatoes	735.0 ton	735.0 ton	58800.0	58800.0
Early Potatoes	0					
Beans	52	Beans	267.4987	267.5	28237.13	28238.0
Early Peas	15	Peas	31.533	31.533	4428.81	4429.0
		Pea Vines	15.0	15.0	789.9	790.0
Late Peas	30	Peas	63.066	63.066	8857.62	8858.0
		Pea Vines	30.0	30.0	1577.8	1580.0
Strawberries	5	Strawberries	1515.1515 lb	1515.1515 lb	500.0	500.0
Raspberries	0					
Barley	38	Barley	2572.5 bu	2572.5 bu	7768.95	7769.0
Cabbage	10	Cabbage Seed	10763 lb	10763 lb	6434.12	6434.0
Turnip	4	Turnip Seed	5870 lb	5870 lb	3522.0	3522.0
Sugar Beet Seed	20	Sugar Beet Seed	37866 lb	37866 lb	6815.88	6815.0

Source: Solution to the linear programming problem and calculated from crop plan and input data.

TABLE F.3

VERIFICATION OF PURCHASED INPUTS

Purchased Input	Quantity		Value	
	Model	Calculated	Model	Calculated
			$	$
PI01	86.85	86.85 in.	86.85	86.85
PI02	123.0	123 gal.	1020.90	1020.90
PI03	3.325	3.375 T	675.00	675.00
PI04	16.9	16.9 T	1740.70	1740.70
PI05	76.0	76.0 gal	2216.16	2216.16
PI06	5.15	5.15 T	489.25	489.08
PI07	13.0	13.0 T	3315.00	3315.00
PI08	60.66667	60.66617 pkg	466.67	460.72
PI09	20000.0	20000.0 l	2000.00	2000.00
PI10	4.0	4 u	80.00	80.00
PI11	4792.0	4792.0 l	458.54	458.60
PI12	10.0	10 u	150.00	150.50
PI13	7770.0	7770 l	726.50	726.50
PI14	-			
PI15	1.755	1.755 T	296.625	296.625
PI16	38.0	38 cwt	266.00	276.00
PI17	2.85	2.85 T	570.00	570.00
PI18	-	-		
PI19	30.0	30 T	5610.00	5610.00
PI20	50.0	50 T	6500.00	6500.00
PI21	1.5	1.5 cwt	42.00	42.00
PI22	50.0	50 gal	1050.00	1050.00
PI23	10.0	10 gal	555.52	555.52
Purple Gasoline	1987.17	1984.17	615.09	615.09
Diesel Fuel	1859.13	1857.13	409.00	409.00

Source: Solution to linear programming problems and calculated from crop plan and farm input data.

TABLE F.4

VERIFICATION OF LABOUR IN THE MODEL

Time Period	Labour Hours		Labour in Slack		Hired Labour	
	Calculated	Actual	Calculated	Actual	Calculated	Actual
0 Jr	-		820.0	810.0		
0 Fb	-		720.0	720.0		
0 Mr	82.10824		697.89176	697.89180		
1 Ap	27.97077		198.02923	198.02923		
2	35.32665		144.67335	144.67335		
3	61.16542		143.83458	143.83459		
4	40.95810	40.95811				
1 My	82.953	82.953				
2	188.49940	188.50000				
3	195.0	195.0	0.0	0.0		
4	95.23334		114.76666	114.76667		
1 Jn	10.28571		169.71429	169.71429		
2	1.0		179.0	179.0		
3	55.0	55.0				
4	55.0	55.0				
1 Jl	145.0	145.0				
2	183.1	183.1				
3	47.97651	47.97650				
4	41.63112	41.63112				
1 Ag	163.61334		16.38666			
2	45.92667	45.92667				
3	26.66667	26.66667				
4	140.43333		51.66667	51.66667		
1 Sp	27.0		183.0	183.0		
2	436.51899		0.0	0.0	160.51899	160.51899
3	481.96202		0.0	0.0	159.96202	159.96203
4	469.85232		0.0	0.0	193.85232	193.85232
1 Oc	49.53256		160.46744	160.46744		
2	13.96774		166.03256	166.03256		
3	15.4		194.6	194.6		
4	18.5	161.5	161.5			
0 Nv	-	750.0	750.0			
0 Dc	-	810.0	810.0			

Source: Solution to linear programming problem and calculated from crop plan and input data.

TABLE F.5

VERIFICATION OF THE TRACTOR SELECTION BLOCK

Horswpower Level	Tractor Hours							Calc. Total
	TA	TB	TC	TD	TE	TF	Total	
14								
13								
12	134.6						134.6	134.6
11	73.1						73.1	73.1
10	52.0						52.0	52.0
09								
08								
07								
06			88.0				88.0	88.0
05			43.8				43.8	43.8
04								
03				120.8			120.8	120.8
02				32.1			32.1	32.1
01				277.2			277.2	277.2
Other			100.0		2.0	10.0	112.0	112.0
Total Hours	259.7		231.8	430.1	2.0	10.0		
Model Rep. Costs	147.73		91.53	43.84	0.56	2.20		
Calculated R & M Costs	147.73		91.53	43.84	0.56	2.20		

Source: Solution to linear programming problem and calculated from crop plan and input data.

APPENDIX G

THE OPTIMAL FARM PLAN

G.1 THE NATURE OF THE FARM REPORT

From a range of alternatives as in Table 5.5 the farm operator may be able to select a farm plan that best suits his subjective evaluation of risk and personal preferences with the knowledge of the effect of his decision on his income. It is conceivable that if a workshop approach is used to utilize the model in its final form by CANFARM that the farm operator could specify levels of crops in some intermediate range and the model could be run in simulation mode to provide a detailed projection of the most important physical and financial records of the farm. For the purposes of the thesis the base plan was selected and a farm report prepared.

The nature and scope of the farm report is of great importance to the usefulness of the planning model. The record system of the farm may be conceptually divided into four categories. There is the main division between physical records and financial records. Both of these categories may be subdivided according to whether the records are independent of the farm plan or not. This is most obvious in the case of the physical records where the input-input, input-output, and the output-output relationships of the production function and the constraints are independent of the farm plan. It is this type of records that have been used to create the documentation of the case farm. Another series of records can be predicted and/or maintained which relate directly to illustrating the effect of the choice of a particular farm plan (point on the production function). This second set of records constitute the Farm Report and constitutes the output of the planning model from the perspective of the farm operator.

In Table G.1 this division of the record system for a farm is illustrated. The types of records that should be included in each section are also illustrated. The term 'Static Records' used to describe records that are independent of the farm plan is somewhat misleading in that it is to be expected that the Static Records may be continually revised based on the results of the farm plan but this is a result of more information and experience becoming available to the farm operator rather than the particular plan selected.

A suitable farm report consisting of the "flow records" for the case farm is given in Appendix G.2. The CANFARM records were followed as closely as possible in formulating the financial records in the report. Several major differences do appear however. A detailed Cash Flow Statement was prepared. The Income Statement is on accrual basis rather than a cash basis. The Enterprise Statements have been abbreviated and an extra column incorporated to illustrate per acre costs.

Although the CANFARM system does not include any physical records, their importance for management purposes should not be underestimated. The Farm Report in Appendix G.3 therefore incorporates Utilization Reports for the resources labour, tractors, implements, and purchased inputs. A crop plan, marketing plan, and a production record are also included. As rotation, risk and marketing constraints were so important in limiting the final plan a report on the shadow prices of these constraints is also given.

TABLE G.1

THE MAIN CATEGORIES OF THE FARM RECORD SYSTEM

	Physical Records	Financial Records
Static Records	Constraints on Resources Prices Machine Operation Coefficients Cultural Practises and Associated Yields	Purchase Records Net Worth Statements Capital Cost Allowance Schedules Depreciation Schedules
Flow Records	Utilization of Resources Crop Plan Actual Production, Yields and Sales Shadow Prices	Income Statement Cash Flow Statement Enterprise Statements Cost Accounts Tax Records

G.2 THE FINANCIAL RECORDS

TABLE G.2

INCOME STATEMENT
1976 OPTIMAL 'PLAN A'

	Accrual $
Crop Sales	
Straw	10,800
Barley	23,760
Field Beans	16,200
Field Peas	25,920
Potatoes	110,380
Strawberries	6,000
Sugar Beet Seed	18,240
Leaf/Fruit Seed (Turnip)	4,500
Cabbage Seed	34,000
Pea Vines	2,925
Raspberries	2,800
Total	255,525
Expenses	
Rent	7,740
Purchased Inputs	
Twine	87
Premerge	747
Pea Fertilizer	675
Potash	2,348
Eptam	2,274
Fertilizer 0-0-22	463
Fertilizer 11-55-0	1,912
Benlate	266
Beet Fertilizer	2,000
Turnip Fertilizer	573
Bees	400
Cabbage Fertilizer	1,453
Raspberry Fertilizer	124
Strawberry Fertilizer	297
Barley Seed	756
Barley Fertilizer	1,620
Early Potato Seed	2,240
Potato Fertilizer	9,312
Late Potato Seed	8,190
Blight	53
Sprout Inhibitor	1,323
Monitor Insecticide	700
Total Purchased Inputs	37,814
Purple Gasoline	977
Diesel Fuel	934
Tractor R & M	678
General Farm Equip. R & M	1,906
Part Time Labour	4,478
Interest on Operating Capital	- 662
Total Variable Inputs	53,864

TABLE G.2 continued

	Accrual $
Fixed Expenses	
Car Gas	1,058
Oxygen	90
Truck R & M	504
Automobile R & M	1,364
Building R & M	4,528
Yard R & M	114
Structures R & M	367
Tools	1
Custom Work	63
General Expenses	99
Handling Charge	120
Freight and Trucking	288
Interest	111
Insurance	857
Equipment & Machine Insurance	22
Car Insurance	406
Truck Insurance	691
Telephone	118
Hydro/Electricity	695
Property Tax	6,119
Administration Costs	45
Fees & Subscriptions	45
Legal Services	55
Other Professional Services	105
Office Supplies	18
Miscellaneous Expense	78
Total Fixed Expenses	17,961
Total Expenses	71,825
Income less Expenses	183,700

Source: Solution to farm planning model in optimization mode and CANFARM records.

TABLE G.3

CASH FLOW STATEMENT : 1976 OPTIMAL 'PLAN A'

	Jan. $	Feb. $	Mar. $	Apr. $	May $	June $	July $	Aug. $	Sep. $	Oct. $	Nov. $	Dec. $
Crop Sales												
Barley									23760			
Straw								5400	5400			
Field Beans									8400	7800		
Fiels Peas									12960	12960		
Potatoes								19200	10080	13602	13603	31215
Strawberries						3000	3000					
Sugar Beet Sd												18240
Leaf/Fruit Sd												4500
Cabbage Seed												34000
Pea Vines									1462	1462		
Raspberries							2800		146			
						3000	5800	24600	62062	35825	13603	87955
Crop Expenses												
Purchased Inputs												
Twine					87							
Premerge					747							
Pea Fert.					675							
Potash					2348							
Eptam					2274							
Fert. 0-0-22					463							
Fert. 11-55-0					1912							
Benlate					266							
Beet Fert.			2000									
Turnip Fert.			573									
Bees						400						
Cabbage Fert.					1453							
Rasp. Fert.					124							
Straw. Fert.					297							
Barley Seed				756								
Barley Fert.					1620							
E. Pot. Seed				2240								
Potato Fert.					9312							

TABLE G.3 continued

	Jan. $	Feb. $	Mar. $	Apr. $	May $	June $	July $	Aug. $	Sep. $	Oct. $	Nov. $	Dec. $
Crop Exes cont.												
L. Pot. Seed					8190							
Blight			53									
Sprout Inhibitor						1323						
Monitor Insect.						700						
Total Purch. Inputs												
Purple Gasoline			93	293	39	3	91	305	153			
Diesel Fuel			130	337	204	5	133	32	22	71		
Rent											7740	
Tractor R & M			67	189	95	4	113	73	112	25		
Gen.Farm Equip R & M			80	369	223	7	221	559	427	20		
Part Time Lab.					215			762	3501			
Int. on Op. Capital	3	7	183	230	348	359	333	201	-225	-474	-508	-1119
Total Var. Exes	3	7	3179	4414	30892	2801	891	1932	3990	-358	7232	-1119
Total Exes												
Car Gas	70	80	80	63	63	63	283	15	110	113	118	
Oxygen							42		37	11		
Truck R & M			7	80	80	76			31	121	9	100
Auto. R & M	26	30	30	121	121	121	66			58	677	114
Build. R & M				1150	1150	1214					90	924
Yard R & M							76			10	29	
Struc. R & M	30	31	31								275	
Tools							1					
Custom Work							63					
Gen. Exes				33	33	33						
Handling Ch.	40	40	40									
Freight & Tr.									160	128		
Interest							103	8				
Insurance							857					
Equip. & Mach. Insur.				7	7	8						

TABLE G.3 concluded

	Jan. $	Feb. $	Mar. $	Apr. $	May $	June $	July $	Aug. $	Sep. $	Oct. $	Nov. $	Dec. $
Total Exes cont.												
Car Insur.			406									
Truck Insur.			691									
Telephone	9	10	10	8	9	10	11	9	8	15	19	
Hydro/Elec.	150	151	151	43	43	43	32	29	25		28	
Property Tax	51	51	51					5966				
Admin. Costs	15	15	15									
Fees & Subs	15	15	15									
Legal Serv.	15	20	20									
Other Prof. Services											105	
Office Sup.		2			8				8			
Misc. Exes											78	
Total Fixed Expenses	421	445	1547	1505	1514	1568	1534	6027	379	455	1428	1138
Total Expenses	424	452	4726	5919	32406	4369	2425	7959	4369	97	8660	19
Cash Surplus	424	-452	-4726	-5919	-32406	-1369	3375	16641	57693	35728	4943	87936
Accum. Cash Surplus	-424	-876	-5602	-11521	-43927	-45296	-41921	-25280	32413	68141	73084	161020

Source: Solution to farm planning model in optimization mode and CANFARM records.

TABLE G.4

ENTERPRISE STATEMENT
63 ACRES OF LATE POTATOES : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	15.59 ton	1,447	91,180
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Potato Fertilizer	1,200 lb.	112	7,056
Herbicide			
Eptam	1 gal.	29	1,827
Sprout Inhibitor	1 gal.	21	1,323
Other Chemical			
Blight Control	3 lb.	1	53
Monitor Insecticide	.2 gal.	11	700
Seed	1 ton	130	8,190
Other			
Total Purchased Inputs			
Purple Gasoline) Diesel Fuel)		7.4	466
Repair & Maintenance Costs			
Tractors		3.8	239
General Farm Equipment		10.9	674
Part Time Labour		59	3,716
Total Variable Expenses		385	24,244
Allocated Overheads		56	3,528
Total Costs		441	27,772
Revenue less Expenses		1,006	63,408

Source: Solution to farm planning model in optimization mode.

TABLE G.5

ENTERPRISE STATEMENT
20 ACRES OF EARLY POTATOES : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	6 ton	960.00	19,200.00
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Potatoe Fertilizer	1,200 lb.	96.00	1,920.00
Herbicide			
Other Chemical			
Seed	1,400 lb.	112.00	2,240.00
Other			
Total Purchased Inputs			
Purple Gasoline) Diesel Fuel)		18.33	366.60
Repair & Maintenance Costs			
Tractors		7.28	145.60
General Farm Equipment		12.47	249.40
Part Time Labour			
Total Variable Expenses		246.08	4,921.60
Allocated Overheads		59.00	1,180.00
Total Costs		305.08	6,101.60
Revenue less Expenses		654.92	13,098.40

Source: Solution to farm planning model in optimization mode.

TABLE G.6

ENTERPRISE STATEMENT
30 ACRES OF BEANS : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	4 ton	540.00	16,200
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Potash	200 lb.	10.30	309
0-0-22	100 lb.	4.75	143
Bean Fertilizer	500 lb.	63.75	1,913
Herbicide			
Eptam	0.5 gal.	14.58	437
Premerge	1.5 gal.	12.45	374
Other Chemical			
Benelate	3.5 units	8.86	266
Seed			
Other			
Total Purchased Inputs		114.69	3,442
Purple Gasoline) Diesel Fuel)		3.35	100.5
Repair & Maintenance Costs			
Tractors		1.57	47
General Farm Equipment		2.24	67
Part Time Labour			
Total Variable Expenses		121.85	3,656
Allocated Overheads		59.00	1,770
Total Costs		181.00	5,430
Revenue less Expenses		359.00	10,770

Source: Solution to farm planning model in optimization mode.

TABLE G.7

ENTERPRISE STATEMENT
15 ACRES OF LATE PEAS : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2.4 ton	576.00	8,640.00
Bi-product Sales	1.0 ton	65.00	975.00
Total Sales		641.00	9,615.00
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Fertilizer	150 lb.	15.00	225.00
Potash	200 lb.	10.30	155.00
Herbicide			
Premerge	1 gal.	8.30	124.5
Other Chemical			
Seed			
Other			
Twine	1.93 units	1.93	28.9
Total Purchased Inputs		35.53	532.95
Purple Gasoline) Diesel Fuel)		3.27	49.05
Repair & Maintenance Costs			
Tractors		1.83	27.45
General Farm Equipment		3.33	49.95
Part Time Labour			
Total Variable Expenses		43.96	659.40
Allocated Overheads		59.00	885.00
Total Costs		112.96	1,544.40
Revenue less Expenses		528.00	7,071.00

Source: Solution to farm planning model in optimization mode.

TABLE G.8

ENTERPRISE STATEMENT
30 ACRES OF EARLY PEAS : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2.4 ton	576.00	17,280.0
Bi-product Sales	1.0 ton	65.00	1,950.0
Total Sales		641.00	19,230.0
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Fertilizer	150 lb.	15.00	450.0
Potash	200 lb.	10.30	309.0
Herbicide			
Premerge	1 gal.	8.30	249.0
Other Chemical			
Seed			
Other			
Twine	1.93 units	1.93	58.0
Total Purchased Inputs		35.53	1,066.0
Purple Gasoline) Diesel Fuel)		3.00	90.0
Repair & Maintenance Costs			
Tractors			
General Farm Equipment		1.60	48.0
Part Time Labour		2.29	68.7
Total Variable Expenses		42.42	1,272.6
Allocated Overheads		59.00	1,770.0
Total Costs		101.42	3,042.6
Revenue less Expenses		540.00	16,200.0

Source: Solution to farm planning model in optimization mode.

TABLE G.9

ENTERPRISE STATEMENT
108 ACRES OF BARLEY : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2 ton	220.00	23,760
Bi-product Sales	80 bales	100.00	10,800
Total Sales		320.00	34,560
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Fertilizer	150 lb.	15.00	1,620
Potash	200 lb.	10.30	1,112
Herbicide			
Other Chemical			
Seed	1 cwt	7.00	756
Other			
Total Purchased Inputs		32.30	3,488
Purple Gasoline) Diesel Fuel)		3.43	370
Repair & Maintenance Costs			
Tractors		1.27	137
General Farm Equipment		3.47	375
Part Time Labour		7.06	762
Total Variable Expenses		47.53	5,133
Allocated Overheads		59.00	6,372
Total Costs		107.00	11,505
Revenue less Expenses		213.00	23.004

Source: Solution to farm planning model in optimization mode.

TABLE G.10

ENTERPRISE STATEMENT
20 ACRES OF SUGAR BEETS : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2,400 lb.	912.00	18,240.00
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Beet Fertilizer	1,000 lb.	100.00	2,000.00
0-0-22	150 lb.	7.12	142.40
Potash	200 lb.	10.30	206.00
Herbicide			
Other Chemical			
Seed			
Other			
Total Purchased Inputs		117.42	2,348.4
Purple Gasoline) Diesel Fuel)		4.96	99.20
Repair & Maintenance Costs			
Tractors		1.51	30.20
General Farm Equipment		7.13	142.60
Part Time Labour			
Total Variable Expenses		131.02	2,620.4
Allocated Overheads		59.00	1,180.0
Total Costs		290.00	5,800.00
Revenue less Expenses		622.00	12,440.00

Source: Solution to farm planning model in optimization mode.

TABLE G.11

ENTERPRISE STATEMENT
5 ACRES OF TURNIP : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2,000 lb.	900.00	4,500
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Turnip Fertilizer	1,198 lb.	114.65	573
0-0-22	150 lb.	7.12	36
Potash	200 lb.	10.30	52
Herbicide			
Other Chemical			
Seed			
Other			
Bees	1.0 unit	20.00	100
Total Purchased Inputs		152.07	760
Purple Gasoline) Diesel Fuel)		4.73	24
Repair & Maintenance Costs			
Tractors		1.39	7
General Farm Equipment		7.07	35
Part Time Labour			
Total Variable Expenses		165.26	826
Allocated Overheads		59.00	295
Total Costs		224.00	1,121
Revenue less Expenses		676.00	3,379

Source: Solution to farm planning model in optimization mode.

TABLE G.12

ENTERPRISE STATEMENT
20 ACRES OF CABBAGE : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	2,000 lb.	1,700.00	34,000
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Cabbage Fertilizer	777 lb.	72.65	1,453
0-0-22	150 lb.	7.12	142
Potash	200 lb.	10.30	206
Herbicide			
Other Chemical			
Seed			
Other			
Bees	1.0 unit	15.00	300
Total Purchased Inputs		105.07	2,101
Purple Gasoline) Diesel Fuel)		4.95	99
Repair & Maintenance Costs			
Tractors		1.18	24
General Farm Equipment		8.79	176
Part Time Labour			
Total Variable Expenses		119.99	2,400
Allocated Overheads		59.00	1,180
Total Costs		179.00	3,580
Revenue less Expenses		1,521.00	30,420

Source: Solution to farm planning model in optimization mode.

TABLE G.13

ENTERPRISE STATEMENT
5 ACRES OF STRAWBERRIES : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	4,000 lb.	1,200.00	6,000.00
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Strawberry Fert.	702 lb.	59.50	297.50
Herbicide			
Other Chemical			
Seed			
Other			
Total Purchased Inputs		59.50	297.50
Purple Gasoline) Diesel Fuel)		0.90	4.50
Repair & Maintenance Costs			
Tractors		1.01	5.05
General Farm Equipment		1.42	7.10
Part Time Labour			
Total Variable Expenses		62.83	314.00
Allocated Overheads		59.00	295.00
Total Costs		122.00	609.00
Revenue less Expenses		1,078.00	5,391.00

Source: Solution to farm planning model in optimization mode.

TABLE G.14

ENTERPRISE STATEMENT
2 ACRES OF RASPBERRIES : 1976 OPTIMAL 'PLAN A'

	Units Per Acre	Costs Per Acre $	Total Costs $
Revenue			
Crop Sales	3,500 lb.	1,400.00	2,800.00
Bi-product Sales			
Total Sales			
Expenses			
Purchased Inputs			
Chemical Fertilizer			
Raspberry Fert.	750 lb.	61.88	123.76
Herbicide			
Other Chemical			
Seed			
Other			
Total Purchased Inputs			
Purple Gasoline) Diesel Fuel)		1.75	3.50
Repair & Maintenance Costs			
Tractors		1.96	2.92
General Farm Equipment		3.34	6.68
Part Time Labour			
Total Variable Expenses		68.93	137.86
Allocated Overheads		59.00	118.00
Total Costs		128.83	255.86
Revenue less Expenses		1,271.17	2,542.34

Source: Solution to farm planning model in optimization mode.

G.3 THE PHYSICAL RECORDS

TABLE G.15

UTILIZATION REPORT FOR LAND : 1976 OPTIMAL 'PLAN A'

Crop	Amount Early Summer			Amount Late Summer			Opportunity Cost		
	Land A	Land B	Rented	Land A	Land B	Rented	Land A	Land B	Rented
Late Potatoes	35	23	5	35	23	5	0.0	0.0	0.0
Early Potatoes	0	0	20	0	0	0	161.5	161.5	0.0
Late Peas	6	9	0	6	9	0	0.0	0.0	65.4
Early Peas	0	30	0	0	0	0	0.0	0.0	65.4
Beans	0	30	0	0	30	20	0.0	0.0	65.4
Barley	47	0	61	0	0	0	0.0	0.0	0.0
Strawberries	5	-	-	5	-	-	0.0	-	-
Raspberries	2	-	-	2	-	-	0.0	-	-
Sugar Beet Seed	20	-	-	40	-	-	0.0	-	-
Cabbage Seed	20	-	-	40	-	-	0.0	-	-
Turnip Seed	5	-	-	10	-	-	0.0	-	-
Total Cropped	140	92	86	138	62	5			
Total Unused	0	0	14	2	30	95			
Shadow Price for Land $	124.00	124.00	91.30	0.0	0.0	0.0			

Source: Solution to farm planning model in optimization mode.

TABLE G.16

CROP FEASIBILITY : 1976 OPTIMAL 'PLAN A'

Constraint	Crops												Bound (acres)				Shadow Price of Constraint $			
	Late Potatoes	Early Potatoes	Beans	Late Peas	Early Peas	Barley	Sugar Beet Seed	Turnip Seed	Cabbage Seed	Strawberries	Raspberries	Unused	Land A	Land B	Rented Land	All Land	Land A	Land B	Rented Land	All Land
A	x	x	.	.	.	.	.	.	.	.	.	.	≤35	≤23	≤25	-	678	678	516	-
B	.	x	.	.	.	.	.	.	.	.	.	.	-	-	-	≤20	-	-	-	120
C	.	.	x	.	.	.	.	.	.	.	.	.	-	-	-	≤30	-	-	-	332
D	.	.	.	x	x	.	.	.	.	.	.	.	-	-	-	≤45	-	-	-	514
E	.	.	.	.	x	.	.	.	.	.	.	.	-	-	-	≤30	-	-	-	1
F	.	.	.	.	.	x	.	.	.	.	.	.	-	-	-	≤25	-	-	-	0
G	.	.	.	.	.	.	x	.	.	.	.	.	≤20	-	-	-	685	-	-	-
H	.	.	.	.	.	.	.	x	.	.	.	.	≤ 5	-	-	-	636	-	-	-
I	.	.	.	.	.	.	.	.	x	.	.	.	≤20	-	-	-	1492	-	-	-
J	.	.	.	.	.	.	.	.	.	x	.	.	= 5	-	-	-	1078	-	-	-
K	.	.	.	.	.	.	.	.	.	.	x	.	= 2	-	-	-	1296	-	-	-

Key: x = Constrained . = Unconstrained

Source: Solution to farm planning model in optimization mode.

TABLE G.17

LABOUR UTILIZATION : 1976 OPTIMAL 'PLAN A'

Date	Hours Available			Hours Utilized		
	Own	Family	Total	Unused	Used	Hired
January 1 - January 31	810	0	810	810	0	
February 1 - February 28	720	0	720	720	0	
March 1 - March 31	780	0	780	589	191	
April 1 - April 8	210	26	226	98	128	
April 9 - April 15	180	0	180	14	166	
April 16 - April 23	210	0	210	93	117	
April 24 - April 30	180	48	228	174	54	
May 1 - May 8	210	48	258	130	128	
May 9 - May 15	180	48	228	0	228	11
May 16 - May 23	195	0	195	0	195	43
May 24 - May 31	210	0	210	127	83	
June 1 - June 8	180	0	180	167	13	
June 9 - June 15	180	0	180	175	5	
June 16 - June 23	210	54	264	210	54	
June 24 - June 30	180	54	234	180	54	
July 1 - July 8	210	54	264	0	264	
July 9 - July 16	210	54	264	0	264	
July 17 - July 23	180	54	234	0	234	
July 24 - July 31	210	54	264	33	231	
August 1 - August 7	180	0	180	0	180	190
August 8 - August 15	210	0	210	114	96	
August 16 - August 23	210	0	210	190	20	
August 24 - August 31	180	0	180	96	84	
Sept. 1 - Sept. 8	210	0	210	175	35	
Sept. 9 - Sept. 15	180	96	276	0	276	310
Sept. 16 - Sept. 23	210	112	322	0	322	214
Sept. 24 - Sept. 30	180	96	276	0	276	352
October 1 - October 8	210	0	210	156	54	
October 9 - October 16	180	0	180	180	0	
October 17 - October 24	210	0	210	210	0	
October 25 - October 31	180	0	180	164	16	
Nov. 1 - Nov. 30	750	0	750	750	0	
Dec. 1 - Dec. 31	810	0	810	810	0	

Source: Solution to farm planning model in optimization mode.

TABLE G.18

UTILIZATION REPORT FOR TRACTORS : 1976 OPTIMAL 'PLAN A'

Power	Tractor Hours						Total Hours	Maximum Shadow Price
	1370 Case TA	D19 TB	D17 TC	D16 TD	Massy TE	JD & DB TF		
130 - 140	0	–	–	–	–	–	0	0
120 - 130	0	–	–	–	–	–	0	0
110 - 120	166	–	–	–	–	–	166	$7.55
100 - 110	0	–	–	–	–	–	0	0
90 - 100	118	–	–	–	–	–	118	$7.18
80 - 90	0	–	–	–	–	–	0	0
70 - 80	0	0	–	–	–	–	0	0
60 - 70	0	0	–	–	–	–	0	0
50 - 60	–	46	189	–	–	–	235	$3.09
40 - 50	–	0	70	–	–	–	70	$2.31
30 - 40	–	–	0	–	–	0	0	0
20 - 30	–	–	14	0	158	0	172	$0.91
10 - 20	–	–	0	0	55	0	55	$0.96
0 - 10	–	–	0	60	391	13	464	$0.57
Unspecified	0	0	152	0	5	10	167	–
Total Hours per Tractor	284	46	425	60	609	23	1447	–
Total R & M Costs	$169	$35	$295	$6	$171	$5	$681	–
Average R & M Costs	59¢	76¢	69¢	10¢	28¢	22¢	47¢	–
Maximum Shadow Price	$3.75	$0.00	$0.00	$0.12	$0.15	$0.00	–	–

Source: Solution to farm planning model in optimization mode.

TABLE G.19

UTILIZATION REPORT FOR IMPLEMENTS : 1976 OPTIMAL 'PLAN A'

Implement Code	Name	Hours of Use	Cost/ Hour	Total Costs	Maximum Shadow Price
IA	17 ft. Cultivator	55.75	.681	37.97	0.0
IB	Packer Mulch	143.62	.9768	140.29	2.66
IC	Harrow	25.52	.12	3.06	0.0
ID	Packer	19.27	.30	5.73	0.0
IG	Stan H Seeder	22.5	.60	13.50	0.0
IH	Seed Drill	52.25	.64	33.44	0.0
II	Fertilizer Spreader	10.70	.30	3.21	0.0
IJ	Swather	78.27	1.40	109.58	0.0
IK	Seed Combine	81.00	4.509	365.23	0.0
IL	Plow	88.67	2.00	177.33	0.0
IN	Sprayer	126.78	.60	76.07	0.0
IO	Tedder	76.5	.32	24.48	347.0
IP	Baler	51.0	.868	44.27	0.0
IQ	Potato Planter	83.0	.648	53.78	0.0
IR	Ridger	27.67	.096	2.66	0.0
IS	Float	16.6	.024	0.40	0.0
IT	Wagons	161.67	.036	5.82	0.0
IU	Potato Combine	166.0	3.20	531.20	0.0
IV	Subsoiler	21.6	.387	8.24	0.0
IW	Rotovator	5.0	.576	2.88	0.0
IX	Rototiller	16.0	.384	6.30	0.0
IZ	Disc Cultivator	22.5	.30	6.75	0.0
JA	DT Cultivator	35.0	.15	5.26	0.0
JB	Row Cultivator	6.0	.12	0.72	0.0
JC	J Deer Row Cultivator	10.0	.30	3.00	0.0
JD	Disc	106.91	.48	51.37	0.0
IE	Rake	79.0	.49	38.71	0.0
IF	Power Mulch	71.36	.929	66.34	0.0
JG	Truck	20.75	3.20	66.40	0.0
				1889.09	

Source: Solution to farm planning model in optimization mode.