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SIMULATION MODEL FOR FIELD CROP PRODUCTION MACHINERY SYSTEM

By

Wan Ishak Wan Ismail

A DISSERTATION

Submitted to
Michigan State University
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ABSTRACT

SIMULATION MODEL FOR FIELD CROP PRODUCTION MACHINERY SYSTEM

By

Wan Ishak Wan Ismail

The Crop Production Machinery System (CPMS) program developed during this research is able to evaluate machinery systems for various tillage systems and crop rotations for different locations, soil types and farm sizes. Users can determine the combinations of crops in a rotation which minimize the machinery costs, evaluate different farming alternatives, or scale up or down a farm operation. The Machinery Selection Model is able to recommend tractor and implement sizes for a power-compatible machinery system that is able to complete the field operations within specified time constraints. The Machinery Cost Analysis Model is able to evaluate machinery costs when the use of implements is shared in several enterprises, when the same machinery is used under different conditions, or when machinery costs are compared for different situations such as farm size and production practices.

The CPMS program was developed to be run on most microcomputers and to have potential for modification to be transferred to and evaluated for other geographical locations and situations. The locations, crops and equations used in this program could

be changed as described in this dissertation. This program helps users to become more knowledgeable about a problem as they interact with the program. The program can be used with external data files to facilitate a sensitivity analysis or other experimentation with this model.

The predicted draft and fuel requirements from this model were tested statistically against a set of data collected during field experiments performed at Michigan State University and in Clinton County, Michigan. The fuel consumption rates for the chisel plow, moldboard plow, disk harrow, field cultivator, row crop planter and grain drill, and the draft requirements for all of these implements, except the disk harrow, correlated well with the measured data.

The implementation of the model shows that producing more crops in a rotation reduced the costs per hectare. It was cheaper to produce corn and wheat in a C-C-FB-W crop rotation as compared to the same crops produced as a single crop operation. The one-tractor operation required larger implements and saved on costs per hectare as compared to the two-tractor operation.

Approved by:

Thomas H Burkhardt
Major Professor

Department Chairperson

This dissertation is dedicated to my mother, Hajjah Wan Minah; my father, Haji Wan Ismail; my wife, Nomi; my sons, Nuaim and Najib; and my daughter, Nazeeha. Thanks for their moral support, prayers and encouragement throughout my studies.

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GLOSSARY

A = Area,ha

APTOP = Tractor Available Power-Take-Off

CC = Implement Capital Consumption Cost

CCT = Tractor Capital Consumption Cost

CI = Cone Index

CN = Dimensionless Ratio

CP = Chisel Plow

CRF = Implement Capital Recovery Factor

CRFT = Tractor Capital Recovery Factor

D = Draft, kN

DBP = Implement Drawbar Power, kW

DBPT = Tractor Drawbar Power, kW

DH = Disk Harrow

E = Field Efficiency, dec

EF = Implement Field Time, h/ha

EFC = Effective Field Capacity, ha/h

EPTOP = Implement Equivalent Power Take-off Power,Kw

F = Fuel Price,$

FC = Fuel Cost,$

FCN = Fuel Consumption,l/h

F.Cult = Field Cultivator

FT = Implement Field Time For One Crop,h

FTIMP = Field Time Required by Implement, h

FTO = Field Operation Time,h

FU = Fuel Use, l

GD = Grain Drill

HD = Hours Available per Day, h/day

HRM1 = Total Hours of Machinery, nth year

HRM2 = Total Hours of Machinery, n+1 years

HRT1 = Total Hours of Tractor, nth year

HRT2 = Total Hours of Tractor, n+1 years

I = Interest Rate

IMP = Number of Implements

L = Expected Life,yr

L$ = Labor Wage, $

LC = Labor Cost, $

LM = Machinery Expected Life,yr

LT = Tractor Expected Life, yr

LPM = Machinery List Price,$

LPT = Tractor List Price,$

MC = Total Machinery Cost,$

O = Oil Price,$

OC = Oil Cost,$

OCN = Oil Consumption, l/h

OU = Oil Use, l

PPM = Machinery Purchase Price, $

PPT = Tractor Purchase Price, $

PWD = Probability Working Days

R&M = Repair and Maintenance Cost,$

RCPL = Row Crop Planter

RF1,RF2 = R & M Factors for Tractor or Implement

RMN = Implement Repair and Maintenance Cost,$

RMT = Tractor Repair and Maintenance Cost,$

RMCM1 = Implement Repair & Maintenance Cost, nth yr

RMCM2 = Implement Repair & Maintenance Cost, (n+1) yr

RMT1 = Tractor Repair & Maintenance Cost, nth yr

RMT2 = Tractor Repair & Maintenance Cost,(n+1) yr

RVN = Machinery Remaining Value, nth yr

RVM = Machinery Remaining Value, n+1 yr

RVNT = Tractor Remaining Value, nth yr

RVMT = Tractor Remaining Value, n+1 yr

S = Operation Speed, km/h

S_g = Ground Speed, km/h

S_w = Wheel Speed, km/h

SL = Wheel Slippage

S$ = Machinery Salvage Value,$

TMC = Total Machinery and Tractor Cost, $

TARN = Accumulated Repair and Maintenance Cost at End of n th year,$

TARM = Accumulated Repair and Maintenance Cost at End of (n-1) year,$

TC = Annual Tractor Cost, $

TE = Tractive Efficiency

TFT = Total Field Time,h

TISM = Implement Taxes,Insurance & Shelter Cost,$

TIST = Tractor Taxes,Insurance & Shelter Cost,$

TS = Compatible Implement to Tractor Size, kW

TSZ = Tractor Size, kW

USEN = Accumulated Hours Used at End of n th year,h

USEM = Accumulated Hours Uses at End of (n-1) year,h

W = Implement Width, m

WD = Working Operation Depth, m

W_L = Dynamic Wheel Load, kN

WN = Number of Rows For Planter or Grain Drill

WNC = Number of Tines for Chisel Plow or Field Cultivator

1. INTRODUCTION

Agricultural production in the United States has increased many fold in response to an ever growing demand for food by the domestic and world population. Scientists, engineers, industries and farmers are challenged to increase agricultural production without increasing the use of energy inputs. Machinery contributes a major capital input cost in most farm businesses (Chen, 1986; Ozkan and Edwards 1986; Singh and Holtman 1979a; Mayfield et al. 1981). Rotz et al. (1983), found that the data collected on actual farms indicated that machinery used on the farms was not always properly matched to the available power, and in several cases machinery was oversized with respect to the area farmed. To increase the profit, producers need to cut production costs. Profits can be increased by selecting the right complement of equipment for their farm size, crops and tillage system. Singh and Holtman (1979a) stated that field machinery cost per unit crop land area can be reduced either by reducing the amount of work done (eg. reduced tillage) for a particular crop or by using a crop rotation that distributes the work more evenly over the cropping year, improving machinery utilization. The crops were assumed to use same machines. The success of many farm-level production systems depends on wise selection of machinery systems.

The application of machines to agricultural production has been one of the outstanding developments in agriculture. Many factors are involved in the process of

equipping a modern farm for field operations. Agricultural production is seasonal, leaving machines standing idle much of the time. Some machines which are extensively used will also stand idle much of the time if not managed properly. There is a need for timely operations in agricultural production because of the seasonal requirements of the crops.

The main aim of tractor and machinery selection studies is to complete a certain field operation during a specified time and at a minimum total cost (Ghassan Al-Soboh et al. 1981). Tractor and machinery selection is an important part of machinery management. Wu and Persson (1986), stated that the matching of machine width and tractor power has an important effect on the time and fuel requirements per unit land area. Oversized implements results in a loss of productivity and fuel efficiency. In practice, farmers depend on their experiences or recommendations of other farmers and machinery dealers when matching tractors and implements.

To adequately evaluate crop production and to be able to choose alternative crop production or tillage systems, information needs to be collected. Among the information is the implement draft requirement on different soils of major crop production systems. Soil types, soil conditions, operation depths, operation speeds and type and size of implements will determine the draft required and the traction ability of the tractor in the field. Implement draft requirement is an important consideration in selecting implements, tillage systems and a tractor size that is compatible with the operation. In addition to the required tractor size, implement draft will also be used to determine the fuel consumed for an operation.

A technique is needed in an easily accessible form to match tractor/implement combinations for optimum performance. The complexity and magnitude of the machinery

selection problem in the analysis of crop production systems have led to numerous efforts to develop models as a decision aid. A model is required to evaluate alternative machinery systems and to select a machinery complement for different tillage practices for a variety of crop rotations.

Number of crops in a rotation, different tillage systems, different land size for different crops in a crop operation, and the use of the same implement with different speed, depth and tractive efficiency complicate the selection of machinery. Large numbers of variables and relationships are involved, thus requiring a computer simulation model for definitive answers. A simulation model for crop production machinery systems to be developed will allow an individual farmer to budget farm operations and evaluate different farming alternatives on a micro computer. Such a model will require selection of machinery complements for different tillage systems for a variety of crop rotations. It must also include a machinery cost analysis.

Systems research relies to a considerable extent on the use of simulation models because it is often impossible or impractical to study the real system. Simulation is a very useful tool that saves time, rather than experimentation on actual farms. In order to exhaustively study a system one must rely on computer simulation. Currently, many agricultural specialists are developing expert systems which will be more effective and comprehensive in dealing with agronomic problems (Downs et al. 1990). Expert systems allow users to become more knowledgeable about a problem as they interact with the program.

Simulation models will describe in a general algorithm which can be transferred, modified and evaluated for other geographical locations and situations. There is a need

to develop a simulation model that can be modified to be used in Malaysia. Technological change in the agriculture of Malaysia is a matter of importing new equipment from developed nations. While this continues to some extent, the question of appropriateness of the imported agricultural machine has been a focal concern. Agricultural machine if not properly introduced and applied, can lead to serious financial and economic losses and bring about undesirable social consequences. A simulation model that could determine the machinery requirements and sizes, and could estimate the cost of production will assist the policy maker to develop the country's agricultural mechanization policy.

1.1 Objectives

The objectives of this dissertation are:

1. To develop a machinery selection model which utilizes parameters collected from field tests and from pertinent literature to determine near optimum machinery sets for various field crop production systems.
2. To develop the machinery cost analysis model to evaluate machinery costs after a complete set of implements and tractors is selected. The machinery cost analysis must be able to evaluate machinery costs when: (a) the use of machinery is shared in several enterprises; (b) the same machinery is used under different conditions (eg. speed, depth, field efficiency, tractive efficiency); and (c) machinery costs are compared for different situations such as farm size and production practices.

3. To develop a machinery selection simulation model and machinery cost analysis simulation model that is user friendly, microcomputer-based program. Beside helping the user make proper decisions, the system must provide education through explanatory and feedback features. It must include programs for the users to create external data files.

4. To compare different farm sizes, tillage systems, and crop production system with respect to costs and machinery requirements. Thus, the user can use this model to determine the most profitable combination of crops in rotations to evaluate different farming alternatives and to scale up or down his farm operation.

5. To design the model to have potential for modification to be transferred to and evaluated for other geographical locations and situations.

6. To carry out field experiments to measure the fuel and draft requirements. To validate the predicted or model fuel and draft requirements with the experimental fuel and draft requirements.

2. REVIEW OF LITERATURE

The Crop Production Machinery System (CPMS) simulation model was developed to evaluate machinery systems for crop production. The computer program consists of the Machinery Selection Model and the Machinery Cost Analysis Model. The Machinery Selection Model will be used to predict the size of tractors and implements required to complete the farm operation during a specified duration of time and to determine the compatibility of tractors and implements by properly matching the available tractor power. The Machinery Selection Model also computes the field time required for the machinery set to complete the tillage and planting operations. The Machinery Cost Analysis Model will be used to estimate the annual cost for the tractors and implements selected in the Machinery Selection Model. Machinery requirements (number and size of each) and costs will be determined for each crop production system with two alternative tillage systems, conservation or conventional tillage systems. The users will have the choice of five different locations in Michigan, three soil textures, different farm sizes, and a maximum of five crops in a single rotation.

The design of the CPMS simulation model involves calculations of machine productivity and costs. The implement's required drawbar power is compared to the tractor's drawbar power. The field time required by the implements to complete a farm operation is compared to the available field operation time. When a well-matched system

is selected, the total annual cost of owning and operating the set of machines is then determined. Several well-matched systems can be found for the same farm, thus cost analysis can be useful to select the "least cost" or "maximum profit" system.

The CPMS model is a computer interactive model developed based on the concept of expert systems which allows the user to interact with the program. The user enters the required inputs and the program will carry out an iterative search. This interactive computer model identifies and searches for the number and type of crops used. For each crop the program identifies and searches for the number and size of the tractor used, and for each tractor, the program identifies and searches for the number and type of implements used.

2.1 Machinery Selection and Cost Models

Several approaches to machinery requirements and associated costs have been developed. 1) The enterprise budgets and custom hire rates; 2) Whole farm, profit maximizing linear programming and mixed integer linear programming models; 3) Cost minimization model which seek a least cost machinery complement; and 4) Heuristic models for selecting multiple enterprise machinery sets. All those models were reviewed by Wolak (1981) and Muhtar (1982).

The enterprise budget and custom hire approach provide a useful approximation of capturing cost difference for labor and machinery. It is limited by failure to adequately address the interaction of weather patterns, operations schedule, and crop rotation. Linear programming models are useful for organizing the enterprise mix to maximize returns given a current machinery complement. These models are less effective for application

to search strategies. The cost minimization models select a minimum cost for a given farm size and crop rotation. It is limited by the number of crops, one or two crops at most. The heuristic machinery models developed at Michigan State University view timeliness as a constraint. Machine productivity is matched to available time during schedule calendar periods such that all operations are completed on time. The heuristic machinery models are restricted to only one type of soil, limited farm land size and the farmer is restrained to buy new machines.

In many machinery selection studies the main objective has been assumed to be the completion of certain field operations before a given set of dates at a minimum cost (Hughes and Holtman,1976; Ozkan and Frisby, 1981). The time constraint algorithm described by Hughes and Holtman (1976) was further developed by Singh (1978). Wolak (1981) further developed the Singh's (1978) machinery selection model. Rotz et al. (1983) developed a time constraint algorithm to include cost analysis cropping plans.

A number of computer programs have been developed to select an optimum machinery set for a particular farm. Ozkan and Edwards (1986) developed a micro computer model for machinery selection for corn and soybean farming. Singh (1978) and Rotz et al. (1983) were among the researchers that developed a multiple crop machinery selection models. Chen (1986) developed a general crop budget model and a budget generator model to allow individual farmers to budget their farm operations and evaluate different farming alternatives. Doster et al. (1990) used the linear programming to determine the machinery size. The microcomputer program crop budget was used to test ways to improve crop mix, machine size, tillage system, and/or farm size.

Currently, many agricultural specialists are developing expert systems to allow

users to become more knowledgeable about a problem as they interact with the program. Besides helping the user make proper decisions, the expert system can provide education through explanatory and feedback features. The importance of expert systems for machinery management was well described by Oskoui et al. (1990). Jones et al. (1987) use expert system concept in an overall systems approach for solving agricultural problems. Downs et al. (1990) developed an expert system and knowledge base to provide information that a farmer would need in making a typical management decision for tractor-implement systems. Kotzabassis et al. (1990), developed a software package to serve as an expert decision aid for cost effective farm machinery selection and management.

2.2 Tractor and Implement Matching

Various methods and guides are available to match farm implements and tractors. A number of computer programs have also been developed to select an optimum machinery set for a particular farm. Capacity and power matching of farm machinery have been described in detail by Hunt (1983). Capacity and power matching model have also been developed by others (Rotz et al. 1983; Ramp and Siemens 1990, Downs et al. 1990). Colvin et al. 1989 developed an interactive computer model, TERMS, to predict farm machinery field capacity and fuel use. Their model was validated with experimental data and found to have a high correlation between the measured and predicted values.

The effective field capacity of an implement and the field operation time are important in determining the number and the sizes of implements and tractors required to complete the job within a specified duration of time. An accurate method for

predicting machine performance rates is an important farm management tool. It would enable a farmer to more accurately determine the total machine time required to handle the farm crop operations, and would also be an important tool to help select the correct machine size. The energy requirements in terms of draft or drawbar power are important to determine the compatibility of the tractor-implement relationship.

The size of implements, speed of operation, and field efficiency are required to determine the implement effective field capacity or the time required to complete a field operations. The commercially available sizes of various machines can be obtained from many sources such as the 1989 Agricultural Equipment Buyer's Guide (Case J.I. 1989), or from Implement and Tractors Red Book (1988). Field efficiency is a measure of relative productivity of a machine under field conditions. Hunt (1983) described various factors affecting the field efficiency of a machine. Typical ranges in operating speed and field efficiency for most types of machines are given in the ASAE STANDARDS (ASAE, 1990). The field time required for each operation is determined by dividing total crop area by the effective field capacity of the operation. This result is compared with the available field time within the specified calendar date constraints. Suitable work time available is generally hard to obtain because of the long period of time required to obtain such data. One source for suitable day data is computer simulation. A model developed by Rosenberg et al. (1982) can be used to generate probabilities of suitable work days (pwd) from weather data for a specified location.

Wu and Persson (1986) developed a modelling relationship for farm machinery performance based upon machinery management standards published by ASAE. Their model examined the effect of variable machine width on time and fuel use when given

a machine type, tractor power and set of field conditions.

Required minimum capacities for each machine are calculated by the CPMS model based upon the operations required, the area covered by each operation, and the time constraints for the operation; all of which are inputs to the model. Based upon the minimum capacities, a set of tractors and implements is selected from commercially available sizes. After the minimum sized set of machinery is selected, all operations are scheduled according to the hours available.

The implement drawbar power requirement or draft is an important factor to determine if the tractor can pull the implement. ASAE STANDARDS (ASAE, 1990) presents draft and power requirements for most field machines for various soil types. Factors often included in the equations are implement speed, depth and width. Implements draft and power requirement were reported by various researchers (White, 1977 and 1978; FMO 1987; Hunt 1983; Self et al. 1983; Zwilling and Hummel 1988). Draft requirements of various machines under Michigan conditions were also reported by a group of scientists at Michigan State University (Rotz and Black, 1985). Summers et al. (1986), stated that draft requirements of tillage equipments are an important consideration in selecting tillage systems. Draft is the major component of forces between the tractor and implement, and in parallel to the soil surface and to the direction of travel. The ability to predict draft, power and fuel requirement for tillage operations is an important consideration in selecting tillage and planting systems.

2.3 Cost Analysis

After scheduling of all operations is completed by the CPMS model, the total

annual cost of owning and operating the complete set of the machines is determined. The cost analysis determines the costs of fuel, oil and labor for each implement used by each crop and the implement's and tractor's repair and maintenance, capital consumption, and taxes, insurance and shelter for each crop. The analysis consists of determining the costs for (a) each implement used per crop, (b) each implement used for all crops, (c) all implements used per tractor, (d) all implements and tractors used per crop, and (e) total implement and tractor costs for all crop operations. This model summarizes the implement and tractor costs for each crop. It calculates the cost of operation per hectare and cost of operation per hour. The machinery cost analysis model also summarizes the total labor cost, fuel cost, oil cost, repair and maintenance cost, capital consumption cost, and taxes, insurance and shelter cost from all the implement for each tractor. After the first set of machines and the associated costs are determined, a check is made to determine if a lower cost set of equipment can be determined. The effect of increasing the sizes of some of the tillage implements of the farm economy is also investigated.

The cost analysis by the CPMS program constitute of machinery cost. Machinery costs are the implement's and tractor's fixed and variable costs. The implements used in this machinery cost analysis consists of moldboard plow and chisel plow for primary tillage, disk harrow and field cultivator for secondary tillage, and row crop planter and grain drill for planting. The repair and maintenance, oil, fuel and operator's labor costs are proportional to the machine use. The capital consumption and taxes, insurance and shelter costs are the fixed costs, which remain relatively constant regardless of use, but are dependent on calendar-year time (Hunt, 1983). The oil, fuel and operator's labor costs are actual operating costs and are directly related to the field time used by the

implements. The repair and maintenance, capital consumption, and taxes, insurance and shelter costs are the costs being shared by other crops in a crop rotation. The shared cost for each implement is calculated based on the proportion of time used by each crop to the total field time used by all the crops.

The costs equations used in the CPMS model are obtained from the ASAE STANDARDS (ASAE, 1990). Simplified equations derived from the ASAE STANDARDS by Kepner et al. (1978) and Hunt (1983) are also used. These costs equations calculate the annual cost of production for the machinery used for a particular year of operation.

The ASAE STANDARDS (ASAE, 1990) suggest that in determining the fuel cost for a particular operation, the fuel requirement should be based on the actual power required. The oil cost is determined by the volume per hour of engine crankcase oil replaced at the manufacturer's recommended change interval. The cost of labor varies with geographical location. For owner operators, labor cost should be determined from alternative opportunities for use of time. For hired operators, a constant hourly rate is appropriate. Labor cost in the CPMS model is computed based on recommendations for local conditions which involve one operator for each tractor. The model allows the user to enter the local fuel price, oil price and labor wage rate to compute the above costs.

Depreciation and interest on investment are the most important items of fixed costs. Two methods commonly used are capital recovery with return method and the straight line depreciation and interest on average investment method. Bartholomew (1981) found out that the capital recovery with return method will be a more accurate measurement. Assuming no salvage value, he defined the annual cost for the capital

recovery with return as cost of asset times the annuity factor. Black (1991) described the case where the capital asset has a salvage value and that the value can be represented as a percent of the purchase price. The present value for the salvage was calculated based on the interest rate and expected life of the machine. The annuity factor was modified to include the present value for the salvage. Hunt (1983) used the machinery purchase price, salvage value and the annuity factor or capital recovery factor (CRF) to estimate the capital consumption of farm equipment. The capital consumption equation by Hunt (1983) is used in this CPMS model. An older machine with relatively low cumulative use may have a higher salvage value than a newer machine with high cumulative use. The salvage value of all the machinery used was assumed to be ten percent of the purchase price in the CPMS model.

Farm machinery is taxed at the same rate as other farm property. Wide variations exist from state-to-state in the amount of sales tax and in the method of determining the assessed valuations. The property tax rate can vary widely within a state. Tax benefits may favor some machines more than others. If one does not want to complicate machinery selection with tax considerations, the rate can be set to zero (Rotz and Black, 1985). It is not a universal practice to insure machinery against loss by fire or windstorm, but the insurance charge is justifiable. Machinery shelter has not been shown to increase machinery life, but it can increase a machine's resale value (Hunt, 1983). A charge must be made against machines for shelter. The ASAE STANDARDS (ASAE, 1990) states that the taxes, insurance and shelter costs can be estimated as percentages of the purchase price. Rotz and Black (1985) suggested that cost analysis of agricultural machinery required parameters to describe the remaining value of the machines at the end

of the period of analysis. The above costs in this CPMS model make use of the implement and tractor remaining value. The remaining values as a percentage of the list price at the end of year n for the implements and tractors are obtained from the ASAE STANDARDS (ASAE, 1990).

Repair and maintenance costs are highly variable and unpredictable as to time of occurrence. Accumulated repair and maintenance costs at a typical speed can be determined using the repair and maintenance factors, purchase price in current dollars and the accumulated hours of use of the machine. The repair and maintenance cost equation used in the CPMS model is obtained from the ASAE STANDARDS (ASAE, 1990).

For convenience of the model, variable cost items such as repair and maintenance, fuel, oil and labor are expressed in terms of today's dollars. Consistency demands that capital consumption cost and taxes, insurance and shelter cost be also expressed in terms of today's dollars. In times of substantial monetary inflation, a machinery manager must include the effects of inflation on machinery planning. Inflation causes increased prices for goods and services in future years (Hunt, 1983). ASAE STANDARDS (ASAE, 1990) stated that in times of rapid inflation, the machine purchase price must be multiplied by $(1 + i)^n$ where i is the average inflation rate and n is the age of the machine.

Various machinery costing techniques, assumptions, and computer programs have been developed for budgeting and economic analysis. Robb et al. (1990) developed a microcomputer spreadsheet program to help analyze the economic and budget aspects of field machinery costs. Mayfield et al. (1981) developed a method to estimate the total cost of owning and operating selected types of farm machinery using a depreciation schedule based on current value of machinery, fuel, equipment and interest rate. Edwards

et al. (1990) used net present value algorithm for computing operating and ownership costs for agricultural machinery. They used the time value of money by estimating all future costs and discounting them to their present value. Future costs were estimated in nominal values first, then discounted by a nominal discount rate that converts all values to current dollars.

2.4 Tillage System

Tillage practices vary widely in terms of equipment, tillage depth, and amount of soil pulverization. The two tillage systems defined here, conventional tillage system and conservation tillage system are based on the type of implements used. A conventional tillage system uses a moldboard plow and a conservation tillage system uses a chisel plow for their respective primary tillage operation. Other implements used with either system include disk harrow, field cultivator, row crop planter and grain drill.

The primary difference between conservation tillage and conventional tillage is the percent of soil surface covered by crop residue after planting. Conservation tillage is any tillage and planting system in which at least 30% of the soil surface is covered by plant residue after planting (Michel, et al. 1985 and Muhtar, 1982). Whereas, under conventional tillage, fields are plowed with a moldboard plow or otherwise worked sufficiently to cover nearly all of the previous crop residue. A conventional tillage system frequently uses fall plowing with the moldboard plow followed by a disk harrow and/or field cultivator operation in the spring.

The conservation tillage system or chisel plow-based tillage systems can also include vertical tine tillage and roller harrowing before planting. Magleby and Schertz

(1988) reported that the adoption of Conservation tillage has been increased from one percent of planted cropland area in 1963 to nearly one-third of United States planted cropland areas in 1986. Conservation tillage practices in crop production save soil, lower energy consumption, reduce machinery investment, and facilitate the return of some marginal land to row crop production (Magleby and Schertz,1988 and Hamlett et al. 1983). Because fewer passes are made over the field than with conventional tillage, both fuel and labor costs are reduced. The practice also reduces the time required to complete tillage and planting operations.

2.5 Crop Rotation

Corn, soybeans, field beans, wheat and oats were chosen for this CPMS model based on Michigan's farmers choices as indicated by previous researchers such as Singh (1978), Muhtar (1982) and Rotz et al. (1983). These crops use similar machines for the operations. The choice of planting equipment is based on the choice of crops. The number of crops using the same tractor and implement determines the implement field time available to complete the operation. The implement field time is used to calculate the implement size.

Singh (1978), found that crop rotations have a strong influence on field machinery requirements. A balanced crop rotation increases machinery utilization and decreases machinery requirements, machinery investment, and annual machinery related costs on a unit crop land area basis. Singh and Holtman (1979a), concluded that using a balanced crop rotation can almost double the area under cultivation without a significant increase in the size of machinery. If a single crop is grown on the farm, then the whole farm area

must be covered within a shorter time constraint which requires larger equipment. As more crops are added, the farm is divided into smaller blocks of land which are worked at different times. Smaller areas done within the same time constraint require smaller equipment. Rotz and Black (1985) stated that selecting machinery for farms which produce several crops is a complex problem. Interactions among machines and between the machinery subsystem created a problem because of the large number of variables and relationships.

Chen et al. (1985) stated that the advantages of double cropping increased the expected net returns because of the distribution of fixed costs associated with land and machinery over more crops and more efficient use of labor. The disadvantage that must be considered was more intensive management required where timeliness appeared to be the key ingredient for success.

2.6 Instrumentation

Microcomputers were increasingly utilized in the acquisition and processing of implement - tractor performance data. The construction, capacity and versatility of the instrumentation packages varies according to individual data collection. The system designed for this research used an Apple IIe[1] microcomputer for collecting data on-board the tractor and an IBM microcomputer for data processing. The Apple IIe data acquisition system was developed by earlier researchers (Tembo, 1986; Guo, 1987 and

[1] Trade names are used in this dissertation solely to provide specific information. Mention of a product name does not constitute an endorsement of the product by the author to the exclusion of other products not mentioned.

Mah, 1990) at Michigan State University. The Apple IIe was chosen for its compactness and durability in adverse physical conditions as observed by Carnagie et al. (1983) and reported by Tembo (1986).

Thomson and Shinners (1987) reported using a portable instrument system to measure draft and speed of tillage implements. Measurements were taken and stored using a data logger, then transferred via magnetic cassette tape to a microcomputer for further processing. Microcomputer - based data acquisition systems have emerged as relatively inexpensive alternatives to instrumentation - type tape recorders or strip chart systems. Lin et al. (1980), Carnegie et al. (1983), Clark and Adsit (1985), Bowers (1986), and Grogan et al. (1987), were examples of researchers who developed microcomputer - based data acquisition systems for measuring in - field tractor performance. Carnegie et al. (1983) reported the use of an Apple IIe personal microcomputer for data collection and analysis. They concluded that Apple IIe personal microcomputer was versatile, yet inexpensive, and performed well under adverse field conditions.

In summary, the CPMS model deals with geographical locations with known probability working days, different soil textures, different crops in a multi-crop farm, different farm sizes, and different types of tillage systems with various combinations of implements. Five different locations in Michigan were selected, and any number of locations can be added in the future. Six different types of implements were available for various combinations of implements to be used on a farm. Five different crops are available with a maximum of five crops in one crop rotation. A maximum of four tractors can be used on one farm operation.

The CPMS model matches the power requirement of the implement and the available power of the tractor, and makes use of field time constraints to complete the farm operation. The model was evaluated on different locations, soil textures, tillage systems, numbers of crops in a crop rotation, and farm sizes. Cost analysis was carried out on several well-matched systems. The draft and fuel requirements for the model were validated with the experimental values.

3.METHODOLOGY

3.1 System Description

Farming systems are characterized by the fact that people are attempting to control biological systems in an uncertain environment to achieve some goal which is predominantly economic in nature. Thus, it is essential to think of the farm as a system made up of subsystems or components. Such subsystems can be isolated and studied by researchers; however, solutions suggested must bear in mind the impact on other components. The systems concept involves a most careful search for interrelationships and interdependencies among interacting components. As these relationships are explored, the boundaries of a given system, its complexity, and the difficulties in its study may grow at an alarming rate. The system boundary arises from the need to define the system or sub-system. The setting of study limits and system boundaries must be closely related to the research objectives (Dent et al. 1979). The placing of a boundary is of considerable importance in modelling a system since it determines exactly which subsystems must be explicitly represented within the model structure. Across the boundary there is assumed to be no interaction. Many farm management decisions will influence the farm system as a whole. The system bounds in this example are the farm as a whole. The subsystems to be studied explicitly will be the tillage and planting operation of the farming system.

Several constraints and assumptions are made to better define the system boundary. Constraints considered in the study include: (a) type and number of crops to be planted; (b) the predominant soil type of the farm; (c) soil and weather condition; (d) tillage implements to be evaluated; (e) planters to be evaluated; (f) tillage systems to be evaluated; (g) the area of operation; (h) type of previous crop; (i) dates of operation; and (j) locations.

The Machinery Selection Model and Machinery Cost Model consist of developing a mathematical model of a system suitable for operation on a computer. This CPMS model design is to a large extent dependent on the data available or on the feasibility of generating data within the time limits. The inputs to these models include those that are controllable and non-controllable. One of the environmental inputs that affects the system but is not, in turn, significantly influenced by it is weather. The weather conditions coupled with soil type and conditions will estimate the suitable field work days.

The technical and economic selection of field equipment is a complex problem that has some unique characteristics compared with other industries. First, farms have diversified enterprises, and are subject to many special local conditions; thus each farm must be treated as a special problem. Second, since agricultural production is seasonal, equipment will necessarily stand idle much of the time. Also, most field implements are operated by a shared power unit, the tractor; and a change in one tractor-implement operation will affect the whole system. Consequently, the complete system of implements must be considered. Third, the supply and ability of farm labor, which usually includes management personnel, is quite varied. Finally, a characteristic that is widely recognized but difficult to analyze is the need for timely operations because of the seasonal

requirements of crops. Thus, the problem of selecting field machinery efficiently is therefore one of adjusting the factors of implement performance, power availability, labor, timeliness, and costs until an optimum economic return results.

3.2 System Limitation

Few field operations are completely independent of other production operations. Typically, production farming involves the operation of a system of machines. As a result the field efficiency of any single machine may be limited by the capacity of other operations in the system.

The timing of one individual operation with respect to another is the feature that defines a machine system. Timeliness of a field operation is a significant factor in field machinery selection. Timeliness is one of the major constraints and its costs arise because of the inability to complete a field operation within a specified duration of time. The timeliness value assumes a reduction in yield for working outside of the most favorable time period for an operation. Weather is one factor of the timeliness that contributes to the risk in operation. It affects the risk due to late planting and harvesting which in turn affects the yield and machine performance. Timeliness in completing a certain job, such as planting, within a certain time period after which equivalent losses become greater through either reduced yields or a less efficient harvest. If lost time is calculated on certain high-importance operations, like planting, with timeliness figured in, it becomes easy to see that delays or undersized machines can cost hundreds of dollars per hour instead of just a few dollars per hour in unused labor. In fact, a good 'rule of thumb' when considering buying a new machine with little cost difference is to purchase

the machine that affords more timely operation (FMO,1987).

The total time required for a field machine operation depends on the capacity of the machine and the number of available working days. Each region of the country has a unique climate, and different machine operations will have different criteria as to what constitutes a working day. Wet soil and wet crops are the usual deterrent to field machine operations. Nevertheless, timeliness of operation for a given farm size varies with the size of machinery which is largely determined by the power requirements during the peak work season. The timeliness of operations, for a given crop rotation and tillage system, also varies with the farm size.

An essential reason for designing and building a simulation model is that information may not be desirable from an experimentation on the real system : either the system as such may not be in existence or experimentation may be too costly, time consuming, or ineffective. Appropriately designed experiments with a simulation model can enhance understanding of the relationships and behaviors of the system and can reveal how management might control the system so as best to achieve certain goals.

Major economic decisions made by a farmer raising row crops include selection of machinery complement and choice of enterprise mix. Year-to-year variation in weather and its resultant impact on the number of good days available for soil preparation, planting, spraying, cultivation and harvest has been a major uncertainty in making good selections and choices. To control this problem, scientists have adopted a framework in which machinery complements are selected such that completion of the assigned tasks is accomplished within an allotted time period for a known percentage of the growing seasons.

Rosenberg et al. (1982), developed an algorithm to provide suitable days data for farm operations based upon weather information and soil structure for an area. These probabilities provide estimates of how many suitable days a farm manager can expect for performing field operations. The design probability is determined by the available work day data set. A work day set at the 80 percent level implies that the given weekly available field work time would occur during or be exceeded eight out of ten years. In general, size of machinery and tractor decrease as confidence level of available suitable work hours change from 80 to 50 percent.

3.3 Research Procedure

In this particular study, the following parameters were dealt with: a) Combinations of five crops in different rotations. These crops are corn, soybeans, field beans, wheat and oats. b) Three soil types, namely fine textured (clay loam), medium textured (loam), and coarse textured (sandy) soils. c) Five different locations in Michigan. These locations are Kalamazoo in Southwest , Adrian in Southeast, East Lansing in Central, Bad Axe in East and Seney in the Upper Peninsular. d) Two tillage systems, namely conventional tillage system or moldboard-based tillage system and conservation tillage system or chisel plow-based tillage system. The implements considered are the moldboard plow, chisel plow, disk harrow, field cultivator, row crop planter and grain drill.

Tractor sizes can be better determined when good draft and power requirement data exist for desired tillage tools in the specified soil types. Implement energy requirement varies greatly with soil types and conditions, previous treatment, ground

cover, speed and tillage depth. Field measurements for the draft and energy requirements of all operations will be determined experimentally. Bowers (1986), states that the draft and fuel data measured in field studies can be more reliably utilized in determining tillage energy requirements for crop production systems.

The first part of the research was to determine the field measurements for draft and fuel requirements for major crop production tillage and planting operations. The tests for measuring power and energy requirements were conducted on the farms at Michigan State University and in Clinton County, Michigan using various types of tillage and planting equipments. Experiments were conducted on different soil series at different depths and speeds using various conservation tillage and conventional tillage implements. The draft and fuel consumptions were determined for the moldboard plow, chisel plow, disk harrow, and field cultivator at various numbers of test runs also consecutive operations (e.g. chisel plow followed by disk harrow twice). The draft and fuel requirements were also be determined for row crop planters and grain drills. They were compared for individual implements and for the total tillage system for each crop. The field experimental data were compared to the prediction equations as provided by the Crop Production Machinery System Model.

3.4 Simulation Model

3.4.1 Development of the Model

This CPMS model is to determine the tractor and implement compatibility, operation timeliness, and cost of production. The first step in the development of the

model was to develop a conceptual model which best describes the crop production system. A conceptual model is the pictorial representation of the system using block diagrams indicating major components and linkages, as shown in Figure 3.1. The field crop production machinery system consists of seven components namely: manpower, land, tractor, machinery/implement, tillage, planting and harvesting. The harvesting component is not considered in the CPMS model. The arrows into the building blocks of the components are the inputs. The farmer provides labor and management to all the components. Among the inputs are tractor and machinery purchase price, fuel and oil price, soil type, crop type and land size. Among the outputs for the CPMS model are sizes and number of each implement and tractor for each operation, machinery costs, and salvage machine. Linkages are the discernable paths of flow among the system components. Figure 3.1 shows an example that the tractor component provides power and energy to tillage and planting implements. The initial selection of components and relationships should be related to the problem specification. The next step was the modelling phase of the simulation model. The modelling phase of simulation consisted of developing a mathematical model of a system suitable for operation on a computer. A pictorial representation of the system is useful. Initially, a series of simple symbolic representations in diagrammatic form was drawn. Finally, a detailed diagram was constructed which is readily translated to a computer program. Selection of the most suitable computer programming language was also a major decision. The model design is, to a large extent, dependent on the data available or on the feasibility of generating data within the time limits (Dent et al. 1979). The mathematical relationships used in these models were primarily obtained from the ASAE STANDARDS (1990) and Hunt

(1983).

The developed model was based on the concept of expert systems. Expert systems provide information and interact with the user to solve problems. The first thing the models do is to interact with the users and check which parameters need to be entered. The user enters the inputs for the farm where the model processes the input and initialize the farm constants. The model deals with the calculations based on user's input, stored data and stored equations. In using the model, the user may want to input computed data or omit any of the field operations, therefore the model should have the capacity to handle this option.

The ASAE published equations for fuel efficiency, tractive efficiencies, oil consumption, draft and power requirements that can be used in the model (ASAE,1990). Fuel efficiency was calculated based on type of fuel and percent load, where percent load is defined as the ratio of equivalent PTO power to maximum available PTO power from the tractor. The ASAE STANDARDS (ASAE,1990) also provides tables to determine repair and maintenance factors, field efficiency and field speed for tractors and implements. Thus, the operating costs including repair and maintenance, fuel, oil and labor costs and interest on operating capital were calculated for each field operation for each crop. Fixed cost per hour of use was calculated as suggested by Hunt (1983). Repair and maintenance costs were based on the accumulated use of the machine.

The CPMS model was divided into two models: The Machinery Selection Model and The Machinery Cost and Analysis Model. The Machinery Selection Model was developed to determine the compatibility of the tractors and machinery used to properly match the available power and to select "best" machinery complements. The Machinery

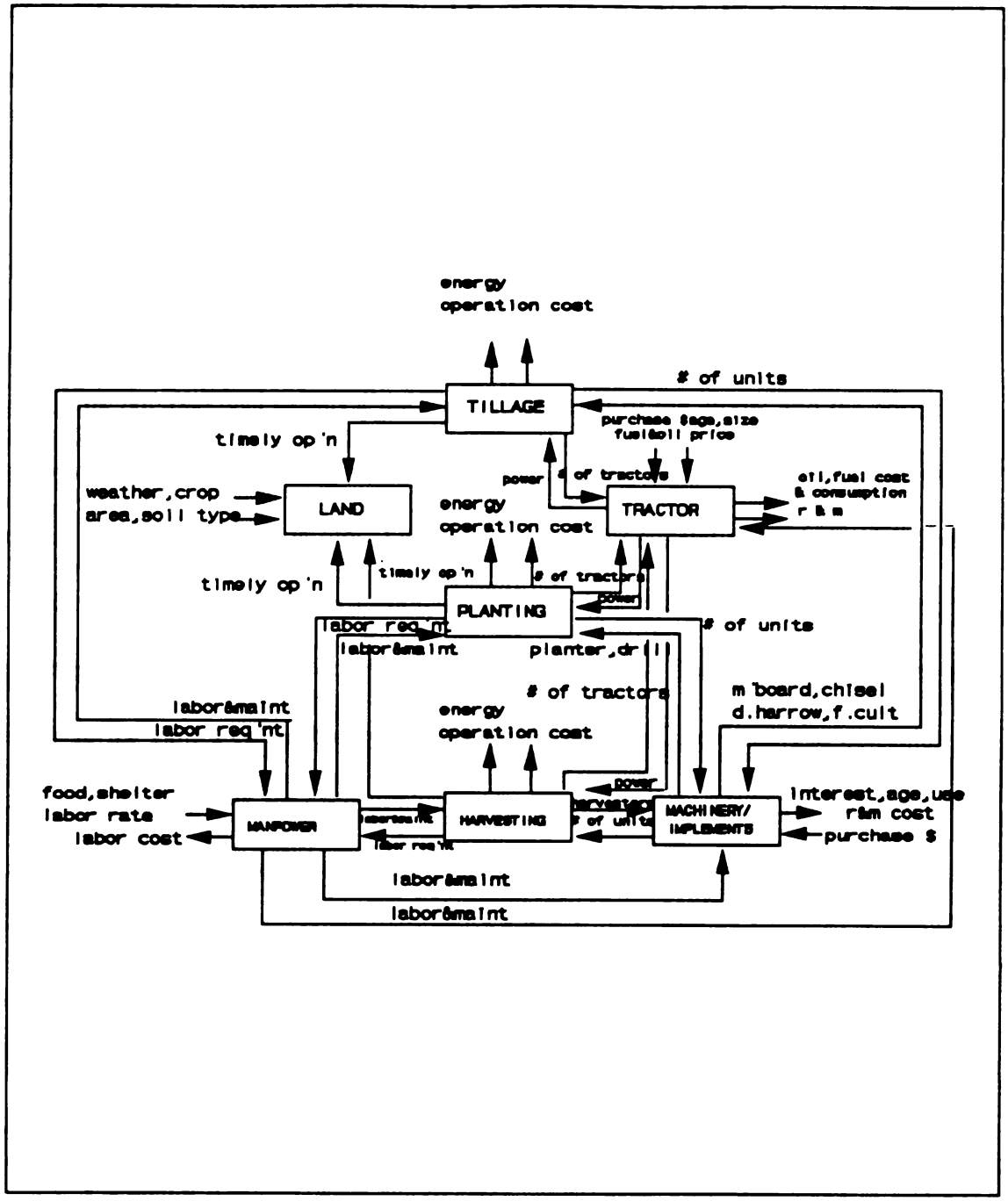

Figure 3.1 Conceptual Model of a Crop Production Machinery System.

Cost and Analysis Model was developed to calculate the production cost for evaluating the tillage system. The users have the option of using these models independently or interactively.

3.4.2 Verification

Verification was done to provide results which are mathematically and logically correct. Its purpose was to check the logical approach of the model and the correctness of the simulation outcome. To verify the results, a hand calculation was carried out for both the machinery selection model and the machinery cost and analysis model. Section 7.1.1 shows sample calculation to determine field time and power requirement for the implements and tractors, implement width and tractor size. These calculated values were used to verify values calculated by the computer model. Calculations to determine the fixed and variable costs for each implement and tractor as shown in Section 7.1.1 were also used to verify the computer model.

3.4.3 Validation

The CPMS model needs to simulate the real system sufficiently well to fulfill the purposes for which it was developed. The use to which this model will be put and the purposes for which it was designed is the framework within which we had to make the assessment of model validity (Dent et al. 1979). The machinery cost model was validated using the "Machinery Cost" program developed by the author's major professor (Burkhardt, 1990). The draft and fuel consumption were validated using the experimental values carried at Michigan State University and Clinton County in 1989 and 1990. The

validation of the model is described in detail in Section 5.4.

3.4.4 Sensitivity Analysis

Sensitivity analysis is a procedure carried out to explore the operation and performance of the model. A sensitive parameter is one which causes a major change in model output; the model is said to be sensitive to such a parameter. Sensitivity analysis is an on-going procedure even when the model is finally approved for application. A sensitivity analysis was carried out to study the reaction of the model to changes in (a) dates of operation, (b) mode of operation, (c) tillage systems, (d) type and number of implements, (e) type and number of crops, (f) sizes, age and purchase price of tractors and implements, (g) farm size and (h) soil texture. Sections 6.2 and 6.3 describe the sensitivity analysis of all of the parameters described above. This analysis was done by changing each parameter or a group of parameters at a time and noting the effect it has on the tractor and implement selection and its cost. Application of the model may indeed be considered as an extension of sensitivity analysis.

3.5 Instrumentation

An on-board computer data acquisition system developed by previous researchers at Michigan State University such as Tembo (1986), Guo (1987) and Mah (1990) was used. A commercially available Dickey john Tractor Performance Monitor II (DjTPMII) was also employed to measure the engine speed and ground speed. An engine rpm sensor was used for determining the engine speed. A single beam Doppler radar unit was used for determining true ground speed. A magnetic pickup sensor was used to measure the

front and rear wheel rotational speeds. This sensor was used in conjunction with the radar unit to determine percent drive wheel slip. The fuel consumption was measured using an EMCO pdp-1 fuel flow meter attached to the engine fuel line. The amount of fuel and time consumed was recorded directly to the data acquisition system. Fuel consumption in liters per hour was calculated during tillage, planting and idling. The draft of the tillage and planting equipment was determined using strain gages attached to the drawbar of the tractor. The draft was also recorded directly using the data acquisition system.

The signal conditioner, analog-to-digital converter, computer, battery power source, and their mounting inside the tractor cab were described in detail by Tembo (1986). The sensors which utilized signals from the DjTPMII were also described in detail by Tembo, 1986 and Mah, 1990. The procedures to calibrate those sensors were the same as described in Tembo's thesis.

The data acquisition system is powered by 12VDC-120VAC, 60 Hz, 500 watt sinusoidal voltage converter. Input power to the converter is supplied by a 12 VDC battery with free floating ground. The signal from each sensor is passed through a signal conditioner and through an analog-to-digital converter. The data were stored as ASCII code in the Random Access Memory (RAM) of a microcomputer which was later transferred to a floppy disk. A second computer was used to convert the data from ASCII code to numerical values for analysis.

In summary the system bounds for the CPMS model will be the farm as whole. The subsystems to be studied explicitly will be the tillage and planting operations of the farming system. The components of the system include the land, tillage, planting, power

unit and machinery. Linkages to the components include labor and maintenance, timely operation, number of implement and number of tractor. The inputs to the system include the farm, soil type, weather, crop type, type of implement, labor rate, shelter, purchase price of implements and tractors, age and expected life of implements and tractors, oil price, oil price and interest rate. Among the output considered are the operation cost and number of tractors and implements required. A conceptual model diagram was drawn followed by a mathematical model of the system. Finally, a computer model was developed. Verification and validation of the model were later carried out. Sensitivity analysis was also carried out to explore the operation and performance of the model.

The development of the model is outlined in Chapter 4. Chapter 5 describes the field experiments. The verifications of the sensors and the validations of the draft and fuel requirements are described in Chapter 5. The implementation of the model with various sensitivity analyses are described as in Chapter 6. The machinery selection and estimation of costs for four example farms are presented in Chapter 7.

4.SYSTEM MODEL

4.1 Crop Production Machinery System Simulation Model

A computer simulation is a valuable tool for solving the problems of agricultural production systems. With increasing power and availability of personal computers, it is becoming a more available tool. Developing a simulation model of an agricultural operation is very time consuming and requires much experience. With the use of a computer, relationships for machine capacity and power requirements can be properly balanced to provide a well matched machinery system.

The Crop Production Machinery System (CPMS) program is a software package for analyzing and evaluating machinery selection and cost. The machinery selection process is subjected to the area of operation, calendar date constraints and the tractor drawbar power. The program was designed for use with microcomputers to assure wide distribution and portability.

The program is written in Turbo Pascal, and is organized into blocks which are algorithms working on data structures. Organizing a pascal program into procedures is a powerful aid in writing programs. Procedures and functions resemble the subroutines and sub-programs of other programming languages. Calls to procedures are simply ways to access blocks of code in a more convenient and clear way in the program.

The CPMS model was developed based on the concept of expert systems which

are thought to be more effective and comprehensive in dealing with the problems. An expert system is a computer program that solves problems in the same way as a human problem-solving expert. Expert systems also allow users to become more knowledgeable about a problem as they interact with the program. A related objective for the expert system is education. Beside helping the user with decision making, the system can provide education through explanatory and feedback features.

The Crop Production and Machinery System consists of five executable files namely MACH2A, MACHCOST, INTRO, DATA and DATECROP. The CPMS main program, namely MACH2A, consists of Tractor and Machinery Selection Model and Tractor and Machinery Cost Analysis Model. The second model requires the output from the first model. The user has the option of using only the first model or executing both of the models using MACH2A. Figure 4.1 shows a simplified block diagram of the Crop Production Machinery System Model. It explains the input and output of both the Machinery Selection Model and the Tractor and Machinery Cost Analysis Model.

MACHCOST is a subsidiary program, independent of MACH2A main program. It is created to allow the user to do a cost analysis for a known farm operation. MACHCOST consists of only the Machinery Cost Analysis Model and is similar to the Machinery Cost Analysis Model of the MACH2A. It requires the implement data and field time data, which are outputs from the Machinery Selection Model. INTRO contains the introduction to the CPMS program. The DATA file will enable the user to create an external data file for implement parameters. The DATECROP file will enable the user to create an external data file for the dates of operation for a maximum of five crops. The user has the option of using the DATA and DATECROP external files in the main

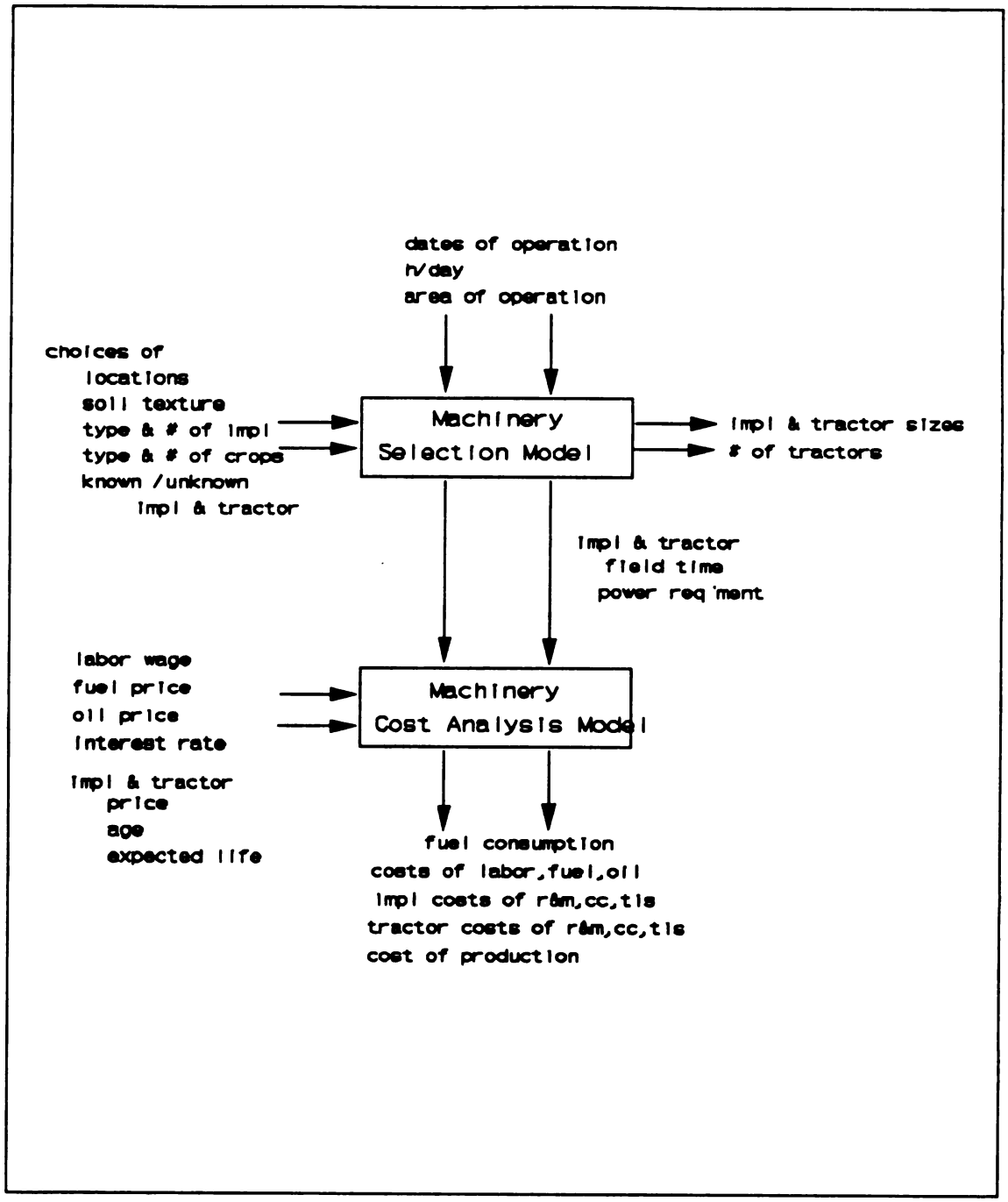

Figure 4.1 Models in a Crop Production Machinery System Model.

program or entering this information interactively during execution of the program. These external files are created to allow the user to rerun the program and to do a sensitivity analysis conveniently.

The CPMS program was created to enable users to easily carry out a sensitivity analysis. Even in using the external data files, the users can change the parameters or values in the main program. Changing the dates of operation, mode of operation, tillage systems, type and number of crops, or size and soil texture of the farm affects the tractor and implement selection. The sizes, ages and purchase prices of tractors and implements along with the fuel price, oil price, labor wage rate, interest rate, and the type and number of crops in a crop rotation affect the tractor and implement cost analysis.

4.2 Machinery Selection Input Data

A primary function of the main program is to initialize most of the user's inputs. The user's inputs consist of:

(1) Geographical locations

(2) Soil texture

(3) Type of tillage system

(4) Number and choices of crops in crop rotation

(5) Land area for each crop in the rotation

(6) Farm operation calendar dates

(7) Choices of known or computed first tractor size

(8) Choices of known or computed implement sizes

4.2.1 Location

The users have the choice of five different locations in Michigan. These locations are Kalamazoo in Southwest, Adrian in Southeast, East Lansing in Central, Bad Axe in East, and Seney in the Upper Peninsular of Michigan. The suitable days information for these locations was obtained from the weather data computer simulation work carried out by Rosenberg et al. (1982). Rosenberg used a probability of 0.8 indicating that during 8 years out of 10 the indicated portion of days will be available for field work. The predicted portion of days suitable for field work, the number of working days and the number of hours per day are used to determine the field time available for operations. The probability of working days (pwd) varies with the months of operations and the locations. This program is designed such that other locations can be added if the pwd are known.

4.2.2 Soil Texture

The choice of soil texture consists of fine, medium and coarse soils. Soil texture is used to determine the drawbar power required by the implements for a farm operation and combines with location to determine the suitable day probabilities. The equations for implement draft for different soil textures are obtained from the ASAE STANDARDS (ASAE,1990) and FMO,(1987). The draft of an implement is calculated based on soil texture, speed of operation, depth of operation and width of an implement. The program selects the draft equations based on the choice of soil texture and the implement to be used. The draft is used to determine the required drawbar power of the implement. The required drawbar power of an implement is compared with the available drawbar power

produced by the tractor to find their compatibility.

4.2.3 Tillage System

The user has the choice of two tillage systems, the conventional tillage system and the conservation tillage system. The primary difference between these tillage systems is the percent of soil surface covered by crop residue after tillage. The conventional tillage system uses a moldboard plow for primary tillage whereas the conservation tillage system uses a chisel plow. Other implements used in the model for both systems include a disk harrow, field cultivator and row crop planter or grain drill. In the program, users will have the choice of using all or any of the implements in the tillage system selected.

4.2.4 Crops and Crop Rotation

This model selects machinery complements for different tillage systems for a variety of crop rotations. The user has the choice of using corn, soybeans, field beans, wheat and oats in various crop rotation combinations. Increasing the number of crops in a crop rotation reduces the machinery cost by increasing machinery utilization. The number of crops also affects the field time of operation and implement field time. The type of crop determines the type of planting equipment to be used and also assists in determining the type of tillage system to be carried out.

4.2.5 Farm Size

The user has to specify the farm size by entering the land area for each crop in the rotation. The farm size affects the field time required by each implement to complete

its field operation within the time constraints. Subsequently, it is used to determine the number and size of tractors and implements to be used. The farm size is also used to determine the approximate minimum size of implements to complete the farm operation.

4.2.6 Calendar Dates of Farm Operation

The user has two choices on the mode of farm operation. The first option is an individual farm operation of primary tillage, secondary tillage and planting. This option allows for the individual farm operations to be in different seasons. The second option is a continuous farm operation covering from the primary tillage through the planting operation. A continuous farm operation is usually carried out in one season. The user is required to enter the beginning and ending dates of the farm operation, and the number of hours per day available. The number of days and the hours available per day for the farm operation are used along with the pwds to calculate the available field time for that operation. The dates of the farm operation are used along with the farm location to determine the pwds. The available field time of operation is used to compare with the field time required by the implements to determine if the operation is completed within the date constraints.

4.3 Tractor and Machinery Selection Model

The functions of the Tractor and Machinery Selection Model are: (a) To determine the tractor and implement optimum size. (b) To determine the compatibility of the tractor and machinery to properly match the required power with the available power, and (c) To complete the field operation during a specified time.

The main program executes based on the choice of implements selected earlier by SELECT. It displays the implement and tractor variables and parameters. If the implement size and parameters were not selected earlier, the program uses the recommended maximum implement size which was computed based on tractor size. The program allows the user to change the implement parameters. The users are advised to use the commercially available tractor sizes and implement sizes in the main program. The tractor and implement sizes recommended are to be used as a guide to select the commercial sizes. Using the recommended minimum implement size will utilize all of the available field operation time. Using the recommended maximum implement size will utilize all of the power available from the tractor. Thus, a compromise must be taken in selecting the commercial implement size to enable utilization of the field time and tractor power.

The first objective of the Tractor and Machinery Selection Model is to match power required by the implement to the available tractor power and to complete the farm operation within the time constraints. The factors affecting the implement's power requirement include implement size, speed and depth of operation, and soil texture. These values are used to calculate the draft and the drawbar power of the implements. The drawbar power requirement of the implement is compared with the available drawbar power from the tractor. The required drawbar power of the implement must be less than or equal to the drawbar power of the tractor for the tractor to be able to pull the implement. If the required drawbar power of the implement is higher than the available drawbar power of the tractor, the implement is too large or the operation is too deep or too fast. The drawbar power requirements must be met before the program will proceed

to the next implement. The user has the options of not using the implement or changing the implement size, operation depth, operation speed, or tractor size.

4.3.1 Machinery Selection Algorithm

Selection of a farm machinery set by the selection algorithm is based on a capacity and power match. The implements are sized to match the power available from the tractor and also sized to complete the job in the time allotted to each operation. Properly sized machinery should match the power available from the tractor as well as possible. Implements cannot be sized larger than the associated tractor can pull. Likewise, implements should not be undersized because this causes inefficient use of the tractor. If two implements are individually pulled by the same tractor, then their power requirements should be similar.

Capacity matching is complicated by the fact that many operations are interrelated by time. When two or more operations are done in sequence, time devoted to one operation takes time away from another. Time, therefore, must be properly divided between sequential operations. Similar operations may also be done parallel to one another when there are two or more crops in a crop rotation.

The first step of the tractor and machinery selection algorithm is to determine the minimum and maximum implement size for a particular operation. The minimum implement size is the smallest implement which is able to complete each field operation within the time interval specified. The maximum implement size is the largest implement which can be pulled by the associated tractor. In the process of determining the minimum implement size, the program also calculates the tractor size. The recommended minimum

and maximum implement sizes are to be used as a guide to select the appropriate commercial sizes of the implement in the main program. Figures 4.2 to 4.7 show the diagrams of the machinery selection algorithm. Figures 4.2 and 4.3 show the algorithm where the inputs are initialized. Figures 4.4 and 4.5 show the algorithm where the program calculate the minimum and maximum implement and tractor sizes.

The second part of the algorithm is the implement analysis program. In this part of the program, the users have to enter commercial implement and tractor sizes. Selecting the recommended tractor and implement sizes ensures compatibility between the tractor and implements, and that the operation is completed within specified date constraints. Figures 4.6 and 4.7 show the algorithm to compare the power and field time requirements of the implement with the available tractor power and the available field operation time.

Figure 6.1 in Chapter 6 shows an example of the implement algorithm to determine the tractor and machinery compatibility for properly matching the available power and for completing the farm operation during a specified duration of time. The drawbar power required by the moldboard plow is compared with the drawbar power of the tractor. Once the drawbar power requirement is met, the program then calculates the field time required by the moldboard plow to complete the farm operation. The field time required by the moldboard plow to complete the operation is compared with the available field operation time. Once the field time requirement is met, the program then proceeds to the next selected implement which is the disk harrow. After the drawbar power and field time requirements for all implements selected for the first tractor and for the first crop operation are met, the program proceeds to the second tractor for the first crop. A maximum of four tractors is allowed in the program. If another tractor is not required,

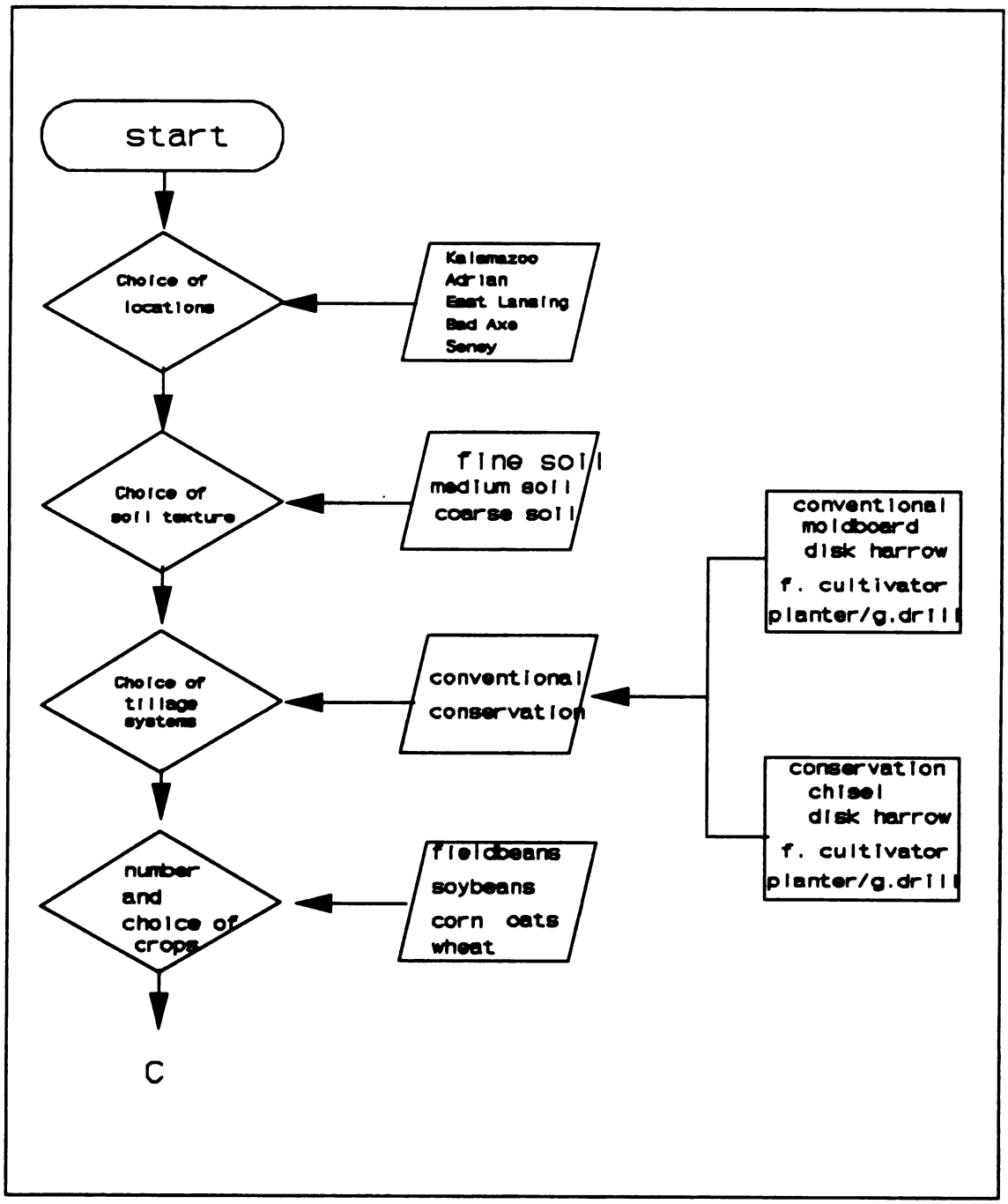

Figure 4.2 Machinery Selection Algorithm.

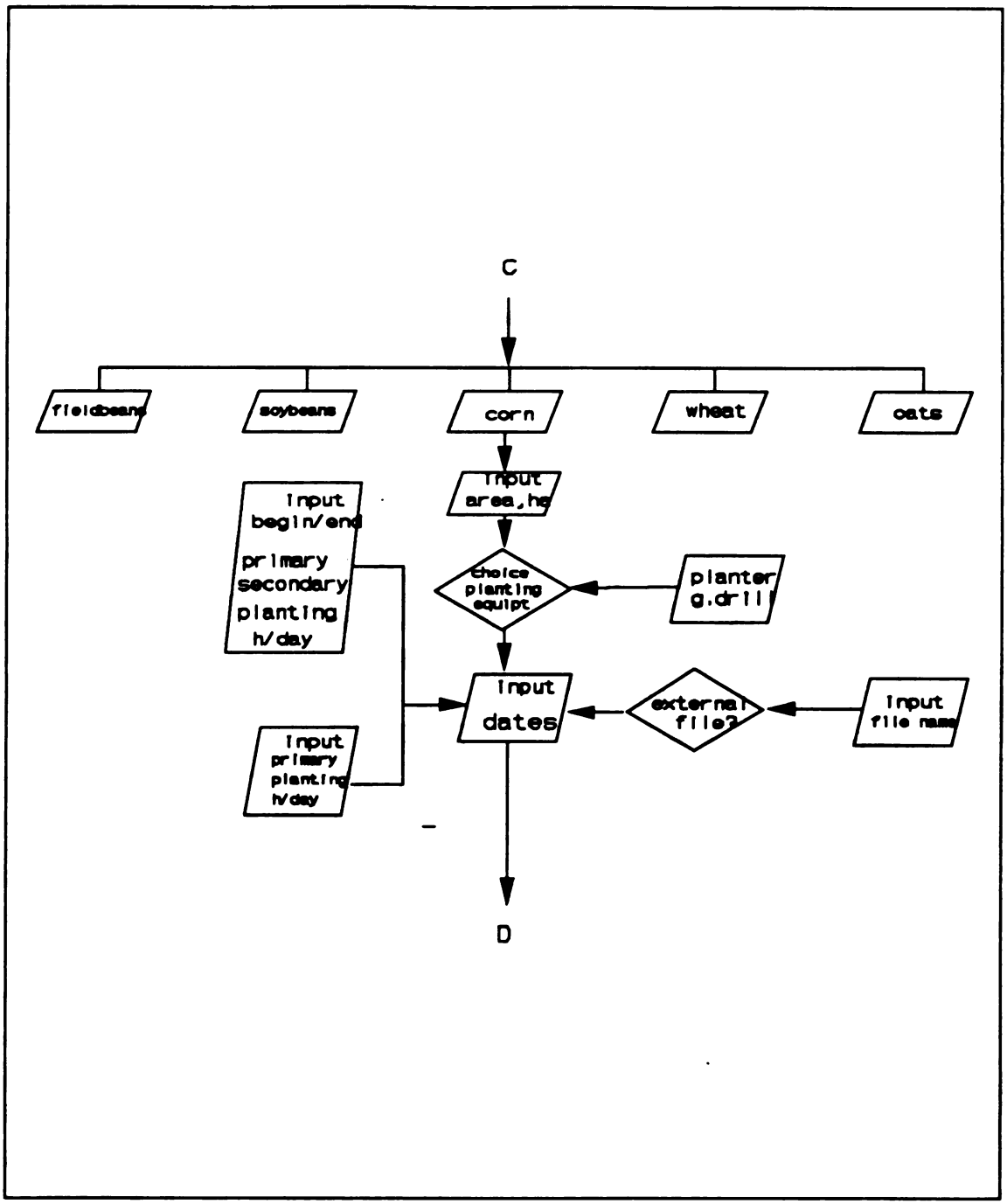

Figure 4.3 Machinery Selection Algorithm (cont).

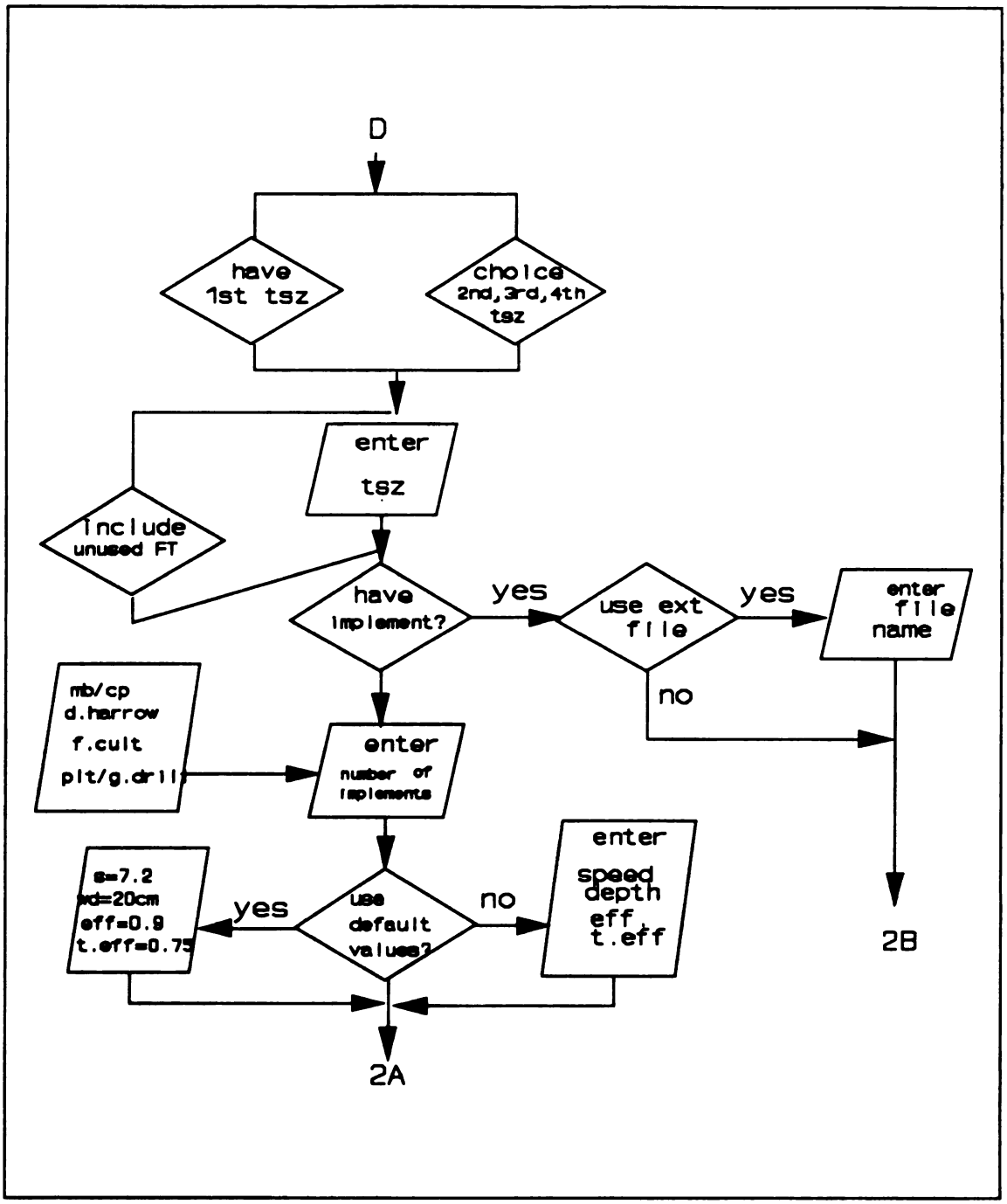

Figure 4.4 Machinery Selection Algorithm (cont).

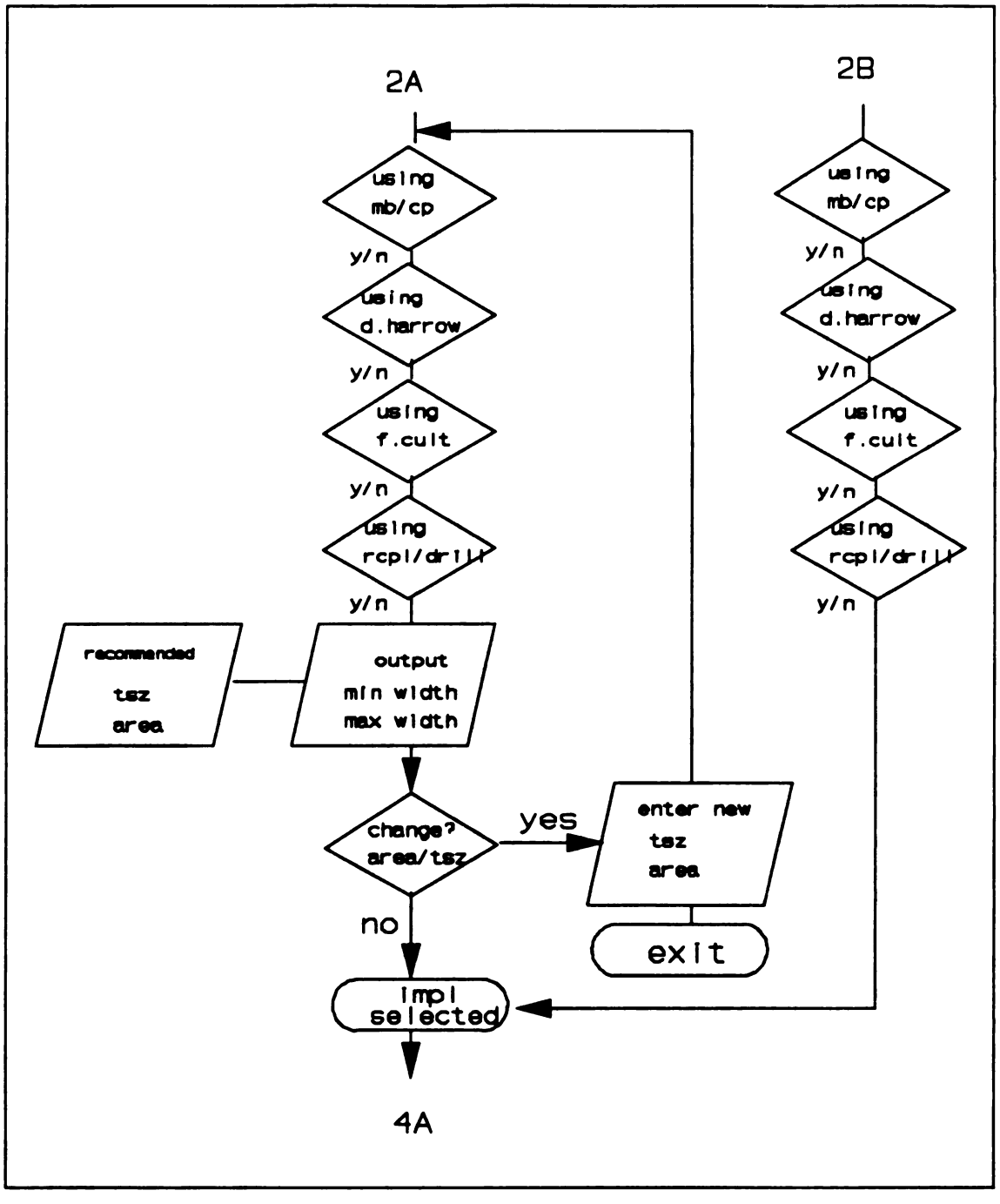

Figure 4.5 Machinery Selection Algorithm (cont).

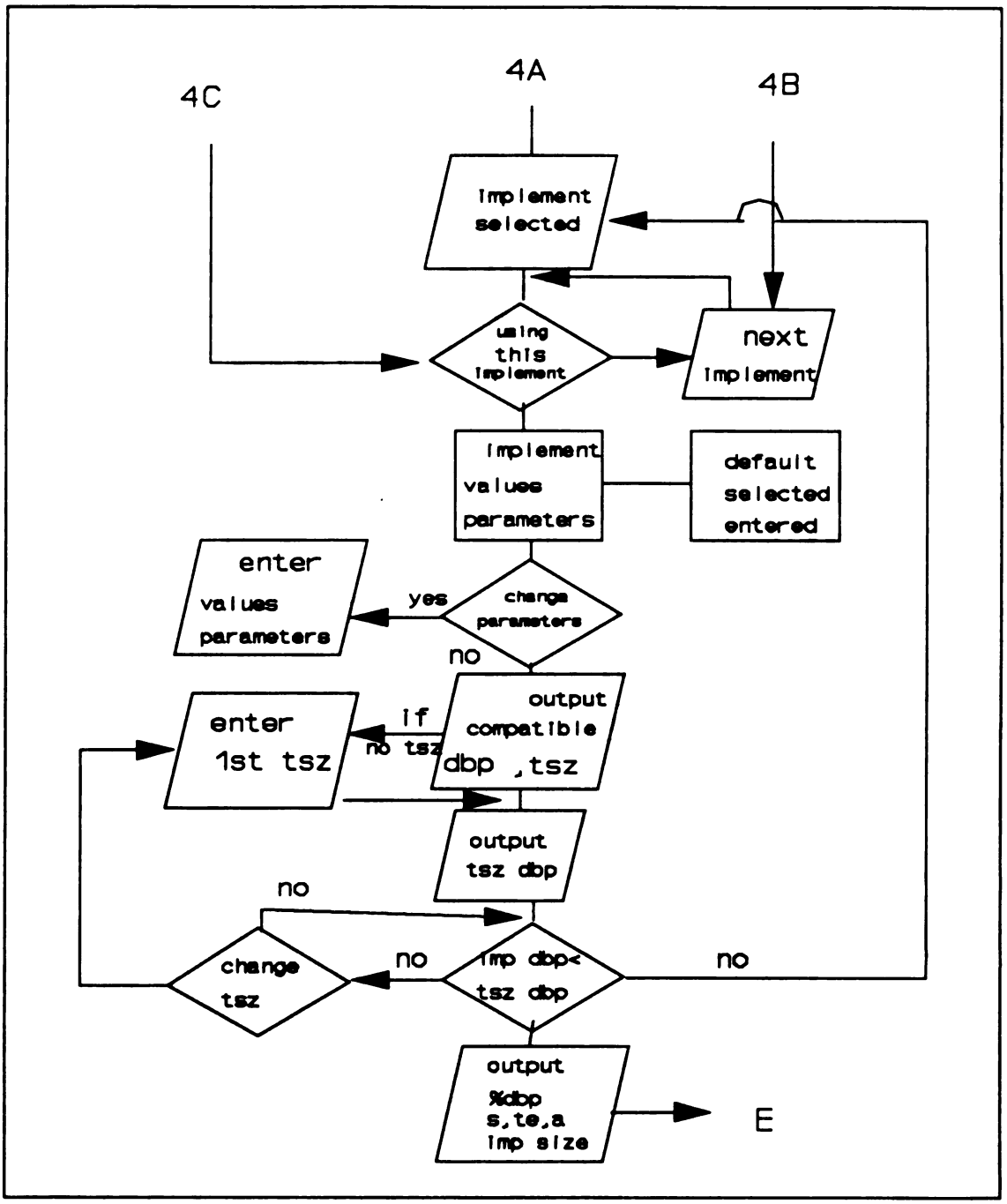

Figure 4.6: Machinery Selection Algorithm (cont).

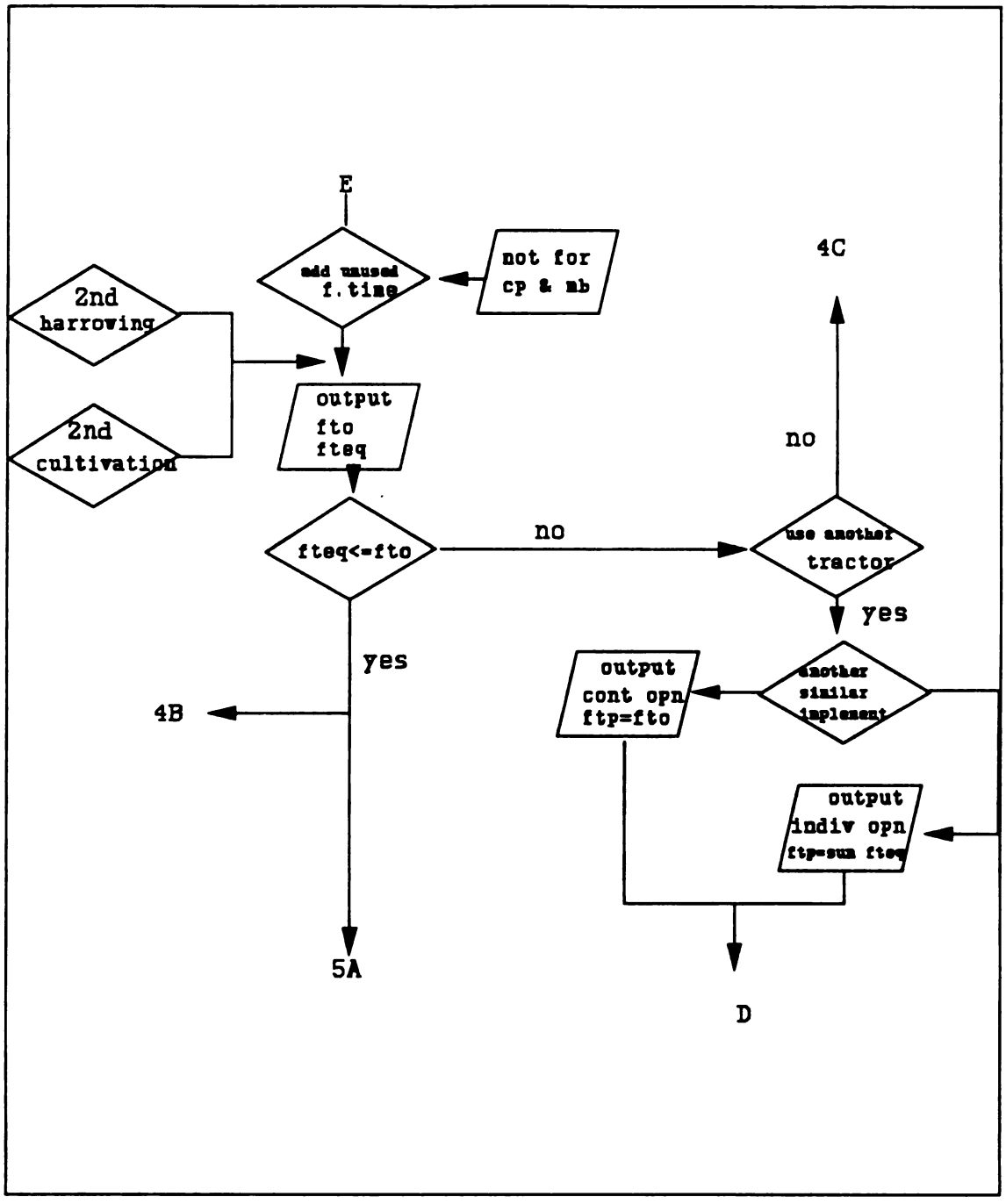

Figure 4.7 Machinery Selection Algorithm (cont).

the program proceeds to the next crop. The same procedures follow for the next crop operation.

4.3.2 Continuous Operation

For the continuous operation the program calculates the available field operation time based on the number of days from the beginning of the primary tillage operation to the end of the planting operation, on the number of hours worked each day, and on the pwds for each time period. The field time required by each implement and cumulative implements used by each tractor are compared with the available field operation time. The program checks to determine if the field time for the first implement is lower than its available field operation time before the program will proceed to the next implement. The program then continues to check for the cumulative field time of the first and the next implement. If the field time required by an implement is higher than the available field operation time, the program shows that the implement is too small to complete the farm operation within the time constraints. This situation indicates that the user needs to increase the size of one or all of the implements selected or distribute one or more of the operations to an additional tractor. The choices of using larger implements or an additional tractor can be evaluated by the cost analysis.

4.3.3 Individual Operation

Individual farm operation uses separate dates of operation. This program feature is useful for those operations which are carried out in two different seasons. For example, this allows the user to schedule primary tillage in the fall and secondary tillage

in the spring. For the individual farm operation, the user is advised not to overlap the dates of the operations, especially for implement operations using the same tractor. Overlap in the dates of operations is allowed for operations using different tractors because they can operate simultaneously. The program calculates the available field time for each operation. The field time required by the first implement operation is compared to the available field time for that operation. The user has the option to use the unused field time remaining from the first implement operation to be added to the available field operation time for the next implement operation. The unused field time from the earlier implement operation will then be used for the later operation with the same tractor during the same season. The user must be careful not to add the available field time of an earlier operation to the later operation if the two operations are carried out in different seasons. The user can use two implements such as a field cultivator and disk harrow for the secondary tillage operation for the same crop. In this case, the program asks if the available field time unused by the primary tillage operation is to be added to the available field operation time for the secondary tillage operation. The new available field time of the secondary tillage operation is used for both the disk harrow and the field cultivator. The total time required by the disk harrow and field cultivator is compared with the available field operation time.

This program compares the field time required by each implement with the field time available for that farm operation. If the implement field time is more than the available field operation time, the program will allow the user the options of not using the implement with that tractor operation, increasing the implement size or ground speed, or completing the farm operation using a similar implement with another tractor. The

option of not using the implement with that particular tractor allows the program to proceed to the next implement operation and allows the implement to be used with another tractor. The user has the second option of choosing a larger implement or increasing the speed of operation to decrease the required implement time. The user is advised to use the same implement size for all the crops in a rotation. Other parameters such as operation speed, operation depth, field efficiency and tractive efficiency can be changed.

4.3.4 Multiple Crop Rotations

Selecting machinery for farms which produce several crops is a complex problem. The field time matching is more complicated, and users must be careful in choosing the dates of operation. The program allows the overlap of operation dates of a similar operation for different crops but does not allow the same ending dates of a similar operation for different crops. The ending operation date of the later crop must come after the ending date of the earlier crop. The program uses the ending date of operation for the earlier crop as the beginning date of operation for the next crop if the beginning date of the later crop falls between the beginning and ending dates of operation for the earlier crop. The beginning and ending dates of operation are important in calculating the available field operation time. Thus, having the same ending dates of similar operations for more than one crop will cause zero field operation time for the later crop. The program automatically adds the unused field time from the operation of the earlier crop to the same operation of the later crop.

Two different approaches were taken to solve the problem of continuous and

individual farm operations for a multiple crop farm. For the continuous operation, the field time required by all implements is added for each tractor used. The total implements' field time is compared with the available field time of operation. The unused field operation time for each tractor operation from the first crop is carried forward to the next crop operation. In the next crop operation, the user has the option of using or not using the available unused field operation time from the previous crop. Users must not use the unused field time from a previous crop if the dates of operation for both crops do not overlap, especially if the planting operation of the later crop requires a specific beginning date to avoid planting a crop too early.

For the individual farm operation, the field time required for each implement will be compared with the time available for each operation. The unused implement field time from a crop operation is or is not added automatically to the similar operation of the later crop depending on whether or not the dates of operation overlap. In most cases, there are overlaps in the dates of operation between the farm operations for a single crop and among the crops in the rotation. The unused field operation time left by each operation is carried forward to the similar operation of the next crop. For the crops with overlap in the dates of operation the program automatically adds the unused field time left by the previous crop operation to the similar operation of the next crop. The program does not add those times where the operation dates of both crops do not overlap. This avoids the unused time left by a similar operation that was carried out in a different season.

4.4 Machinery Selection Procedures

This program can deal with a variety of tractor and machinery availability

situations. If the user has a set of implements, but no tractors, the program can determine tractor sizes which are properly matched with the implements' power requirements. If the user has tractors but no implements, the program can determine implement sizes which are properly matched with the tractors' available power. The program can determine if the system's capacity is sufficient to complete all field operations within the time constraints for either of these situations. If the user has neither implements nor tractors, the program can select a tractor and implement set which is sized to complete all field operations within the time constraints.

4.4.1 Procedures to Determine Drawbar Power

The procedures to determine drawbar power consist of procedures DBPP which calculates the implement drawbar power and equivalent power take off power, and procedure TRACTORDBP which calculates the tractor drawbar power. The variables required in these calculations are in the equations below:

$$DBP = \frac{D * S}{3.6} \tag{4.1}$$

$$EPTOP = \frac{DBP}{0.96 * TE} \tag{4.2}$$

$$DBPT = \frac{TSZ * 0.96 * TE}{1.25} \tag{4.3}$$

$$DT = \frac{3.6 * DBPT}{S} \tag{4.4}$$

Where:

DBP = Implement required drawbar power, K

D = Implement required draft, kN

S = Operation speed, km/h

TE = Tractive efficiency

EPTOP = Implement equivalent power take-off power, kW

DBPT = Tractor available drawbar power, kW

TSZ = Tractor size, kW

DT = Draft available from tractor, kN

The speed of operation (S) and tractive efficiency (TE) are inputs entered by users. The tractor size (TSZ) can be an input entered by users or a value computed in the program. The draft (D) is the variable calculated by other procedures (Section 4.4.3).

4.4.2 Procedures to Determine Fieldtime

After the drawbar power requirement is met, the program will then calculate the field time required by the implements to complete the farm operation. The factors affecting the field time required by the implements are the size of implement, speed of operation, field efficiency and farm size. Larger farm size requires more time to complete the operation for a given implement size. Larger implements require less time to complete the operation for a given farm size. The field time required by the implement is compared to the available field time of operation.

Procedure FTEQUIP calculates the implement effective field capacity and field

time. Procedure FTOP calculates the total field time available to complete the field operation for each implement. The variables required in these calculations are in the Equation 4.9 and in the equations below:

$$FT = \frac{A}{EFC}$$

$$FTO = HD * PWD$$

Where:

FT = Implement field time, h

FTO = Field operation time, h

HD = Number of hours available per day

PWD = probability of working day (pwd)

The width of the implement (W) is determined in the program and later entered by the user. The field efficiency, area and number of hours available per day for the operation are inputs entered by users. The probability of working days (pwd) are computed by the procedure in Section 4.4.4.

4.4.3 Procedures to Determine Implement Draft and Width

If the user starts with no tractors and no implements, steps (a) through (f) show the procedure to determine the approximate tractor size and maximum implement widths.

(a) The user has the option of using the default values for speed of operation, depth of operation, tractive efficiency and field efficiency. These default values will be used by all implements for each tractor. The user also has the option to replace any or all of the default values with different values.

(b) The user enters the number and type of implements to be used with the first tractor.

(c) Then the program calculates the field time allocated for each implement based on the available field time of operation between two date constraints and the number of implements to be used for each tractor operation within those date constraints.

$$FTIMP = \frac{FTO}{IMP} \tag{4.5}$$

where:

FTIMP = Field time required by the implement,h

FTO = Field operation time,h

IMP = Total number of implements used per tractor

(d) The effective field capacity is then calculated. The width of the implement is determined using the effective field capacity, the speed of operation and the field efficiency.

$$EFC = \frac{A}{FTIMP} \tag{4.6}$$

$$W1 = 10 * \frac{EFC}{S * E} \quad (4.7)$$

Where:

EFC = Effective field capacity,ha/h

A = Area of operation,ha

W1 = Implement width,m

S = Operation speed, km/h

E = Field efficiency

e) The width so obtained is used for the primary tillage implement to determine the required implement draft. This draft is then used to calculate the required tractor size required to pull the primary tillage implement. The primary tillage implement usually requires more draft than the other implements.

$$TSZ = \frac{1.25 * D * S}{0.96 * 3.6 * TE} \quad (4.8)$$

Where:

TSZ = tractor size, kW

D = Draft, kN

TE = Tractive efficiency

(f) The obtained tractor size is then used to determine the maximum width of

all other implements for this tractor. The size of these implements is selected so that they use up all of the power available from the tractor. The program displays the tractor size as drawbar power and the maximum size of implements as machine width.

The program also determines the minimum width for each implement to complete the farm operation on time. The procedure to determine the minimum implement width is discussed in steps (g) through (i).

(g) The maximum implement widths are then used to calculate the effective field capacity, for each implement. The inverse effective field capacity (EF), is the amount of time for each implement to complete one hectare.

$$EFC = \frac{S * W * E}{10} \tag{4.9}$$

$$EF = \frac{1}{EFC}$$

Where:

EF = Implement field time per hectare, h/ha

W = Implement width, m

(h) The program then calculates the amount of time allocated to each implement based on the available field operation time and the field time per hectare for each implement.

$$FTIMP = FTO * \frac{EF1}{EF1 + EF2 + EF3 + ...}$$

EF1,EF2 and EF3 represent the amount of time required by the respective implements to complete one hectare.

(i) The next step is to calculate the required effective field capacity for each implement. The minimum width for each implement is then determined based on the speed of operation, field efficiency and required effective field capacity.

Example: To determine the minimum chisel plow size.

(1) The allocated field time for a chisel plow from a set of implement operations of chisel plow, disk harrow and planter is calculated. Assuming the field time per hectare for the chisel plow, disk harrow and row crop planter are EF2, EF3, and EF5 respectively, the total implement field time (IT) will be:

$$IT = EF2 + EF3 + EF5$$

$$FTIMP = FTO * \frac{EF2}{IT}$$

(2) The effective field capacity and minimum implement width are determined using Equations 4.2 and 4.3.

$$EFC2 = \frac{A}{FTIMP}$$

$$WCP2 = 10 * \frac{EFC2}{S * E}$$

Where:

EFC2 = Chisel plow effective field capacity,ha/h

WCP2 = Chisel plow minimum width,m

If the user has tractors but no implements, the procedure will be the same as described in steps (a) and (b), and (f) through (i) as above. If the user has a set of implements but no tractors, the program will skip the above procedure as described from steps (c) through (i) and will go directly to the main program.

In the process of determining the minimum and maximum implement sizes the program recommends the minimum tractor size to pull the minimum implement size, and the minimum area of operation to fully utilize the implement's field capacity for the maximum implement size.

For a continuous operation, the minimum implement size recommended will be based on the number and type of implements to be used for each tractor. The available field time of operation is the total time available for all implements to be used. Using the combination of implements recommended, uses up all of the total available field time of operation. The recommended tractor size is compatible with all of the implements selected.

For an individual operation, the field time of the operation is the total time available for that particular implement operation. The minimum implement size recommended is based only on the implement to be used for that operation. Thus, the minimum size of an implement for a particular operation uses up all of the available field time for that operation. The tractor size recommended is based only on the primary tillage implement.

The farm size and the number and type of implements to be used for the farm operation affect the minimum size of the implements. The computed tractor size affects the maximum size of the implements. Reducing the number of implements used by each tractor results in more operation time available and the selection of smaller implements and more tractors. Decreasing farm size and tractor size will require smaller implements. This information allows the user to decide on the compromise in utilizing the available power from the tractor or utilizing the available operation field time. The recommended minimum and maximum implement sizes are used as a guide to select the appropriate commercial sizes of the implement in the main program.

The routine SELECT computes a preliminary implement size using the same speed, depth, field efficiency and tractive efficiency for each implement. In the main program the user can specify different values for any of these parameters for each implement. This program feature allows the user to develop a more refined estimate of the required machinery set.

The main program displays the input parameters and the computed variables. This part of the program uses a second procedure to determine minimum implement size which uses the same equations as in routine SELECT. The minimum implement size is

calculated based on the values of speed, depth, efficiency and tractive efficiency entered by the user and the available field time of operation left from the earlier implement operation. Using this newly recommended minimum implement size, will leave no additional time available for the next implement.

The program also recommends the implement size if there is an overlap in the dates of operation for multiple crops in a rotation. In this case, the user has to enter the beginning date of the operation for the first crop and the ending date of the same operation for the last crop in a crop rotation. Each individual operation may have different numbers of crops that have an overlap in the dates of operation. The implement size is calculated based on the total available field operation time for all crops which have an overlap in the dates of operation.

For the first tractor and crop operation, the user has to enter the implements' parameters either through the keyboard or from an external implement data file. The program will use the implement parameters to calculate the implement power requirements which are used to calculate the tractor size. The users are encouraged to select the tractor size large enough to be able to pull other implements as well.

Procedure SOIL1 calculates the chisel plow and field cultivator drafts and widths. Procedure SOIL2, Procedure SOIL3, Procedure SOIL4 and Procedure SOIL5 calculate the drafts and widths for the moldboard plow, disk harrow, row crop planter and grain drill, respectively. Draft equations for the row crop planter are available for seeding only or for a planter equipped with seed, fertilizer and herbicides attachments. Draft equations for the grain drills are available for regular and deep furrow. The variables required in these calculations are in the equations below. The draft equations for the chisel plow,

moldboard plow, field cultivator, row crop planter and grain drill were obtained from the Agricultural Machinery Management Data, 1989. (ASAE, 1990) The draft equations for the disk harrow were obtained from Machinery Management (FMO, 1987).

Procedure Soil1: chisel plow, and field cultivator.

Coarse Soil

$$D=(520+49.2*S)*\frac{WNC}{1000}*\frac{WD}{0.0826}$$

$$WNC=D*\frac{1000*0.0826}{(520+49.2*S)*WD} \qquad (4.10)$$

Medium Soil

$$D=(480+48.1*S)*\frac{WNC}{1000}*\frac{WD}{0.0826}$$

$$WNC=D*\frac{1000*0.0826}{(480+48.1*S)*WD}$$

Fine Soil

$$D=(527+36.1*S)*\frac{WNC}{1000}*\frac{WD}{0.0826} \qquad (4.11)$$

$$WNC=D*\frac{1000*0.0826}{(527+36.1*S)*WD}$$

Where:

WNC = Number of tines

WD = Operation depth, m

D = Draft, kN

The widths of the chisel plow and field cultivator are calculated based on the number of tines (WNC) and the distance between tines. The width of the implement is used to calculate the field time as in Section 4.4.5.2.

Procedure SOIL2: Moldboard plow

Coarse Soil

$$D=(2.8+0.013*S^2)*WD*W*10 \tag{4.12}$$

$$W=\frac{D}{(2.8+0.013*S^2)*WD*10}$$

Medium Soil

$$D=(3.0+0.02*S^2)*WD*W*10$$

$$W=\frac{D}{(3.0+0.02*S^2)*WD*10} \tag{4.13}$$

Fine Soil

$$D=(7+0.049*S^2)*WD*W*10$$

$$W=\frac{D}{(7+0.049*S^2)*WD*10}$$

Where:

W = Implement width,m

Procedure SOIL3: Disk Harrow

Coarse Soil

$$D=1.46*W*\frac{S}{9.7}$$

$$W=\frac{D*9.7}{1.46*S} \qquad (4.14)$$

Medium Soil

$$D=2.92*W*\frac{S}{8}$$

$$W=\frac{D*8}{2.92*S}$$

Fine Soil

$$D=4.37*W*\frac{S}{6.4}$$

$$W=\frac{D*6.4}{4.37*S}$$

Procedures SOIL4: Row crop planter (seeding only)

Coarse Soil

$$D=450*\frac{WN}{1000}$$

$$WN=\frac{D*1000}{450} \qquad (4.15)$$

Medium Soil

$$D=625*\frac{WN}{1000}$$

$$WN=\frac{D*1000}{625}$$

Fine Soil

$$D=800*\frac{WN}{1000}$$

$$WN=\frac{D*1000}{800}$$

Row crop planter (seeding, fertilizer, herbicides)

Coarse Soil

$$D = 1100 * \frac{WN}{1000}$$

$$WN = \frac{D * 1000}{1100}$$

Medium Soil

$$D = 1550 * \frac{WN}{1000}$$

$$WN = \frac{D * 1000}{1550}$$

Fine Soil

$$D = 2000 * \frac{WN}{1000} \qquad (4.16)$$

$$WN = \frac{D * 1000}{2000}$$

Where: WN = Number of rows

The width of the row crop planter is calculated based on the number of rows and the distance between rows. The width is used to calculate the field time as in Section 4.4.5.2.

Procedure SOIL5: Grain drill (regular)

Coarse Soil

$$D = 130 * \frac{WGD}{1000}$$

$$WGD = \frac{D * 1000}{130} \qquad (4.17)$$

Medium Soil

$$D = 290 * \frac{WGD}{1000}$$

$$WGD = \frac{D * 1000}{290}$$

Fine Soil

$$D = 450 * \frac{WGD}{1000}$$

$$WGD = \frac{D * 1000}{450}$$

Grain drill (deep furrow)

Coarse Soil

$$D=335*\frac{WGD}{1000}$$

$$WGD=\frac{D*1000}{335}$$

Medium Soil

$$D=502.5*\frac{WGD}{1000}$$

$$WGD=\frac{D*1000}{502.5}$$

Fine Soil

$$D=670*\frac{WGD}{1000} \qquad (4.18)$$

$$WGD=\frac{D*1000}{670}$$

Where:

WGD = Number of openers

The width of the grain drill is calculated based on the number of openers and the distance between openers. The width of the grain drill is used to calculate the field time as in Section 4.4.5.2.

4.4.4 Procedures to Determine the Probability of Working Days

Procedure DATES is where users enter the operation dates and the number of hours available per day and this procedure calls the Procedure DATELIST to calculate the total probability of working days. The Procedure DATELIST contains a list of monthly working day probabilities for five locations in Michigan. This data base was obtained from the work carried out on a computer simulation based upon 24 to 30 years of historical weather data by Rosenberg et al. (1982). Procedure DATES determines the probability of working days(pwd) which are used later to calculate the field operation time.

mm1 = nlist (mnum)

D1 = mm1 - DD1

PWD1 = mlist (mnum)

PWD2 = mlist (num)

PWD3 = mlist (mnum + 1)

PWD4 = mlist (mnum + 2)

PWD5 = mlist (mnum + 3)

The mlist(mnum) is the pwd value for the particular month of mnum. The nlist (mnum) is the number of days in a particular month, and DD1 and DD2 are the dates that are entered by the user. The DD1 is the day for the beginning month of an operation and DD2 is the day for the ending month of an operation. The mnum and num are the months to begin and to end an operation, respectively. The PWD1, PWD2, PWD3, PWD4 and PWD5 are the probability of working days (pwd) for the particular months selected. The pwd are calculated based on the beginning and end dates of operation and the calculations are shown below.

If the calendar month to end the operation is equal to the calendar month to begin operation:

$$PWD = PWD1 * (DD2 - DD1)$$

If the calendar month to end the operation is one calendar month after beginning operation:

$$PWD = PWD1 * D1 + PWD2 * DD2$$

If the calendar month to end the operation is two calendar months after the begin of the operation:

$$PWD = PWD1 * D1 + PWD2 * nlist(mnum + 1) + PWD3 * DD2$$

If the calendar month to end the operation is three calendar months after the begin of the operation:

$$PWD = PWD1 * D1 + PWD2 * nlist(mnum + 1) + PWD3 * nlist(mnum + 2) + PWD4 * DD2$$

The PWD above is defined as the number of days suitable for field work within the date constraints. The PWD times the number of hours worked each day will determine the available field operation time. Procedure DATES also compares the dates of operation for the earlier crop with the dates of operation for the later crop. If overlaps occur, the program will use the ending date of the earlier crop operation as the beginning date of the later crop operation. Thus, the available field operation time of the later crop will be calculated based on the ending dates of the earlier crop and ending dates of the later crop.

4.4.5 Procedure to Determine Implement and Tractor Size

Section 4.3.1 described the algorithm to determine the implement and tractor size. This algorithm includes Procedure DATES, Procedure TILLAGE, Procedure IMPNUM and Procedure IMPCALC. Procedure DATES was described earlier.

These procedures determine the approximate sizes of the implements to be used for the farm operation. The user has to enter the number and the choice of implements to be used with each tractor for the farm operation. The approximate minimum implement sizes are calculated based on the ratio of the field time for each implement and the area of farm operation. The program also recommends the tractor size after

estimating the primary tillage implement size.

The maximum widths of the implements are calculated based on the selected tractor size. The implement sizes calculated here may not be commercially available. These implement sizes are used as a guide to select the appropriate commercial sizes for the implements in the main program.

4.4.5.1 Procedure TILLAGE

Procedure TILLAGE is where users will have the choice of using their own implements or allowing the program to compute for the approximate implement size. To determine the implement size using Equation 4.7, users have to identify the number and type of implements to be used with each tractor. This procedure also approximates the tractor size for the primary tillage implement, which is used later in Procedure IMPNUM. The approximate tractor size is estimated based on the draft equations of the primary tillage implements. As an example, Equation 4.12 would be used to determine draft for moldboard plows on a coarse soil. The tractor size is calculated using Equation 4.8.

The field operation time, FTO is calculated using Procedure FTOP as described earlier. IMP is the number of implements to be used. FTIMP is the approximate field time required for each implement. The actual field time required by each implement is calculated using Procedure IMPNUM and Procedure IMPCALC. Thus, the calculated implement width, W1, and tractor size, tsz, are only used as preliminary values to compute for the actual width and tractor size.

Procedure TILLAGE calls the procedure on implements and executes the implement selection and cost analysis only for the selected implements.

4.4.5.2 Procedure IMPNUM

A user enters the choice of implements to be used. For a selected implement, the program calculates the implement width based on the tractor draft using the "W" equations in Section 4.4.3. The tractor draft is determined from the tractor size selected in Procedure TILLAGE using Equation 4.4. The implement field time, hours per hectare, is determined using the calculated width and the entered values of speed and field efficiency as in Equation 4.9.

Example for coarse texture soil:

Moldboard plow

As in Equation 4.12, the width and field time for the moldboard plow are:

$$WB = \frac{D}{(2.8 + 0.013 * S^2) * WD * 10}$$

$$EF1 = \frac{10}{S * WB * E}$$

Chisel Plow

As in Equation 4.10, the width and field time for the chisel plow are:

$$WNC = \frac{D * 1000 * 0.0826}{(520 + 49.2 * S) * WD}$$

$$WW2 = WNC * \frac{L}{100}$$

$$EF2 = \frac{10}{S * WW2 * E}$$

Field cultivator

As in Equation 4.10, the width and field time for the field cultivator are:

$$WNC=\frac{D*1000*0.0826}{(520+49.2*S)*WD}$$

$$WW1=WNC*\frac{L}{100}$$

$$EF4=\frac{10}{S*WW1*E}$$

Disk Harrow

As in Equation 4.14, the width and field time for the disk harrow are:

$$WH1=\frac{D*9.7}{1.46*S}$$

$$EF3=\frac{10}{S*WH1*E}$$

Row Crop planter

As in Equation 4.15, the width and field time for the row crop planter are:

$$WN=\frac{D*1000}{450}$$

$$WW5=WN*\frac{L}{100}$$

$$EF5=\frac{10}{S*WW5*E}$$

Grain Drill

As in Equation 4.17, the width and field time for the grain drill are:

$$WGD=\frac{D*1000}{130}$$

$$WW6=WGD*\frac{L}{100}$$

$$EF6=\frac{10}{S*WW6*E}$$

The WB, WW2, WW1, WH1, WW5 and WW6 are the widths for the moldboard plow, chisel plow, field cultivator, disk harrow, row crop planter and grain drill, respectively. These are the maximum implement widths which can be pulled by the selected tractor and which are calculated based on the estimation of the draft, D, as calculated in Procedure TILLAGE. The same draft is used to determine the maximum implement width for all implements required for the operation. These implement widths are used to calculate the implement field time, EF. L is the spacing between tines for the chisel plow and field cultivator or between rows for the planter and grain drill, and WD refers to the operation depth. EF1, EF2, EF3, EF4, EF5 and EF6 are the field times in hours per hectare for the implements mentioned above. These implement field times are calculated based on the maximum implement width.

4.4.5.3 Procedure IMPCALC

Procedure IMPCALC is used to determine the minimum implement width required

to complete the operations within the date constraints, recommended tractor size, and recommended area of operation. The equations below show the steps to determine these values.

(a) Total implement field time, hours per hectare:

$$IT = EF1 + EF2 + EF3 + EF4 + EF5 + EF6$$

The total field time, IT depends on the type and number of implements to be used.

(b) Minimum moldboard plow width:

$$FTIMP = FTO * \frac{EF1}{IT}$$

$$EFC1 = \frac{A}{FTIMP}$$

$$WV2 = 10 * \frac{EFC1}{S * E}$$

(c) Minimum chisel plow width:

$$FTIMP = FTO * \frac{EF2}{IT}$$

$$EFC2 = \frac{A}{FTIMP}$$

$$WCP2 = 10 * \frac{EFC2}{S * E}$$

(d) Minimum disk harrow width:

$$FTIMP = FTO * \frac{EF3}{IT}$$

$$EFC3 = \frac{A}{FTIMP}$$

$$WDH3 = 10 * \frac{EFC3}{S * E}$$

(e) Minimum field cultivator width:

$$FTIMP = FTO * \frac{EF4}{IT}$$

$$EFC4 = \frac{A}{FTIMP}$$

$$WFC4 = 10 * \frac{EFC4}{S * E}$$

(f) Minimum row crop planter width:

$$FTIMP = FTO * \frac{EF5}{IT}$$

$$EFC5 = \frac{A}{FTIMP}$$

$$WPL5 = 10 * \frac{EFC5}{S * E}$$

(G) Minimum grain drill width:

$$FTIMP = FTO * \frac{EF6}{IT}$$

$$EFC6 = \frac{A}{FTIMP}$$

$$WGD6 = 10 * \frac{EFC6}{S * E}$$

EF1, EF2, EF3, EF4, EF5 and EF6 are the field times in hours per hectare as was discussed in Section 4.4.5.2. FTIMP is the implement field time required by each implement to complete the farm operation for a given duration of field time. The EFC1 through EFC6 are the effective field capacity for the respective implements calculated based on the area and implement field time. The WV2, WCP2, WDH3, WFC4, WPL5, and WGD6 are the minimum implements width of the moldboard plow, chisel plow, disk harrow, field cultivator, row crop planter and grain drill, respectively, required to complete the operations within the date constraints.

The total implement field time, IT, is the sum of all the implement operations required to complete the operations within the date constraints. These date constraints are based on the type of operations, either continuous or individual operation. For the continuous operation, the total field time, hours per hectare, is the sum of all field times for only the implements selected. For the individual operation, the total field time is the sum of all field times for the implements used for either primary tillage, secondary tillage, or planting. Thus, the widths of the implements used for an individual operation are the

minimum implement widths required to complete that particular farm operation. Equation 4.8 is used to determine the recommended tractor size.

The recommended tractor size is calculated based on the draft of the primary tillage implement, either a moldboard plow or a chisel plow. For the continuous operation, the recommended tractor size is compatible with all of the implements selected. For the individual operation, the recommended tractor size is compatible with primary tillage implements only which would utilize the tractor and machinery set during all of the time available between the date constraints. In this case the user has to select secondary tillage implements and planting equipment which are compatible with the tractor size.

The equations below are used to determine the recommended area of operation.

For a moldboard plow:

$$FTX1 = EF1 * \frac{FTO}{IT}$$

$$EFCX1 = \frac{S * WB * E}{10}$$

$$AX1 = FTX1 * EFCX1$$

For a chisel plow:

$$FTX2 = EF2 * \frac{FTO}{IT}$$

$$EFCX2 = \frac{S * E * WW}{10}$$

$$AX2 = FTX2 * EFCX2$$

The recommended areas of operation, AX1 and AX2, are calculated based on the field time and the effective field capacity of the primary tillage implements, moldboard plow or chisel plow. FTX1 is the field time required by a moldboard plow to complete the farm operation. EFCX1 is the effective field capacity for the implement calculated based on the speed of operation, field efficiency and width of the implement. The program can compute the recommended area of operation based on the primary tillage operation.

The Procedure IMPNUM as described in Section 4.4.5.2 was designed to enable the users to change the area of operation and tractor size before proceeding to the main program. This is especially important when the calculated maximum implement size which a tractor can pull is smaller than the required implement size. Changing both the area of operation and tractor size changes the recommended minimum and maximum implements sizes. The user has to reboot the program at this point in order to change both the area size and tractor size.

4.4.6 Procedures on Crops

The procedures on crops consists of Procedure CORN, Procedure SOYBEAN, Procedure WHEAT, Procedure OATS and Procedure FIELDBEANS. The names for these crops can be easily changed to other crops using Procedure KROP as desired by the programmer. The user has the choice of the number and type of crops in a rotation. Procedure CROP is where the user enters the number and type of crops required in a crop rotation. This procedure determines which procedures on crops are to be executed. For each crop selected, the user enters the land area used for that crop. Each procedure on crop calls Procedure DATES to enter the beginning and ending dates for each farm operation for that crop. The farm size, implement size and operation dates are used to calculate available operation field time, and field time required by the implements to complete the farm operation. The number of crops and dates of operation determine the available operation field time.

Each procedure on crop calls Procedure TRACTOR, Procedure TILLAGE, and procedures on implements. For each crop selected, the program executes the machinery selection and machinery cost analysis.

4.4.7 Procedure on Implements

The main program allows the users to choose either the conventional or conservational tillage system. For each tillage system, the program asks for the number and choice of implements to be used in the program. The conventional tillage system uses a moldboard plow whereas the conservational tillage system uses a chisel plow for the primary tillage. The other implements used by both systems include a disk harrow,

field cultivator, row crop planter and grain drill. The procedures on implements consist of Procedure MOLDBOARD, Procedure CHISEL, Procedure HARROW, Procedure CULTIVATOR, Procedure PLANTER and Procedure DRILL. The user has the options of using any or all of the implements in the selected tillage system.

Procedure TILLAGE is where the user enters the choice of implements for the system. The program executes only for the implements selected by the user. For each of the implements selected, it displays the available field time of operation. The program displays the implement size and parameters entered or chosen by the users in the routine SELECT. The procedure on implements uses the computed maximum implement size to be pulled by the selected tractor size as the default implement size. The user has to input the commercial sizes for implements and tractors using the computed sizes as guidelines. Once an implement is selected and used in the program, the default values for the later crops will be the implement selected for an earlier crop. Each procedure on implement initially calls the procedures to determine the implement draft. The program calculates and compares the required drawbar power of the implements with the tractor's available power. The implement drawbar power must be less than or equal to the drawbar power of the tractor before the program can proceed. The implement is too large if the drawbar power of the implement exceeds the available drawbar power of the tractor. Thus, the user has the choice of using a smaller implement or skipping this implement and going on to the next implement execution. The larger implement could be assigned to the next larger tractor, if necessary. The program then calculates the field time required by the implement and compares it with the available field time of operation. The implement is too small if the required field time of the implement exceeds the available field time of

operation. The total field time required by the implements is calculated for each tractor.

If the drawbar power of the implement is higher than the drawbar power of the tractor, then the tractor cannot pull the implement. The program suggests the minimum implement width which is based on the size of the tractor selected. The program will iterate back to the same implement until drawbar power of the implement is less than or equal to the drawbar power of the tractor. The user can reduce the size of the implement and/or depth of operation and/or speed of operation. The program is designed to ensure that the tractor and implement are compatible in terms of power requirement before it will proceed to calculate the field time requirement.

If field time required by an implement is higher than the available field time of operation, the implement size is too small to complete the farm operation in time. The minimum implement size recommended here will be based on the available field time of operation unused by the previous implement operation. The maximum implement size is based on the size of tractor selected. If the field time for the maximum implement size is more than the available field time for the operation, the user has the option of completing the operation using another similar implement with another tractor or increasing the size of the implement. The program will iterate until the field time requirements are fulfilled. The user could also opt for not using this implement with this tractor and thus proceed to the next implement or next tractor. If the user intends to use more than one implement with one tractor, the program calculates the cumulative field time required by the implements and compares it with the available field time of operation. If the cumulative field time required by the implements is higher than the available field time of operation, then the latest implement of the set is too small to

complete the farm operation in time. The program will not calculate the cumulative field time for the implements if primary tillage, secondary tillage,and planting operations are not continuous. For the individual operation, only the field time for the field cultivator and disk harrow is cumulative and compared with the available secondary tillage operation time.

4.4.8 Procedures on Tractors

Procedures on tractors consist of Procedure TRACTOR1, Procedure TRACTOR2, Procedure TRACTOR3 and Procedure TRACTOR4. Procedure TRACTOR is used to call those procedures in consecutive order depending on the number of tractors required by the user or the program. The model permits the use of a maximum of 4 tractors.

Each crop will call Procedure TRACTOR. The Procedure TRACTOR checks for unused time left by the first tractor operation from the previous crop. Procedure TRACTOR then calls Procedure TRACTOR1, the first tractor to be used for the operation. The user has the option of using a known tractor size or allowing the program to compute for the required tractor size. The methodology to determine the approximate tractor size uses Procedure TILLAGE and Procedure IMPCALC, that were discussed in Sections 4.47 and 4.4.5.3, respectively.

The procedure on implements allows the users to enter the commercial implement size, the operation depth and speed, field efficiency, and tractive efficiency. These values are then used to calculate the drawbar power required for the implement. The computer then changes the drawbar power into the equivalent tractor size in kilowatts. The computer program displays the compatible tractor size associated with the selected

implement. If the user does not have the first tractor, the program asks the user to enter the tractor size. The user is encouraged to use the commercial tractor size based on the calculated compatible tractor size. Selection of tractor size can be carried out for a single or multiple-implement tractor operation. For the multiple-implement tractor operation, the user has to select the tractor size for the first implement and use the same tractor for the other implements. As such, the user must make a wise decision in selecting the tractor size such that it will be compatible for all implement to be used. Having chosen the tractor size, the drawbar power of the tractor is then calculated and compared with the drawbar power of the implement. The field time of implement(s) is compared with the available operation field time. The user has an option of using another tractor with this implement to complete the farm operation, if the total implement field time exceeds the available field time. The user also has an option to use another tractor for the other implements. In these cases, the Procedure TRACTOR2 and so forth is called. Thus, the number of tractors used can be determined by the program and user. In a multiple-crop rotation, the program displays the sizes of the tractors used for the earlier crop. The users are given the choice of using any or all of the tractors being used for the subsequent crops. The users can even use a different tractor for the next operation. For complex systems with a multiple crop rotation, the user may have to use the program several times to obtain the best set of machines.

Each procedure on tractors calculates the field time used for each tractor. For the continuous operation, the cumulative field time required for all tractors used is compared to the available field operation time. The program recommends the number of tractor drivers required. As an example, assume we use four tractors for the farm operation. If

the total field time for the four tractors is lower than the available field operation time, then the operation requires only one driver for all four tractors. This means that the same worker will drive all four tractors consecutively. If the total field time for all four tractors is higher but the total field time for the first, second and third tractors is lower than the available field operation time, then the operation requires two workers. One worker is required for the fourth tractor and another worker is required for the other three tractors. The number of workers required will determine the number of tractors that could work simultaneously.

4.5 Machinery Cost Analysis Input Data

The Machinery Cost Analysis Model is the second model for the CPMS program. This model depends on output from the Tractor and Machinery Selection Model.

4.5.1 Estimation of Costs

The cost of owning an implement or tractor, as for other assets can be divided into two components, namely; fixed or ownership costs and variable or operating costs. Fixed costs are those which remain relatively constant regardless of whether the level of machine use is nil or at 100% capacity. The fixed costs in this case are capital consumption, interest on investment, and taxes, insurance and shelter. Variable costs are those which are generally proportional to the machine use, and are repair and maintenance cost, oil cost, fuel cost, and operator's labor cost associated with use of the tractor.

The mathematical relationships used in calculating the annual machinery and tractor costs were obtained from the ASAE STANDARDS (ASAE,1990) and Hunt (1983).

Estimations of these costs for farm machines is important to farm managers. With good estimations the costs of production can be predicted, alternatives such as custom work or machine leasing can be evaluated, and size selection and replacement decisions can be made.

A cost analysis of tractor and machinery requires user's input information for labor wage, fuel price, oil price, and interest rate along with purchase price, age and expected life for the tractors and implements. One must be careful when choosing the tractor and implement prices because prices vary considerably as influenced by different financial arrangements. At the moment prices for the tractors and implements used for the model were obtained from the Minnesota Farm Machinery Economic Cost Estimates For 1990 (Fuller and Nordquist, 1990). Another good source of this information is commercial suppliers of agricultural equipment. The computations for the cost analysis depend on the number, sizes and field time for the implements and tractors as well as the equivalent power-take-off power (EPTOP). These values are obtained from the output of the Tractor and Machinery Selection Model.

Rotz and Black (1985) state that interest, discount and inflation rate should always be set in relation to one another. Under a stable economy, these factors will not have much effect on machinery selection. To simplify the selection procedure, the discount and inflation rates can be set equal so that money does not change value over time. The equations used in this model assumed a stable economy as suggested by Rotz and Black (1985).

A machine life must be estimated to predict capital cost. Capital cost is a fixed cost that is unaffected by subsequent monetary inflation if the purchase price is

considered as an investment financed over the length of life of the implement at a competitive interest rate at the time of purchase. Charges for shelter, insurance, and taxes are not so free from inflation but can be assumed as fixed costs to produce a complete annual cost estimate. The variable costs are the most sensitive to inflation. ASAE (1990) suggested that in times of rapid inflation they must be multiplied by an inflation factor $(1 + I)^n$ for year n after the purchase of the machines. I is the average inflation rate and n is the age of the machine in question.

4.5.2 Capital Cost

Simple interest on the average investment over the life of the machine can be added to the annual depreciation to estimate the yearly capital costs of ownership. A method which includes the time value of money and which makes use of a capital recovery factor (CRF) was used for determining the capital costs of ownership (CC). The investment in a machine is multiplied by the proper CRF to give a series of equal payments over the life of the machine which includes both the cost of depreciation and interest. These payments plus the interest on the un-depreciated amount of salvage value of machinery (S$) can be used to estimate the capital cost of the machinery. The mathematical relationships used in calculating capital cost were obtained from the ASAE STANDARDS (1990), Hunt (1983) and Barry et al. (1988).

$$S\$ = 0.1 * PPM$$

$$CC = (PPM - S\$) * CRF + S\$ * I \qquad (4.19)$$

$$CRF=\frac{I(1+I)^L}{(1+I)^L-1} \tag{4.20}$$

where:

CC = Capital Cost of Ownership

CRF = Capital Recovery Factor

I = interest, decimal

L = life of the investment in years (predicted life of implement)

PPM = machinery purchase price, $

S$ = Salvage value, $

4.5.3 Taxes, Insurance and Shelter Cost

Taxes, insurance and shelter costs (TIS) can be estimated as percentages of the purchase price. Instead, in this model the TIS costs make use of the implement and tractor remaining value (RV). The equations below are obtained from the ASAE STANDARDS (1990) and Kepner et al. (1978).

The remaining value for a tractor at the end of the nth year is given as:

$$RVNT=LPM*0.68*0.92^n \tag{4.21}$$

The remaining value for a tractor at the end of the (n-1)th year is given as:

$$RVMT=LPM*0.68*0.92^{n-1} \tag{4.22}$$

Thus, the taxes, insurance and shelter cost for a tractor at the end of the nth year is given as:

$$TIST = 0.04 * \frac{RVMT + RVNT}{2} \tag{4.23}$$

The remaining value for an implement at the end of the nth year is given as:

$$RVNM = LPM * 0.60 * 0.89^{n} \tag{4.24}$$

The remaining value for an implement at the end of the (n-1)th year is given as:

$$RVMM = LPM * 0.60 * 0.89^{n-1} \tag{4.25}$$

Thus, the taxes, insurance and shelter cost for an implement at the end of the nth year is given as:

$$TISM = 0.04 * \frac{RVMM + RVNM}{2} \tag{4.26}$$

4.5.4 Repair and Maintenance Cost

Expenditures due to part wear failure, accidents, and natural deterioration are necessary to keep the tractor and implement operable. Good management will keep costs lower. The size of a machine, as reflected by its price, and the amount of use are factors affecting these costs. Total accumulated repair and maintenance costs (TAR) at a typical

field speed can be determined with the following relationship using the repair and maintenance factors (RF1 and RF2) and the accumulated hours of machine use (USE). The accumulated machine field time is based on the age and the annual field time. The values for the RF1 and RF2 for the tractors and implements were obtained from ASAE EP 391.1 (ASAE,1990).

The accumulated hours of use for a tractor or implement at the end of the nth year are given as:

$$USEN = FT * n \tag{4.27}$$

The accumulated hours of use for a tractor or implement at the end of (n-1)th year are given as:

$$USEM = FT * (n-1) \tag{4.28}$$

The total accumulated repair and maintenance cost for a tractor or implement at the end of the nth year is given as:

$$TARN = LPM * RF1 * \left(\frac{USEN}{1000}\right)^{RF2} \tag{4.29}$$

The total accumulated repair and maintenance cost for a tractor or implement at the end of the (n-1)th year is given as:

$$TARM = LPM * RF1 * \left(\frac{USEM}{1000}\right)^{RF2} \tag{4.30}$$

The total repair and maintenance cost for a tractor or implement is given as:

$$RMN = TARN - TARM \tag{4.31}$$

where:

USEN = total use of a tractor or implement, hours at the end of nth year.

USEM = total use of a tractor or implement, hours at the end of (n-1)th year.

LPM = list price of tractor or implement

RF1 = R & M factor for tractor or implement

RF2 = R & M factor for tractor or implement

RMN = Implement R & M cost at end of nth year

TARN = total accumulated R & M cost at end of nth year

TARM = total accumulated R & M cost at end of (n-1)th year

4.5.5 Fuel Cost

Fuel efficiency varies by type of fuel and by percent load on the engine. Typical farm tractor engines above 20% load are modelled by the equations below, and typical fuel consumption (FCN) is given in L/kW.h (ASAE,1990).

The diesel fuel consumption of a tractor operating an implement is given as:

$$FCN = 2.64 * \frac{EPTOP}{APTOP} + 3.91 - 0.203 \sqrt{738 * \frac{EPTOP}{APTOP} + 173} \tag{4.32}$$

The fuel use and fuel cost are given as:

$$FU = FCN * FT * EPTOP \tag{4.33}$$

$$FC = FU * F$$

where:

FCN = Fuel consumption, L/kW.h

FU = Fuel use for one operation and one crop, L

FC = Fuel cost for one operation and one crop, $

F = Fuel price, $/L

The price of diesel fuel was assumed to be 21 cents per liter (Fuller and Nordquist,1990). All tractors were assumed to be diesel powered.

4.5.6 Oil Cost

Oil consumption is defined as the volume of engine crankcase oil per hour replaced at the manufacturer's recommended change interval. Consumption is in L/h where the rated engine power is assumed to be equivalent to maximum available power from the PTO (APTOP) (ASAE,1990).

The oil consumption of a tractor operating an implement is given as:

$$OCN = 0.00059 * APTOP + 0.02169 \tag{4.34}$$

The oil use and oil cost are given as:

$$OU=OCN*FT$$

$$OC=OU*O$$

where:

OCN = oil consumption, L/h

OU = oil use for one operation and for one crop, L

OC = oil cost for one operation and for one crop, $

O = oil price, $/L

4.5.7 Labor Cost

Labor cost is computed based on recommendations for local conditions which involve one operator for each tractor. Labor is charged at an hourly wage rate, which includes 30 percent for benefits, of $7.00 per hour for unskilled labor (Fuller and Nordquist,1990). The field time was increased by 10 percent to allow for travel time between fields.

$$LC=1.1*FT*L\$ \tag{4.35}$$

where:

LC = labor cost for one operation and for one crop, $

L$ = labor rate, $/h

4.5.8 Timeliness Cost

Timeliness is a measure of the ability to perform field operations during a period of time that gives optimum quality and quantity of product. The timeliness cost was defined as the loss in crop value experienced because the job was not completed within a certain period of time. Consideration of the timeliness cost allows the selection of the maximum profit system. Hunt (1983) and Bowers (1985) gave estimates of timeliness loss factors for some specific crops and operations. Rotz and Black (1985), compiled a set of data on timeliness costs for various crops that has been prepared by scientists at Michigan State University.

In some cases it is less expensive overall to allow some crop loss and to own a smaller machinery set. In most cases, though, it is less expensive to own larger machinery and avoid all crop loss (Rotz and Black, 1985). Some investigators (Hughes and Holtman, 1974; Bowers, 1985) considered timeliness as a system design constraint. Suitable calendar periods for each operation were established and machinery system size was optimized subject to timeliness constraints. The heuristic machinery models developed by Singh (1978), and Wolak (1981) at Michigan State University view timeliness as a constraint, rather than a penalty. This strategy results in a less complicated model structure which selects machinery sets sized to avoid all timeliness cost; therefore field operations must be completed within specified date constraints. The CPMS program uses timeliness as a constraint.

4.5.9 Machinery Cost

Estimation of future costs for farm machine use is important to machinery

managers. Estimated costs are predicted by summing expected fixed and variable costs.

The mathematical relationships used in calculating the annual machinery costs were obtained from Hunt (1983). The equation below expresses the approximate annual cost for an implement in constant dollars.

$$AC=CC+TIS+RMN+LC+OC+FC+TC$$

where:

AC = annual cost of implements, $/yr

TC = annual tractor cost attributed to this implement, $

Other terms were defined earlier.

4.5.10 Tractor Cost

The procedure in calculating the costs of owning a tractor were explained in Sections 4.5.2 to 4.5.4. The labor cost, fuel cost and oil cost are the actual operating costs directly related to the field time used by an implement, and were included in the annual implement operating cost calculations. The repair and maintenance cost, capital consumption cost, and taxes, insurance and shelter cost for each tractor and for each implement are the costs being shared by other crops in a rotation. The shared costs for each implement and each tractor are calculated based on the proportion of time used by each crop to the cumulative field time used by all the crops. The repair and maintenance factor RF1 and RF2 for a tractor are 0.012 and 2.0, respectively. The total annual cost

for one tractor is:

$$TC_o = RMT + CC + TIS$$

For a single crop farm, the total tractor and machinery cost is:

$$AC = \sum MC + \sum TC$$

MC (for each implement) = LC + FC + OC + RMI + CC + TIS

TC_o (for each tractor) = RMT + CCT + TIST

where:

RMT = Tractor repair and maintenance cost,$

CCT = Tractor capital cost of ownership, $

TIST= Tractor taxes, insurance and shelter,$

Other terms were defined earlier.

For multiple crop farms, the total tractor and machinery cost will be:

$$AC = \sum MC_A + \sum MC_S + \sum TC_S$$

MC_A (for each implement) = LC + FC + OC

MC_S (for each implement) = (RMI + CC + TIS) * FT/TFT

TC_S (for each tractor) = (RMT + CCT + TIST) * FTT/TFTT

Where:

FT = Implement field time for each implement used by each crop

TFT= Implement field time for each implement used by all crops

FTT= Total implement field time used by each crop for each tractor

TFTT= Total implement field time used by all crops for each tractor

4.6 Tractor and Machinery Cost Model

The Tractor and Machinery Cost Analysis Model works interactively with the Tractor and Machinery Selection Model. The inputs to the Tractor and Machinery Cost Analysis Model are the size, number, and field time for the implement, and tractor and implement power requirements from the Tractor and Machinery Selection Model.

When a well-matched system is selected, the total annual cost of owning and operating this set of machines can be determined. Several well-matched systems can be found for the same farm, and cost analysis can be useful to select the "least cost" or "maximum profit" system. This section of the program is used to determine the costs for the tractors and machines that were selected in the Tractor and Machinery Model. The Tractor and Machinery Selection Model determines the number and sizes of the tractors and implement to be used for the farm operation. The selection model also computes the field time and the equivalent power take-off power (EPTOP) for each of the implements and tractors selected. These variables are used to calculate the tractor and machinery costs. The computations for the costs also depend on the user's input of labor wage, fuel price, oil price and interest rate as well as age, expected life and purchase price for the tractors and implements. Those values can be entered from the keyboard or from an

external file as described in Section 4.1.

The Tractor and Machinery Cost Model is used to calculate the fixed and operating costs for the tractors and implements used. The outputs from the machinery cost model for each implement include the fuel consumption, fuel cost, oil cost, labor cost, capital consumption cost, repair and maintenance cost, taxes, insurance and shelter cost, and total machinery cost. The outputs for each tractor include the taxes, insurance and shelter cost, capital consumption cost, repair and maintenance cost, and total tractor cost. The program calculates the machinery cost for each implement used with each tractor and the tractor cost for each tractor used by all implements for each crop. It also calculates the machinery cost for each implement used by all crops and tractor costs for each tractor used by all implements for each crop. The program summarizes the costs for labor, fuel, oil, repair and maintenance, capital consumption and taxes, insurance and shelter by implement used for all crops. Total cost is determined as the sum of all costs of owning and operating the system.

The Tractor and Machinery Cost Model will enable users to compare the cost of using each implement, tractor and crop. This program calculates the total machinery and tractor cost, cost per hectare and cost per hour for each crop in a crop rotation. It will enable a user to compare between crops, crop systems and tillage systems. Various sensitivity analyses were carried out and described in Sections 6.2 and 6.3.

4.6.1 Cost Analysis Algorithm

The first part of the tractor and machinery cost analysis algorithm is to enter the labor wage, fuel price, oil price and interest rate. Labor is charged at an hourly wage rate

of $7.00 per hour. Fuel price of farm fuel is assumed to be 21 cents per liter for diesel. The oil price is assumed to be $1.35 per liter. The interest rate is assumed to be 12 percent (Fuller and Nordquist 1990). The user can enter values other than the above for different geographical locations.

Figures 4.8 and 4.9 show the algorithm where the user has to enter the required values. For each of the tractors and implements selected, the user enters the age, estimated expected life and the purchase price. For the tractor purchase price, the user has the option for the program to estimate the price. The program uses the regression formula developed by Singh, 1978. The equation was multiplied by a factor of 2.45 to allow for inflation since 1978. The user has to enter these values only once.

Figure 4.9 shows the algorithm to determine the implement and tractor costs by tractor and crop. For each crop, the computer model identifies the number of tractors used and the type of implement used for each tractor. For each implement used by each tractor and crop, the program calculates the costs for the labor, fuel, oil, repair and maintenance, capital consumption, and taxes, insurance and shelter. The program calculations are based on the entered values and the values generated by the machinery selection model. These costs are calculated based on the field time used by each implement for each crop. For each tractor, the program calculates the costs for the repair and maintenance, capital consumption, and taxes, insurance and shelter, and total tractor cost. These costs are calculated based on the total field time of all implements used by that tractor for each crop. The capital consumption cost and taxes, insurance and shelter cost are not affected by the implement or tractor field time. Implement costs for all crops in the rotation are calculated. Implement costs for each crop are also calculated

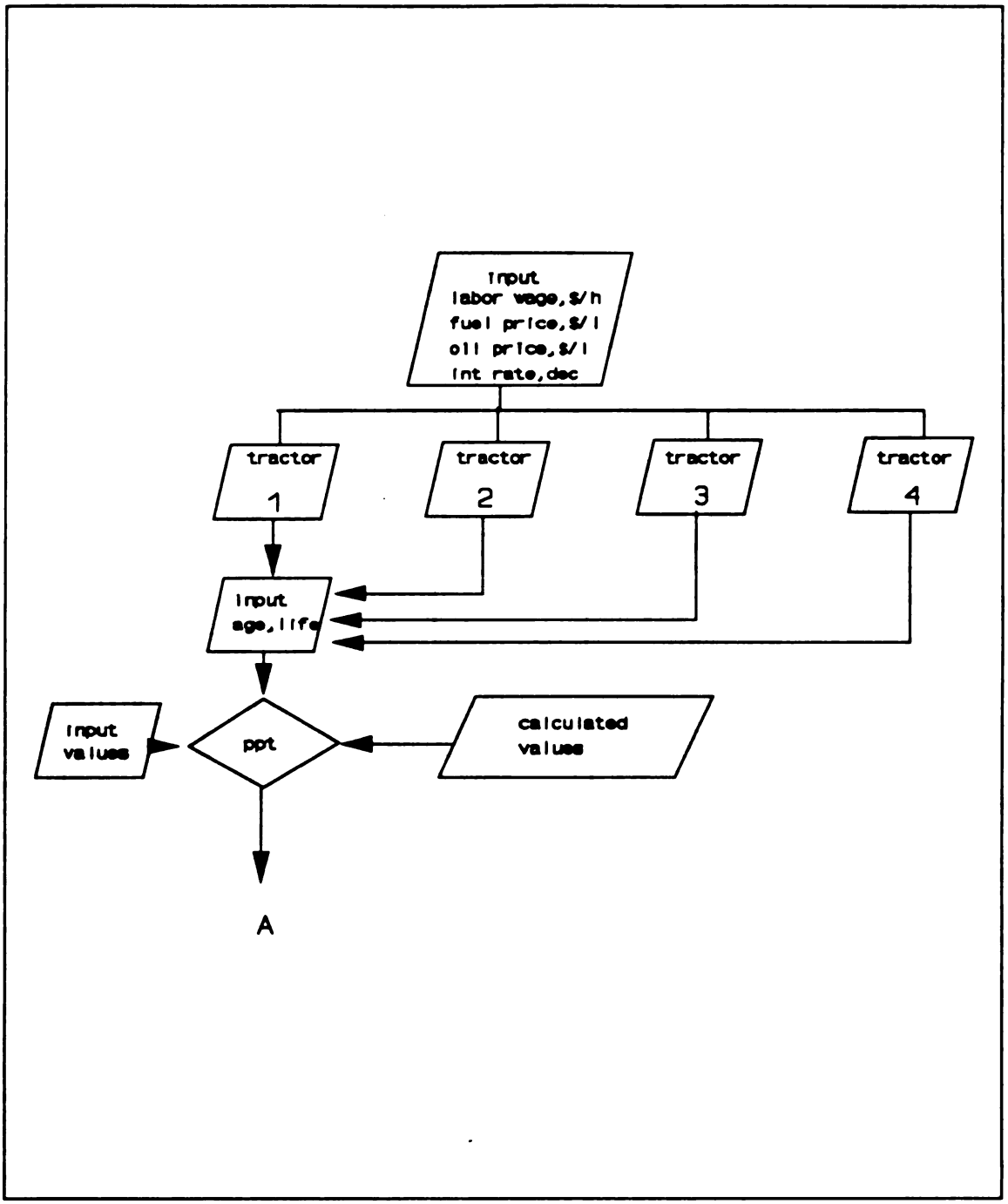

Figure 4.8: Machinery Cost Analysis Algorithm.

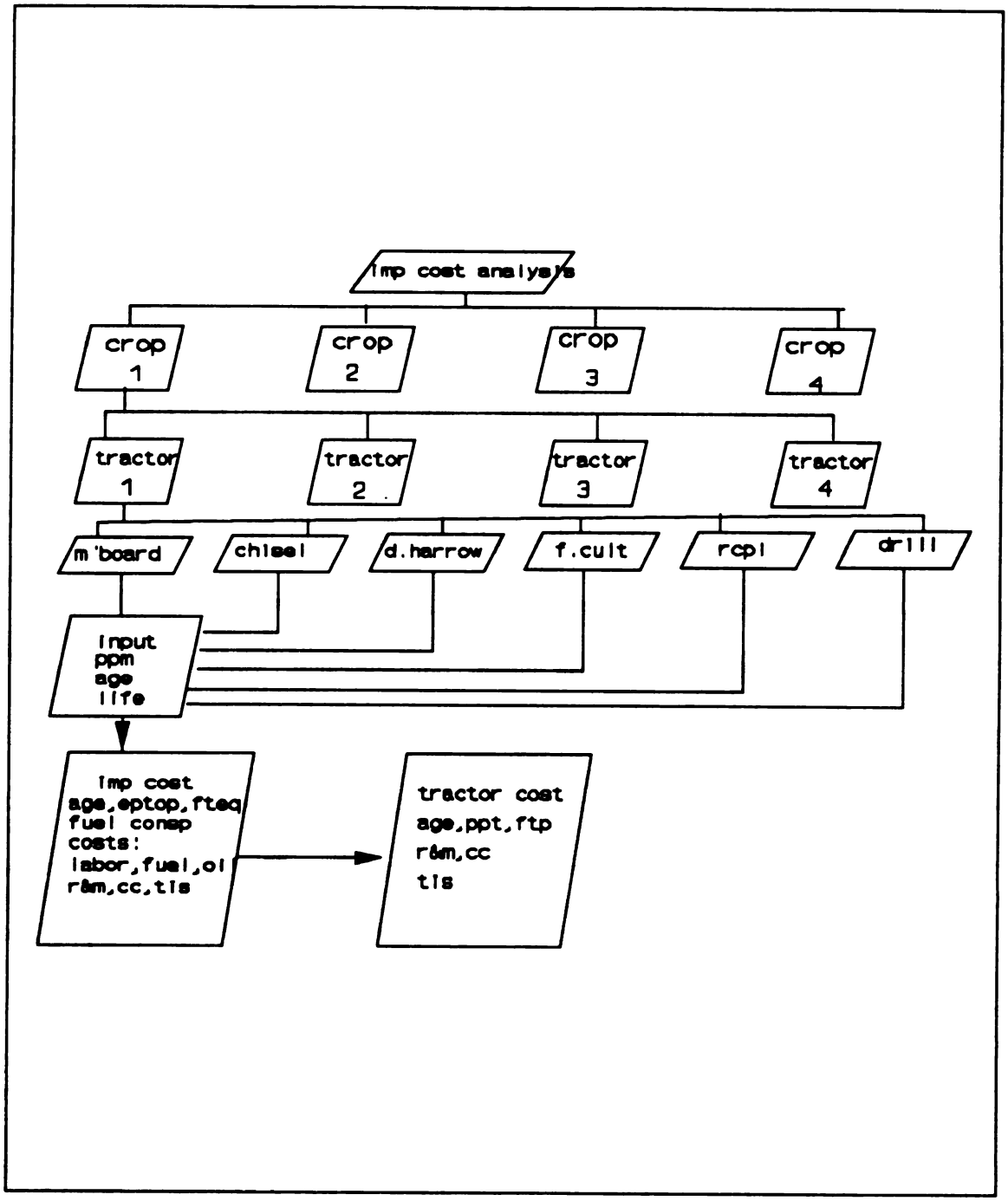

Figure 4.9: Machinery Cost Analysis Algorithm (cont).

individually assuming a series of single crop farms. The single farm computations assume the same set of machines that is used for the multiple crop farm.

Figure 4.10 shows the algorithm to determine the total machinery and tractor costs for all crop operations. For each tractor, the program identifies the number and type of implements used. For each implement type, the program determines the fuel consumption, labor cost, fuel cost, oil cost, repair and maintenance, capital consumption, taxes, insurance and shelter, and total implement cost for all crops.

The costs of repair and maintenance, capital consumption, and taxes, insurance and shelter are calculated based on the ratio of field time used by each implement for a specific crop to the total field time used by each implement for all crops. For each tractor used for each crop in a crop rotation, the repair and maintenance, capital consumption, and taxes, insurance and shelter are calculated based on the ratio of implement field time used by each tractor for a specific crop to the total implement field time used by each tractor for all crops. The total tractor cost is the total cost of using all tractors for all crops. The total machinery and tractor cost is the sum of the total machinery costs and the total tractor costs for all crops.

For each tractor the program calculates and summarizes the labor cost, fuel cost, oil cost, repair and maintenance cost, capital consumption cost and taxes, insurance and shelter cost each implement used by all crops. These values are tabulated for the user to identify and analyze which cost for which implement involves the highest cost in the crop production. The program also calculates and summarizes the repair and maintenance cost, capital consumption cost and taxes, insurance and shelter cost for each tractor used for the crop production.

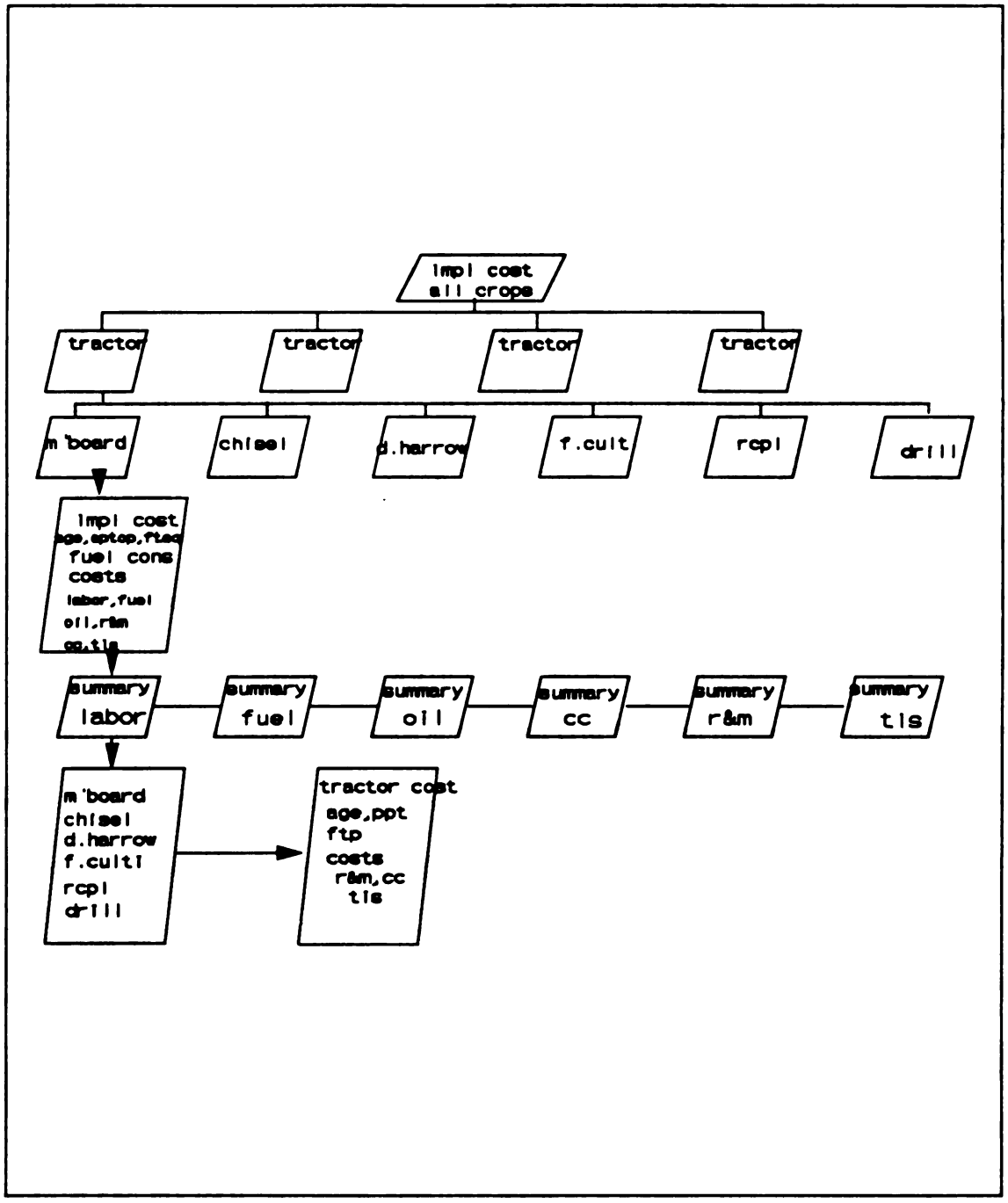

Figure 4.10: Machinery Cost Analysis Algorithm (cont).

Figure 4.11 shows the algorithm of the summary for the machinery and tractor costs by crop. For each crop produced, the computer model identifies the area of operation and the total field time, and uses them to determine the machinery costs and tractor costs. The program calculates the total machinery and tractor cost, cost per hectare, and cost per hour for each crop. The first analysis will determine the machinery costs and tractor costs for each crop done as if a single cropping. The single crop operation was assumed to use the same dates of operation and same type and size of implements as used for the same crop in a crop rotation. The land area used for a crop is assumed to be the same as that occupied by that crop in the multiple crop farm. The costs are calculated based on the field time used by each implement for each crop as a single crop. The labor cost, fuel cost, oil cost and repair and maintenance cost are the actual operating costs based on the field time used by each implement. The capital consumption cost and taxes, insurance and shelter cost for each implement and tractor are the costs calculated based on the only crop produced. This analysis determines the cost of producing a single crop and allows the user to compare the cost of production between crops. The above assumptions for the single cropping must be considered before any conclusions can be made.

The second analysis will determine the machinery cost and tractor cost for each crop in a rotation. For each crop produced, the computer model identifies the area of operation and the total field time, and uses them to determine the machinery costs and tractor costs. This analysis determined the machinery cost, tractor cost, cost per hectare and cost per hour for each crop in a rotation. The labor cost, fuel cost and oil cost are the actual operating costs based on the field time used by each implement. The repair

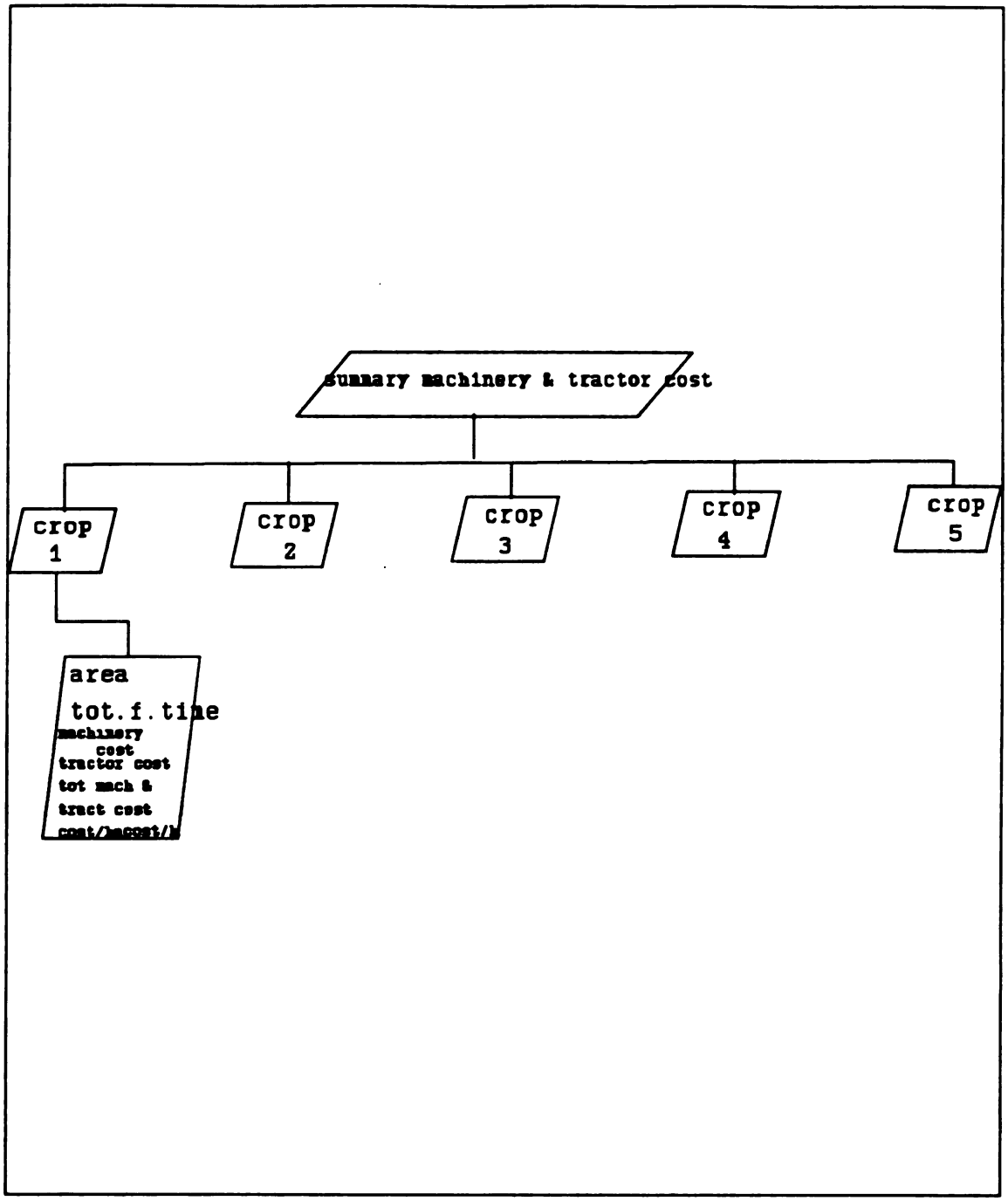

Figure 4.11: Machinery Cost Analysis Algorithm (cont).

and maintenance cost, capital consumption cost and taxes, insurance and shelter cost for each implement are the costs being shared by all crops. These costs are calculated based on the ratio of field time used by each implement and crop to the total field time used by each implement for all crops. The above costs for each tractor are also the costs being shared by all crops. Those costs are calculated based on the ratio of field time used by all implements for each crop to the total field time used by all implements and all crops.

Figure 4.12 shows the algorithm for the summary costs of all implement operations by tractor and the calculations to determine the total cost of production for a typical farm. This program summarizes the total costs for the labor, fuel, oil and repair and maintenance for all implements used by each tractor. The total cost for the labor, fuel, oil and repair and maintenance for all implements is also calculated for all tractors. The capital consumption cost, and taxes, insurance and shelter cost for each implement are calculated for each tractor. The program is written, not to add the capital consumption cost and taxes, insurance and shelter cost for each implement and tractor more than once, in adding the total cost of production.

4.7 Machinery Cost Analysis Procedures

4.7.1 Procedure for Implement Cost

The Tractor and Machinery Selection Model can be used independently, but the Tractor and Machinery Cost Analysis Model works interactively with the Tractor and Machinery Selection Model. The Tractor and Machinery Selection Model selects the type, size and number of machines, number and size of tractors, field time required by each implement, total implements for each tractor, and the equivalent power take-off

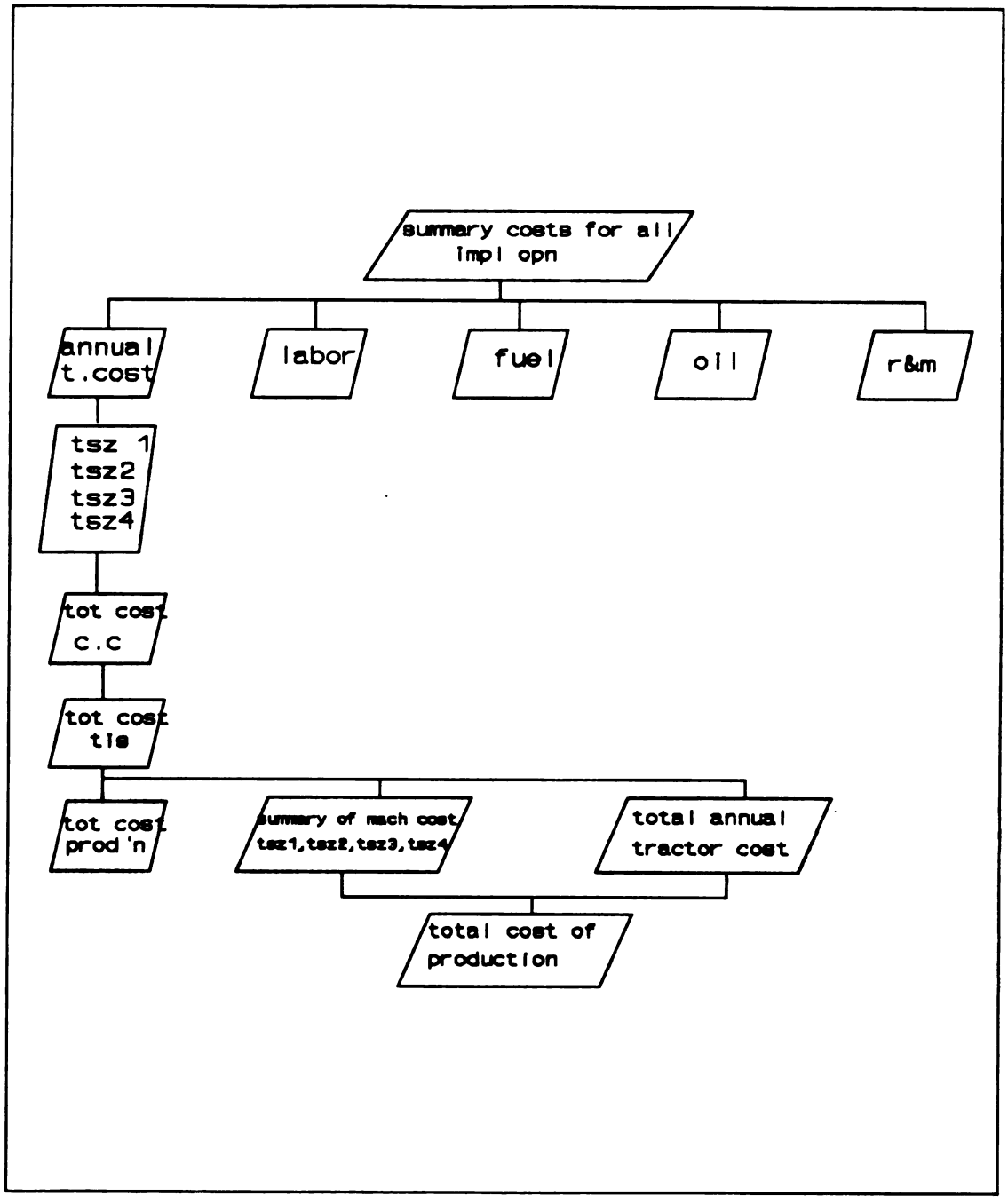

Figure 4.12: Machinery Cost Analysis Algorithm (cont).

power (EPTOP) requirement of each implement. These values are used by the Tractor and Machinery Cost Analysis Model.

Procedures for implement cost consist of Procedure COSTANAL and Procedure COSTCAL. The Procedure COSTANAL identifies the type of implement used or selected for a particular tractor for each crop. It gathers and stores the information on field time and EPTOP calculated from the Tractor and Machinery Selection Model. The field time for each implement is for each crop operation, and the cumulative implement field time is for all crops in a crop rotation. Procedure COSTANAL contains information on the purchase price, age and expected life of the selected implements entered by the user. The user needs to enter these variables only once in the program. For each implement, Procedure COSTANAL calls upon the Procedure COSTCAL to determine the implement cost analysis. The Procedure COSTCAL calculates the labor cost, fuel cost, oil cost, repair and maintenance cost, capital consumption cost, and the taxes, insurance and shelter cost. It also calculates the fuel consumption and the total machinery cost. The equations to determine these costs were discussed earlier in Section 4.5.

4.7.2 Procedure on Tractor Cost

This procedure starts with the user's input on age and estimated life expectancy for the tractors used in the program. The user is given an option of entering the purchase price of the tractor or the program will estimate that price based on equations developed by Singh (1978). A value of 2.45 was multiplied to the equation to estimate an increase in price due to inflation. The user is encouraged to enter the actual purchase price obtained from their local community.

$$PPT = 2.455 * (233.26 * TSZ1 - 0.308 * TSZ1^2)$$

The Procedure TCOST calculates the variable cost of repair and maintenance and the fixed costs of capital consumption and taxes, insurance and shelter cost. The repair and maintenance cost requires information on purchase price and field time used for each tractor. The main program gathers information on field time used by the implements for each crop and all crops in a rotation for each tractor. The capital consumption and taxes, insurance and shelter costs requires data on interest rate, purchase price, age and expected life for each tractor. The method to determine these costs were described earlier under the procedure of implement cost in Section 4.5.

4.7.3 Procedure CROPTYPE

The cost analysis for each implement and tractor for a single crop or for all crops in a rotation is carried out by Procedure CROPTYPE. Procedure CROPTYPE identifies the type and number of crops selected from the Tractor and Machinery Selection Model. For each crop selected, this procedure determines the number and type of implements used for each tractor. Cost analyses are carried out for each implement, tractor and crop. At this point, the total machinery cost for each tractor for each particular crop is listed.

Procedure SUMMARY2 determines the type and number of implements used with each tractor for all crops selected in the crop rotation. The cumulative field time used by each implement is used to determine the variable costs.

Procedure SUMMARY2 interacts with Procedure COSTANAL and Procedure

COSTCAL where the implement fixed and variable costs are calculated. Most of the values for each implement are constant except for the field time factors. The field time and accumulated use changes depending on the use of the machine. The total accumulated use for each implement is estimated based on the average field time used and the age of the implement. The variables affected by the field time are labor cost, fuel cost, oil cost and repair and maintenance cost.

Procedure SUMMARY2 also interacts with Procedure TCOST to calculate the tractor fixed and variable costs. The field time of the tractor is calculated based on the total field time of all implements used with each tractor. The accumulated use of the tractor is estimated for each tractor based on the average field time used and the age of the tractor. Repair and maintenance cost is the only variable affected by the time used. Procedure CROPTYPE also summarizes the fixed and variable costs for all implements related to each tractor, for all crops. It uses the Procedure SUMCOST to calculate the costs for individual implements and also the total costs for all implements. The total fixed costs and variable costs for each tractor for all crops are also calculated.

4.7.4 Procedure CONCLUDE

Procedure CONCLUDE summarizes the machinery and tractor costs, for all crops selected in the rotation. The output is the area of operation, total field time used to complete the farm operation, machinery cost, and tractor cost. This procedure calculates the cost per hectare and the hourly cost for each crop produced. It also summarizes the annual cost of using the tractor. The program ends by calculating the total cost of production.

4.8 Assumptions

The following assumptions were set in the development of the model.

1. The implement draft equations were obtained from the ASAE STANDARDS, (ASAE,1990) and FMO,1987.
2. The suitable days information for the locations in Michigan were obtained from the work carried out by Rosenberg et al. (1982). Their probability of working days were used to calculate the available field operation time.
3. The cost analysis equations were obtained from the ASAE standards, Hunt (1983) and major professor's class notes.
4. The recommended minimum implement size was based on the field time requirement. The recommended maximum implement size was based on the tractor size. The recommended implement and tractor sizes were not necessarily those commercially available. The users have to enter the commercially available implement and tractor sizes in the program.

5. EXPERIMENTAL PROCEDURE

A joint research effort with Mungai (1991) was carried out. The author of this dissertation focussed on the research to determine the average draft and fuel consumption for various tillage and planting implements at various field speeds, and depths of operation. The tractor used in this research was a Ford[1] agricultural tractor, model 7610, with front wheel assist. The nominal PTO power of this tractor was 64.1 kW (86 hp). The implements used for the field test were a moldboard plow, chisel plow, disk harrow, field cultivator, row crop planter and grain drill. The data obtained during the field experiments were recorded directly using an on-board computer data acquisition system. A commercially available Dickey John Tractor Performance Monitor II (DjTPMII) was used to measure the engine speed, ground speed and tractor front and rear wheel rotation speeds. The sensors which utilized signals from a DjTMPII were described in detail by Tembo (1986) and Mah (1990). An Emco[1] pdp-I (PDP-I) fuel flow transducer was used to measure the fuel consumption. The draft of implements was measured using a drawbar equipped with strain gages. The data obtained from the transducers were then recorded directly by the data acquisition system.

[1] Trade names are used in this dissertation solely to provide specific information. Mention of a product name does not constitute an endorsement of the product by the author to the exclusion of other products not mentioned.

5.1 Calibration of Transducers

Calibration of the transducers were carried out prior to the field experimentation that was conducted between September and November 1989. Calibration of the strain gages for draft measurement was done using a Universal Testing Machine with a maximum load of 4627 kg (10200 lb). The calibration of the other transducers were carried at the Agricultural Engineering Laboratory using a frequency function generator. Regression equations for each transducer were obtained. The procedures to calibrate these sensors were the same as described by Tembo (1986).

The method used to arrive at the calibration equations was through estimating the maximum load expected for each of the transducers. The maximum expected loads (i.e., engine rpm, fuel consumption, ground speed, rear wheel speed and front wheel speed) were converted into frequencies. A frequency function generator was used to generate the maximum frequencies for their respective transducers which were later fed into the signal conditioner to obtain analogous voltages. Depending on the range of the voltage, a suitable gain code was selected. All six transducers were calibrated for a gain code of 0 viz for a voltage of 0 - 5 volts.

About 10 - 12 frequencies were generated by the frequency generator which was hooked up to an oscilloscope to obtain an accurate reading of the frequencies. The signal was transmitted to the signal conditioner and the computer, which calculated an equivalent voltage. The computer then provided coefficients and constants for calibration equations to convert the computer outputs (mv) to the analog parameters. The respective equations and the coefficients of determination for each channel are listed in Table 5.1.

Table 5.1 Regression Equations for the Transducers.

Channel	Gain Code	Transducer	Equations	R^2
6	0	Engine Rpm	Hz = mv*0.08914+1.6936	0.9998
7	0	Ground Speed	Hz = mv*0.0978+2.2774	0.9992
8	0	Rear Wheel Rpm	Hz = mv*0.0835+2.7575	0.9988
9	0	Front Wheel Rpm	Hz = mv*0.0902+1.1103	0.9986
10	0	Draft	N = v*24000.664-12.857	0.9991
11	0	Fuel Consumption	Hz = mv*0.2036+0.8803	0.9999

The calibration of the fuel flow meter was done using a custom made frequency simulator that was designed to expand the narrow signal obtained from the sensor to one that the conditioner could display. The frequency simulator had four preset frequency levels of 100, 250, 500, and 1000 Hz., which were used to determine the calibration equation for the fuel consumption.

5.1.1 Verification of the Engine RPM

The engine RPM was verified using a photo-tachometer, the DjTMPII and the tractor's tachometer to determine the accuracy of using the computer data acquisition system. The data from these instruments were recorded simultaneously at various engine

speeds. The analysis of the data from these tests were found to be satisfactory to verify the accuracy of the data acquisition system for measuring the engine speed.

5.1.2 Verification of the Wheel Speeds

The front and rear wheel revolutions were verified by manual counting and using an oscilloscope to determine the accuracy of using the computer data acquisition system. The tractor was jacked up allowing the four wheels to rotate freely. The results of manual counting of wheel revolutions were recorded simultaneously with the transducers' reading using the on-board computer system. The transducers were then connected to the oscilloscope. The manual counting of wheel revolutions was again recorded simultaneously with the transducers reading from the oscilloscope. Both of these experiments were carried out using the same engine RPMs and ground speeds. The analysis of the data from these tests was found to be satisfactory to verify the accuracy of the data acquisition system for measuring the engine speed.

5.1.3 Verification of the Fuel Flow Meter

In order to ascertain that the values of the fuel consumption obtained from PDP1 were accurate, the system was tested manually in a laboratory. A gravity fuel feed system was devised to monitor the rate of fuel consumption at various engine speeds at no load and with tractor PTO loading. A graduated cylinder was filled with fuel and the time taken to consume 100 or 200 cc, depending on engine speed, was noted. Simultaneously, measurement of fuel consumption was done with the PDP1 for a direct comparison. Analysis of the data showed that the rate of fuel consumption registered by

the PDP1 was lower by a fixed constant factor of 1.1296 as compared to the manual fuel consumption rate.

The tractor was then connected to a PTO dynamometer and the experiments were repeated for loads ranging between 6.75 kW to 64.5 kW (9hp to 86hp). The aim was to load the tractor to the maximum horsepower level. The fuel consumption for the manual, PDP1 and the calculated values using ASAE Standards fuel consumption formula were compared. Again a consistent and parallel difference was noted. The PDP1 registered lower than the calculated values by a constant factor of 1.1296. Consequently, the values obtained from the data acquisition system were multiplied by 1.1296.

5.1.4 Verification of the Ground Speed

The tractor ground speed was verified by measuring the distance and time at various tractor ground speeds. The calculated values and the values obtained from the DjTPMII were verified with the data obtained from the computer data acquisition system. The manual calculations were found to agree with the values obtained from the data acquisition system.

5.2 Model Equations

The equations for the draft and fuel consumption used in the model were obtained from ASAE D230.4 (ASAE, 1990) and Machinery Management (FMO,1987). The implement draft was estimated based on the operation speed, operation depth and implement width. The operation speed and depth used were obtained from the experiment. The fuel required by each implement operation was estimated based on the

implement equivalent power take-off power (EPTOP) and the tractor available power take-off power (APTOP). The implement EPTOP was calculated using the drawbar power and tractive efficiency. The implement drawbar power was calculated using the implement draft and operation speed. The tractive efficiency was estimated from the wheel slippage and soil cone index obtained from the field experiments. The tractor used in the experiment produced APTOP of 64.1 kW.

Equation 5.1 shows an example to determine the draft for a moldboard plow used on coarse soil. The operation speed and operation depth are values which were obtained from the experiment. The experimental draft obtained from the field experiment was compared to the draft obtained from the CPMS Model using the above equation. Using the calculated values of slippage (SL) and dimensionless ratio (CN) from Equations 5.2 and 5.3, an individual TE can be estimated as in Equation 5.4. CN is a function of the Cone index (CI) of the soil. The values for the CI were obtained from the research using a cone penetrometer. SL was calculated using the rear and front wheel speeds, and the ground speed. These speeds are experimental data and were obtained from the on-board computer data acquisition system. Based on the individual values of TE, the power required by the implement was calculated as in Equation 5.5. Based on the implement equivalent power take-off power (EPTOP) and tractor available power take-off power (APTOP), the predicted fuel was obtained as in Equation 5.6. The experimental fuel consumption was compared with the fuel requirement estimated by the model using the above equations.

As in Equation 4.12:

$$D=(2.80+0.013*S^2)*WD*W*10 \tag{5.1}$$

Where

D = Draft,kN

S = Operation speed, Km/h

WD = Operation Depth, m

W = Implement width (Moldboard plow), m

$$CN=\frac{CI*B*D}{W_L} \tag{5.2}$$

Where

CN = Dimensionless ratio

CI = Cone Index (from cone penetrometer reading)

B = Unloaded tire section width (34.5cm), cm

D = Unloaded overall tire diameter (131 cm)

W_L = Dynamic wheel load

$$SL=\frac{S_w-S_g}{S_w} \tag{5.3}$$

Where

SL = Wheel slippage

S_w = Wheel speed

S_g = Ground speed

$$TE=(1-SL)\left(1-\frac{\frac{1.2}{CN}+0.04}{0.75(1-e^{0.3*CN*SL})}\right) \tag{5.4}$$

As in Equations 4.7 and 4.14;

$$EPTOP=\frac{DBP}{0.96*TE} \tag{5.5}$$

$$PCN=\left(2.64*\frac{EPTOP}{APTOP}+3.91-0.203\sqrt{7.38*\frac{EPTOP}{APTOP}+173}\right)*EPTOP \tag{5.6}$$

5.3 Field Experiments

The field experiments were carried out on farms at Michigan State University (MSU) and in Clinton County, Michigan. Initial laboratory and field experiments were carried out to determine the validity of the transducers and the recording systems, and to establish field test procedures. The implements used for the field experiments were a moldboard plow, chisel plow, tandem disk harrow, field cultivators, row crop planters,

and grain drills. Tables 5.2a and 5.2b show the list of implements and implement sizes used for the field experiments at MSU and Clinton County, respectively. The field tests for the first season were carried out in the Summer and Fall of 1989 at the MSU farms. The field tests for the second season were carried out in the Summer and Fall of 1990 at the MSU farms and at Clinton County, Michigan. Experiments were carried out on different soils at different speeds and depths of operation. Data were also obtained and recorded on previously tilled areas.

The signal conditioner, analog-to-digital converter, computer, battery power source, and their mounting inside the tractor cab were described in more detail by Tembo (1986). Special care was taken to provide a stable source of electrical power during operation. At the beginning of the experiment, the operator entered the number of data sets to be collected. The operator initiated the data collection procedure when the tractor reached steady state operation during an experimental run. The data were stored temporarily in RAM memory during each experimental run of the tractor. After each experimental run, the data were verified before being saved on a floppy disk. The data were stored as an ASCII file in order to provide ease in transferability to other computers for analysis. A sample of ten data sets from each experimental run was retrieved directly and recorded manually from the Apple IIe computer to check and verify the approximate results before further experiments were carried out. About 500 to 1000 data sets at 20 Hz frequency sampling were obtained for each experimental run. Each data set contained one data point for each of the six measured parameters. These data sets were used to calculate the engine rpm, ground speed, rear wheel revolution, front wheel revolution, wheel slip, implement draft, implement power requirement and fuel consumption.

Table 5.2a List of Implements used for the Field Experiments at Michigan State University Farm.

Implement	Make	Size	Width,m
Chisel Plow	White Farm Equipment	8 tines	2.20
Moldboard Plow	International 450	3 bottoms	1.20
Field Cultivator	Glencoe 300	25 tines	4.27
Disk Harrow	John Deere, Dura-Cushion		4.27
Grain Drill	Tye Min. Till	15 openers	2.84
Grain Drill	John Deere	21 openers	3.56

5.3.1 Data Acquisition and Analysis

The data recorded using the on-board data acquisition system were then retrieved and transferred to an IBM computer. The transfer of the data was carried out using cross-over RS232 wires connecting the modem ports of the Apple IIe and IBM computers. The ASCII Express program was used with the Apple IIe computer to send the files. The Modem 7 PC program was used with the IBM computer to receive the files from the Apple IIe computer. The data saved in IBM format were then changed to ASCII files by

Table 5.2b List of Implements Used for the Field Experiments at Clinton County, Michigan.

Implement	Make	Size	Width,m
Chisel Plow	Fema S&H Farms	7 tines	2.5
Moldboard Plow	Melroe 900 Series	6 bottoms	2.43
Disk Harrow	Tandem Allis Chalmers		3.96
Disk Harrow	John Deere		3.04
Disk Harrow	Unknown Brand		3.17
Corn Planter	John Deere	6 rows	3.83
Grain Drill	Tye	10 openers	1.83
Grain Drill	Vermeer 107	18 openers	3.05

adding the .PRN extension. The extension PRN files were then imported to the LOTUS 1-2-3 program for analysis. LOTUS 1-2-3 was used to determine the average values of the voltages for each transducer. These average voltage values were then converted by the appropriate calibration equations to calculate the parameters measured by each sensor. These parameter values were then stored on disks for later analysis and for use by the simulation model.

Table 5.3 and Tables A.1 through A.26 in Appendix A show the draft and fuel

Table 5.3 Experimental and Model Draft and Fuel Requirements for Moldboard Plow on Owosso-Marlette Sandy Loam.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
4.42	28	22.63	19.70	23.08	18.23
3.63	28	24.13	17.52	22.21	18.81
3.79	28	23.16	17.69	22.36	16.54
5.23	20	18.86	14.96	17.24	15.22
7.39	13	13.54	15.57	12.92	14.17
6.73	20	17.15	18.70	18.98	17.83

Location: Clinton County, Michigan

Implement: Moldboard Plow Size: 6-Bottom Width: 2.43 m

consumption data obtained from the experiments. These tables also show the draft and fuel consumption estimated from the CPMS Model. Experiments at MSU were carried out on Capac Loam which is fine texture soil. The experiments using chisel plow, moldboard plow, disk harrow and field cultivator were carried out using different operation speeds and depths as indicated in Table 5.3 and Tables A.1 through A.26 in Appendix A. A single depth was used for the grain drill experiments. The experiments

using a semi-mounted moldboard plow were carried out at different depths, but no draft was recorded. The experiments using a disk harrow were carried out on an untilled area, a previously moldboard plowed area and a previously chisel plowed area. The field cultivator experiments were carried out on an untilled area, after moldboard and disk harrow operations, and after chisel plow and disk harrow operations. The Tye Minimum Till grain drill was tested on an untilled area, a previously moldboard plowed area and a previously chisel plowed area. The John Deere grain drill was tested on a chisel plowed area and a moldboard plowed area.

Experiments on farms at Clinton County were carried out on four different soils, namely, Owosso - Marlette Sandy loam, Metamora Capac Sandy Loam, Granby Loamy soil, and Palms Muck soil. The chisel plow, moldboard plow and disk harrow experiments were carried out for different operation speeds and depths. The disk harrow experiments were carried out for single and double passes on an unplowed area and previously plowed area. The grain drill was tested on unplowed area, previously chisel plowed area, previously moldboard plowed area, and previously moldboard plowed and disk harrowed area. The corn planter was tested on an untilled area and after a disk harrow operation.

At least 10 random samples of depths were manually collected after each implement operation. About 10 random samples of cone penetrometer readings were collected for each field before each field experiment. The engine speed, wheel speed, ground speed, implement draft, and fuel consumed were recorded using the data acquisition system during the experiments. They were later converted to the actual parameters, using the calibration equations as in Table 5.1. The tractive efficiency was

calculated based on the front wheel slippage, rear wheel slippage, and soil cone index obtained from the experiment. The tractive efficiency equation from ASAE D230.4 (ASAE, 1990) was used. The fuel consumption, draft and drawbar power required by the implement were compared with the values computed by the CPMS Model.

5.4 Validation of the CPMS Model

Simple regression analysis was performed to find the relationship between model outputs and experimental outputs. A perfect model would provide a line passing through the origin with a slope of 1, i.e. a 1:1 correspondence. For this study, the general form of the regression model is $y = a + bx + e$ where y is the predicted or model value, x is the experimental value, a is the intercept, b is the slope of the regression equation and e is the error term. The estimated value of b must be one or close to one indicating the model value is equal or close to the experimental value.

A student's t test is used to determine whether a and b are significantly different from zero. The computed t is compared with the tabular t at 5% level of significance. If the computed t is greater than the tabular t, the null hypotheses of $a = 0$ and $b = 0$ are rejected and the coefficients are said to be "statistically significant". An F-statistic is used to determine whether the relation expressed by the regression line is statistically significant.

A coefficient of determination, R^2 is computed to measure the goodness of fit of the regression equation. R^2 can be interpreted as the proportion of variation in predicted values explained by variation in experimental values. An R^2 value of 1 occurs if the experimental and predicted values all lie on a straight line, so that the residuals are zero.

A correlation coefficient R is computed to give a quantitative measure of how close the association is between the experimental value, x and model value, y. A value of R near + 1 indicates a very close correlation.

Data gathered from the experiments carried out on the farms at MSU and Clinton County were used to test the predictions of this model. The tractor size, type and size of implement, soil texture, operation speed, operation depth and tractive efficiency were used as inputs to the CPMS model to generate the predicted draft and fuel requirements. The model's predicted drafts for the chisel plow and field cultivator were calculated based on the number of blades or tines at 0.305 meters spacing as indicated by the equation from ASAE D230.4 (ASAE, 1990). Figures 5.1 and 5.2 show example graphs of the predictions from the model plotted against the experimentally measured fuel requirement and draft requirement. The statistical analysis gave the regression lines as shown. Tables 5.4 through 5.10 were the summary of the regression analyses carried out on all the implements used on different types of soil.

The example below shows the data recorded for the moldboard plow operation on Owosso - Marlette-Sandy Loam soil carried out at Clinton County. Table 5.3 shows the experiments carried out using moldboard plow at different operation depths and ground speeds. The experimental data for the ground speed, draft and fuel were recorded using the on-board data acquisition system. The model draft and fuel requirements were calculated based on the experimental values. Figures 5.1 and 5.2 show the prediction of the CPMS Model plotted against the experimental fuel requirement and draft requirement, respectively. The regression equation for the draft requirement is $y = 1.631 + 0.896x$. From the t tests, the intercept is not significantly different from zero at the 0.05 level.

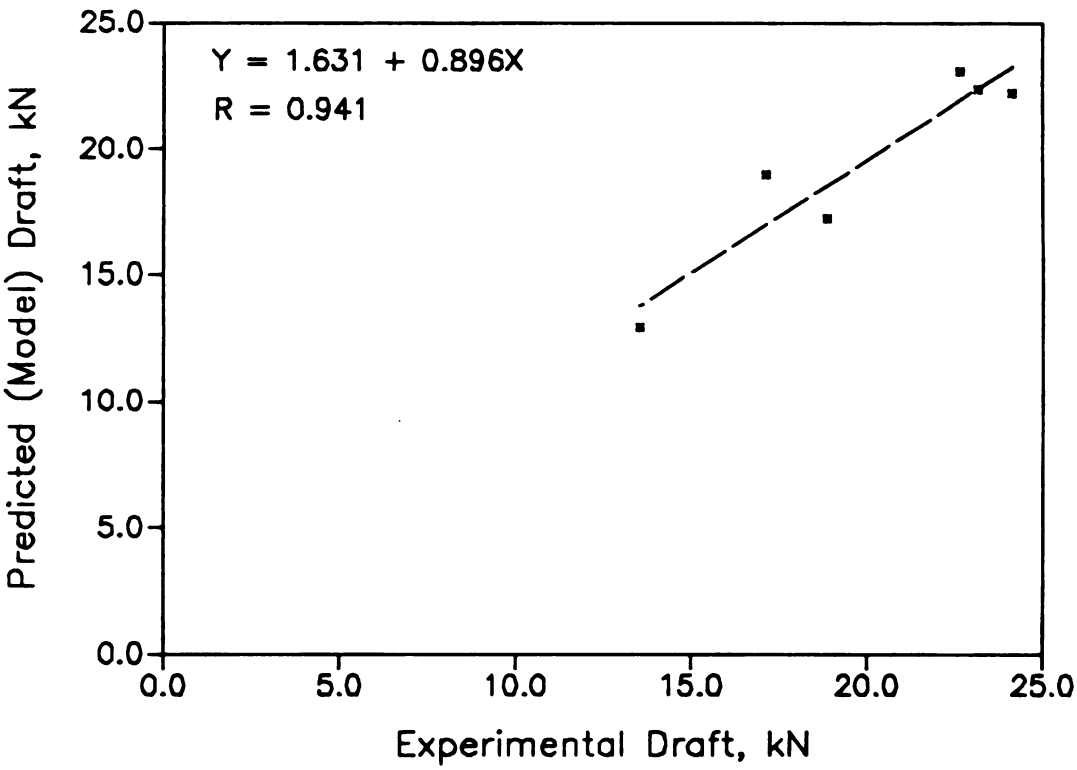

Figure 5.1 Comparison of Draft Requirements for Moldboard Plow on Owosso–Marlette Sandy Loam Soil

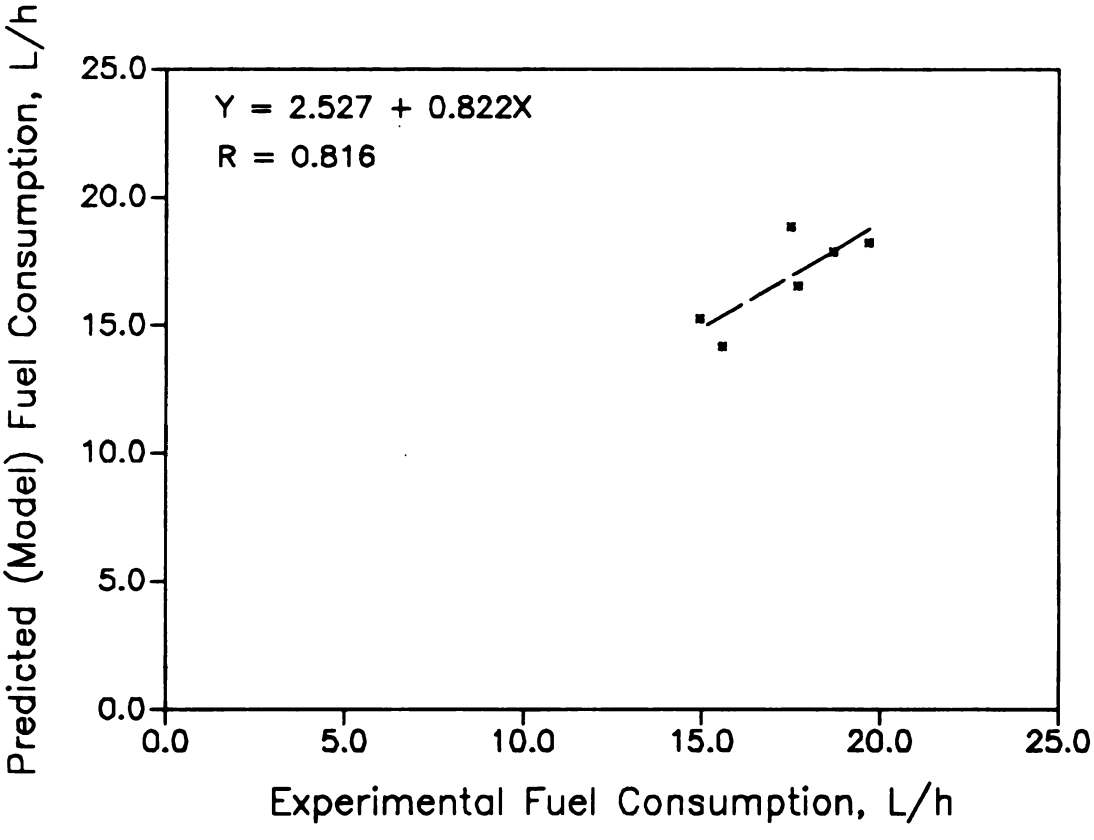

Figure 5.2 Comparison of Fuel Requirements for Moldboard Plow on Owosso–Marlette Sandy Loam Soil

The slope of the draft requirement equation is 0.896, and it is statistically significant at the 0.05 level. We can say that model output for the draft requirement does not differ significantly from field data. R^2 for the above equation is 0.886. This indicates that the variation of the predicted draft requirements is highly explained by the experimental draft requirement. The correlation coefficient was calculated to be 0.941, showing a very close association between the experimental draft and the predicted draft. The regression equation for the fuel requirement is $y = 2.527 + 0.822x$. From the t tests, the intercept is not significantly different from zero at 0.05 level. The slope of the fuel requirement equation is 0.822, and it is statistically significant at the 0.05 level. The model output for the fuel requirement does not differ significantly from field data. About 66.7 percent of the predicted fuel requirements variability is explained by the experimental fuel requirement. The experimental fuel and the model fuel values showed a correlation of 0.816. There was a high correlation across the range of conditions tested between measured and predicted values. The summary of the above analysis is shown in Table 5.5.

Table 5.4 shows the regression analysis for the draft and fuel requirements for the moldboard plow, chisel plow, disk harrow, field cultivator, row crop planter and grain drill. A student's t test was carried out to determine the significance of the intercept and the slope of the regression line. The * beside each coefficient denotes the significant difference at 95 percent level of confidence. An F-statistic was used to determine the relationship expressed by the regression lines. The @ beside the dependent variable y indicates that the model-output does not differ significantly from the field data. For each regression equation, a correlation of coefficient was determined to measure how close the

association between the experimental value, x and model value, y.

Tables 5.5, 5.6, 5.7, 5.8, 5.9 and 5.10 show the summary of the regression analysis for each experiment carried out using the moldboard plow, chisel plow, disk harrow, field cultivator, row crop planter, and grain drill, respectively. These tables provide the regression equations for the draft and fuel consumption and the coefficient of correlation for each experiment and for each implement. The results of the student's t-test on the slope of the regression line and the intercept are discussed in the following paragraphs. Tables A.1 to A.26 in Appendix A show the experimental data and the model or predicted data for each implement tested on different kind of soils at different operation speeds and depths.

Experiments using the moldboard plow were carried out to validate the draft and fuel requirements. A 6-bottom moldboard plow was tested on Owosso-Marlette Sandy Loam and Metamora-Capac Sandy Loam. Experiments were carried out at different operations speeds and depths. Table 5.4 shows that the regression equation for the draft requirement is $y = 0.743 + 0.937x$. From the t tests, the intercept is not significantly different from zero at 0.05 level. The slope is significantly different from zero. The F-statistic shows that the model-output for the draft requirement does not differ significantly from the field data. The correlation of coefficient, R was calculated to be 0.943, showing a very close association between the experimental draft and the predicted or model draft.

The regression equation for the fuel requirement for the moldboard plow operation is $y = 2.167 + 0.844x$. From the t tests, the intercept is not significantly different from zero and the slope is significantly different from zero at 0.05 level. The model output for the fuel requirement does not differ significantly from the field data. There was a high

Table 5.4 Summary of the Regression Analysis for the Implements.

Implement Types	Regression	Regression Equation	Coefficient of Correlation, R
Moldboard Plow	Draft	$Y^{\bullet} = 0.743 + 0.937X^{*}$	0.943
	Fuel	$Y^{\bullet} = 2.167 + 0.844X^{*}$	0.935
Chisel Plow	Draft	$Y^{\bullet} = 2.539^{*} + 0.668X^{*}$	0.974
	Fuel	$Y^{\bullet} = 8.913^{*} + 0.312X^{*}$	0.742
Disk Harrow	Draft	$Y = 8.358 + 0.753X$	0.362
	Fuel	$Y^{\bullet} = 6.600^{*} + 0.656X^{*}$	0.776
Field Cultivator	Draft	$Y^{\bullet} = 7.759^{*} + 0.849X^{*}$	0.869
	Fuel	$Y^{\bullet} = 10.814 + 0.215X^{*}$	0.572
Row Crop Planter	Draft	$Y^{\bullet} = 4.560^{*} + 0.697X^{*}$	0.831
	Fuel	$Y = 8.839^{*} + 0.324X$	0.339
Grain Drill	Draft	$Y^{\bullet} = -4.401^{*} + 2.048X^{*}$	0.847
	Fuel	$Y^{\bullet} = 1.946^{*} + 0.601X^{*}$	0.860

$^{\bullet}$ Model-output does not differ significantly from field data (F-statistic).

* Significant difference at 95 percent level of confidence (*t*-test).

Table 5.5 Summary of the Regression Analysis for the Moldboard Plow.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Metamora Capac Sandy Loam	Draft	$Y^{\bullet} = 1.631 + 0.896X^{*}$	0.941
	Fuel	$Y^{\bullet} = 2.527 + 0.822X^{*}$	0.816
Owosso-Marlette Sandy Loam	Draft	$Y = -0.243 + 0.991X$	0.919
	Fuel	$Y = 1.768 + 0.872X$	0.990

Table 5.6 Summary of the Regression Analysis for the Chisel Plow.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Metamora Capac Sandy Loam	Draft	$Y^{\bullet} = 0.048 + 0.856X^{*}$	0.982
	Fuel	$Y^{\bullet} = 9.628^{*} + 0.247X^{*}$	0.946
Capac Loam Soil	Draft	$Y^{*} = 3.029^{*} + 0.637X^{*}$	0.975
	Fuel	$Y^{\bullet} = 7.552^{*} + 0.429X^{*}$	0.723

$^{\bullet}$ Model-output does not differ significantly from field data (F-statistic).
* Significant difference at 95 percent level of confidence (*t*-test).

Table 5.7 Summary of the Regression Analysis for the Disk Harrow.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (After chisel plow operation)	Draft	$Y^{\bullet}= -23.048 + 3.300X^{*}$	0.835
	Fuel	$Y^{\bullet}= 9.017^{*} + 0.443X^{*}$	0.959
Granby Loamy Sand Soil (no-till area)	Draft	$Y = -4.116 + 1.868X$	0.674
	Fuel	$Y^{\bullet}= 0.224 + 1.140X^{*}$	0.979
Palms Muck Soil (after moldboard plow operation)	Draft	$Y= 12.671^{*} - 0.086X$	0.064
	Fuel	$Y^{\bullet}= 8.793^{*} + 0.605X^{*}$	0.958
Granby Loamy Sand Soil (after moldboard plow operation)	Draft	$Y^{\bullet}= 0.990^{*} + 0.874X^{*}$	0.894
	Fuel	$Y= 6.785 + 0.519X$	0.790
Palms Muck Soil (no-till area)	Draft	$Y = 0.792 + 1.419X$	0.610
	Fuel	$Y = 17.814^{*} - 0.127X$	-0.486

• Model-output does not differ significantly from field data (F-statistic).
* Significant difference at 95 percent level of confidence (*t*-test).

Table 5.8 Summary of the Regression Analysis for the Field Cultivator.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (after chisel plow & d.harrow)	Draft	$Y^{\bullet} = 7.363^{*} + 0.801X^{*}$	0.921
	Fuel	$Y^{\bullet} = 7.568^{*} + 0.409X^{*}$	0.800
Capac Loam Soil (after mb plow & d.harrow)	Draft	$Y^{\bullet} = 5.973^{*} + 1.102X^{*}$	0.860
	Fuel	$Y = 10.513^{*} + 0.263X^{*}$	0.595
Capac Loam Soil (no-till area)	Draft	$Y^{*} = 8.960^{*} + 0.683X^{*}$	0.942
	Fuel	$Y = 12.245^{*} + 0.116X$	0.646

• Model-output does not differ significantly from field data (F-statistic).

* Significant difference at 95 percent level of confidence (*t*-test).

Table 5.9 Summary of the Regression Analysis for the Row Crop Planter

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Palms Muck Soil	Draft	$Y^{\bullet} = 9.300^{*} + 0.407E\text{-}05X^{*}$	1.000
	Fuel	$Y = 9.290^{*} + 0.096X$	0.891
Capac Loam Soil	Draft	$Y^{\bullet} = 12.000^{*} - 0.421E\text{-}05X^{*}$	1.000
	Fuel	$Y^{\bullet} = 8.010^{*} + 0.451X^{*}$	0.849
Gilford Sandy Loam	Draft	$Y^{\bullet} = 9.300 + 0.328E\text{-}04X^{*}$	1.000
	Fuel	$Y^{\bullet} = 12.268^{*} + 0.0712X^{*}$	0.953

$^{\bullet}$ Model-output does not differ significantly from field data (F-statistic).

* Significant difference at 95 percent level of confidence (*t*-test).

Table 5.10 Summary of the Regression Analysis for the Grain Drill.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (after moldboard plow)	Draft	$Y^{\bullet} = 6.751^{*} - 0.101E\text{-}03X^{*}$	1.000
	Fuel	$Y = 8.600 + 0.068X$	0.173
Capac Loam Soil (after chisel plow)	Draft	$Y^{\bullet} = 6.750^{*} - 0.199E\text{-}05X^{*}$	1.000
	Fuel	$Y = 8.206^{*} + 0.421E\text{-}01X$	0.219
Granby Loamy Sand Soil (after mb plow & d.harrow)	Draft	$Y = 2.340 + 0.204E\text{-}05X^{*}$	1.000
	Fuel	$Y^{\bullet} = -0.529 + 0.741X^{*}$	0.959
Granby Loamy Sand Soil (no-till)	Draft	$Y^{\bullet} = 2.900^{*} + 0.158E\text{-}05X^{*}$	1.000
	Fuel	$Y^{\bullet} = 2.910^{*} + 0.395X^{*}$	0.995

$^{\bullet}$ Model-output does not differ significantly from field data (F-statistic).

* Significant difference at 95 percent level of confidence (*t*-test).

correlation of 0.935, showing a very close association between the experimental fuel and the predicted or model fuel. Table 5.5 show the regression analysis for each experiment carried out using the moldboard plow for each soil type.

Two different sizes of chisel plow were used to validate the draft and fuel requirements. The 2.5-m chisel plow was experimented on Metamora-Capac Sandy Loam. The 2.2-m chisel plow was experimented on Capac Loam Soil. All experiments were carried out at different operation speeds and depths. Table 5.4 shows the regression analysis for the chisel plow operation. The model output for the draft and fuel requirements for the chisel plow operations do not differ significantly from the field data. There was a high correlation of 0.974, showing a very close association between the experimental draft and the predicted or model draft. The correlation coefficient was calculated to be 0.742, showing a close association between the experimental fuel consumption and the predicted fuel consumption. Table 5.6 shows the regression analysis for each experiment carried out using the chisel plow for each soil type.

Three different sizes of disk harrow were used to validate the draft and fuel requirements. The 3.04-m and 3.96-m disk harrows were tested on Palms Muck Soil and Granby Loamy Sand Soil. The 4.27-m disk harrow was tested on Capac Loam Soil. All experiments were carried out at different operation speeds and depths. Table 5.4 shows the regression analysis for the disk harrow operation. The F - statistic shows that the model output for the draft requirement is statistically different from the field data. There was a low correlation coefficient of 0.362, showing a low association between the experimental draft and the model draft. The model draft equation obtained from the ASAE STANDARDS (ASAE, 1990) and FMO, 1987 is dependent on speed and does not

include the operation depth, as depicted by the experiment. The model output for the fuel requirement does not differ significantly from the field data. There was a correlation of 0.776. Table 5.7 shows the regression analysis for each experiment carried out using the disk harrow operations on different kind of soil.

Experiments using the field cultivator were carried out on Capac Loam Soil on an untilled area, after moldboard plowing and disk harrowing, and after chisel plowing and disk harrowing. Table 5.4 shows the regression analysis for the field cultivator operation. The model outputs for the draft and fuel requirements for the field cultivator operations do not differ significantly from the field data. There was a high correlation for the draft requirement of 0.869, showing a very close association between the experimental draft and the model draft. The correlation coefficient for the fuel requirement was 0.572. Table 5.8 shows the regression analysis for each experiment carried out using the field cultivator operations on different kind of soil.

Experiments using the row crop planter were carried out on Capac Loam Soil, Palms Muck Soil and Gilford Sandy Loam on no till and previously plowed areas. Table 5.9 shows that the experiments carried out using the row crop planter show a high correlation of 1.00, showing a perfect association between the experimental draft and the model draft. The model output for the draft requirement does not differ significantly from the field data. The model draft equation obtained from the ASAE STANDARDS (ASAE, 1990) is dependent on width and independent of the operation speed. Thus the model draft obtained was at zero slope.

The data obtained from the experiment and the model for all the experiments using the row crop planter were combined and analyzed. Table 5.4 shows that the model output

for the draft requirement for the row crop planter operations does not differ significantly from the field data. The correlation coefficient was calculated to be 0.831, showing a close association between the experimental draft and the model draft. The F-statistic shows that the model output for the fuel requirement for the row crop planter operations is statistically significant from the field data. The correlation coefficient was calculated to be 0.339. There was a low association between the experimental fuel requirement and the model fuel requirement. Table 5.9 shows that correlation coefficients for the individual row crop planter operation on different soils were 0.849, 0.891 and 0.953. Those coefficients show that there were close association between the experimental fuel requirement and the model fuel requirement. The above results indicate that the regression analysis for the row crop planter operation on specific soil type gave a higher correlation.

Three different sizes of grain drills were used in the experiment to validate the draft and fuel requirements. The 2.84-m grain drill was tested on previously moldboard plowed and previously chisel plowed areas on a Capac Loam Soil. The 3.05-m grain drill was tested on a Grandby Loamy Sand Soil that was previously moldboard plowed and disk harrowed. The 1.83-m grain drill was tested on a non tilled Grandby Loamy Sand Soil. Table 5.10 shows that the experiments carried out using the grain drill show a high correlation of 1.00, showing a perfect association between the experimental draft and the model draft. The model output for the draft requirements does not differ significantly from the field data. The model draft equation obtained from the ASAE STANDARDS (ASAE, 1990), is dependent on width and independent of operation speed. Thus, the model draft obtained has a zero slope.

The data obtained from the experiments and the model using the grain drill were combined and analyzed. Table 5.4 shows that model outputs for the draft and fuel requirements for the grain drill operations do not differ significantly from the field data. The correlation of coefficient for the draft and fuel requirement regression equations were 0.847 and 0.860 respectively. There were a close association between the experimental values and the model values.

In summary, the model outputs of the moldboard plow operations, chisel plow operations, field cultivator operations, row crop planter operations and grain drill operations for the draft requirements do not differ significantly from the field data. There were very close association between the experimental draft and the predicted draft for the experiments of the above implements.

The model output of the disk harrow operations for the draft requirement is statistically different from the field data. There was a low association between the experimental draft and the model draft for the disk harrow operations. The low coefficient of determination indicates that the variation of the predicted draft requirement is not well explained by the experimental draft requirement. Research should be carried out to determine the disk harrow draft equation that also depends on the depth of operation.

The model draft regression equations for the row crop planter and the grain drill show a zero or almost zero slope. The drafts stay constant which is independent of the operation speed. There was a perfect association between the experimental draft and the model draft for the individual row crop planter and grain drill operations. The correlation of coefficient was reduced when all the experiments were combined. Research should be

carried out to determine the row crop planter and grain drill draft equations to reduce the variability among the experiments.

The model outputs of the moldboard plow operations, chisel plow operations, field cultivator operations, disk harrow operations and grain drill operations for the fuel requirements do not differ significantly from the field data. There was very close association between the experimental fuel requirement and the predicted fuel requirement for the above implements. There was a low correlation between the experimental fuel requirement and the model fuel requirement for the overall row crop planter experiment. There was a high correlations between the experimental fuel and the model fuel for the individual row crop planter experiments. The variations of the experimental draft affect the model fuel consumption. Thus, further research must be carried out.

6. IMPLEMENTATION OF THE MODEL

6.1 CPMS Executable Files

The CPMS program was written in Turbo Pascal programming language, with executable files which are program files that can execute independently without the use of any programming language. The CPMS program consists of five executable files, namely INTRO, DATA, DATECROP, MACHCOST and MACH2A.

The CPMS batch file was created to access the above executable files. The user has the option of using the CPMS batch file or executing directly from each program file. The CPMS batch file is accessed by typing "CPMS" at the prompt. The program will execute the "INTRO" file which asks if the user would like an introduction to the program. The next executable file will be the DATA file followed by the DATECROP file. The CPMS batch file will finally execute the MACH2A executable file, which is the main program.

The DATECROP file enables the user to create an external file of the operation dates for a maximum of five crops. The five crops selected in this program consist of corn, field beans, wheat, oats and soybeans. The program can be changed to other crops if necessary. The user will have the choice of using any or all of the crops given in the program. For each crop, the user will enter the dates for the continuous operation from primary tillage to planting or the dates for the individual operation for primary tillage,

secondary tillage and planting.

The DATA executable file enables the user to create external data files for known implement parameters. The user has the choice of using metric units or English units in creating DATA files. The English units are converted by the program to metric units for use by the main program. The parameters needed are implement width, ground speed, tillage depth, field efficiency, tractive efficiency, purchase price, age, and expected life. Other parameters required are the fuel price, oil price, labor wage, and interest rate.

The MACH2A is the main program consisting of the Tractor and Machinery Selection Model and Tractor and Machinery Cost Analysis Model. The outputs of the former model are the inputs to the latter model. The implement and tractor field times and power requirements from the Tractor and Machinery Selection Model are used to determine the costs in the Tractor and Machinery Cost Analysis Model.

The user has the option of using external files or using the computer keyboard to enter the values required to execute the main program. The external files include the DATECROP file and DATA file, and these files must be given a file name before being retrieved into the main program. The DATECROP file consists of the dates of operation. The dates of operation cannot be changed in the main program when using the external DATECROP file. The implement parameters retrieved from the external DATA file into the main program will be saved in the computer memory. The user can change the implement parameters in the main program. This flexibility allows the user to determine the most suitable implement size to be used for the crop production. The main program also allows the user to save the implement parameters into a file similar to the external DATA file. Simultaneously, it will also allow the user to save the implement field time,

implement power requirement, and tractor size to an external file. Both files can be saved after the tractor and machinery selection for each crop and also at the end of the main program. Saving the files at the end of the tractor and machinery selection for each crop will save the implement operation speed, operation depth, width, field efficiency, tractive efficiency, tractor sizes, and tractor and implement field time. Saving the files at the end of the main program will save these data as well as the fuel price, oil price, labor wage, interest rate, and the tractor and machinery purchase prices, ages and expected lives. The DATA file and the tractor and implement field time file are to be used for the MACHCOST program. The MACHCOST program is used to analyze the tractor and machinery cost of the selected tractors and implements, whereas the MACH2A main program analyzes the machinery selection as well as machinery costs. The user is not required to save the outputs from the Tractor and Machinery Selection Model to be used for the Tractor and Machinery Cost Analysis Model using the MACH2A main program.

The MACHCOST is an executable file to analyse the cost for the tractors and implements selected in the main program, MACH2A. It is similar to the Tractor and Machinery Cost Analysis Model of the MACH2A program. It requires the data obtained from the Tractor and Machinery Selection Model to be saved from the MACH2A program. This program is provided for the convenience of a user who does not want to continue the cost analysis provided in the MACH2A program.

6.2 Implement and Tractor Sizes Selection

The methodology to determine the minimum and maximum implement and tractor

sizes were discussed earlier in Section 4.4.3. The methodology of determining the implement size depends on the available field operation time, area of operation, tractor size, and type and number of implements to be used. When the tractor size is unknown, the program will calculate the approximate tractor size based on the number of implements to be used. The recommended implement and tractor sizes may not necessarily be commercially available.

Example 1:

Location: East Lansing Soil texture: Coarse Crop: Corn

Date of operation:

Beginning primary tillage operation : April 11

Ending planting operation : May 22

Number of hours per day : 12

Area of operation: 100 ha

From the above dates of operation :

Field operation time = d * pwd * hd

= [(19 * 0.34) + (22 * 0.663)] * 12 = 252.5 h.

assumed speed = 7.2 km/h

depth of operation = 10 cm

Field efficiency = 0.8

tractive efficiency = 0.75

Table 6.1 shows the implement sizes determined by the program. The first column indicates the type of implements used on the farm. Columns (a) to (d) show various combinations of implements to be used for a farm operation. The program determines the size of each implement in a set of implements selected. The implement size changes with the number and type of implements used. Columns (a) and (b) indicate that implement size decreased when fewer implements and fewer tillage operations were used. More field operation time was available with fewer implements and fewer passes across the field for a given crop. Replacing the moldboard plow with a chisel plow increased the size of other implements (a and c). Replacing the row crop planter with a grain drill increased the size of other implements (c and d). Thus, different implement combinations required different size implements for the same dates and area of operation. The above implements, when chosen, utilized all of the available field operation time. Smaller implements required more time and larger implements required less time to complete operations for the given farm. Larger implements required a larger tractor. The tractor size was calculated based on the primary tillage implement size. In each case (a through d) the selected tractor size was compatible with all implements selected for the continuous farm operation.

Table 6.2 demonstrates the effect of the area of operation and tractor size on the implement sizes. Comparisons were carried out for the conventional tillage system using moldboard plow, disk harrow, field cultivator and row crop planter for different sizes of farm. Column (a) here was obtained from column (a) of Table 6.1. It shows the recommended implement sizes and tractor size for a 100-ha farm. Using the recommended implements will utilize all of the available field operation time and all of

Table 6.1 Implement Size Determined by the Model for a 100-Ha Corn Farm with Coarse Soil.

	(a)	(b)	(c)	(d)
Chisel Plow			1.79	1.82
Moldboard Plow	2.02	1.19		
Disk Harrow	6.49	3.82	6.95	7.06
Field Cultivator	1.67		1.79	1.82
Row Crop Planter	4.79	2.82	5.13	
Grain Drill				4.64
Tractor Size,kW	24.41	14.38	26.14	26.58

the power available from the tractor. The recommended or selected tractor sizes as in columns (a) and (c) are able to pull any of the implements in their respective column. Column (b) shows the implement field time for the respective implements to complete the 100-ha farm during a specified duration of time. The total field time required to complete all the operations was 252.49 hours. Column (c) shows the recommended implement sizes based on a tractor size of 40 kW. Column (d) shows the implement field time for the implement sizes of column (c) for a 100-ha farm. The total field time required to complete the 100-ha farm was calculated to be 154.10 hours. Column (d) demonstrates that there were 98.46 hours unutilized when using larger implements for a 100-ha farm.

Table 6.2 Implement Size with the Required Time to Complete the Field Operations for a 100-Ha Corn Farm with Coarse Soil.

	(a)	(b)	(c)	(d)
	size	time	size	time
Moldboard Plow	2.02	85.79	3.32	52.35
Disk Harrow	6.49	26.76	10.63	16.33
Field Cultivator	1.67	103.73	2.74	63.33
Row Crop Planter	4.79	36.21	7.85	22.10
Area ,ha	100		163.89	
Tractor Size,kW	24.41		40	
Total Field Time,h		252.49		154.10

The program recommended the land area of 163.89 hectares to fully utilize the recommended implement sizes of column (c).

Columns (a) and (c) show that the larger farm size required larger implements. The larger farm size and larger implement size required a larger tractor. Using a larger tractor with smaller implements will waste the tractor power. Using implement sizes larger than recommended will not utilize all of the available field operation time.

Table 6.3 shows the implement sizes, implement field times, and tractor sizes required for each soil texture to complete a 100-ha corn farm. The cumulative field time

for all implements computed for each soil texture indicates that these combinations of implement sizes can complete the farm operations on time. The fine soil required a larger tractor but not necessarily larger implements.

Table 6.4 demonstrates that the program also determines the minimum implement width based on the available field time left by an earlier implement operation. This example demonstrates the operation using the moldboard plow (M'board), disk harrow (Harrow), field cultivator (F.cult) and row crop planter (Planter). The available field operation time was calculated to be 252.5 hours. Column (d) shows the implement sizes recommended by the program for a 100-ha farm. These implements when chosen, utilized all of the available field operation time. In this example it was assumed that the user used all of the recommended implements and also wanted to know the option of other implement sizes based on the unused field time left by the earlier implement operations.

The Procedure MOLDBOARD in the main program calculated the field time required by the 2.02-m moldboard plow and also recommended the minimum moldboard plow size to complete the farm operation based on the available field operation time. In this case, the available field operation time of 252.5 hours was used to determine the minimum moldboard plow size. Column (a) shows that the 0.69-m moldboard plow required 252.5 hours to complete the farm operation. The 2.02-m moldboard used about 85.79 hours leaving 166.71 hours available for the other implement operations. The Procedure HARROW then calculated the field time required by the 6.49-m disk harrow and also recommended the minimum disk harrow width based on the available left by the moldboard plow. Column (b) shows that the minimum disk harrow width of 1.04 meters

Table 6.3 Implement Size and Field Time for 100-Ha Farm with Different Soil Textures.

	coarse soil		medium soil		fine soil	
	size	time	size	time	size	time
M'board	2.02	85.79	2.16	80.26	1.51	115.3
Harrow	6.49	26.76	3.32	52.24	2.92	59.39
F.Cult.	1.67	103.7	2.20	78.94	3.00	45.68
Planter	4.79	36.21	4.23	41.08	5.39	32.21
Time,h		252.5		252.5		252.5
Tractor Size,kW	24.41		30.32		49.90	

Table 6.4 Minimum Implement Width Based on Available Field Operation Time for a 100-Ha Farm with Coarse Soil.

	(a)		(b)		(c)		(d)	
	size	time	size	time	size	time	size	time
M'board	0.69	252.5	2.02	85.79	2.02	85.79	2.02	85.79
Harrow			1.04	106.6	6.49	26.76	6.49	26.76
F.Cult.					1.24	140.00	1.67	103.8
Planter							4.79	36.20
Time,h		252.5		252.40		252.60		252.22

used up the 166.43 hours unused from the moldboard plow operation. Column (b) shows that the 2.02-m moldboard plow and 1.04-m disk harrow used all of the field operation time. The 6.49-m disk harrow used about 26.76 hours. The 2.02-m moldboard plow and 6.49-m disk harrow used a total of 112.55 hours leaving 139.95 hours for the field cultivator and row crop planter operations. The available field time unused after the operation of the 2.02-m moldboard and the 6.49-m disk harrow was then used to calculate the minimum width for the field cultivator. Column (c) shows that the minimum field cultivator width of 1.24 meters used up the 139.95 hours unused from the previous implement operations. Column (d) shows that the 2.02-m moldboard plow, 6.49-m disk harrow, and 1.67-m field cultivator used a total of 216.35 hours leaving 36.15 hours for the row crop planter. The minimum row crop planter width of 4.79 meters used up the 36.15 hours from the previous implement operations.

Example 2:

Location: East Lansing Soil texture: coarse Crop: corn

Individual dates of operation

(a) Primary tillage operation

Beginning dates of operation	:	October 20
Ending dates of operation	:	November 30
Number of hours per day	:	10
Field operation time,hours	:	146.60

(b) Secondary tillage operation

Beginning dates of operation	:	April 15

Ending dates of operation	:	May 10
Number of hours per day	:	12
Field operation time,hours	:	140.76

(c) Planting operation

Beginning dates of operation	:	May 11
Ending dates of operation	:	May 22
Number of hours per day	:	12
Field operation time,hours	:	87.52

Area of operation: 100 ha

assumed speed	=	7.2 km/hr
depth of operation	=	10 cm
field efficiency	=	0.8
tractive efficiency	=	0.75

Example 2 shows dates for the individual operations different from those used in Example 1. The primary tillage operation was carried out in the Fall with a total field operation time of 146.60 hours. The secondary tillage and planting operations were to be carried out in the Spring with total field operation times of 140.76 hours and 87.52 hours, respectively. The program advises the user not to overlap the dates of operation, especially for operations using the same tractor. The user planned to start secondary tillage on April 15 and to complete the planting operation on May 22. The user had 11

days to complete the planting operation. If the secondary tillage was completed earlier, the user could use the available field time unused for tillage to complete the planting operation.

Table 6.5 demonstrates the effect of implement sizes on field operation time that is not continuous. For the individual farm operation, the 1.18-m chisel plow required 146.60 hours, the 1.23-m disk harrow required 140.76 hours, and the 1.98-m row crop planter required 87.52 hours. The chisel plow, disk harrow and row crop planter were found to fulfill the field time requirements for each operation. For the individual operation as shown in column (a), the recommended tractor size of 17.28 kW was based only on the primary tillage implement, namely the chisel plow in this example.

Column (b) shows the maximum implement sizes calculated for the computed tractor size of 17.28 kW. The field times unused after the chisel plow, disk harrow and row crop planter operations were calculated to be 0 hours, 26.35 hours and 25.58 hours, respectively. These selected implement sizes utilized the maximum power available from the tractor but did not fully utilize the available field operation time for secondary tillage and planting. The implements recommended above are not necessarily available in the market. Thus, the user had to select commercially available implements to be used in the program. For this example farm, the selected commercially available implements had to be at least as large as the implement sizes in column (a) to complete the operations within the time constraints.

6.3 Implement Analysis

Examples in this section demonstrate the implement analysis using flow charts.

Table 6.5 Implement Size and Field Time for the Individual Farm Operation.

	(a)		(b)	
	size	time	size	time
Chisel Plow	1.18	146.60	1.18	146.60
Harrow	1.23	140.76	1.52	114.41
Planter	1.98	87.52	2.85	61.94
Area,ha	100			
Tractor Size	17.28			
Recommended Area,ha			100.03	
Selected Tractor,kW			17.28	

This example was for a 100-ha of corn farm with coarse soil located at East Lansing. The implements used were a 6-bottom moldboard plow, 2.74-m (9 ft) disk harrow, 2.74-m (9 ft) field cultivator, and a 12-row planter. The field times required by the moldboard plow, disk harrow, field cultivator and row crop planter were calculated to be 73.19, 70.19, 47.71, and 28.48 hours, respectively. The power requirements calculated for the moldboard plow, disk harrow, field cultivator and row crop planter were 60.66 kW, 25.41 kW, 56.91 kW and 48.5 kW, respectively.

Figure 6.1 demonstrates the four implement operations using one tractor for a continuous farm operation. The selected 65 kW tractor was able to pull all of the required implements. The available field operation time was calculated to be 223.99 hours, and was compared to the field time required by the moldboard plow to complete the farm operation. The field time unused by the moldboard plow operation was then compared to the field time required by the disk harrow to complete the farm operation. The field time unused after the disk harrow operation was compared to the field time required by the field cultivator, and finally, the field time unused after the field cultivator operation was compared to the field time required by the row crop planter. Figure 6.1 shows that the field time of moldboard plow, the cumulative field time for moldboard plow and disk harrow, the cumulative field time for moldboard plow, disk harrow and field cultivator, and the cumulative field time for moldboard plow, disk harrow, field cultivator and row crop planter were all less than the available field operation time. The field time unused after the planting operation was 4.43 hours. Thus, this set of implements selected was suitable, although the tractor power was under utilized in pulling the disk harrow.

Figure 6.2 demonstrates the use of two tractors with individual dates of farm operations in the same season. The operation was carried out on a 100 ha-farm of coarse soil at East Lansing. The first tractor was used only for the moldboard plow, and the second tractor was used for the disk harrow, field cultivator and row crop planter. The tractor and implement sizes were kept the same as in the previous example for the field time comparison purposes. The field operation time for the primary tillage was calculated to be 144.43 hours. The field time unused by the first tractor was 71.24 hours indicating

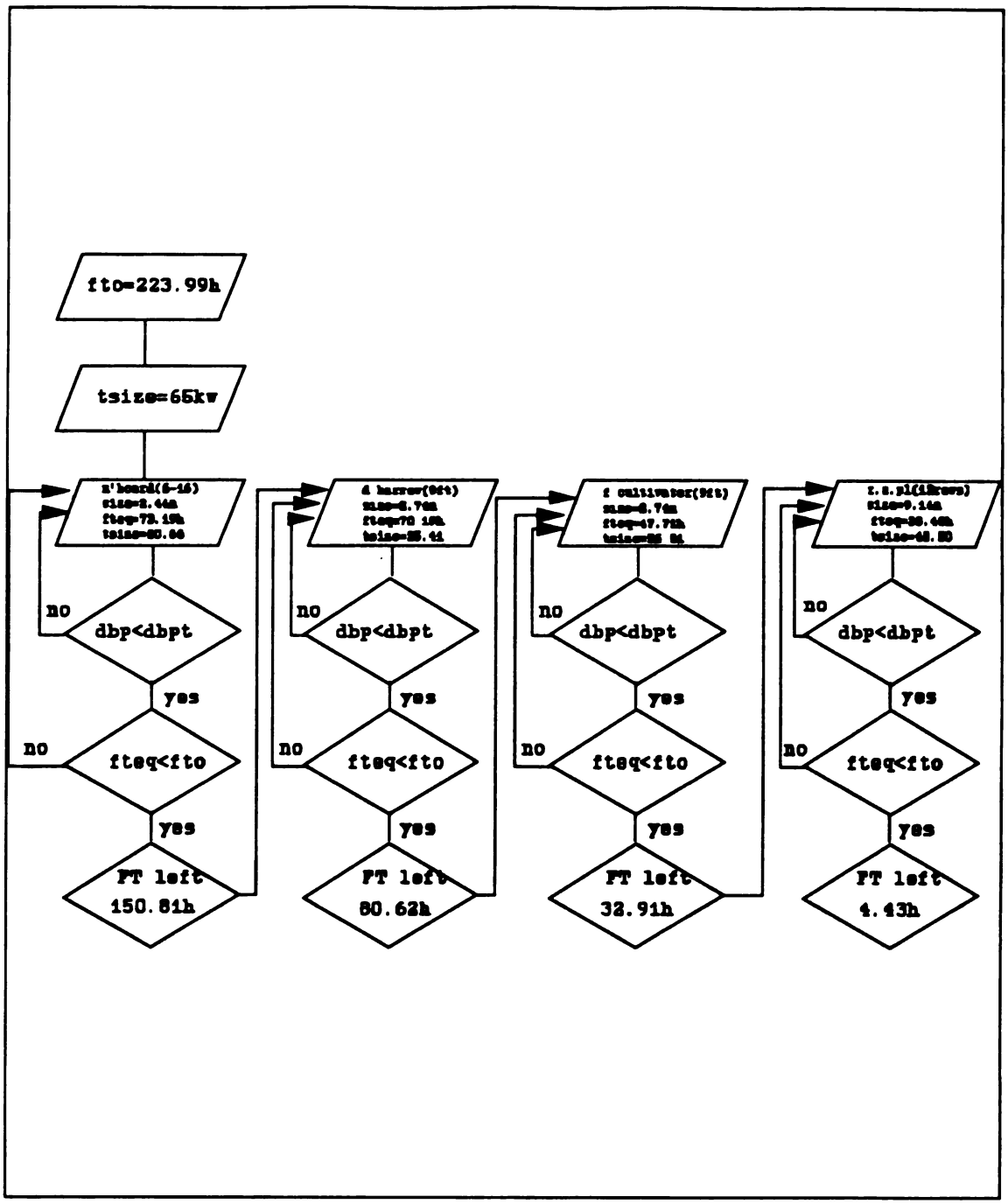

Figure 6.1 Farm Operations on 100 Ha of Coarse Soil Using One Tractor.

Begin date of operation : April 18 Ending date of planting : May 22 H/day = 12

Field operation time : 223.99 hours Tractor size selected : 65 kW

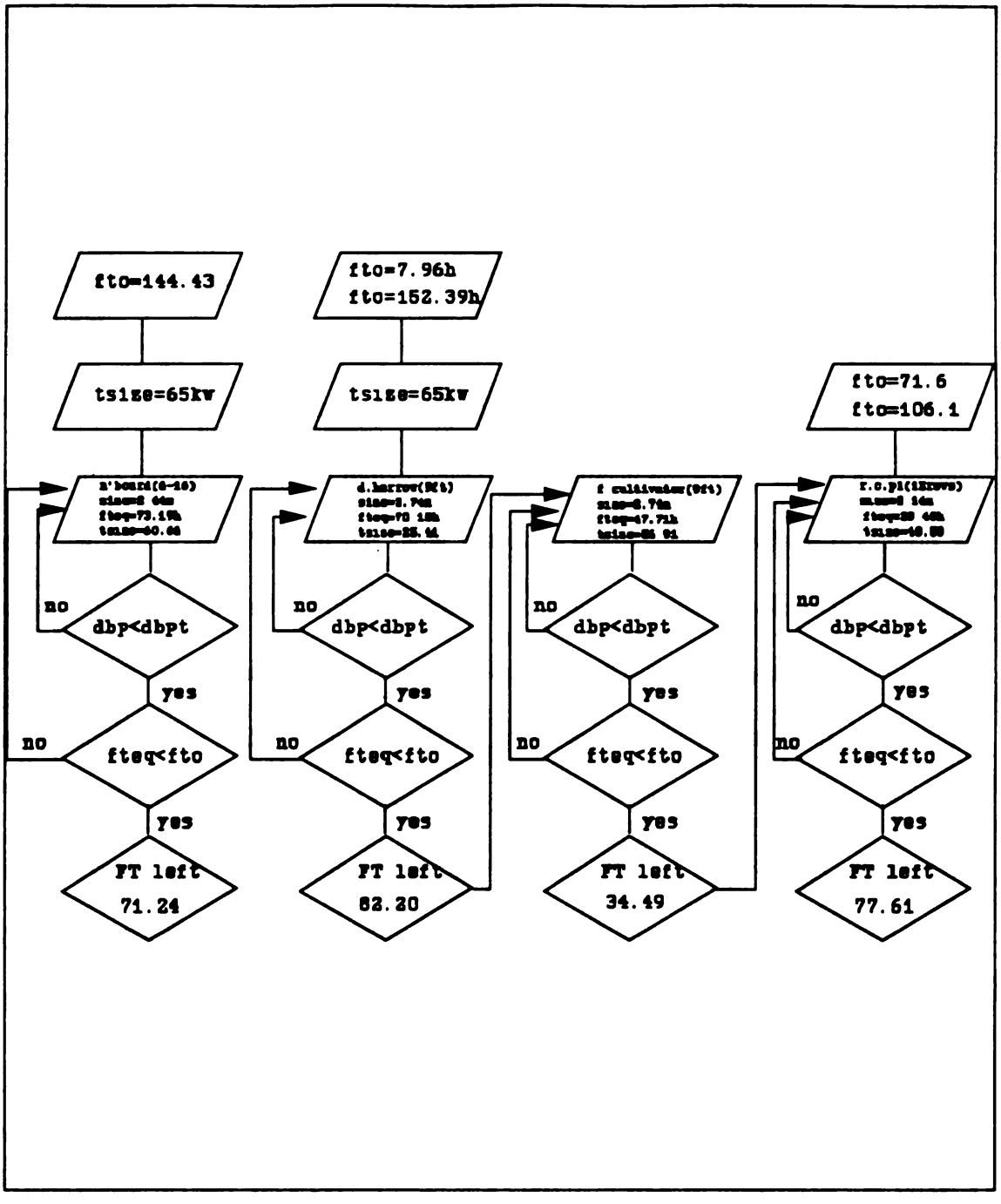

Figure 6.2 Farm Operation on 100 Ha of Coarse Soil Using Two Tractors.

Primary Tillage Operation: 4/18-5/12 Secondary Tillage Operation: 4/18-5/13

Planting Operation : 5/13-5/22 First tractor: 65 kW Second tractor: 65 kW

that the user could have used a smaller moldboard plow or else this tractor had to be left idle. The user had an option of using this tractor with the moldboard plow to cover additional area or with another implement which required a field time less than 71.24 hours to complete the operation.

The program allows the user to have the choice of using the field time unused by an earlier implement to be used for a later implement. The decision to use the unused field time from the earlier implement depends on the dates of operation and the tractor used. In this example farm the individual primary tillage, secondary tillage and planting operations were carried out in the same season. The secondary tillage operation was carried out simultaneously with the primary tillage operation because of the use of different tractors. The available field operation times for secondary tillage and planting was calculated to be 152.39 hours and 71.60 hours, respectively. The field time required by the disk harrow was compared with the 152.39 hours. The field time required by the field cultivator was added to the field time required by the disk harrow before being compared to the field operation time. The total field time unused by the disk harrow and field cultivator was calculated to be 34.49 hours. This unused field time was carried to the planting operation, making 106.10 hours available to be used by the planter. The row crop planter required 28.48 hours, thus leaving 77.61 hours unused. If the dates to begin planting had to be fixed on May 13, the program would have used the available field operation time of 71.60 hours based on the dates given. Then, the unused field time after planting would have been 43.12 hours.

Figures 6.3a and 6.3b demonstrate various options for the tractor-implement combinations to satisfy the field time requirements. The same implements and implement

sizes were used as in the previous example with more restrictive time constraints. Figure 6.3a shows the field time algorithm for the corn farm operations on a 100-ha farm of coarse soil using one tractor. Table 6.6 shows the dates of operation and field operation times. The operations were carried out continuously from April 29 to May 17, with a field operation time of 139.33 hours. Figure 6.3a shows that the total field time required for the moldboard plow and disk harrow was more than the available field operation time by 4.04 hours. The user had the options of using more than one tractor for this farm or using a larger tractor with larger implements. The user had the option of using the first tractor for the moldboard plow and field cultivator and/or planter and using the second tractor for the disk harrow and other implements. The user could also have used this disk harrow and continued to complete the disk harrow operation using another similar disk harrow with the next tractor. This strategy would have increased the number of implements and tractors. In this example, the user chose not to use the disk harrow with the first tractor. The second tractor was chosen to be used for the disk harrow, field cultivator and row crop planter. Figure 6.3b shows that the cumulative field time for the disk harrow, field cultivator and row crop planter was more than the available field operation time by 7.05 hours. This situation caused a delay for planting and harvesting which means an addition of timeliness cost. The program allows the parameters of the last implement in execution to be changed.

Figure 6.3c, shows that the user opted to use the moldboard plow and field cultivator with the first tractor, and Figure 6.3d shows the disk harrow and row crop planter used with the second tractor. The implement field times for the moldboard plow, disk harrow, field cultivator, and row crop planter were 73.19, 70.19, 47.71, and 28.48

Table 6.6 Dates of Operation and Field Operation Time.

	Corn	Field beans	Wheat
Dates of Operation	4/29 - 5/17	5/17 - 6/1	9/18 - 10/9
Number of h/day	12	12	12
Field Operation Time,h	139.33	111.38	168.84

hours, respectively. The disk harrow operation was carried out simultaneously with the moldboard plowing. Both plowing and disking operations were assumed to be completed after about the same duration of time. The planting operation had to be completed after the field cultivator operation. Thus, the planting operation has to start at least 19.23 hours after the start of field cultivator operation to ensure that the tillage is completed before the planting. The unused field time calculated by the program for the second tractor had to be readjusted and decreased by 19.23 hours. The user could also have opted to use the moldboard plow and row crop planter with the first tractor, and the disk harrow and field cultivator with the second tractor. In this case, the field times unused by the first tractor and second tractor were calculated to be 37.67 hours and 21.44 hours, respectively. Thus, this program with the use of Expert System concept will allow the user to be knowledgeable about the problem and allow the user to make wise decisions.

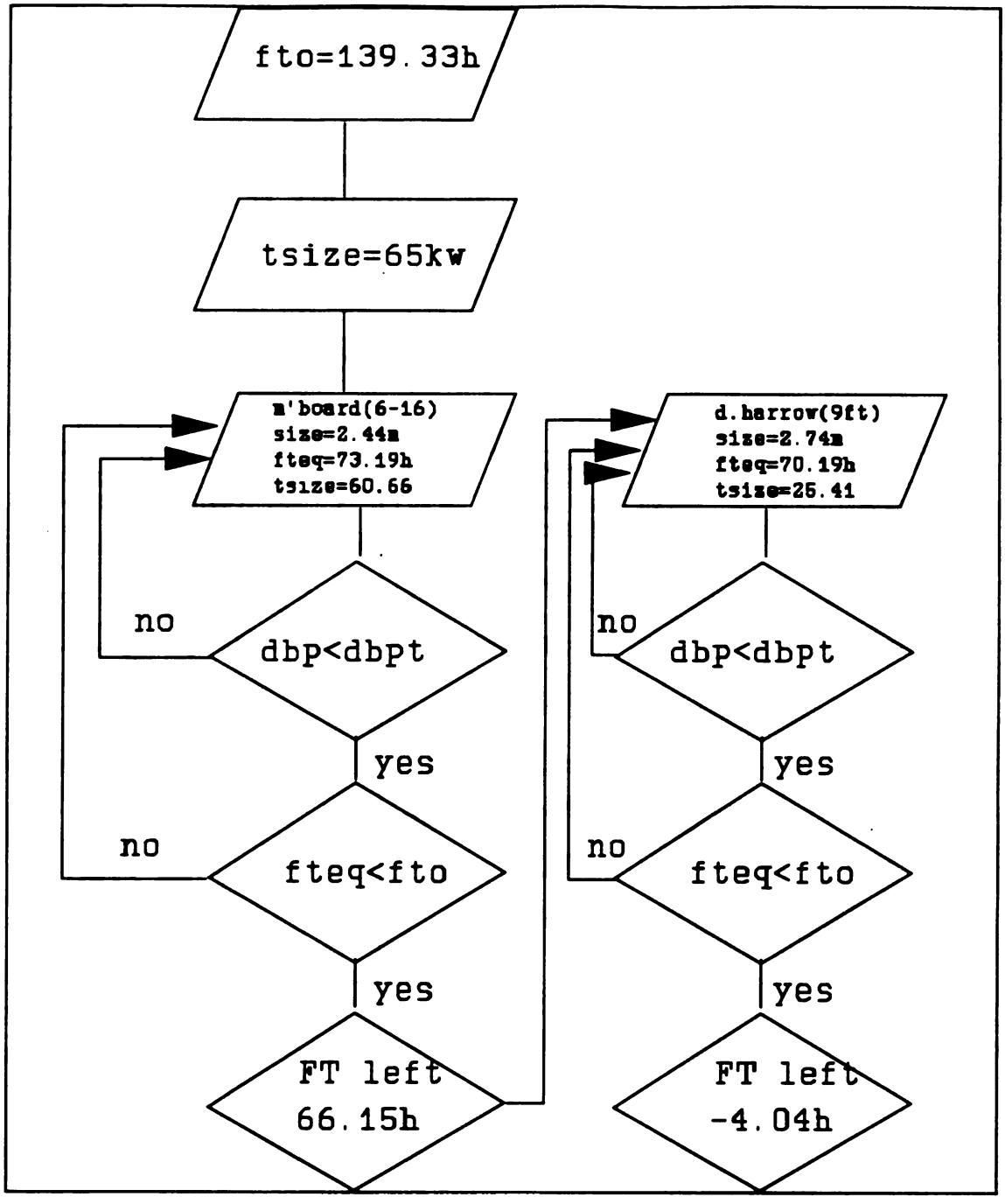

Figure 6.3a: Field Time Algorithm for Corn Farm Operations on 100-Ha of Coarse Soil Using One Tractor.

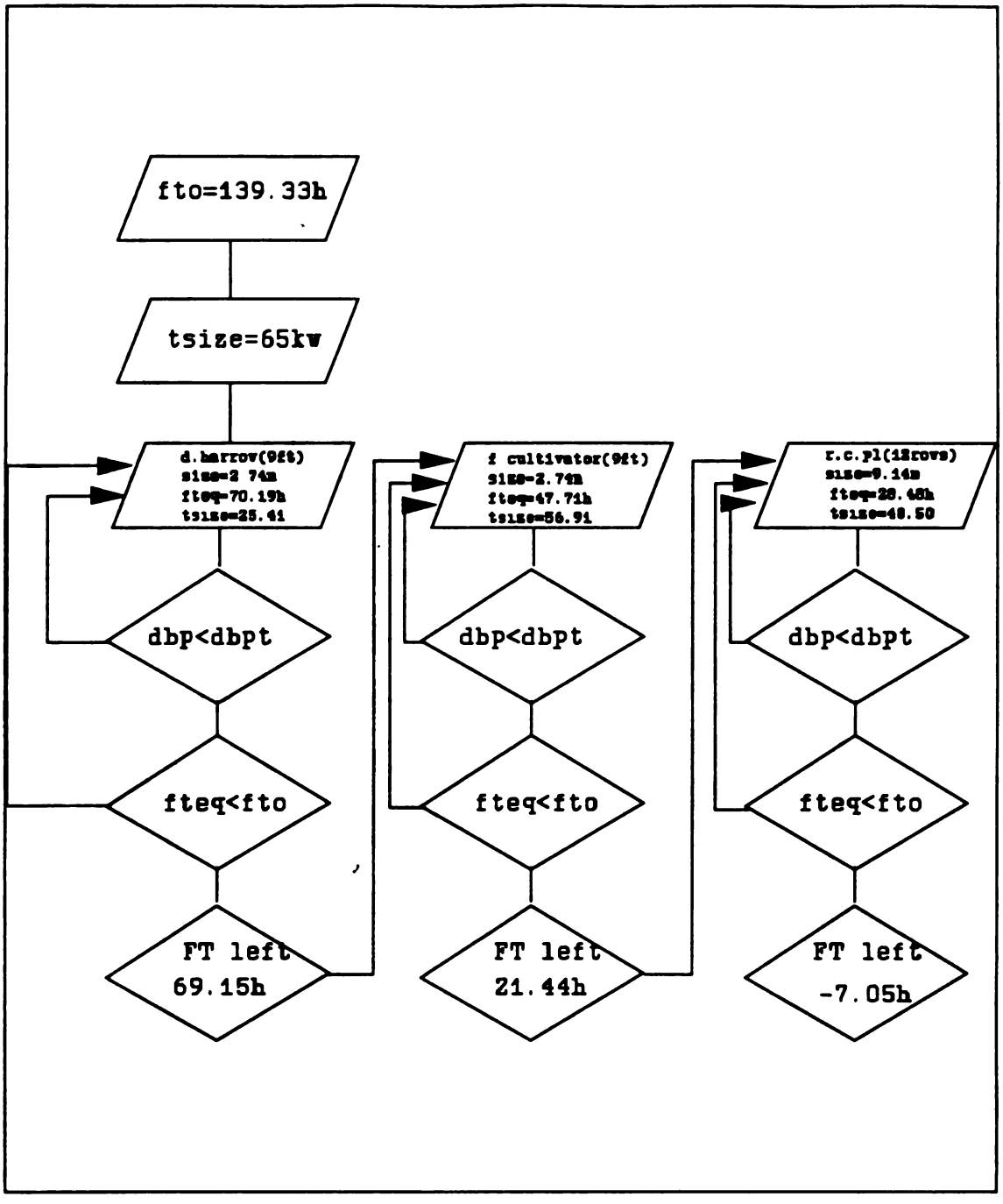

Figure 6.3b Field Time Algorithm Using a Second Tractor for Secondary Tillage and Planting.

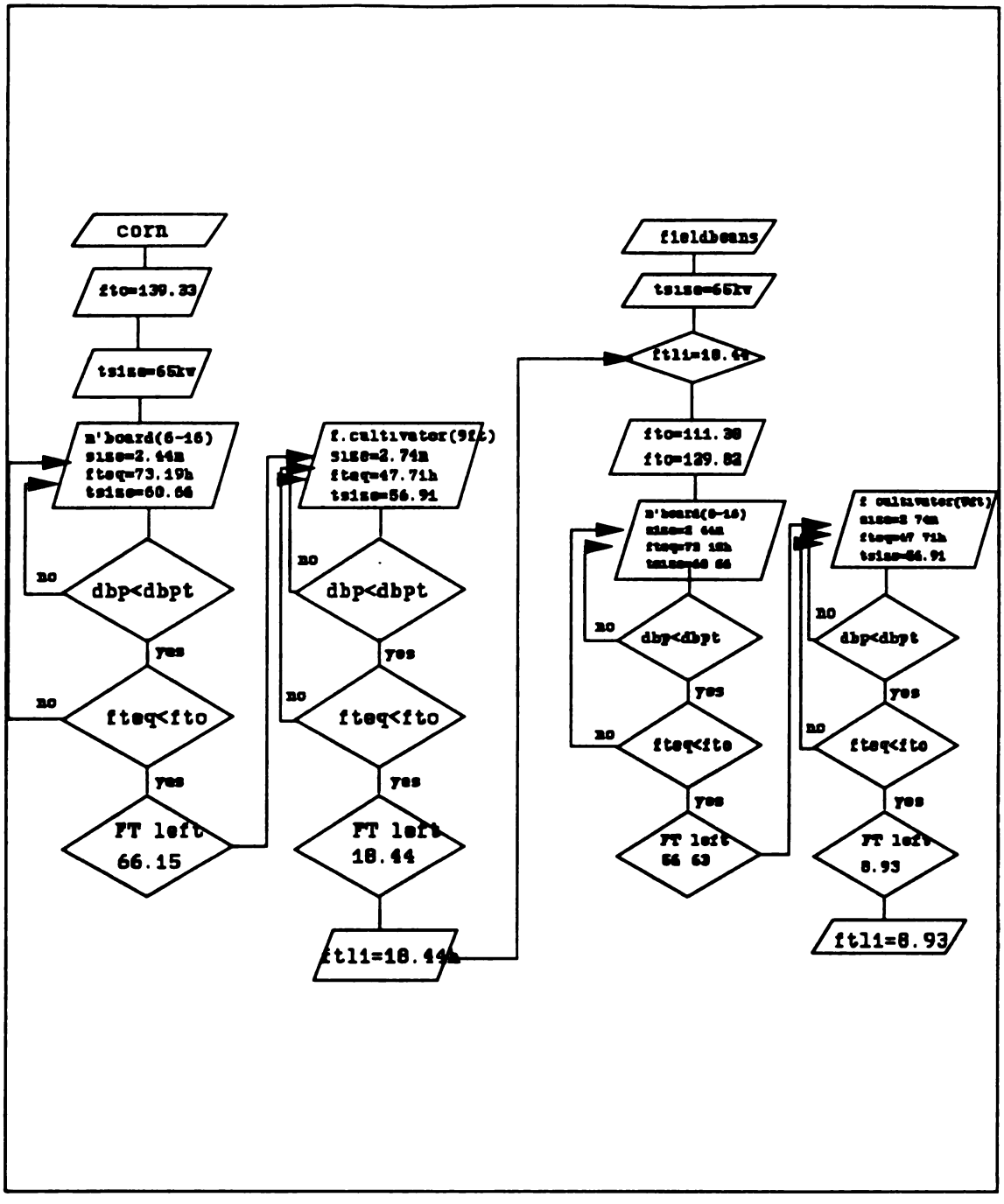

Figure 6.3c Field Time Algorithm for Corn and Field Beans Using First Tractor Operation.

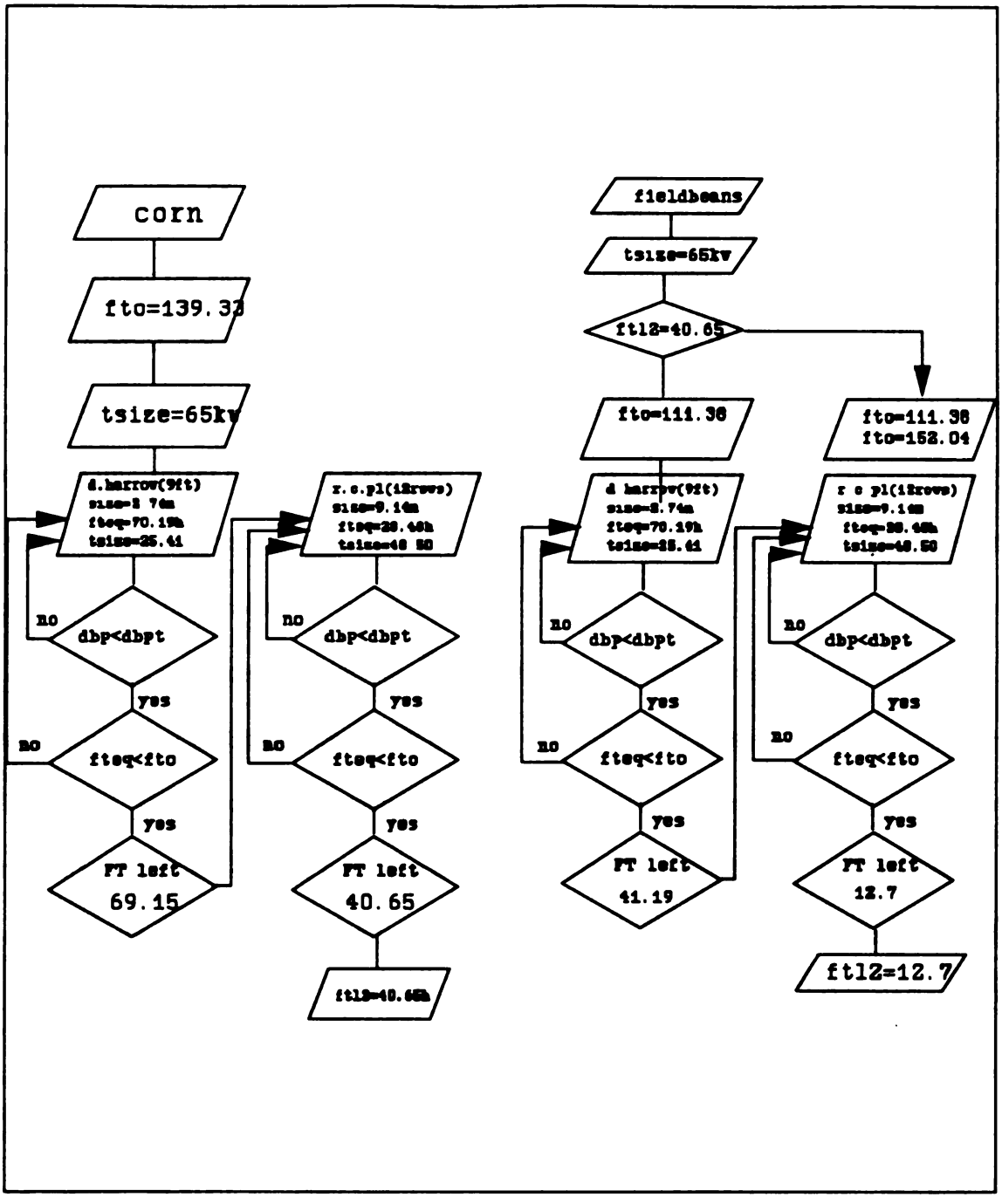

Figure 6.3d Field Time Algorithm for Corn and Field Beans Using Second Tractor Operation.

Selecting machinery for farms which produce several crops is a complex problem. As was mentioned earlier, capacity matching is complicated by the fact that many operations of different crops in a crop rotation are interrelated by time. Let us assume an example farm of corn - fieldbeans - wheat rotation with 300 hectares land area. The field operations for each crop were considered to be continuous. The dates of operation for all the crops were given in Table 6.6. Figure 6.3c shows the implement field time algorithm for the corn and field beans using the first tractor of size 65 kW. Figure 6.3d shows the implement field time algorithm for the corn and fieldbeans using second tractor of size 65 kW. Figure 6.3e shows the implement field time algorithm for the wheat using the first and second tractor.

The dates of operation for the corn and field beans crops overlapped and thus, the program used the ending dates of the corn as the beginning dates of operation for the field beans. The field beans production was carried out simultaneously with the corn production. The user had the option to use the field time unused by the tractors from the corn crop operation for the field beans operation. The field time unused by the first and second tractors after the corn operation were 18.44 hours and 40.65 hours, respectively. Figure 6.3c shows that the primary tillage operation for the field beans was carried out immediately after completing the field cultivation operation for the corn. The field time left by the first tractor from the corn operation was added to the field beans operation. The primary tillage field operation time for the field beans was increased from 111.38 hours to 129.82 hours. The field time unused by the first tractor from the field beans operation was calculated to be 8.93 hours. Figure 6.3d shows that the user opted not to add the field time unused by the second tractor from the corn production to the

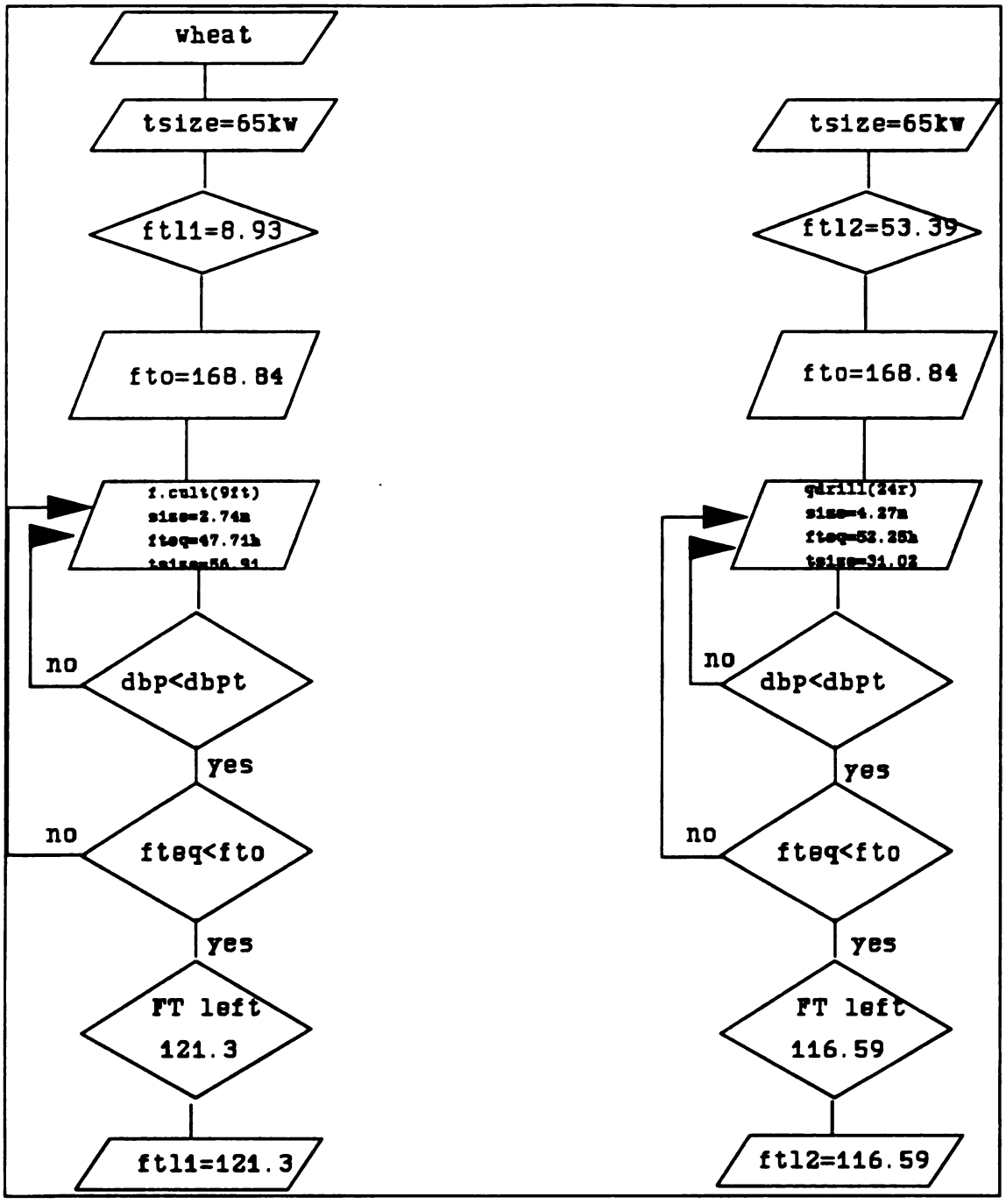

Figure 6.3e Field Time Algorithm for Wheat Production on Coarse Soil Using Two Tractors.

field beans production. As was mentioned, those field times were not correct when the field time required by the field cultivator was higher than the field time required by the planter. This was to ensure that the planting operation was completed after the secondary tillage operation. The field time unused by the second tractor from the field beans operation was calculated to 12.70 hours. The unused field time left by the first and second tractors from the field beans operation were not carried forward for the wheat operation. In this example, the wheat operation was carried out in the Fall. Wheat was assumed to use only a field cultivator and grain drill. The first tractor was used for the field cultivator and the second tractor for the grain drill. Figure 6.3e shows that the unused field time left by the first tractor and second tractor from the wheat operation were 121.3 hours and 116.59 hours, respectively. This indicates that the field cultivator and grain drill used were too large for the wheat production.

7. EXAMPLE FARMS

Four example farms are given in this chapter. These farms are assumed to be 242.3 hectares in size and located in East Lansing. Three crops, five implements and two tractors are considered in these example farms. The three crops are corn, field beans and wheat. The five implements to be used are a chisel plow, disk harrow, field cultivator, row crop planter and grain drill.

The first example farm is a 242.3-hectare farm with a corn-corn-field beans-wheat rotation using a two-tractor operation. The second example farm is similar to the first example farm except only one tractor is used to complete the farm operation. The third example farm demonstrates a single cropping of the above crops on the same farm size using only one tractor. This example farm include the single cropping of corn, field beans, and wheat. The fourth example farm is a 242.3-hectare farm with a single cropping of corn, field beans and wheat using two tractors.

7.1 Two-Tractor Operation for Corn-Corn-Field Beans-Wheat Crop Rotation.

7.1.1 Problem Methodology

Step 1 : General Information

Location : East Lansing

Soil texture : Fine

Farm Size : 242.3 hectares (600 acres)

Crop Rotation : Corn - corn - field beans - wheat, (C-C-FB-W)

Implements : Chisel plow, field cultivator(f.cult), row crop planter(rcpl) and grain drill(drill)

Step 2: Identify the implements to be used for each crop and tractor.

Table 7.1 List of Implements for Each Tractor and Each Crop.

corn		corn		fbeans		wheat	
tract1	tract2	tract1	tract2	tract1	tract2	tract1	tract2
chisel	rcpl	chisel	rcpl	chisel	rcpl	f.cult	drill
f.cult		f.cult		f.cult			

Step 3: List the dates of operation for each crop.

(a) Dates must not overlap between different operations for the same crop, using the same tractor.

(b) Dates were allowed to overlap between operations using different tractors.

(c) Dates were allowed to overlap between the same operation for different crops, but the ending dates of the operation were not allowed to be the same.

(d) To avoid timeliness cost, the beginning dates and ending dates for tillage and planting were chosen so that yield losses will not occur.

Table 7.2 Dates of Operation.

	corn (after wheat)	corn (after corn)	fieldbeans	wheat
primary tillage	8/1 - 9/1	10/15-11/30	10/15-11/30	-
secondary tillage	4/24-5/22	4/24-5/22	5/15-6/19	9/18 - 10/9
planting	4/24-5/22	4/24-5/22	5/15-6/19	9/18 - 10/9

This farm operations has dates of operation that overlap between one operation to the other for the same crop operation and between similar operations for different crops in a rotation. Table 7.2 shows the dates of operation for the corn-corn-field beans-wheat rotation. The primary tillage for the corn (after wheat), corn (after corn) and field beans were carried out in the fall season, followed by the secondary tillage and planting in the spring. There were no overlaps in the dates of operation between the primary and secondary tillage operations. Both the secondary tillage and planting operations for wheat were carried out in the fall season. There were overlaps in the dates between the secondary tillage and planting operations for all crops selected in this crop rotation. There were also overlaps in the dates of operation for the primary tillage, secondary tillage and planting operations between crops. To use this program, dates of operation were chosen so that time periods which cause problems for this program would be avoided. The dates of operation were adjusted as shown in Table 7.3. Dates were allowed to overlap between different crops for the same operation, but the operation ending dates were not allowed to be the same. The program calculates the field operation time for the later crop based on the ending date of operation for the earlier crop and the ending date of operation for the later crop. Having the same dates will cause an error in the computation.

This example farm illustrates the use of a two-tractor operation for a C-C-FB-W crop rotation on a 242.3-hectare farm. In this example farm, the primary tillage operation for the corn (after corn) was adjusted to end one day earlier than the ending date of the same operation for the field beans. The secondary tillage and planting dates of operation for the corn (after wheat) were also adjusted by one day for the same reason. The field

Table 7.3 Adjusted Dates of Operation.

	corn (after wheat)	corn (after corn)	fieldbeans	wheat
primary tillage	8/1 - 9/1	10/15-11/29	10/15-11/30	-
secondary tillage	4/24-5/21	4/24-5/22	5/15-6/19	9/18- 10/9
planting	4/24-5/21	4/24-5/22	5/15-6/19	9/18- 10/9

time unused from the operation of the earlier crop will automatically be added to the similar operation for the next crop. The secondary tillage and planting dates of operation were not adjusted although there were overlaps between them for all crops. This was because different tractors were used for the secondary tillage and planting operations. The secondary tillage operation can be carried out simultaneously with the planting operation.

The primary tillage operations for all crops were carried out in the fall season using the same tractor, which was also used for spring secondary tillage. The primary tillage operation for corn (after wheat) started on August 1 during the harvesting of wheat. It ended on September 1 before the start of the secondary tillage operation for wheat. The secondary tillage and planting operations for wheat started on September 18 and ended on October 9. The primary tillage operation for the corn (after corn) and field beans started on October 15 during the harvesting of corn. The primary tillage operation

dates for the corn (after corn) and field beans overlapped, and must start after the fall tillage and planting for wheat because of using one tractor for all the tillage operations.

Step 4: Determine the minimum width for each machine. If there is a date constraint overlap between crops for the same operation, the user is encouraged to have a trial run of the program. The earliest beginning dates of the operation for the first crop and the latest ending dates of operation for the last crop should be entered. The largest recommended implement size of the same implement computed with and without date constraint overlap between the same operation should be chosen. The recommended implement size is used to select a commercially-sized implement. Parameters from Table 7.4 are used for the calculations.

Table 7.4 Parameters Used for Each Implement.

	field efficiency	speed of op'tion (km/h)	tractive efficiency	depth of op'tion,cm
chisel plow	0.85	7.00	0.70	20
field cultivator	0.85	9.00	0.60	10
crop planter	0.60	6.40	0.60	-
grain drill	0.70	6.40	0.60	-

(a) Determine field operation time.

Field operation time = d * pwd *hd

For the example dates of operation from 10/15 to 11/30

Field operation time = [(16 * 0.61) + (30 * 0.265)] * 12 = 212.52 h.

(b) Determine minimum width for the chisel plow with date constraint overlap between different crops for the same operation.

Dates of operation: 10/15 - 11/30

Number of operations (crops) = 2 (corn(after corn) and field beans)

Total field operation time = 212.52 hours

Field operation time per crop = 106.26

$$\text{width} = \frac{A * 10}{S * E * FT} \qquad (7.1)$$

= (60.7 * 10)/(7.0 * 0.85 * 106.26) = 0.96 m.

(c) Determine minimum width of chisel plow for corn (after wheat) operation.

Dates of operation: 8/1 - 9/1

Field operation time = 253.38 hours

As in Equation 7.1:

width = (60.7 * 10)/(7.0 * 0.85 * 253.38)= 0.40 m.

(d) Determine minimum width for the field cultivator with date constraint overlap between different crops for the same operation.

Dates of operation : 4/24 - 6/19

Number of operations (crops) = 4 (corn, corn and field beans twice)

Total field operation time = 428.44 hours

Field operation time per crop = 107.11

As in Equation 7.1:

width = (60.7 * 10)/(9.0 * 0.85 * 107.11) = 0.74 m.

(e) Determine minimum width of field cultivator for the wheat operation.

Dates of operation : 9/18 - 10/9

Field operation time : 168.84 hours

As in equation 7.1:

width = (60.7 * 10)/(9.0 * 0.85 * 168.84) = 0.47 m.

(f) Determine minimum width of row crop planter with date constraint overlap between crops for the same operation.

Dates of operation : 4/24 - 6/19

Number of operations (crops) = 3 (corn, corn and field beans)

Total field operation time = 428.44

Field operation time per crop = 142.81

As in Equation 7.1

width = (60.7 * 10)/(6.4 * 0.60 * 142.81) = 1.11m.

(g) Determine minimum width of grain drill for wheat.

Dates of operation : 9/18 - 10/9

Total field operation time = 168.84

As in Equation 7.1:

width = (60.7 * 10)/(6.4 * 0.7 * 168.84) = 0.80 m.

The step 4 above shows the methodology to determine the minimum implement width. The minimum width for each implement was calculated based on the dates of operation, number of operations, area of operation, and the expected operation speed and field efficiency. Step 4 shows the calculations to determine the implement width based on the field operation time and the number of operations or crops using the same implement continuously. Table 7.5 shows the recommended size of implements for those operations with and without overlap in the dates of operation. The largest recommended size of each implement was used to determine the commercial implement size. In this example, the recommended implements were smaller than the smallest available commercial implement. Thus, the smallest available commercial implements were selected to be used in this farm operation. The commercial sizes selected for the chisel plow, field cultivator, row crop planter and grain drills were 2.13 meters, 2.13 meters, 3.05 meters and 2.31 meters respectively.

Table 7.5 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m no-overlap	recommended size,m overlap	commercial size,m	power req'ment, kW	field time,h
chisel	0.40	0.96	2.13*	47.8	47.9
f.cult	0.47	0.74	2.13*	39.2	37.25
rcpl	-	1.11	3.05a	30.9	51.86
drill	0.80	-	2.31b	33.60	58.65

* smallest available commercial size: 7 shanks @ 0.305m

a smallest available commercial size: 4 rows @ 0.762m

b smallest available commercial size: 13 rows @ 0.178m

Tractor size for chisel plow and field cultivator : 48.5kW(65hp)

Tractor size for row crop planter and grain drill : 34.30kW(46hp)

Step 5 : Determine the power required by each implement.

(a) Determine the power required by the chisel plow.

As in Equation 4.11:

$$D=(527+36.1*S)*\frac{WNC}{1000}*\frac{WD}{0.0826}$$

draft = (527 + 36.1 * 7.0) * (7/1000) * (0.2/0.0826) = 13.215 kN.

As in Equation 4.4:

$$TS=\frac{1.25*D*S}{0.96*3.6*TE}$$

tractor size = (1.25 * 13.215 * 7.0) / (0.96 * 3.6 * 0.7) = 47.8 kW.

(b) Determine the power required by the field cultivator.

As in Equation 4.11:

draft = (527+ 36.1 * 9) * (7/1000) * (0.1/0.0826) = 7.219 kN.

As in Equation 4.4:

tractor size = (1.25 * 7.219 * 9)/(0.96 * 3.6 * 0.6) = 39.2 kW.

(c) Determine the power required by the row crop planter.

As in Equation 4.16:

draft = 2000 * 4/1000 = 8 kN.

As in Equation 4.4:

tractor size = (1.25 * 8 * 6.4)/(0.96 * 3.6 * 0.6) = 30.9 kW.

(d) Determine the power required by the grain drill.

As in Equation 4.18:

draft = 670 * 13/1000 = 8.71 kN.

As in Equation 4.4:

tractor size = 1.25 * 8.71 * 6.4)/(0.96 * 3.6 * 0.6) = 33.6 kW.

The program calculates the power and field time required by each implement. Implement power requirement was calculated based on the implement size, operation speed, operation depth, tractive efficiency and the soil texture. The soil texture determines the draft required by each implement. Implement power requirement is important to determine the tractor size required to pull the implement. The power requirement for the chisel plow, field cultivator, row crop planter and grain drill were 47.8, 39.2, 30.9, and 33.6 kW, respectively. Tractors to pull those implements must be based on the highest power required by any one of the implements. In this example, two tractors will be used, a 48.5 kW tractor for the chisel plow and field cultivator and a 34.30 kW tractor for the row crop planter and grain drill. If the tractors had already been selected earlier, the implement power requirement would have been used to compare with the available power from the selected tractor. The implement power requirement must be smaller than the available tractor power so that the tractor can pull the implement. The program will not execute further until this power matching requirement is met.

Step 6: Determine the field time required by the implement to complete the farm operation.

(a) Determine the field time required by the chisel plow of 2.13 meters.

field time = (60.7 * 10)/(7.0 * 0.85 * 2.13) = 47.9 h.

$$FT = \frac{A * 10}{S * W * E} \tag{7.2}$$

(b) Determine the field time required by the field cultivator of 2.13 meters.

As in Equation 7.2:

field time = (60.7 * 10)/(9 * 0.85 * 2.13) = 37.25 h.

(c) Determine the field time required by the row crop planter of 3.05 meters.

As in Equation 7.2:

field time = (60.7 * 10)/(6.4 * 0.60 * 3.05) = 51.83 h.

(d) Determine the field time required by the grain drill of 2.31 meters.

As in Equation 7.2:

field time = (60.7 * 10)/(6.4 * 0.7 * 2.31) = 58.65 h.

Step 6 shows the methodology to calculate the field time required by each implement to complete the operation on time for one crop. The field time required by the chisel plow, field cultivator, row crop planter, and grain drill were calculated to be 47.9, 37.25, 51.86, and 58.65 hours, respectively. The program will compare the field time for each implement with the available field operation time. If the implement field time is larger than the available field operation time, the implement is too small to complete the farm operation on time. Table 7.5 summarized the power and field time required by each selected implement.

Figure 7.1 shows the algorithm of field time for four crops in a crop rotation

system. The various dates of operation were given in Table 7.3. The first tractor was used for the primary and secondary tillage operations, and the second tractor was used for the planting operations. The field time unused by the primary tillage implement operation was not carried forward for the secondary tillage implement operation because both of the operations were in different seasons (i.e. not a continuous operation). The field time unused by the secondary tillage implement operation was not carried forward for planting operation because of the use of different tractors. The planting operation can be carried out simultaneously with the secondary tillage operation.

The first tractor was used for the following sequence of fall operations: (a) The primary tillage operation for the corn (after wheat). (b) The secondary tillage operation for the wheat. (c) The primary tillage operations for the corn (after corn) and field beans consecutively. The first tractor was used for the spring secondary tillage operations for the corn (after wheat), corn (after corn) and field beans, consecutively. The second tractor was used as follows: (a) The planting operation for the wheat in the fall season. (b) The planting operations for the corn (after wheat), corn (after corn) and field beans, consecutively, in the spring.

The first tractor operation started with the primary tillage operation for the corn (after wheat). There were no overlaps in the dates of primary tillage operations between crops and among other operations of the same crop. The first tractor was then used for the secondary tillage operation for the wheat. The second tractor was used to complete the planting operation for the wheat. The secondary tillage and planting operation dates for the wheat were allowed to overlap because different tractors were used. Both of these operations could operate simultaneously.

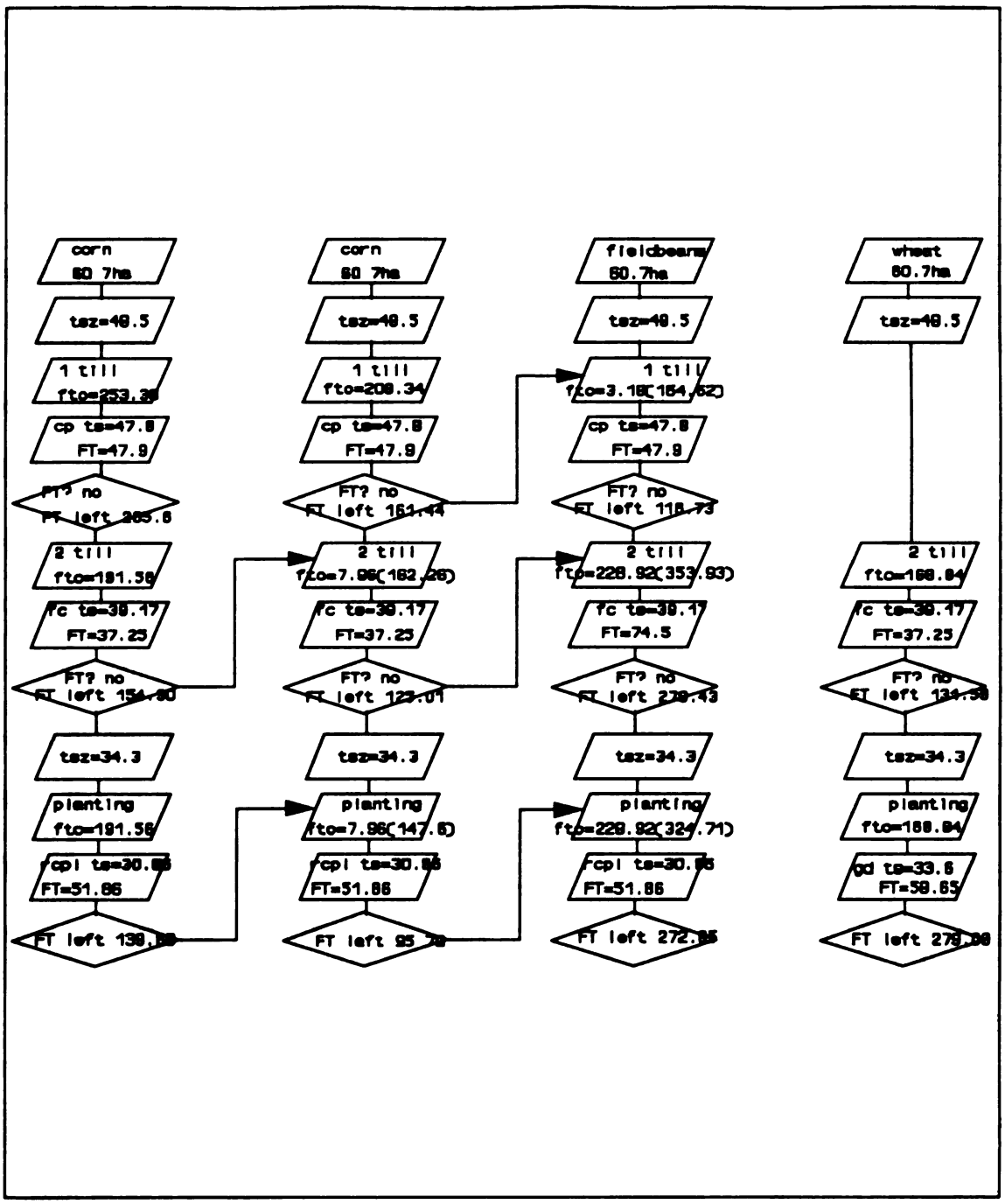

Figure 7.1 Field Time Algorithm for Four Crops in Rotation Using Two Tractors.

The first tractor was then used for the primary tillage operations for the corn (after corn) and field beans. The primary tillage operations for both crops were allowed to overlap so that the field time unused from the early crop will be automatically added to the field operation time for the later crop. The available primary tillage field operation time for the corn (after corn) was calculated to be 209.34 hours. Chisel plowing required 47.9 hours, leaving 161.44 hours unused to be carried forward for the primary tillage operation for the field beans. The field time for the field beans was then increased from 3.18 hours to 164.67 hours.

The primary tillage for the corn (after corn), corn (after wheat) and field beans occurred in the fall season followed by the secondary tillage and planting operations for these crops in the spring season. The dates of operations for the secondary tillage operations overlapped with the dates of operation for the planting of the corn and field beans. The available field operation time for the secondary tillage operation for the corn (after wheat) was calculated from April 24 to May 21. The available field operation time of the secondary tillage for the corn (after corn) was calculated from May 21 (ending date of the previous crop) to May 22. Thus, the 154.30 hours unused by the secondary tillage operations for the corn (after wheat) was automatically added to be used in the secondary tillage operation for the corn (after corn). The secondary tillage operation time was increased from 7.96 hours to 162.26 hours. The field cultivator required 37.25 hours, leaving 125.01 hours unused to be carried forward for the secondary tillage operation for the field beans. The available field operation time for the secondary tillage operation for the field beans was calculated from May 22 (ending date of the previous crop) to June 19 with 228.92 hours available. The secondary tillage field time for the field beans was

then increased to 353.93 hours by adding the unused time from corn tillage.

The second tractor was used for all planting operations. The secondary tillage and planting operation dates for all the crops were allowed to overlap because of the use of different tractors so that both operations could operate simultaneously. The dates of planting for the corn and field beans were allowed to overlap, so that the field time unused from the early crop was automatically added to the field operation time for the next crop. The available field operation time for the planting operation for corn (after wheat) was calculated from April 24 to May 21. The available field operation time of the planting operation for the corn (after corn) was calculated from May 21 (ending date of the previous crop) to May 22. The 139.69 available hours unused by the planting operation for the corn (after wheat) was automatically added to the planting operation for the corn (after corn) to make 147.60 hours available. The row crop planter required 51.86 hours, leaving 95.78 hours unused to be carried forward to the planting operation for the field beans. The available field operation time for the field beans planting operation was calculated from May 22 to Jun 19. The planting field time was then increased from 228.92 hours to 324.71 hours. There were no overlaps for the farm operations between the field beans and wheat operations or between the wheat and corn (after wheat) operations. All of the farm operations for wheat production were carried out in the Fall season. The secondary tillage operation for the wheat was carried out after the primary tillage operation for the corn (after wheat) ended.

The user is encouraged to use the commercial implement sizes as close as possible to the recommended sizes. Using the recommended sizes will enable use of most of the available field operation time. The field time unused after using the chisel plow for the

corn (after corn) and field beans operations were 205.60 hours and 116.73 hours. This unused time indicates that the chisel plow chosen was too large for the farm size. There was also ample field time unused after the secondary tillage and planting operation showing that the selected implements were too large for the farm size. However the chisel plow, field cultivator, row crop planter and grain drills selected were the smallest available in the market. Thus, the unused field time by each operation was unavoidable.

The first tractor size had to be larger than 47.80 kW to be able to pull the chisel plow and field cultivator. The second tractor size had to be at least 33.60 kW to be able to pull the 6-row planter and 13-row grain drill. The first tractor size selected was 48.5 kW and the second tractor size selected was a 34.30 kW tractor.

Step 7 : Determine the cost of using each implement for each crop.

This example shows the calculations to determine the machinery cost of the chisel plow for the corn production. The chisel plow was assumed to be 3 years old before the beginning of the operation. The expected life was assumed to be 10 years. The labor wage, fuel price, oil price and tractor price were obtained from Minnesota Farm Machinery Economic Cost Estimates for 1990 (Fuller et al. 1990).

The labor cost, fuel cost and oil cost are the actual cost, directly related to the field time used by the implement. Table 7.6 shows the implement costs based on the field time used by each implement. The field time used for the example chisel plow for corn production was 47.90 hours.

(a) Labor Cost

As in Equation 4.35:

$$LC = 1.1 * FT * L\$$$

$$= 1.1 * 47.9 * 7.00 = \$368.80$$

(b) Fuel Cost

(i) Fuel Consumption

As in Equation 4.32:

$$FCN = \left(2.64 * \frac{EPTOP}{APTOP} + 3.91 - 0.203\sqrt{738 * \frac{EPTOP}{APTOP} + 173}\right) * EPTOP$$

$$FCN = \left(2.64 * \frac{38.24}{48.5} + 3.91 - 0.203\sqrt{738 * \frac{38.24}{48.5} + 173}\right) * 38.24$$

$$= 15.83 \text{ l/h}$$

(ii) Fuel Cost

$$FC = FCN * FT * F$$

$$= 15.83 * 47.90 * 0.21 = \$159.25$$

(c) Oil Cost

(i) Oil Consumption

As in Equation 4.34:

$$OCN = 0.00059 * APTOP + 0.02169$$

$$= 0.00059 * 48.5 + 0.02169 = 0.0503 \text{ l/h.}$$

(ii) Oil Cost

$$OC = OCN * FT * O$$

$$= 0.0503 * 47.9 * 1.00 = \$2.41$$

The repair and maintenance cost, capital consumption cost, and taxes, insurance and shelter cost are the costs being shared by other crops in a crop rotation. The shared cost for each implement were calculated based on the proportion of time used by each crop to the total field time used by all of the crops. Table 7.9 shows the total field time used for each implement by all crops. The total field time used for chisel plow was 143.69 hours.

(d) Total Repair and Maintenance Cost

As in Equations 4.29 to 4.31:

$$RMCM1 = LPM * RF1 * \left(\frac{HRM}{1000}\right)^{RF2}$$

$$= 2275.00 * 0.38 * ((143.69 * 3)/1000)^{1.4}$$

$$= \$266.15$$

$$RMCM2 = LPM * RF1 * \left(\frac{HRM2}{1000}\right)^{RF2}$$

$$= 2275.00 * 0.38 * ((143.69 * 4)/1000)^{1.4}$$

$$= \$398.15$$

$$RMC = RMCM2 - RMCM1$$

$$= 398.15 - 266.15 = \$\ 132.00$$

The repair and maintenance cost of the chisel plow for the corn (after wheat) production is:

$$RMC = \frac{RMC * FT}{TFT} \qquad (7.3)$$

$$= (132.00 * 47.90)/143.69 = \$\ 44.00$$

(e) Capital Consumption Cost

As in Equations 4.19 and 4.20:

$$CRF = I\frac{(1+I)^L}{(1+I)^L - 1}$$

$$= 0.12(1.12)^{10}/((1.12)^{10} - 1 = 0.1770$$

$$CC=(PPM-S\$)*CRF+S\$*I$$

$$= (1820 - 182) * 0.1770 + 182 * 0.12 = \$ 311.74$$

The capital consumption cost of the chisel plow for corn (after wheat) production is:

$$CC=\frac{(CC*FT)}{TFT}. \qquad (7.4)$$

$$= (311.74 * 47.90)/143.69 = \$ 103.92$$

(f) Taxes, Insurance and Shelter

As in Equation 4.23 and 4.24:

$$RVM=LPM*0.6*0.89^{AGE-1}$$

$$= (1820 * 1.25) * 0.6 * 0.89^{(2)} = \$ 1081.22$$

$$RVN=LPM*0.6*0.89^{AGE}$$

$$= (1820 * 1.25) * 0.6 * 0.89^{(3)} = \$ 962.28$$

$$TIS=0.04*\frac{RVM+RVN}{2}$$

$$= 0.04 * (1081.22 + 962.28)/2 = \$ 40.87$$

The taxes, insurance and shelter cost of the chisel plow for the corn (after wheat) production is:

$$TIS = \frac{TIS * FT}{TFT} \qquad (7.5)$$

$$= (40.87 * 47.90)/143.69 = \$\ 13.92$$

Determine the equivalent power-take-off power(EPTOP) for the chisel plow.

d = 13.215 kN (as calculated earlier)

S = 7 km/hr

TE = 0.7

As in Equation 4.6:

$$DBP = \frac{D * S}{3.6}$$

$$= (13.215 * 7)/3.6 = 25.70 \text{ kW.}$$

As in Equation 4.7:

$$EPTOP = \frac{DBP}{0.96 * TE}$$

$$= 25.70/(0.96 * 0.7) = 38.24 \text{ kW.}$$

Step 8 : Determine the cost of using each tractor for each crop.

This example shows the calculations to determine the first tractor cost for the corn production. The tractor was assumed to be 3 years old before the beginning of the operation. The tractor's expected life was assumed to be 15 years. Table 7.7 shows the total field time for each tractor used by each crop. The corn (after wheat) used 85.15 hours for the first tractor to operate the chisel plow and field cultivator. It used 51.83 hours for the second tractor for the row crop planter. Table 7.10 shows the total field time for each tractor used by all crops. The total field time used for the first and second tractors were 329.94 and 214.14 hours, respectively.

To determine the field time used by the tractor

FT = Summation of field time used by chisel plow and field cultivator for the first tractor (as in Table 7.6).

= 47.90 + 37.25 = 85.15 h.

(a) Total Repair and Maintenance Cost

Similar to Equations 4.27 to 4.31:

HRT1=FTP*AGET

= 329.94 * 3 = 989.82 h.

$$HRT2 = FTP * (AGET + 1)$$

$$= 329.94 * 4 = 1319.76 \text{ h.}$$

$$RMT1 = LPT * RF1 * \left(\frac{HRT1}{1000}\right)^{RF2}$$

$$= 28437.50 * 0.01 * (989.82/1000)^2 = \$278.61$$

$$RMT2 = LPT * RF1 * \left(\frac{HRT2}{1000}\right)^{RF2}$$

$$= 28437.50 * 0.01 * (1319.76/1000)^2 = \$495.31$$

$$RMT = RMT2 - RMT1$$

$$= \$495.31 - \$278.61 = \$216.70$$

The repair and maintenance cost of the first tractor for the corn (after wheat) production will be calculated as in Equation 7.3.

$$RMT = \frac{RMT * FT}{TFT}$$

$$= (216.70 * 85.15)/329.94 = \$55.93$$

(b) Capital Consumption

As in Equations 4.19 and 4.20:

$$CRFT=\frac{I(1+I)^L}{(1+I)^L-1}$$

$$= 0.12\ (1.12)^{15}/((1.12)^{15} - 1) = 0.1468$$

$$CCT=(PPT-ST)*CRFT+ST*I$$

$$= (22750 - 2275) * 0.1468 + 2275 * 0.12 = \$3279.23$$

The capital consumption cost of the first tractor for the corn (after wheat) production will be calculated as in Equation 7.4.

$$CCT=\frac{CCT*FT}{TFT}$$

$$= 3279.23*85.15/329.94 = \$846.29$$

(c) Taxes, Insurance and Shelter

As in Equations 4.21, 4.22 and 4.23:

$$RVMT=LPT*0.68*0.92^{AGET-1}$$

$$= 28437.50 * 0.68 * 0.92^{\ 2} = \$16367.26$$

$$RVNT=LPT*0.68*0.92^{AGET}$$

$$= 28437.50 * 0.68 * 0.92^{\ 3} = \$15057.88$$

$$TIST = 0.04 * \frac{RVMT + RVNT}{2}$$

$$= 0.04 * (16367.26 + 15057.88)/2 = \$628.50$$

The taxes, insurance and shelter cost of the first tractor for the corn (after wheat) production will be calculated as in Equation 7.4.

$$TIST = \frac{TIST * FT}{TFT}$$

$$= (628.50 * 85.15)/329.94 = \$162.20$$

Step 9 : Determine the machinery and tractor cost for each crop in a crop rotation.

This example demonstrates the calculations to determine the machinery and tractor costs for corn production in a crop rotation.

(I) Machinery Costs

(i) Machinery cost of using chisel plow.

(a) Actual operating costs (from Table 7.10)

LC = \$368.79; FC = \$159.26; OC = \$2.41.

(b) Shared costs (from Table 7.6)

As in Equations 7.3 to 7.6:

$$RMC = RMC * \frac{FT}{TFT}$$

$$= 131.99 * 47.90/143.69 = \$44.00$$

$$CC = CC * \frac{FT}{TFT}$$

$$= 311.74 * 47.90/143.69 = \$103.92$$

$$TIS = TIS * \frac{FT}{TFT}$$

$$= 40.87 * 47.90/143.69 = \$13.62$$

$$MC1 = LC + FC + OC + RMC + CC + TIS$$

$$= 368.79 + 159.26 + 2.41 + 44.00 + 103.92 + 13.62$$

$$= \$692.02$$

(ii) Machinery cost of using field cultivator

(a) Actual operating costs (from Table 7.10).

LC = \$286.84; FC = \$108.08; OC = \$1.87.

(b) Shared costs (from Table 7.6).

As in Equation 7.3 to 7.6:

$$RMC = RMC * \frac{FT}{TFT}$$

$$= 158.50 * 37.25/186.26 = \$31.70$$

$$CC = CC * \frac{FT}{TFT}$$

$$= 329.73 * 37.25/186.26 = \$65.94$$

$$TIS = TIS * \frac{FT}{TFT}$$

$$= 43.23 * 37.25/186.26 = \$8.65$$

$$MC2 = LC + FC + CC + RMC + CC + TIS$$

$$= 286.84 + 108.08 + 1.87 + 31.70 + 65.94 + 8.65 = \$503.08$$

(iii) Machinery cost of using row crop planter.

(a) Actual operating costs (from Table 7.10).

LC = \$399.07; FC = \$113.74; OC = \$2.17.

(b) Shared costs (from Table 7.6).

As in Equations 7.3 to 7.6:

$$RMC = RMC * \frac{FT}{TFT}$$

$$= 966.41 * 51.83/155.48 = \$322.16$$

$$CC = CC * \frac{FT}{TFT}$$

$$= 1466.21 * 51.83/155.48 = \$488.77$$

$$TIS = TIS * \frac{FT}{TFT}$$

$$= 192.22 * 51.83/155.48 = \$64.08$$

$$MC3 = LC + FC + OC + RMC + CC + TIS$$

$$= 399.07 + 113.74 + 2.17 + 322.16 + 488.77 + 64.08$$

$$= \$1390.00$$

$$MC = MC1 + MC2 + MC3$$

$$= 692.02 + 503.08 + 1390.00 = \$2585.10$$

(II) Tractor Cost

(i) Tractor cost of using first tractor

(a) Shared costs (from Table 7.7).

$$TC1 = TC1 * \frac{FT}{TFT} \qquad (7.12)$$

$$= 4124.44 * 85.15/329.44 = \$1064.40$$

(ii) Tractor cost of using second tractor

(a) Shared cost (from Table 7.7).

As in Equation 7.8 to 7.12:

$$TC2 = TC2 * \frac{FT}{TFT}$$

$$= 2830.07 * 51.83/214.14 = \$684.98$$

(b) Total Tractor Cost

$$TC = TC1 + TC2$$

$$= 1064.40 + 684.98 = \$1749.38$$

Total machinery and tractor cost

As in Equation 7.9 to 7.11:

$$T = MC + TC$$

$$= 2585.10 + 1749.38 = \$4334.48$$

$$\frac{\text{COST}}{\text{HECTARE}} = \frac{\text{T}}{\text{A}}$$

= 4334.48/60.70 = $71.41

$$\frac{\text{COST}}{\text{HOUR}} = \frac{\text{T}}{\text{FT}}$$

= 4334.48/136.98 = $31.64

Table 7.6 Total Implement Costs for Each Implement for All Crops in a Rotation.

	chisel	f.cult	planter	drill	Total
crop	c,c&fb	c,c,fb&w	c,c&fb	w	
price($)	1820.00	1925.00	8560.00	4775.00	
age(yr)	3	3	3	3	
life(yr)	10	10	10	10	
EPTOP(kW)	38.24	31.33	24.69	26.88	
time(h)	143.69	186.26	155.48	58.65	
fuel(l)	2274.61	2574.11	1624.77	653.36	7126.85
fuel(l/h)	15.83	13.82	10.45	11.14	
Costs Labor($)	1106.38	1434.20	1197.21	451.64	4189.42
fuel($)	477.77	540.40	341.22	137.25	1496.65
oil($)	7.23	9.37	6.52	2.46	25.58
r&m($)	131.99	158.50	966.41	69.59	1326.49
capital $	311.74	329.73	1466.21	817.89	2925.56
tis($)	40.87	43.23	192.22	107.23	383.55
Total($)	2075.98	2515.42	4169.79	1586.06	10347.24

Table 7.7 Total Tractor Costs for Each Tractor for all Crops in a Rotation.

	tract1	tract2	tract1 & tract2
crop	c,c,fb & w	c,c,fb & w	c,c,fb & w
age(yr)	3	3	3
life(yr)	15	15	15
price($)	22750	16100.00	38850.00
time(h)	329.94	214.14	544.08
r&m($)	216.71	64.60	271.31
capital($)	3279.23	2320.68	5599.91
tis($)	628.50	444.79	1073.29
Total($)	4124.44	2830.07	6954.51

Table 7.8 Summary for Fixed and Variable Costs for Each Tractor.

	tract1	tract2	Total($)
Tractor cost($)			
Repair & maintenance($)	216.71	64.60	271.31
Capital Consumption ($)	3279.23	2320.68	5599.91
Taxes,Ins & Shelter ($)	628.50	444.79	1073.29
Machinery Cost($)	2540.58	1648.84	4189.42
Labor cost($)			
Fuel cost($)	1018.18	478.48	1496.65
Oil cost($)	16.60	8.98	25.58
Repair & maintenance($)	290.49	1036.00	1326.49
Capital Consumption($)			2925.56
Taxes,Ins & Shelter($)			383.55
Total($)			17301.9

Table 7.9 Summary for Machinery and Tractor Costs for Each Crop in a Rotation.

	corn (after) (wheat)	corn (after) (corn)	f.beans	wheat	total
Area(ha)	60.7	60.7	60.7	60.7	242.3
Total field time(h)	136.98	136.98	174.23	95.90	544.09
machinery cost($)	2585.10	2585.10	3088.15	2089.05	10347.4
tractor cost($)	1749.38	1749.38	2215.01	1240.75	6954.52
Total M & T cost($)	4334.48	4334.48	5303.16	3329.80	17301.9
cost per hectare ($/ha)	71.41	71.41	87.37	54.86	avg 71.41
cost per hour($/h)	31.64	31.64	30.44	34.72	avg 31.80

Step 10 : Determine the Machinery and Tractor Cost for Single Crop.

This example demonstrates the calculations to determine the machinery and tractor costs for single cropping of corn on a 60.7 hectare farm. This example assumes the same tractors and machines and the same dates of operation which were used in the previous example with the C-C-FB-W rotation. This example also assumes the same combination of implements such as; chisel plow, field cultivator and row crop planter for the corn and field beans productions, and field cultivator and grain drill for the wheat production. Table 7.12 shows the summary of these costs. The machinery costs for each implement are shown in Table 7.10. The costs for each tractor are shown in Table 7.11.

(a) Machinery Cost

(i) Machinery cost of using chisel plow

$$\mathbf{MC1=LC+FC+OC+RMC+CC+TIS} \quad (7.6)$$

$$= 368.79 + 159.26 + 2.41 + 28.35 + 311.74 + 40.87$$

$$= \$911.42$$

(ii) Machinery cost of using field cultivator

As in Equation 7.6:

$$MC2 = 286.84 + 108.08 + 1.87 + 16.65 + 329.73 + 43.23$$

$$= \$786.40$$

(iii) Machinery cost of using crop planter

As in Equation 7.6:

$$MC3 = 399.07 + 113.74 + 2.17 + 96.21 + 1466.21 + 192.22$$

$$= \$2269.62$$

(iv) Total machinery cost for producing single crop corn

$$\mathbf{MC=MC1+MC2+MC3}$$

$$= 911.42 + 786.40 + 2269.62 = \$3967.44$$

(b) Tractor Cost

(i) Tractor cost for using first tractor

$$TC1 = RMT + CC + TIS \quad (7.7)$$

$$= 14.43 + 3279.23 + 628.50 = \$3922.16$$

(ii) Tractor cost for using second tractor

As in Equation 7.7:

$$TC2 = 3.78 + 2320.68 + 444.79 = \$2769.25$$

(iii) Total Tractor Cost

$$TC = TC1 + TC2 \quad (7.8)$$

$$= 3922.16 + 2769.25 = \$6691.41$$

(c) Total machinery and tractor cost

$$T = MC + TC \quad (7.9)$$

$$= 3967.44 + 6691.44 = \$10658.85$$

$$\frac{COST}{HECTARE} = \frac{T}{A} \quad (7.10)$$

$$= 10658.85/60.7 = \$175.60$$

$$\frac{COST}{HOUR} = \frac{T}{FT} \quad (7.11)$$

$$= 10658.85/136.98 = \$77.82$$

Table 7.10 Implement Costs for Each Crop Assumed as a Single Crop Operation.

	chisel	f.cult	f.cult	planter	drill
crop	Ea.Crop c,fb	Ea.Crop c,w	fb	Ea.Crop c,fb	w
price($)	1820.00	1925.00	1925.00	8560.00	4775.00
age(yr)	3	3	3	3	3
life(yr)	10	10	10	10	10
EPTOP(kW)	38.24	31.33	31.33	24.69	26.88
time(h)	47.90	37.25	74.50	51.83	58.65
fuel(l)	758.26	514.80	1029.59	541.62	653.36
fuel(l/h)	15.83	13.82	13.82	10.45	11.14
costs labor($)	368.79	286.84	573.68	399.07	451.64
fuel($)	159.25	108.08	216.16	113.74	137.25
oil($)	2.41	1.87	3.75	2.17	2.46
r&m($)	28.35	16.65	43.95	96.21	69.59
capital($)	311.74	329.73	329.73	1466.21	817.89
tis($)	40.87	43.23	43.23	192.22	107.23
Total($)	911.42	786.40	1210.49	2269.62	1586.06

Table 7.11 Tractor Costs for Each Tractor for Each Crop Assumed as a Single Crop Operation.

	tract1	tract1	tract1	tract2	tract2
crop	Ea.Crop c	w	fb	Ea.Crop c,fb	w
age(yr)	3	3	3	3	3
life(yr)	15	15	15	15	15
price($)	22750	22750	22750	16100	16100
time(h)	85.15	37.25	122.40	51.83	58.65
r&m($)	14.43	2.76	29.82	3.78	4.85
capital($)	3279.23	3279.23	3279.23	2320.68	2320.68
tis($)	628.50	628.5	628.50	444.79	444.79
Total($)	3922.16	3910.49	3937.55	2769.25	2770.32

Table 7.12 Summary for Machinery and Tractor Costs for Single Cropping Using Two-Tractor Operation.

	corn	f.beans	wheat
Area(ha)	60.7	60.7	60.7
Total field time(h)	136.98	174.23	95.90
machinery cost($)	3967.44	4391.53	2372.46
tractor cost($)	6691.41	6706.81	6680.81
Total M & T cost($)	10658.8	11098.3	9053.26
cost per hectare($/ha)	175.60	182.84	149.15
cost per hour($/h)	77.82	63.70	94.40

7.1.2 Machinery and Tractor Cost Analysis.

7.1.2.1 Single Cropping and Multiple Cropping.

(a) Implement Cost

Table 7.6 shows the implement cost analysis to determine the total machinery cost for each implement which was used for a multiple crop farm. The implement cost analysis was calculated based on the user's input and the machinery and tractor selection program inputs. The machinery and tractor cost analysis program calculated the fuel consumption, fuel cost, oil cost, labor cost, capital consumption cost, repair and maintenance cost, taxes, insurance and shelter cost and total machinery cost. The chisel plow was used for corn (after wheat), corn (after corn) and field beans productions. The field cultivator was used for all crops. The row crop planter was used for corn (after wheat), corn (after corn) and field beans. The grain drill was used only for the wheat. The total machinery costs of using the chisel plow, field cultivator, row crop planter and grain drill for all the crops mentioned were $2075.98, $2515.42, $4169.79 and $1586.06, respectively.

Table 7.10 shows the costs of using each implement for a single crop in a single crop operation. The machinery cost of using the chisel plow for an individual crop of corn and field beans was calculated to be $911.42. The machinery cost of using the field cultivator for an individual crop of corn and wheat was calculated to be $786.40. Field beans production required field cultivation twice. The machinery cost of using the field cultivator for the field beans was calculated to be $1210.49. Note that the double field time used by the field cultivator for the field beans doubled the fuel cost, oil cost and

labor cost compared with the corn and wheat. The repair and maintenance cost increased by 2.6 times. There were no changes in the capital consumption cost and taxes, insurance and shelter cost.

The total machinery cost of using each implement for the individual crop (Table 7.10) was compared to the total machinery cost of using the same implement when used for all crops (Table 7.6). The cost of fuel, oil and repair and maintenance increased with an increased in the utilization of the implement. The cost of fuel and oil increased proportionately with the time used. The total capital consumption cost and the total taxes, insurance and shelter cost were not affected by the time or number of crops used. More crops in a rotation will increase machinery utilization and distributes the cost which ultimately reduces the machinery cost per hectare. The total costs of using the chisel plow for the individual corn and combination of corn (after wheat), corn (after corn) and field beans were calculated to be $911.42 and $2075.98 respectively. If the machinery cost of using the chisel plow for the multiple crops is equally divided by the number of crops used, then the cost will be $691.99 for each crop. When compared to the individual corn production, it shows a saving of $219.43 per crop for the chisel plow. The above comparisons show a saving of $147.54 per crop and $879.69 per crop for the field cultivator and row crop planter. The above example is just to demonstrate the utilization of the implements with the multiple crops. A better comparison will be discussed later in this chapter in part (c), Machinery and Tractor Cost. These above savings were found by distributing the capital consumption cost and taxes, insurance and shelter cost to all the crops involved.

(b) Tractor Cost

Table 7.7 shows the total costs for each tractor for all crops in a rotation. An example was given to determine the first tractor cost for the corn production. The cost was calculated based on the age, expected life and purchase price of the tractor, and the field time used with each tractor for the operation. The tractor field time used was the time required by all implements used with that tractor. This example farm shows that all of the crops used both tractors. The total field times used by the first and second tractor were 329.94 hours and 214.14 hours, respectively. The total repair and maintenance cost, capital consumption cost and taxes, insurance and shelter cost of using the first tractor for all the crops were calculated to be $216.71, $3279.23 and $628.50 respectively. The total tractor cost for the first and second tractors were $4124.44 and $2836.07 respectively.

Table 7.11 shows the tractor cost analysis by crop for each tractor used for a single crop farm. Step 8 shows the calculations to determine the tractor cost. For the corn production, the first tractor and second tractor were used 85.15 hours and 51.83 hours, respectively. For this crop production the first tractor was used for the chisel plow and field cultivator and the second tractor was used for the row crop planter. The total tractor costs for the first and second tractors were #3922.16 and $2769.25, respectively for corn production. The total tractor cost for the first and second tractors for the field beans and wheat were $3937.55 and $2769.25, and $3910.49 and $2770.32, respectively.

The total tractor cost of using each tractor for each crop (Table 7.11) was compared to the total tractor cost of using the same tractor was used for all crops (Table 7.7). As an example, the total costs of using the first tractor for the corn individually and with a multi crop farm of C-C-FB-W crop rotation were calculated to be $3922.16 and

$4124.44 respectively. It shows an increase of $202.28 from one crop operation to four crop operations. The total costs of using the second tractor for the individual corn and C-C-FB-W crop rotation were calculated to be $2769.25 and $2830.07. It shows an increase of $60.82 from one crop operation to four crop operations. The total tractor costs for individual corn, field beans and wheat were $6691.41, $6706.80 and $6680.81 respectively. The total tractor cost for a multi-crop of C-C-FB-W crop rotation was calculated to be $6954.51. The above example shows that it requires an additional tractor cost of $263.10 to increase from one crop operation of corn to multiple crop operations of the C-C-FB-W crop rotation. Thus, the tractor cost per hectare will be reduced when used with more crops. The tractor will be more utilized where the capital consumption and taxes, insurance and shelter cost will be well distributed.

(c) Tractor and Machinery Cost

The CPMS program calculates the total field time, machinery cost, tractor cost, total machinery and tractor cost, cost per hectare, and cost per hour for each crop produced. The cost per hectare is calculated based on the total machinery and tractor cost for a crop divided by the area of operation. The cost per hour is calculated based on the total machinery and tractor cost for a crop divided by the total field time used for the operation.

Table 7.9 shows the summary for the machinery and tractor costs for each crop in a crop rotation. The machinery cost and the tractor cost for each crop were calculated based on sharing machinery and tractors among the crops in the crop rotation. The machinery cost for each crop includes the actual operation costs and the shared costs of

using the implements. The actual operation costs consist of the labor cost, fuel cost and oil cost. These costs were the direct costs of using the implements. The shared costs were costs of repair and maintenance, capital consumption, and taxes, insurance and shelter for all of the implements shared by the other crops. The shared costs for each implement were calculated based on the proportion of time used by each crop to the cumulative time used by all the crops in a crop rotation. Step 9 shows an example of calculations to determine the machinery and tractor cost for the corn production in a four-crop rotation. The actual costs for the labor, fuel and oil for each implement were obtained from Table 7.10. The total repair and maintenance cost, capital consumption cost and taxes, insurance and shelter cost for each implement used by all crops were obtained from Table 7.12. The machinery costs were determined for the chisel plow, field cultivator and row crop planter. The calculations in step 9 show that the repair and maintenance cost, capital consumption cost, and taxes, insurance and shelter cost for the chisel plow are $44.00, $103.92 and $13.62, respectively. The machinery costs of using the chisel plow, field cultivator and row crop planter for the corn production are $692.02, $503.08 and $1390.00, respectively.

Table 7.12 shows the machinery and tractor costs for the single cropping of corn, field beans and wheat on a 60.7- hectare farm. The single crop operation was assumed to use the same dates of operation and same type and size of implements as used for the same crop in a crop rotation. The total machinery and tractor costs for the single cropping of corn, field beans and wheat were calculated to be $10658.86, $11098.33 and $9053,26 respectively. Step 10 shows an example of calculations to determine the machinery and tractor cost for the corn production. The cost per hectare for the single

cropping of corn, field beans and wheat were calculated to be $175.60, $182.84 and $149.15, respectively. The cost per hour for the corn, field beans and wheat were calculated to be $77.82, $63.70 and $94.40, respectively.

The costs of production for the single cropping were compared to the costs of production for each crop in a crop rotation. Tables 7.9 and 7.12 were used for the following discussions. The total machinery and tractor costs for the corn, field beans and wheat for the single cropping were calculated to be $10658.80, $11098.30 and $9053.26 respectively. The total machinery and tractor costs for the same crops in a C-C-FB-W rotation were calculated to be $4334.48, $5303.16 and $3329.80 respectively. This comparison shows that the total machinery and tractor costs for the corn, field beans and wheat could save $6324.32, $5795.14 and $5723.46, respectively, for multi crop operations. The cost savings per hectare for the corn, field beans and wheat were calculated to be $104.19, $95.47 and $94.29, respectively. This example demonstrates that more crops in a rotation will increase machinery utilization and distribute the cost which ultimately reduces the tractor and implement costs.

Table 7.8 shows the summary for the machinery and tractor cost for all the crops in a crop rotation. The total labor cost, fuel cost, oil cost, repair and maintenance cost, capital cost, and taxes, insurance and shelter cost for all the implements used were calculated to be $4189.42, $1496.65, $25.58, $1362.49, $19289.46 and $383.55 respectively. The total machinery and tractor cost was calculated to be $17301.70. This value was verified to be the same as shown in Table 7.9.

7.2 One-Tractor Operation For Corn-Corn-Field Beans-Wheat Crop Rotation.

7.2.1 Dates of operation.

(a) The dates for secondary tillage and planting cannot overlap within a crop because only one tractor is available.

(b) Both of the corn operations had similar dates of operation to complete the corn production together.

(c) Secondary tillage operation for corn (after wheat) started on April 24 and ended on May 12 for corn (after corn)

(d) The dates for the secondary tillage operations can overlap between corn crops.

(e) The dates for planting can overlap between corn crops.

Table 7.13 Adjusted Dates of Operation.

	corn (after wheat)	corn (after corn)	fieldbeans	wheat
primary tillage	8/1 - 9/1	10/15-11/29	10/15-11/30	-
secondary tillage	4/24-5/11	4/24-5/12	5/22-5/29	9/18- 9/30
planting	5/12-5/21	5/12-5/22	5/29-6/19	9/30- 10/9

The example farm here is to demonstrate the machinery selection and cost analysis of using a one-tractor operation. As was mentioned earlier, there were overlaps in the dates of all farm operations within and among the crops in a crop rotation. In this example, the dates of operation were adjusted for the one-tractor operation. The one-tractor operation requires operations to be carried out in sequence, where time devoted to one operation takes time away from another. Thus, the dates of completion for each operation had to be carefully considered. The primary and secondary tillage operations had to be completed before the first day of planting operation.

The user had the option of completing all operations by crop or completing all crops by operation. The earlier option means that the tillage and planting operations for each crop have to be completed before starting an operation for another crop. The later option means that the same operation for all crops have to be completed before proceeding the next operation for all crops. This example demonstrates the use of a one-tractor operation with the first option. The primary tillage operations for the corn (after wheat), corn (after corn) and field beans were carried out in the fall season followed by the secondary tillage and planting operations in the spring. There were overlaps in the dates of operation between the secondary tillage and planting operations within and among the crops. Both of the corn operations had similar dates of operation to complete the operations together. In this example, the secondary tillage operation for the corn had to be completed on or before May 12. Planting of corn had to begin on May 12 and had to be completed on or before May 22. After completing the corn (after corn) planting operation, the same tractor began the secondary tillage operation for the field beans. The dates of secondary tillage and planting operations for the field beans and corn (after corn)

could not overlap. This prevented the program from automatically adding the unused field time from an operation for the corn (after corn) to the same operation for field beans.

The dates for the secondary tillage operations for both of the corn crops overlapped so that the field time unused by the corn (after wheat) was automatically added to the secondary tillage operation for the corn (after corn). The dates for the planting operations for both corn crops also overlapped for the same reason. The secondary tillage operations had to be completed before starting the planting operations for both corn crops together and for field beans and wheat. The field time unused by the secondary tillage operations was used for the planting operation.

7.2.2 Determine the Minimum Width for Each Machine.

(a) Eliminating the second tractor does not change the conditions for the primary tillage so the 2.13 meter chisel plow used in the two-tractor example is also appropriate for this example.

(b) Determine the width for the field cultivator with date constraint overlap between the same operations for different crops.

Dates of operation : 4/24 - 5/12

Number of operations (crops) = 2 (corn and corn)

Total field operation time = 119.95 hours

Field operation time per crop = 59.98 hours

As in Equation 7.1:

$$\text{width} = \frac{A * 10}{S * E * FT}$$

$$= (60.7 * 10)/(9.0 * 0.86 * 59.98) = 1.32 \text{ m.}$$

(d) Determine minimum width of field cultivator for field beans operation.

Dates of operation : 5/22 - 5/29

Field operation time = 55.69 hours

Number of operations = 2

As in Equation 7.1:

width = (60.7 * 10)/(9.0 * 0.85 * 27.85) = 2.85 m.

(e) Determine minimum width of field cultivator for wheat operation.

Dates of operation : 9/18 - 9/30

Field operation time = 102.96 hours

As in Equation 7.1:

width = (60.7 * 10)/(9.0 * 0.85 * 102.96) = 0.77 m.

(f) Determine the minimum width for the row crop planter with date constraint overlap between different crops for the same operation.

Dates of operation : 5/12 - 5/22

Number of operations (crops) = 2 (corn and corn)

Total field operation time = 79.58 hours

Field operation time per crop = 39.78 hours

As in Equation 7.1:

width = (60.7 * 10)/(6.4 * 0.60 * 39.78) = 3.97 m.

(g) Determine the minimum width of row crop planter for the field beans operations.

Dates of operation : 5/29 - 6/19

Field operation time = 173.23 hours

As in Equation 7.1:

width = (60.7 * 10)/(6.4 * 0.60 * 173.23) = 0.91 m.

(h) Determine the minimum width of grain drill for wheat operation

Dates of operation : 9/30 - 10/9

Field operation time = 65.88 hours

As in Equation 7.1:

width = (60.7 * 10)/(6.4 * 0.70 * 65.88) = 2.67 m.

This example shows the calculations to determine the implement width with and without overlaps for the dates of operation between farm operations. There was an overlap in the dates for the primary tillage operation between corn (after corn) and field beans, for the secondary tillage operations between corn (after wheat) and corn (after corn), and for the planting operations between corn crops. Thus, the same implement was used continuously for the crops with an overlap in the dates of operation. The recommended size for each implement is tabulated in Table 7.14. The commercial sizes

selected for the chisel plow, field cultivator, row crop planter, and grain drill are 2.13, 3.05, 4.57, and 2.31 meters respectively. The one-tractor operation required larger implements to complete some of the farm operation as compared to the two-tractor operation. This operation required 3 extra tines for the field cultivator and 2 extra rows for the row crop planter to complete the farm operation. The size of the chisel plow and grain drill were found to be the same as for the two-tractor operation. The program calculated the power requirement and field time required to complete the farm operation for each implement selected.

7.2.3 Determine the Implement Power Requirement.

(a) The power requirement for the chisel plow of size 2.13 meters was calculated to be 47.8 kW for the previous two-tractor example.

(b) To determine the power required by the field cultivator.

As in Equation 4.11:

$$D=(527+36.1*S)*\frac{WNC}{1000}*\frac{WD}{0.0826}$$

draft = (527+ 36.1 * 9) * (10/1000) * (0.1/0.0826) = 10.31 kN.

Table 7.14 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m no-overlap	recommended size,m overlap	commercial size,m	power req'ment kW	field time,h
chisel	0.40	0.96	2.13a	47.80	47.90
f.cult	0.77, 2.85	1.32	3.05b	55.95	26.02
rcpl	0.91	3.97	4.57c	46.30	34.59
drill	2.06	-	2.31d	33.60	58.55

a smallest available commercial size: 7 shanks @ 0.305 m.

b commercial size: 10 shanks @ 0.305 m.

c commercial size: 6 rows @ 0.762 m.

d smallest available commercial size: 13 rows @ 0.178 m.

Tractor size selected : 59.7 kW (80 hp).

As in Equation 4.4:

$$TS = \frac{1.25 * D * S}{0.96 * 3.6 * TE}$$

tractor size = (1.25 * 10.31 * 9)/(0.96 * 3.6 * 0.6) = 55.95 kW.

(c) Determine the power required by the row crop planter.

As in Equation 4.4:

draft = 2000 * 6/1000 = 12 kN

tractor size = (1.25 * 12 * 6.4)/(0.96 * 3.6 * 0.6) = 46.30 kW.

(d) The power requirement for the grain drill of size 2.31 meters was calculated earlier to be 33.60 kW for the previous two-tractor example.

7.2.4 Determine the Implement Field Time.

(a) The field time required by the chisel plow of 2.13 meters to complete the farm operation was calculated earlier to be 47.9 hours for the previous two-tractor example.

(b) Determine the field time required by the field cultivator of 3.05 meters.

As in Equation 7.2:

$$FT = \frac{A * 10}{S * W * E}$$

field time = (60.7 * 10)/(9 * 0.85 * 3.05) = 26.02 h.

(c) Determine the field time required by the row crop planter of 4.57 meters.

As in Equation 7.2:

field time = (60.7 * 10)/(6.4 * 0.60 * 4.57) = 34.59 h.

(d) The field time required by the grain drill of 2.31 meters to complete the farm operation was calculated to be 58.65 hours for the previous two-tractor example.

This example shows the calculations to determine the power requirements and field times required to complete the farm operation for each implement. The power requirements for the chisel plow, field cultivator, row crop planter, and grain drill were calculated to be 47.8, 55.95, 46.30, and 33.60 kW, respectively. The largest recommended power requirement from the above implements was used to determine the commercial tractor size. The tractor size selected was a 59.7 kW tractor that was able to pull all of the selected implements. This tractor size was found to be larger than the largest tractor size required for the two-tractor operation on a C-C-FB-W crop rotation farm as discussed earlier.

The program calculates the power requirement for each implement and compare it with the power available from the tractor. The program proceeds to calculate the field time required by each implement to complete the farm operation after the power requirement is met. The selected chisel plow, field cultivator, row crop planter, and grain drill required 47.90, 26.02, 34.59, and 58.55 hours, respectively to complete the farm operation. When the implement field time is larger than the available field operation time, the implement is too small to complete the farm operation on time. Table 7.14 shows the power requirement and field time requirement for each implement.

7.2.5 Implement Field Time Algorithm

Figure 7.2 shows the field time algorithm for the four crop operations using one tractor. The one-tractor operation required operations to be carried out in sequence, where time devoted to one operation took time away from the others. Table 7.13 shows the dates for various crops and operations used for this example farm. The tractor operation started with the primary tillage operation for the corn (after wheat). There were no overlaps in the dates of primary tillage operations between this crop and other crops or among other operations of the same crop. The next operation was to complete the secondary tillage and planting operations for the wheat. The field time unused for the secondary tillage operation was used for the wheat planting operation. In this example farm, the 76.94 hours unused from the field cultivator operation was carried over to the planting operation. The field time for planting of wheat was increased from 65.88 hours to 142.82 hours. The grain drill required 58.65 hours to complete the planting operation, leaving 84.17 hours unused.

After wheat was planted, the tractor was used for the primary tillage operation for the corn (after corn) and for field beans. The primary tillage operation dates for the corn (after corn) and field beans were allowed to overlap so that the field time unused from the early crop was automatically added to the field operation time for the later crop. The primary tillage field operation time for the corn (after corn) was calculated from October 15 to November 29. The operation time of the primary tillage for the field beans was calculated from November 29 (ending date of previous crop) to November 30. In this

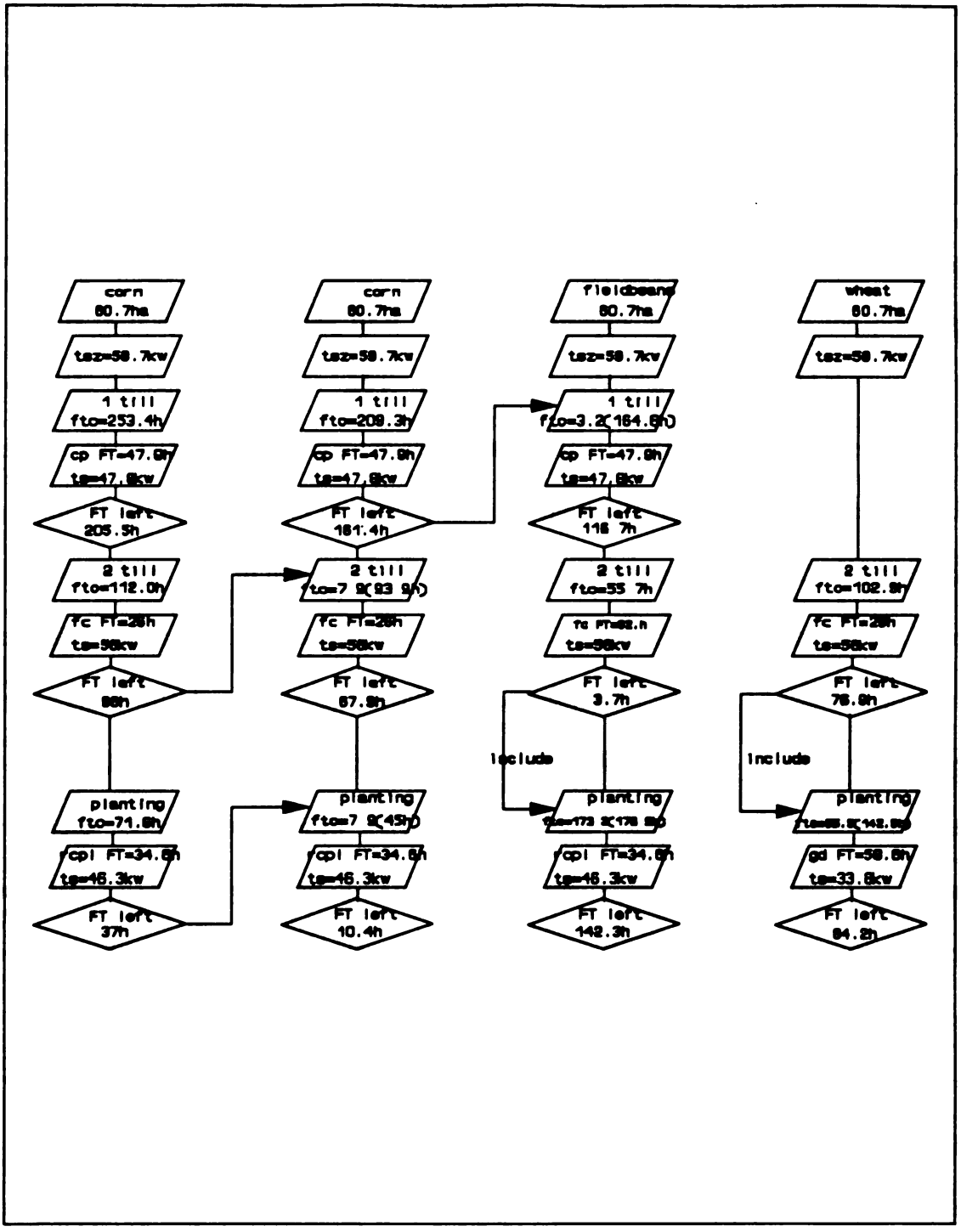

Figure 7.2 Field Time Algorithm for Four Crops in Rotation Using One Tractor.

example, the 161.44 hours unused from the corn (after corn) primary tillage operation was automatically added to the same operation for field beans increasing the latter to 164.62 hours.

The secondary tillage and planting operations for all crops other than wheat were carried out in the spring season. Both corn crops had to be completed before proceeding to the farm operations for the field beans. The secondary tillage and the planting operations for both corn crops had to overlap. The secondary tillage field time unused from the corn (after wheat) was automatically added to the secondary tillage operation for the corn (after corn). The 85.98 hours unused by the earlier crop was added to the 7.96 hours of the later crop to become 93.94 hours. The field operation time of the later crop was calculated from the ending date of the earlier crop to the ending date of the later crop. The 37.01 hours left by the planting operation of the corn (after wheat) was automatically added to planting operation of the corn (after corn). After the planting operations for both corn crops were completed, the tractor was then used for the secondary tillage and planting operation for the field beans. The ending dates for the secondary tillage and planting operations for the corn (after corn) were not allowed to overlap with the beginning dates of the same operations for the field beans. This was to prevent unused time from the earlier crop from being added to the same operation of the later crop. The secondary tillage operation for field beans started on May 22 after the planting operation for the corn ended. The unused secondary tillage field time for the field beans operation must added to the planting operation of the same crop. The 3.66 hours unused by the secondary tillage operation was added to the field time for the planting operation increasing it to 176.89 hours.

The users are encouraged to use commercial implement sizes as close as possible to the recommended size. In this example, the field times unused by the tractor after the primary tillage operation for the corn (after wheat) and field beans were 205.48 hours and 116.73 hours, respectively. The selected chisel plow was the smallest available implement in the market, so the unused field time was unavoidable. The field cultivator recommended for the field beans was larger than the one recommended for both corn operations because field beans required field cultivation twice. The unused field times after the field cultivator operation for the corn (after corn) and field beans were 67.92 hours and 3.66 hours. The field cultivator selected was thus suitable for the field beans operation but too large for the corn operation. The row crop planter recommended for the corn operation was larger than the one recommended for the field beans. The row crop planter was selected based on the size required for the corn operation. The selected row crop planter was suitable for the corn operation, but too large for the field beans operation.

7.2.6 Cost Analysis

7.2.6.1 Single Cropping and Multiple Cropping

(a) Machinery Costs

Table 7.15 shows the implement cost analysis for each implement used by a number of crops in a C-C-FB-W rotation. The chisel plow was used for corn (after

Table 7.15 Total Implement Costs for Each Implement for All Crops in a Rotation.

	chisel	f.cult	planter	drill	total
crop	c,c& fb	c,c,w&fb	c,c& fb	w	
price	1820.00	2750.00	12840.00	4775.00	
age(yr)	3	3	3	3	
life(yr)	10	10	10	10	
EPTOP(kW)	38.24	44.76	37.04	26.88	
time(h)	143.69	130.08	103.77	58.65	436.19
fuel(l)	2431.23	2436.40	1725.70	844.56	7437.89
fuel(l/h)	16.92	18.73	16.63	14.40	
Costs Labor($)	1106.38	1001.59	799.01	451.64	3358.61
fuel($)	510.68	511.64	362.50	177.31	1562.13
oil($)	8.18	7.40	5.91	3.34	24.82
r&m($)	131.99	136.97	620.09	69.59	958.65
capital($)	311.74	471.04	2199.31	817.89	3799.97
tis($)	4087	61.75	288.34	107.23	498.19
Total($)	2109.84	2190.40	4275.15	1627.00	10202.38

wheat), corn (after corn) and field beans. The total chisel plow machinery cost used for all these crops was calculated to be $2109.84. The field cultivator was used for all crops in this rotation. The total field cultivator machinery cost for all crops was calculated to be $2190.40. The row crop planter was used for corn (after wheat), corn (after corn) and field beans and the total planter machinery cost was calculated to be $4275.15. The grain

drill was used only by wheat with a total machinery cost of $1627.00. The implement cost analysis for each implement used by each crop (Table 7.16) was compared with the implement cost analysis using the same implement when used for all the crops (Table 7.15).

Table 7.16 shows the implement cost analysis for using the chisel plow, field cultivator, row crop planter and grain drill for each crop assumed as a single crop operation. The program calculates machinery costs for all implements used by each crop. The total machinery costs for each crop for the chisel plow, row crop planter and grain drill were calculated to be $922.71, $2938.51 and $1627.00, respectively. The total field cultivator machinery costs for corn (after wheat), corn (after corn), and wheat, and for field beans were calculated to be $851.31 and $1179.02, respectively. Step 7 in the previous example farm demonstrates an example to determine the cost of using each implement for each crop. Step 10 demonstrated an example to determine the machinery and tractor cost for a single crop.

Table 7.16 shows that the total machinery cost of using the chisel plow, row crop planter, and grain drill for each individual crop assumed as a single crop operation were $922.71, $2938.51 and $1627.00, respectively. The total cost of using the field cultivator for the individual crops of corn and wheat was $851.31. The same field cultivator used for the individual field beans cost $1179.02, where field beans requires field cultivation twice. Table 7.15 shows that chisel plow, field cultivator, row crop planter and grain drill required a total machinery cost of $2109.84, $2190.40, $4275.15 and $1627.00, respectively. If the machinery cost of using these implements for the multiple crops is equally divided by the number of crops used, then the machinery cost for each crop for

Table 7.16 Implement Cost Analysis for Each Crop Assumed as a Single Crop Operation.

	chisel	f.cult	f.cult	planter	drill
crop	Ea.Crop c,fb	Ea.Crop c,w	fb	Ea.Crop c,fb	w
price($)	1820.00	2750.00	2750.00	12840.00	4775.00
age(yr)	3	3	3	3	3
life(yr)	10	10	10	10	10
EPTOP(kW)	38.24	44.76	44.76	37.04	26.88
time(h)	47.90	26.02	52.03	34.59	58.65
fuel(l)	810.47	487.35	974.52	575.23	844.56
fuel(l/h)	16.92	18.73	18.73	16.63	14.40
Costs Labor($)	368.79	200.32	400.63	266.34	451.64
fuel($)	170.23	102.33	204.66	120.83	177.31
oil($)	2.73	1.48	2.96	1.97	3.34
r&m($)	28.35	14.39	37.98	61.73	69.59
capital($)	311.74	471.04	471.04	2199.31	817.89
tis($)	40.87	61.75	61.75	288.34	107.23
Total($)	922.71	851.31	1179.02	2938.51	1627.00

the chisel plow, field cultivator, row crop planter and grain drills were then be $703.28, $547.60, $1425.05 and $1627.00, respectively. The grain drill was used only for wheat. The above machinery costs for each implement were compared with the same implement when used for all crops in the rotation.

The above comparisons show savings of $219.43 per crop, $303.71 per crop, and

$1513.46 per crop for the chisel plow, field cultivator, and row crop planter. It shows a saving of $631.42 per crop if the field cultivator is used in a multiple crops operation rather than for field beans alone. This example demonstrates the utilization of the implements with the multiple crops for a 242.3-hectare farm compared with single cropping for a 60.7-hectare farm.

(b) Tractor Cost

Table 7.17 shows the tractor cost analysis used for all crops in a rotation. The total tractor cost was calculated to be $5275.64. Table 7.18 shows the tractor cost analysis for the individual crop operations assumed as a single crop operation. The costs of using the tractor for the corn, field beans and wheat were calculated to be $4838.35, $4853.84 and $4827.08, respectively. The above tractor costs for each crop assumed as a single crop operation were compared with the tractor cost used for all crops. The comparisons show that it requires an additional tractor cost of $437.29 to increase from one crop operation of corn to multiple crops operation of corn (after wheat), corn (after corn), field beans and wheat. It requires additional tractor costs of $421.80 and $448.56 to increase from a one-crop operation of field beans and wheat, respectively, to multiple crop operations for these crops. If the tractor cost of using the tractor for multiple crops is equally divided by the number of crops used, then the tractor cost for each crop will be $1318.91. These comparisons show a saving of $3519.44 per crop, $3534.93 per crop, and $3508.17 per crop for corn, field beans, and wheat, respectively. This example demonstrates the utilization of the tractor with the multiple crops compared with single cropping.

Table 7.17 Total Tractor Costs for All Crops in a Rotation.

	tract1
crop	c,c,fb & w
age(yr)	3
life(yr)	15
price($)	28000.00
time(h)	436.18
r&m($)	466.13
capital consumption($)	4035.97
taxes, ins & shelter($)	773.54
Total($)	5275.64

Table 7.18 Costs for Each Tractor for Each Crop Assumed as a Single Crop Operation.

	tract1	tract1	tract1
crop	Ea. Crop c	fb	w
age(yr)	3	3	3
life(yr)	15	15	15
price($)	28000.00	28000.00	28000.00
time(h)	108.50	134.51	84.67
r&m($)	28.84	44.33	17.56
capital($)	4035.97	4035.97	4035.97
tis($)	773.54	773.54	773.54
Total($)	4838.35	4853.84	4827.08

The total field time and machinery costs required by each implement to complete the farm operation for two-tractor operation was compared with the one-tractor operation. Tables 7.6 and 7.15 were used for this comparison of field time and implement cost analysis. The one-tractor operation required a larger field cultivator and row crop planter as compared to the implements used for the two-tractor operation. Both farm operations required the same size chisel plow and grain drill. The chisel plow and grain drill used the same amount of time for both example farms. Both implements were the smallest available and were used for both farms. The field cultivator and row crop planter used more time for the two- tractor operations than for the one-tractor operation.

The implement cost analysis was compared between the two-tractor operations and one-tractor operation. The total repair and maintenance cost of implements used for the two-tractor operation was higher than the cost of using one tractor. The capital, and taxes, insurance and shelter costs for the implement used with the two-tractor operation were lower. The two-tractor operation used 48.5 kW and 34.30 kW tractors, whereas the one-tractor operation used a larger tractor size of 59.7 kW. The two-tractor operation saved on fuel by $65.48 but required $0.76 more oil as compared to the one-tractor operation. The one-tractor operation saved $144.86 on the overall machinery cost.

The tractor cost analysis was compared between the two-tractor operation and one-tractor operation. Tables 7.7 and 7.17 show the total tractor cost analysis for the two-tractor operation and one-tractor operation, respectively. The two-tractor operation required a total field time of 544.08 hours as compared to only 436.18 hours used for the one-tractor operation. The one-tractor operation saved on the capital consumption cost by $1563.94, and taxes, insurance and shelter cost by $299.75. The overall tractor cost

saving using the one-tractor operation was $1678.87. The two-tractor operation saved $194.82 on the repair and maintenance cost.

7.2.6.2 Machinery and Tractor Cost

(a) Single Cropping and Multiple Cropping

Table 7.19 shows the summary for the machinery and tractor costs for the single cropping of corn, field beans and wheat. This table demonstrates the machinery and tractor costs for single cropping of corn, field beans and wheat on 60.7 hectares. The single crop operation was assumed to use the same dates of operation and same type and size of implements as used for the same crop in a crop rotation. The total machinery and tractor costs for single cropping of corn, field beans and wheat were calculated to be $9550.88, $9894.08, and $7305.38, respectively. The methodology to calculate the machinery and tractor costs for single crop was shown in step 10 of the previous example farm. The cost per hectare for the single cropping of corn, field beans and wheat were calculated to be $157.35, $163.00, and $120.35, respectively. The cost per hour for the single cropping of corn, field beans, and wheat were calculated to be $88.03, $73.55, and $86.28, respectively.

Table 7.21 shows the summary for the machinery and tractor costs for each crop in a C-C-FB-W crop rotation. The machinery costs for each crop includes the actual operating costs and the shared costs of using the implements. The actual costs were the operating cost of using each implement. They consist of labor cost, fuel cost, and oil cost. The shared costs consist of the repair and maintenance, and the fixed costs of

Table 7.19 Summary for Machinery and Tractor Costs for Single Cropping Using a One-Tractor Operation

	corn	f.beans	wheat
Area(ha)	60.7	60.7	60.7
Total field time(h)	108.50	134.51	84.67
machinery cost($)	4712.53	5040.24	2478.30
tractor cost($)	4838.35	4853.84	4827.08
Total M & T cost($)	9550.88	9894.08	7305.38
cost per hectare($/ha)	157.35	163.00	120.35
cost per hour($/h)	88.03	73.55	86.28

Table 7.20 Summary for Fixed and Variable Costs for a One-Tractor Operation.

	tract1
Tractor Cost($)	
Repair & Maintenance($)	466.13
Capital Consumption($)	4035.97
Taxes,Ins & Shelter($)	773.54
Machinery Cost($)	
Labor cost($)	3358.61
Fuel cost($)	1562.13
Oil cost($)	24.82
Repair & maintenance($)	958.65
Capital Consumption($)	3799.97
Taxes,Ins & Shelter($)	498.19
Total($)	15478.02

capital consumption, and taxes, insurance, and shelter. The shared costs for each implement were calculated based on the proportion of time used for each crop to the total time used for all crops in a rotation. The methodology to determine the machinery and tractor costs for each crop in a rotation was shown in step 9 of the previous section. The total machinery and tractor cost for the corn, field beans, and wheat were calculated to be $3878.88, $4631.44, and $3089.17, respectively. The total machinery and tractor cost for all crops was $15478.03.

Tables 7.19 and 7.21 were used to compare the tractor and machinery costs between a single cropping farm and the same crop in a crop rotation. The comparison shows a saving of $5672.00, $5262.64 and $4216.21 for corn, field beans, and wheat, respectively, when these crops were produced in a multiple crop farm. The cost per hectare savings were calculated to be $93.45, $86.70 and $69.46 for corn, field beans, and wheat, respectively. This example demonstrates that more crops in a rotation will increase machinery and tractor utilization.

Table 7.20 shows the cost summary for the tractor and machinery used for all the crops in a crop rotation. The total machinery and tractor cost for all the crops was also calculated to be $15478.03.

(b) One-Tractor and Two-Tractor Operations.

The machinery and tractor costs were compared between the two-tractor operation and one-tractor operation. Table 7.9 shows the machinery and tractor costs for each crop in a C-C-FB-W rotation using a two-tractor operation. Table 7.21 shows the machinery

Table 7.21 Summary for Machinery and Tractor Costs for Each Crop in a C-C-FB-W Crop Rotation.

	corn (after) (wheat)	corn (after) (corn)	f.beans	wheat	total
Area(ha)	60.7	60.7	60.7	60.7	242.30
Total field time(h)	108.50	108.50	134.51	84.67	436.18
machinery cost($)	2566.41	2566.41	3004.49	2065.08	10202.4
tractor cost($)	1312.30	1312.30	1626.91	1024.09	5275.60
Total M & T cost($)	3878.88	3878.88	4631.44	3089.17	15478.0
cost per hectare($/ha)	63.90	63.90	76.30	50.89	avg 63.75
cost per hour($/h)	37.75	37.75	34.43	36.48	avg 35.49

and tractor costs for each crop in a C-C-FB-W rotation using a one-tractor operation. The total tractor and machinery costs for each of the crops produced using the two-tractor operation was higher when compared to the same crop produced using the one- tractor operation. The one-tractor operation could save $455.60, $671.72 and $240.63 for the corn, field beans and wheat production respectively. The overall saving was calculated to be $1823.90 for the C-C-FB-W farm. The corn, field beans and wheat production could save $7.51, $11.07 and $3.97, respectively for each hectare.

The fixed and variable costs used by each tractor for all crops was also compared between the two-tractor operation and the one-tractor operation on a C-C-FB-W farm. Tables 7.8 and 7.20 show the summary for the machinery and tractor cost for all crops

Table 7.22 Summary for Fixed and Variable Costs for One-Tractor and Two-Tractor Operations for a Multiple Crop Farm.

	1 tractor-operation	2 tractor-operation
Tractor Cost($) Repair & Maintenance($) Capital Consumption($) Taxes,Ins & Shelter($)	 466.13 4035.97 773.54	 271.31 5599.91 1073.29
Machinery Cost($) Labor cost($)	3358.61	4189.42
Fuel cost($)	1562.13	1496.65
Oil cost($)	24.82	25.58
Repair & maintenance($)	958.65	1326.49
Capital Consumption($)	3799.97	2925.56
Taxes,Ins & Shelter($)	498.19	383.55
Total($)	15478.02	17301.90

for the two-tractor operation and the one-tractor operation, respectively. Table 7.22 shows the summary from the above two tables. The total machinery and tractor costs using the one-tractor operation and the two-tractor operation were calculated to be $15478.02 and $17301.90, respectively. The comparison shows a saving of $1823.90 for the one-tractor operation farm. The one-tractor operation saved $830.81, $0.76 and $958.65 on costs of labor, oil and implements repair and maintenance, respectively. The two-tractor operation saved $65.48, $874.41, and $114.64 on fuel cost, capital consumption cost, and taxes, insurance and shelter cost, respectively.

7.3 Single Crop, One-Tractor Operation.

Location : East Lansing

Soil Texture : Fine

7.3.1 Corn Crop

Implement : Chisel plow, field cultivator, and row crop planter.

Farm size = 242.3 hectares.

(a) Dates of Operation

Primary tillage : 10/15 - 11/30

Secondary tillage : 4/24 - 5/11

Planting : 5/12 - 5/22

The dates of each farm operation for the single cropping were different from the dates of operation for this crop in a crop rotation. The primary tillage operation for the single cropping of corn depends on the harvesting operation of the previous corn crop.

This example demonstrates a single cropping of corn on a 242.3-hectares farm using one tractor. The primary tillage operation was carried out in the fall season and the secondary tillage and planting operations were carried out in the spring season. The dates of the secondary tillage and planting operation were not allowed to overlap because both operations used the same tractor. The field time left unused by the secondary tillage operation was used by the planting operation. The beginning and ending planting dates were important to avoid timeliness cost. The secondary tillage operation had to be completed on or before May 11.

Table 7.23 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment kW	field time,h
chisel	1.92	2.13a	47.80	191.19
f.cult	2.83	3.05b	55.95	103.85
rcpl	7.93	9.14c	92.59	69.04

a smallest available commercial size: 7 shanks @ 0.305 m.

b commercial size: 10 shanks @ 0.305 m.

c commercial size: 12 rows @ 0.762 m.

Tractor size selected: 93.72 kW (125.68 hp).

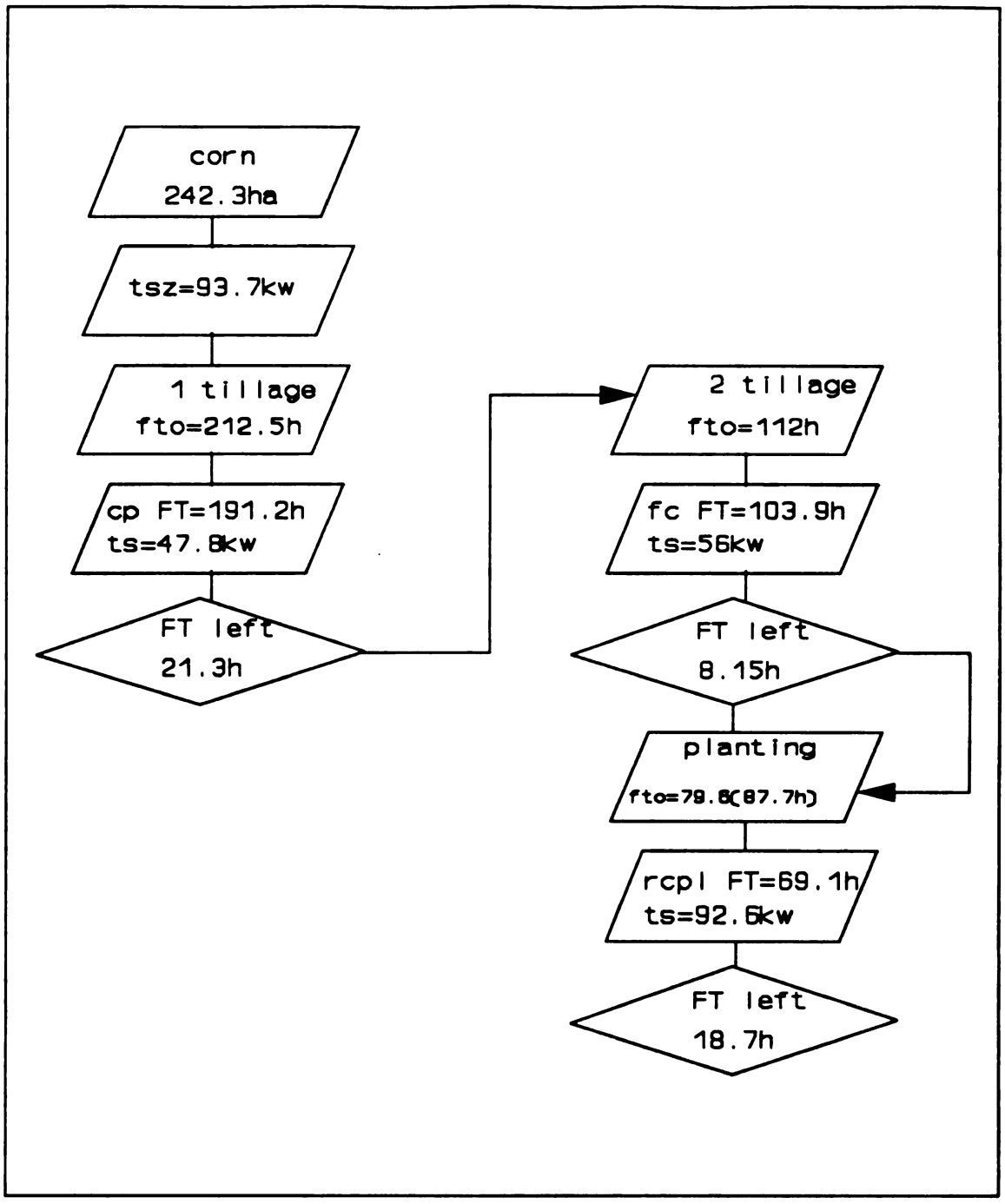

Figure 7.3 Field Time Algorithm for Corn Using One Tractor.

Table 7.24 Implement Costs for Each Implement for Corn.

	chisel	f.cultivator	r.c.planter
price($)	1820.00	2750.00	21400.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	44.76	74.07
time(h)	191.19	103.85	69.04
fuel(l)	4145.00	2405.17	2116.77
fuel(l/h)	21.68	23.16	30.66
Costs Labor($)	1472.13	799.62	531.58
fuel($)	870.49	505.14	444.50
oil($)	14.72	7.99	5.31
r&m($)	196.88	99.93	439.17
capital($)	311.74	471.04	36665.52
tis($)	40.87	61.75	480.56
Total($)	2906.84	1945.47	5566.64

Table 7.25 Tractor Costs for Corn.

	tract1
age(yr)	3
life(yr)	15
price($)	43988.00
time(h)	364.07
repair & maintenance($)	510.16
capital consumption($)	6340.51
taxes,insurance & shelter($)	1215.23
Total($)	8065.91

7.3.2 Field Beans Crop.

Implements : Chisel plow, field cultivator, and row crop planter.

Farm size = 242.3 hectares.

(a) Dates of Operation

Primary tillage : 9/15 - 11/30

Secondary tillage : 5/13 - 5/28

Planting : 5/29 - 6/19

Table 7.26 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment, kW	field time,h
chisel	0.90	2.13a	47.80	191.19
f.cult	2.65	2.74b	50.36	115.60
rcpl	3.64	4.57c	46.30	138.07

a smallest available commercial size: 7 shanks @ 0.305 m.

b commercial size: 9 shanks @ 0.305 m.

c commercial size: 6 rows @ 0.762 m.

Tractor size selected: 52.2 kW (70 hp)

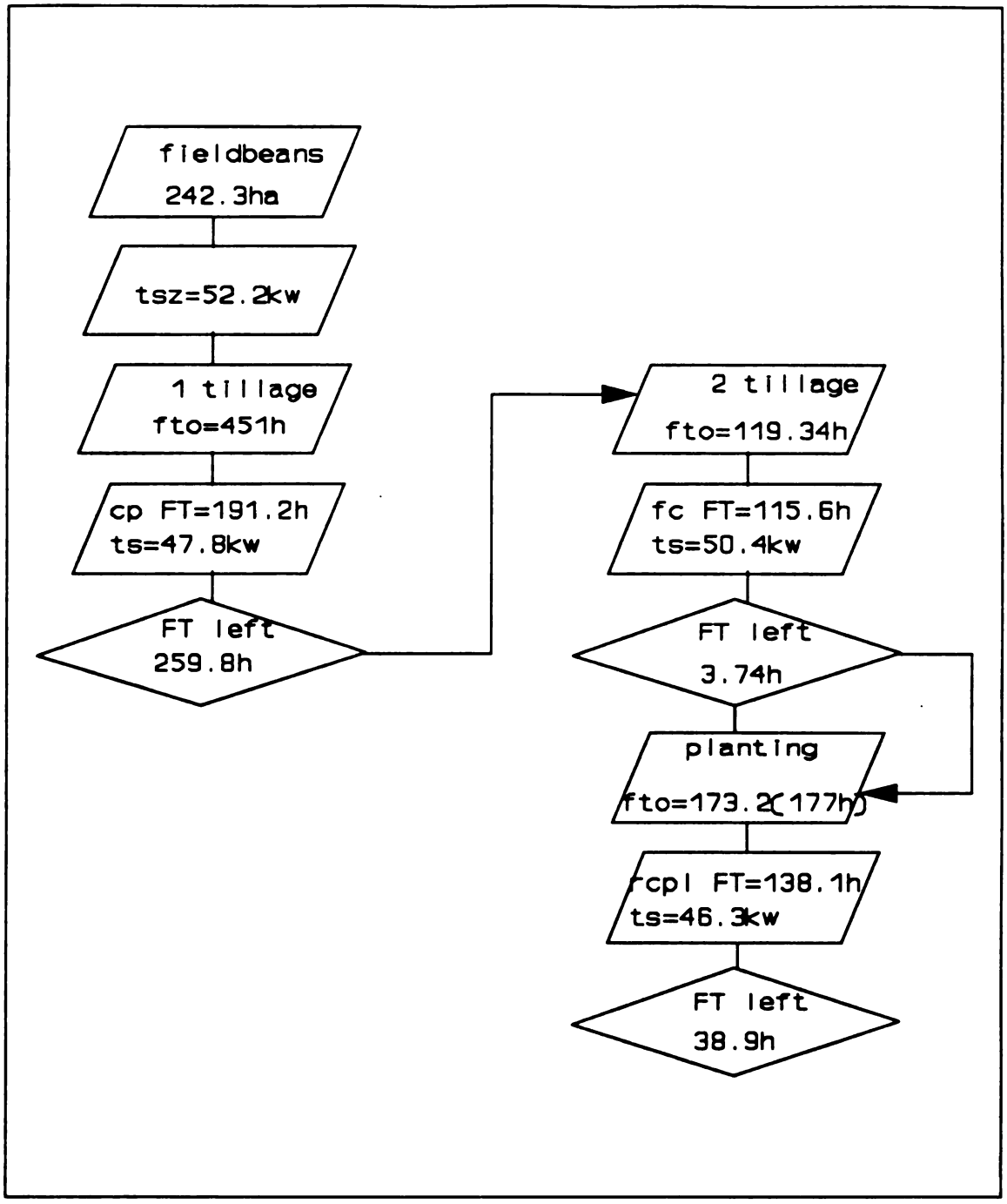

Figure 7.4 Field Time Algorithm for Field Beans Using One Tractor.

Table 7.27 Implement Costs for Each Implement for Field Beans.

	chisel	f.cultivator	r.c.planter
price($)	1820.00	2472.00	12840.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	40.29	37.04
time(h)	191.19	115.60	138.07
fuel(l)	3078.16	1936.30	2174.60
fuel(l/h)	16.10	16.75	15.75
Costs Labor($)	1472.13	890.09	1063.16
fuel($)	646.42	406.55	456.64
oil($)	10.03	6.07	7.25
r&m($)	196.88	104.38	1129.66
capital($)	311.74	423.42	2199.31
tis($)	40.87	55.51	288.34
Total($)	2678.08	1886.01	5144.35

Table 7.28 Tractor Costs for Field Beans.

	tract1
age(yr)	3
life(yr)	15
price($)	24500.00
time(h)	444.85
repair & maintenance($)	424.24
capital consumption($)	3531.47
taxes,ins & shelter($)	676.85
Total($)	4632.56

7.3.3 Wheat Crop.

Implement : Chisel plow, disk harrow, and grain drill.

Dates of operation :

Primary tillage : 8/1 - 8/30

Secondary tillage : 8/30 - 9/15

Planting : 9/15 - 10/15

Table 7.29 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment, kW	field time,h
chisel	1.72	2.13a	47.8	191.19
d.harrow	3.40	3.56b	78.58	133.13
drill	2.27	2.31c	33.60	234.13

a smallest available commercial size: 7 shanks @ 0.305 m.

b commercial size: 3.5 m.

c smallest available commercial size: 13 rows @ 0.178 m.

Tractor size selected: 79.37 kW (106.44 hp).

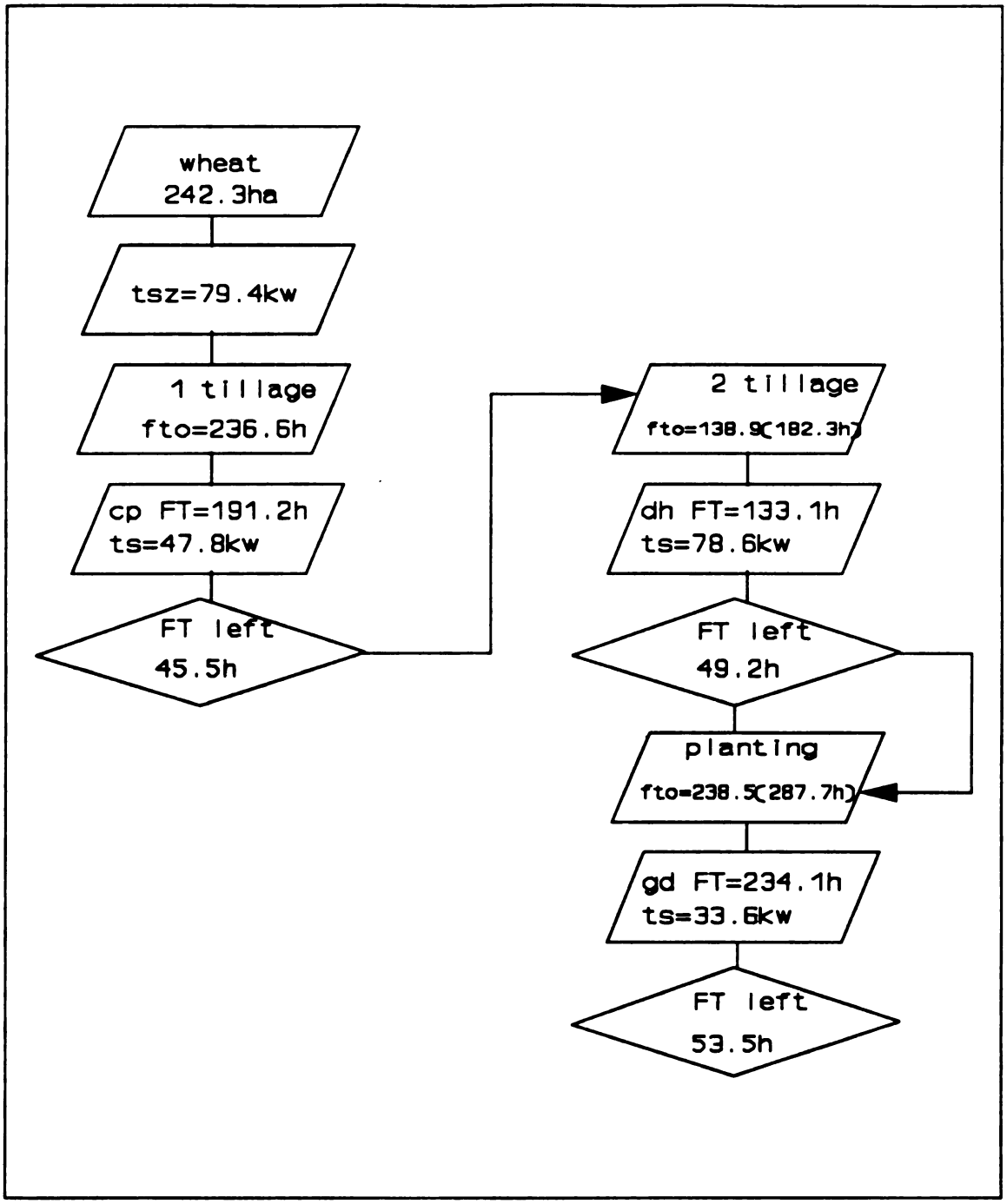

Figure 7.5 Field Time Algorithm for Wheat Using One Tractor.

Table 7.30 Implement Costs for Each Implement for Wheat.

	chisel plow	disk harrow	grain drill
price($)	1820.00	6545.00	4775.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	62.87	26.88
time(h)	191.19	133.13	234.13
fuel(l)	3814.24	3462.71	3961.48
fuel(l/h)	19.95	26.01	16.92
Costs Labor($)	1472.13	1025.12	1802.83
fuel($)	790.45	727.25	831.75
oil($)	13.10	9.12	16.04
r&m($)	196.88	195.14	1273.52
capital($)	311.74	1121.07	817.89
tis($)	40.87	146.97	107.23
Total($)	2825.18	3224.68	4849.26

Table 7.31 Tractor Costs for Wheat.

	tract1
age(yr)	3
life(yr)	15
price($)	37275.00
time(h)	558.45
repair & maintenance($)	1017.18
capital consumption($)	5372.89
taxes,ins & shelter($)	1029.78
Total($)	7419.84

7.3.4 Summary and Discussion

These examples demonstrate a single cropping of corn, field beans and wheat using one tractor. The recommended implements were the smallest implements required to complete the farm operation during a specified duration of time. Section 7.3.1 demonstrates the tractor and implement size selections for the corn production on a 242.3-hectare farm. The implements selected, were the minimum implement sizes to complete the farm operation on time. The unused field times after fall tillage, and spring tillage and planting were 21.3 and 18.7 hours, respectively. The user had the choice of using a 13-shank chisel plow and a 16-shank field cultivator that were compatible with the 93.72 kW tractor. The unused field times after fall tillage, and spring tillage and planting were 109.81 and 74.59 hours respectively. For the wheat production, the user also had the choice of using a 11-shank chisel plow and 30-row grain drill that were compatible with the the 79.37 kW tractor. The unused field time after planting operation was 258.24 hours. The unused field time after planting operation for the minimum width implements

selected earlier was only 53.5 hours.

Table 7.32 shows the summary for the machinery and tractor costs for the single cropping versus the multiple crop farm operation. The single cropping of corn required less time to produce when compared with the total time for all crops in a C-C-FB-W rotation. Other crops required more time under single cropping. Total tractor and machinery cost for producing field beans as a single crop was $1137.00 less than the total cost for all crops in a crop rotation. The field cultivator operation for single cropping of field beans was carried out once as compared to twice for the field beans in a C-C-FB-W rotation. The corn and wheat required an additional $3006.86 or $12.40 per hectare and $2840.96 or $11.72 per hectare, respectively, when produced as a single crop. Single cropping of wheat required three implement operations of chisel plow, disk harrow and grain drill. The wheat operation in a C-C-FB-W crop rotation required only the field cultivator and grain drill.

Table 7.33 shows the summary for each cost required to produce a single crop or the C-C-FB-W crop rotation. The single cropping of field beans could save $643.08 on tractor cost, $52.52 on fuel cost, $1.47 on oil cost, $865.50 on capital consumption cost, and $113.47 on taxes, insurance and shelter cost. The single cropping of corn and wheat required an additional of $2790.27 and $2144.20, respectively, for the total tractor cost. The single cropping of corn required an additional $258.00 on fuel cost, $3.21 on oil cost, $648.32 on implement capital consumption cost, and $84.99 on implement taxes, insurance and shelter. The single cropping of wheat required an additional $941.47 on labor cost, $787.33 on fuel cost, $13.44 on oil cost, and $706.90 on implement repair and maintenance cost.

Table 7.32 Summary for Machinery and Tractor Costs for Single and Multiple Cropping Using One Tractor.

	Single Cropping corn	Single Cropping f.beans	Single Cropping wheat	Multiple Cropping c-c-fb-w
Area(ha)	242.3	242.3	242.3	242.3
Total field time(h)	364.07	444.85	558.45	436.18
machinery cost($)	10418.95	9708.44	10899.11	10202.39
tractor cost($)	8065.91	4632.56	7419.84	5275.60
Total M & T cost($)	18484.86	14341.00	18318.96	15478.00
cost per hectare($/ha)	76.29	59.19	75.60	avg 63.75
cost per hour($/h)	50.77	32.24	32.80	avg 35.49

Table 7.33 Summary For Fixed and Variable Costs for Single and Multiple Cropping Using One Tractor.

	Single Cropping corn	Single Cropping fbeans	Single Cropping wheat	Multiple Cropping c-c-fb-w
Tractor C.($)				
R & M ($)	510.16	424.24	1017.18	466.13
C.C ($)	6340.51	3531.47	5372.89	4035.97
TIS ($)	1215.23	676.85	1029.78	773.54
Machinery C($)				
Labor ($)	2803.33	3425.38	4300.08	3358.61
Fuel ($)	1820.13	1509.61	2349.46	1562.13
Oil ($)	28.03	23.35	38.26	24.82
R & M ($)	735.99	1430.92	1665.55	958.65
C.C ($)	4448.29	2934.47	2250.69	3799.97
TIS ($)	583.18	384.72	295.07	498.19
Total($)	18484.8	14341.00	18318.96	15478.02

7.4 Single Crop, Two-Tractor Operation.

Location : East Lansing

Soil Texture : Fine

7.4.1 Corn Crop.

First : Chisel plow and field cultivator.

Second tractor : row crop planter.

Farm size = 242.3 hectares.

(a) Dates of Operation

Primary tillage : 10/15 - 11/30

Secondary tillage : 4/24 - 5/22

Planting : 4/24 - 5/22

This example farm demonstrates a single cropping of corn using a two-tractor operation. The first tractor was used for the fall primary tillage and spring secondary tillage operations. The second tractor was used for the planting operation. The field time unused during the primary tillage operation was not added to the secondary tillage operation. The dates for the secondary tillage and planting operations were allowed to overlap because of the use of different tractors. The secondary tillage and planting operations were allowed to work simultaneously.

Table 7.34 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment, kW	field time,h
chisel	1.92	2.13a	47.80	191.19
f.cult	1.59	2.13b	39.17	148.70
rcpl	3.16	4.57c	46.30	138.07

a smallest available commercial size: 7 shanks @ 0.305 m.

b smallest available commercial size: 7 shanks @ 0.305 m.

c commercial size: 6 rows @ 0.762 m.

First tractor size selected : 48.5 kW (65 hp)

Second tractor size selected : 48.5 kW (65 hp)

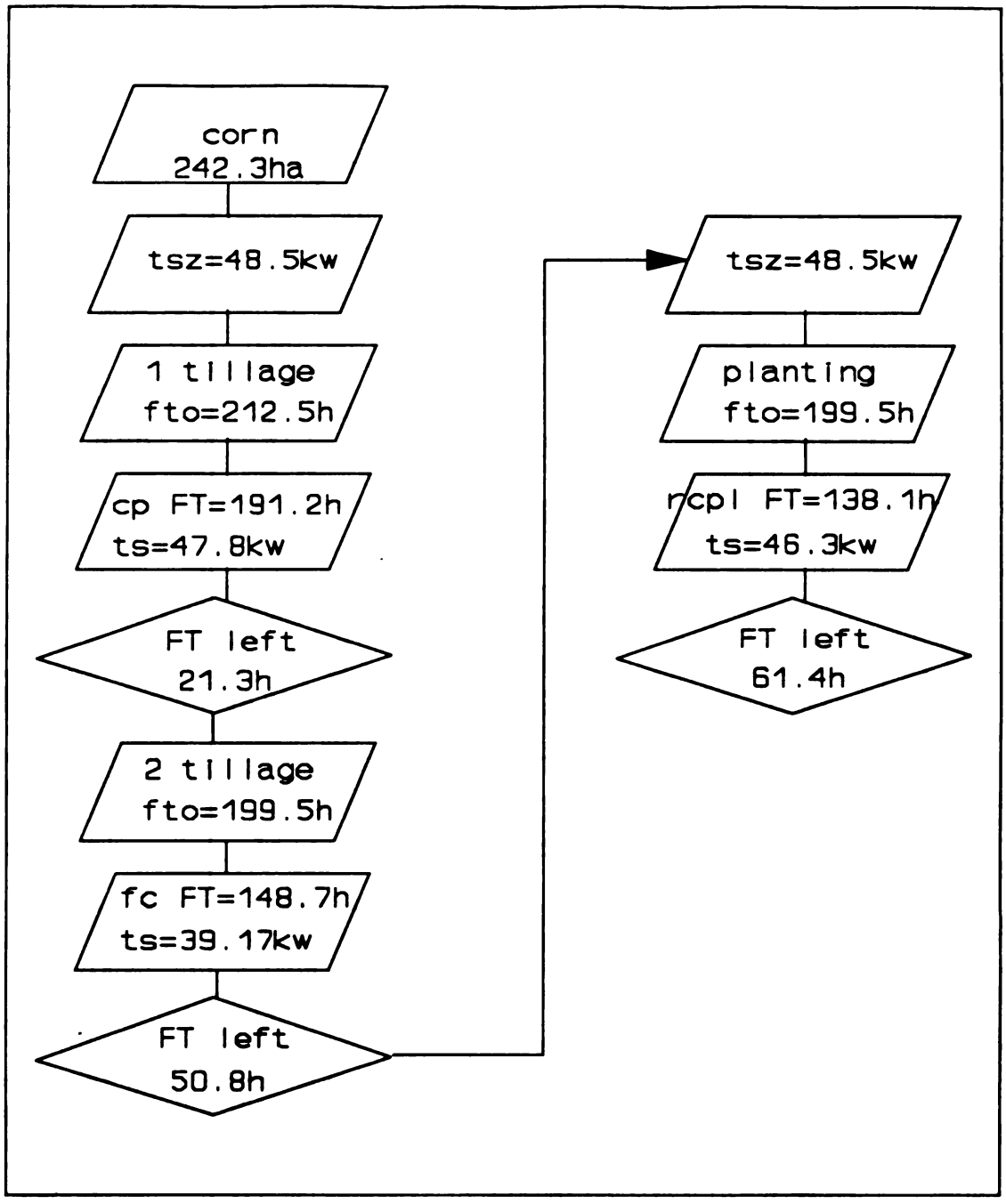

Figure 7.6 Field Time Algorithm for Corn Using Two Tractors.

Table 7.35 Implement Costs for Each Implement for Corn.

	chisel	f.cultivator	r.c.planter
price($)	1820.00	1925.00	12840.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	31.33	37.04
time(h)	191.19	148.70	138.07
fuel(l)	3026.54	2055.03	2130.42
fuel(l/h)	15.83	13.82	15.43
Costs Labor($)	1472.13	1144.99	1063.16
fuel($)	635.72	431.43	447.43
oil($)	9.62	7.48	6.95
r&m($)	196.88	115.64	1129.66
capital($)	311.74	329.73	2199.31
tis($)	40.89	43.23	288.34
Total($)	2666.96	2072.50	5134.83

Table 7.36 Tractor Costs for Each Tractor for Corn.

	tract1	tract2
age(yr)	3	3
life(yr)	15	15
price($)	22750.00	22750.00
time(h)	339.89	138.07
repair & maintenance($)	229.96	37.95
capital consumption($)	3279.23	3279.23
taxes,ins & shelter($)	628.50	628.50
Total($)	4137.69	3945.68

Table 7.37 Summary for Fixed And Variable Costs for Corn Production Using Two Tractor.

	tract1	tract2	Total
Tractor Cost($)			
Repair & Maintenance($)	229.96	37.95	267.91
Capital Consumption($)	3279.23	3279.23	6558.46
Taxes,Ins & Shelter($)	628.50	628.50	1257.00
Machinery Cost($)	2617.13	1063.16	3680.28
Labor cost($)			
Fuel cost($)	1067.15	447.43	1514.58
Oil cost($)	17.10	6.95	24.04
Repair & maintenance($)	312.52	1129.66	1442.18
Capital Consumption($)			2840.77
Taxes,Ins & Shelter($)			372.43
Total($)			17957.66

7.4.2 Field Beans Crop.

First tractor : Chisel plow and field cultivator.

Second tractor : row crop planter.

Farm size = 242.3 hectares.

(a) Dates of Operation

Primary tillage : 9/15 - 11/30

Secondary tillage : 5/13 - 6/19

Planting : 5/15 - 6/19

Table 7.38 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment, kW	field time,h
chisel	0.90	2.13a	47.80	191.19
f.cult	1.11	2.13b	39.17	148.70
rcpl	2.22	3.05c	30.86	206.88

a smallest available commercial size: 7 shanks @ 0.305 m.

b smallest available commercial size: 7 shanks @ 0.305 m.

c smallest available commercial size: 4 rows @ 0.762 m,

First Tractor Selected : 48.5 kW (65 hp)

Second Tractor Selected : 34.3 kW (46 hp)

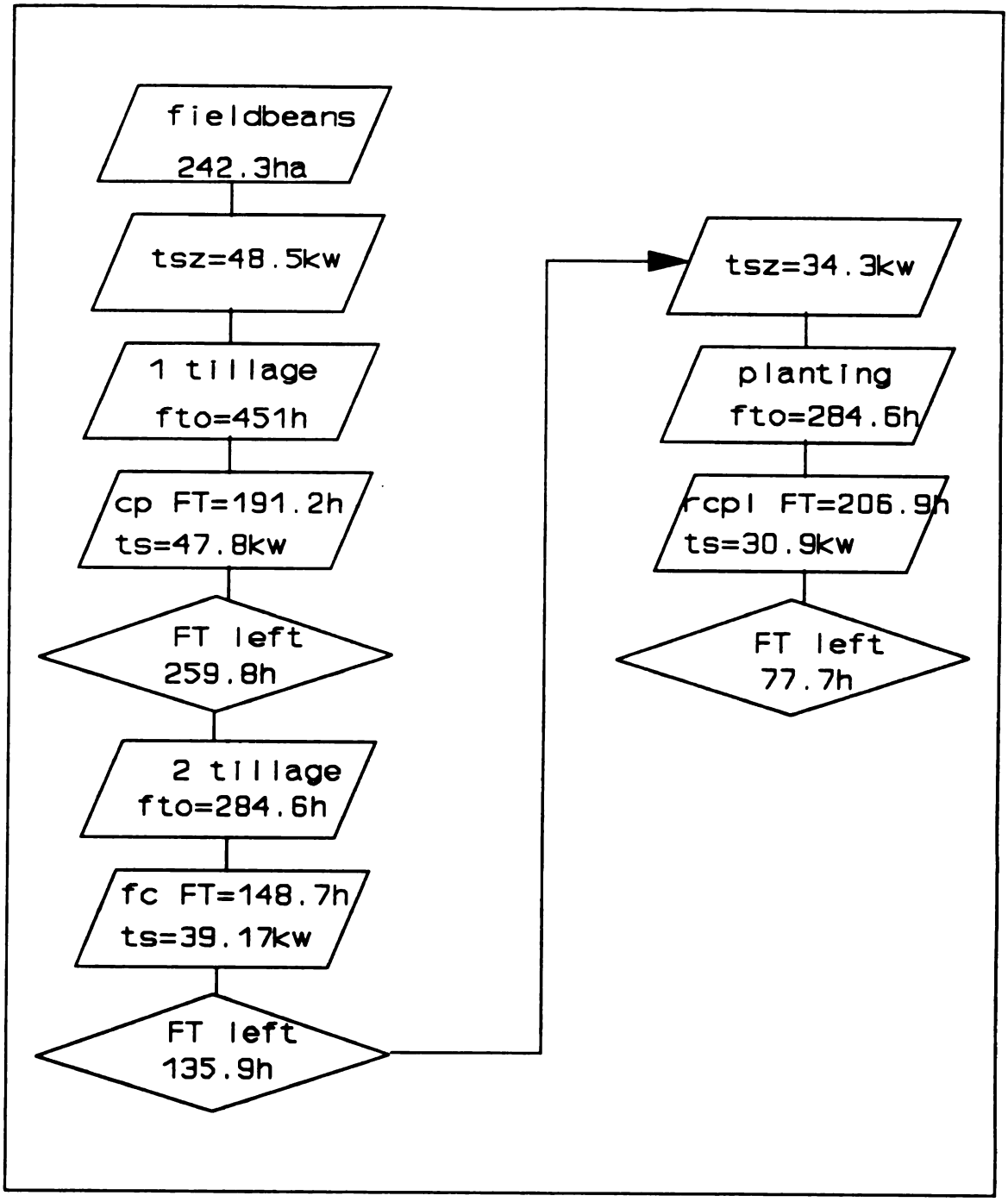

Figure 7.7 Field Time Algorithm for Field Beans Using Two Tractors.

Table 7.39 Implement Costs for Each Implement for Field Beans.

	chisel	f.cultivator	r.c.planter
price($)	1820.00	1925.00	8560.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	31.33	24.69
time(h)	191.19	148.70	206.88
fuel(l)	3026.54	2055.03	2161.90
fuel(l/h)	15.83	13.82	10.45
Costs Labor($)	1472.13	1144.99	1592.99
fuel($)	635.72	431.43	454.03
oil($)	9.62	7.48	8.67
r&m($)	196.88	115.64	1760.56
capital($)	311.74	329.73	1466.21
tis($)	40.87	43.23	192.22
Total($)	2666.90	2072.50	5474.68

Table 7.40 Tractor Costs for Each Tractor for Field Beans.

	tract1	tract2
age(yr)	3	3
life(yr)	15	15
price($)	22750.00	16100.00
time(h)	339.89	206.88
repair & maintenance($)	229.96	60.29
capital consumption($)	3279.23	2320.68
taxes, ins & shelter($)	628.50	444.79
Total($)	4137.69	2825.76

Table 7.41 Summary for Fixed and Variable Costs for Field Beans Production Using Two Tractors.

	tract1	tract2	Total
Tractor Cost($)			
Repair & Maintenance($)	229.96	60.29	290.25
Capital Consumption($)	3279.23	2320.68	5599.91
Taxes,Ins & Shelter($)	628.50	444.79	1073.29
Machinery Cost($)	2617.13	1592.99	4210.12
Labor cost($)			
Fuel cost($)	1067.15	454.03	1521.18
Oil cost($)	17.10	8.67	25.77
Repair & maintenance($)	312.52	1760.56	2073.08
Capital Consumption($)			2107.67
Taxes,Ins & Shelter($)			276.32
Total($)			17177.60

7.4.3 Wheat Crop.

First tractor : Chisel plow and disk harrow

Second tractor : grain drill

Farm size = 242.3 hectares.

Dates of operation

Primary tillage : 8/1 - 8/30

Secondary tillage : 8/30 - 10/15

Planting : 9/15 - 10/15

Table 7.42 Implement Size, Power Requirement and Field Time for Each Implement.

	recommended size,m	commercial size,m	power req'ment, kW	field time,h
chisel	1.72	2.13a	47.80	191.19
d. harrow	1.24	1.70b	38.17	274.10
drill	2.27	2.31c	33.60	234.13

a smallest available commercial size: 7 shanks @ 0.305 m.

b commercial size: 1.7 m.

c smallest available commercial size: 13 rows @ 0.178 m.

First tractor size selected : 48.5 kW (65 hp)

Second tractor size selected : 34.30 kW (46 hp)

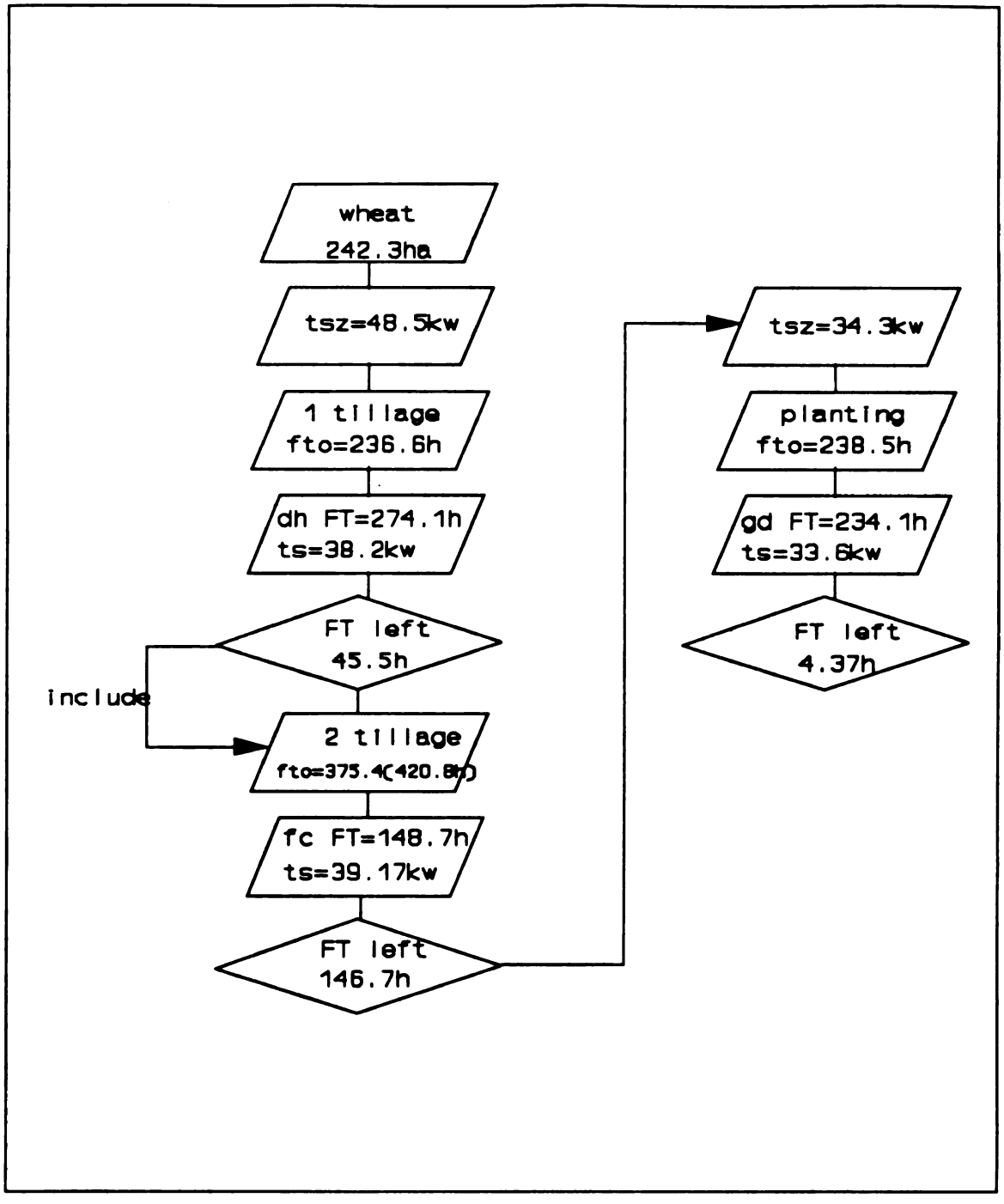

Figure 7.8 Field Time Algorithm for Wheat Using Two Tractors.

Table 7.43 Implement Costs for Each Implement for Wheat.

	chisel plow	disk harrow	grain drill
price($)	1820.00	3179.00	4775.00
age(yr)	3	3	3
life(yr)	10	10	10
EPTOP(kW)	38.24	30.54	26.88
time(h)	191.19	274.10	234.13
fuel(l)	3026.54	3733.24	2601.18
fuel(l/h)	15.83	13.62	11.11
Costs Labor($)	1472.13	2110.53	1802.83
fuel($)	635.72	784.01	546.11
oil($)	9.62	13.79	9.72
r&m($)	196.88	323.51	1273.52
capital($)	311.74	544.52	817.89
tis($)	40.87	71.39	107.23
Total($)	2666.96	3847.74	4557.30

Table 7.44 Tractor Costs for Each Tractor for Wheat.

	tract1	tract2
age(yr)	3	3
life(yr)	15	15
price($)	22750.00	16100.00
time(h)	465.28	234.13
repair & maintenance($)	430.94	77.23
capital consumption($)	3279.23	2320.68
taxes,ins & shelter($)	628.50	444.79
Total($)	4338.67	2842.70

Table 7.45 Summary for Fixed and Variable Costs for Wheat Production Using Two Tractors.

	tract1	tract2	Total
Tractor Cost($)			
Repair & Maintenance($)	430.94	77.23	508.17
Capital Consumption($)	3279.23	2320.68	5599.91
Taxes,Ins & Shelter($)	628.50	444.79	1073.29
Machinery Cost($)			
Labor cost($)	3582.67	1802.83	5385.49
Fuel cost($)	1419.73	546.11	1965.84
Oil cost($)	23.41	9.72	33.13
Repair & maintenance($)	520.39	1273.52	1793.92
Capital Consumption($)			1674.15
Taxes,Ins & Shelter($)			219.49
Total($)			18253.37

7.4.4 Summary and Conclusion

Table 7.46 shows the summary for machinery and tractor costs for single cropping of crops and multiple crops in a rotation using a two-tractor operation. The total machinery and tractor costs show that it was cheaper to produce a C-C-FB-W crop rotation on a 242.3 hectare farm as compared to single cropping of corn and wheat. It required a higher total machinery cost and total tractor cost for the wheat and a higher total tractor cost for the corn. The single cropping of corn and wheat required an additional $2.70 per hectare and $3.92 per hectare, respectively. It was found to be cheaper to produce a field beans as a single crop than a C-C-FB-W crop rotation. Single cropping of field beans could save $124.30 or $0.51 per hectare.

Table 7.47 shows the summary for each cost required to produce single cropping or C-C-FB-W crop rotation. The single cropping of corn required an additional of $1128.87 for tractor cost, $17.93 for fuel cost and $115.69 for implement repair and maintenance cost. The single cropping of wheat required an additional $226.87 for tractor cost, $1196.07 for labor cost, $469.19 for fuel cost, $7.55 for oil cost and $467.42 for implement repair and maintenance cost. This crop required an additional $951.47 total cost as compared to C-C-FB-W crop rotation. The single cropping of field beans could save $817.89 for implement capital consumption cost and $107.23 for implement taxes, insurance and shelter cost.

Table 7.46 Summary for Machinery and Tractor Costs for Single and Multiple Cropping Using Two Tractors.

	Single Cropping corn	Single Cropping f.beans	Single Cropping wheat	Multiple Cropping c-c-fb-w
Area(ha)	242.30	242.30	242.30	242.30
Total field time(h)	477.96	546.77	699.41	544.09
machinery cost($)	9874.29	10214.44	11072.1	10347.40
tractor cost($)	8083.37	6963.46	7181.37	6954.52
Total M & T cost($)	17957.66	17177.60	18253.37	17301.90
cost per hectare($/ha)	74.11	70.89	75.33	avg 71.41
cost per hour($/h)	37.57	31.42	26.10	avg 31.80

Table 7.47 Summary for Fixed and Variable Costs for Single and Multiple Cropping Using Two Tractors.

	Single Cropping corn	Single Cropping fieldbeans	Single Cropping wheat	Multiple Cropping c-c-fb-w
Tractor($)				
R & M ($)	267.91	290.25	508.17	271.31
C.C ($)	6558.46	5599.91	5599.91	5599.91
T.I.S ($)	1257.00	1073.29	1073.29	1073.29
Machinery($)				
labor ($)	3680.28	4210.12	5385.49	4189.42
fuel ($)	1514.58	1521.18	1965.84	1496.65
oil ($)	24.04	25.77	33.13	25.58
R & M ($)	1442.18	2073.08	1793.92	1326.49
C.C ($)	2840.77	2107.67	1674.15	2925.56
T.I.S($)	372.43	276.32	219.49	383.55
Total cost($)	17957.66	17177.60	18253.37	17301.90

8. SUMMARY AND CONCLUSIONS

The Crop Production Machinery System, CPMS model was developed based on the concept of expert systems using the Turbo Pascal programming language. The advantage of Turbo Pascal language is that the program is organized into blocks which are algorithms working on data structures. The advantage of expert systems is that they allow users to become more knowledgeable about a problem as they interact with the program. Beside helping the user make proper decisions, the system can provide education through explanatory and feedback features.

The CPMS program was developed for five different locations, three soils textures, and two tillage systems. The moldboard plow, chisel plow, field cultivator, disk harrow, row crop planter and seed drill were chosen to be used in this program. The program allows a maximum of five different crops or a combination of any one or more of these crops in a rotation. A maximum of four tractors is allowed in this program.

This program was developed to run on most microcomputers to increase its user availability. It was designed to be modified, transferred, and evaluated for other geographical locations and situations. In this model, there are procedures designed to be easily modified for other situations and geographical locations. Procedures DATELIST can be changed to accommodate different probabilities of working days for other locations. Other locations could be added or changed if the probability of working days

(pwd) of those locations are known. Procedures to determine the implement draft such as SOIL1, SOIL2, SOIL3, SOIL4, SOIL5, and SOIL6 can be easily changed for different geographical locations and implements. These procedures contain equations which use speed of operation, depth of operation and size of implements. At the moment, the program makes use of the draft equations obtained from the ASAE STANDARDS (ASAE, 1989) and Machinery Management (FMO, 1987). The fixed and variable costs equations were obtained from the ASAE STANDARDS (ASAE, 1989), Hunt (1983) and Kepner et al.(1987). These equations could be easily changed for other locations. Corn, soybeans, field beans, wheat and oats were selected to be used in this program. Procedures CROP can be changed to crops other than what were used in this program as desired by the user.

The CPMS model consists of the Machinery Selection Model and Machinery Cost Analysis Model. The Machinery Selection Model is used to determine the compatibility of the tractors and implements, to properly match the available power, and to complete the field operations during a specified duration of time. The tractor size is calculated based on the drawbar power required by the implement. The required implement drawbar power is compared to the available tractor drawbar power. The field time required by the implements to complete the farm operation is compared to the available field operation time. The best size and combination of implements are those implements that could utilize the maximum available power from the tractor and the available field operation time. When a well - matched system is selected, the total annual cost of owning and operating the set of machines is then determined. Several well-matched systems can be found for the same farm, thus cost analysis can be used to select the "least cost" system.

Various sensitivity analyses can be carried out using the CPMS model. This analysis could be done by changing each parameter or a combination of parameters at a time and noting the effect it has on the tractor and implement selection and costs. Chapters 6 and 7 discussed some of the parameters being changed to explore the operation and performance of the model. Chapter 6 discussed on the effect of the number and type of implements used on the implement size selection. Implement size decreases when fewer implements were used for the same land area. Different tillage systems require different implements and implement sizes. Different implement combinations will require different size implements for the same dates and area of operation. Chapter 7 shows examples of a farm with a single crop operation and a C-C-FB-W crop operation. The number of crops in a crop operation will affect the dates of operation and the field time available for the implement operation thus affecting the implement and tractor size selection. Different crop operations have a different set of implements suitable for the farm operation. The above farms were also tested using one-tractor and two-tractor operations. The number of tractors used also determined the size of implements to be used for the farm operation.

Different farm locations have different probabilities of working days which determine the field operation time when coupled with the dates of operation. The farm size affects the field time required by an implement to complete the operation in time. Subsequently, farm size determines the number and size of tractors and implements to be used. Larger farm size requires larger implements. Larger farm size and larger implements require larger tractors. The type and number of implements used will determine the time required to complete the farm operation. Increasing the number of

passes of operations for the disk harrow and field cultivator will require additional field time, which will affect the required implement sizes. With the fixed farm operation time, the model determines the size of the implement required. The mode of operation for either continuous tillage to planting or individual farm operation of tillage and planting affect the field operation time for the implement operation. For the continuous operation, unused field time from an earlier operation can be used for the later implement operation. Thus, the implement size will be based on the number of implements to be used and the total time available from the tillage to planting operation. For the individual operation, the available field time will be used to determine the implement size for that particular operation.

The Machinery Cost Analysis Model is used to determine the cost of owning and operating a set of machines selected in the Machinery Selection Model. This model calculates the fuel required, fuel cost, oil cost, and labor cost for each implement used by each crop and for all crops in a rotation. It calculates the implement repair and maintenance cost, capital cost, and taxes, insurance and shelter cost for each implement used for each crop assumed as a single crop operation and for each crop in a rotation. These costs calculated for each implement used for each crop in a rotation will be based on the proportion of time used by each crop compared to the total time used by all crops. The model will also calculate the tractor's repair and maintenance cost, capital cost, and taxes, insurance and shelter cost for each tractor used for each crop in a single crop operation or for each crop in a rotation. The costs calculated for each tractor used for each crop in a crop rotation will be based on the proportion of time used by each crop compared to the total time used by all the crops. The total machinery cost, total tractor

cost, cost per hectare and cost per hour for each crop assumed as a single crop operation and for each crop in a rotation will also be calculated. Other calculations given are the total tractor costs for repair and maintenance, capital consumption and taxes, insurance and shelter for all the tractors used in the operation. The total machinery costs for labor, fuel, oil, repair and maintenance, capital consumption and taxes, insurance and shelter will also be calculated for all the implements used in the operation. The above calculations allow the user to compare the fixed and variable costs within and among the implements used for each crop produced. The user can also compare the total machinery and tractor cost between crops. The total machinery and tractor cost, cost per hectare and cost per hour can also be compared for each crop assumed as a single crop operation to the same crop in a multiple-crop operation. Examples in Chapter 7 show that more crops in a crop rotation will increase machinery and tractor utilization which reduces the costs. The implement's and tractor's capital consumption cost and taxes, insurance and shelter cost will be evenly distributed. As in the above example, the one tractor operation required relatively larger implements as compared to the two tractor operation on the same land size. The corn - corn - field beans - wheat rotation on a 242.3 hectare farm is cheaper to produce using one tractor operation as compared to the two tractor operation. As in Chapter 7, it was cheaper to produce corn and wheat in a C-C-FB-W crop rotation as compared to those crops produced as a single crop operation. It was cheaper to produce field beans as a single crop operation as compared to the same crop in the above crop rotation, using either one tractor or two tractor operations. The field cultivator operation for the single cropping of field beans was done once as compared to twice for the field beans in a C-C-FB-W rotation.

The labor wage, fuel price, oil price and interest rate will affect the cost analysis. Sensitivity analyses on the cost analysis can also be carried out by changing the implement's and tractor's purchase price, age and expected life. The fuel cost, oil cost and labor cost are actual costs calculated based on the implement field time. Thus, the implement size and number of hours used will affect those costs. The repair and maintenance cost, capital consumption cost, and taxes, insurance and shelter cost are also calculated based on the tractor and implement field time. These costs for each crop, vary with the number of crops used, as these costs are calculated based on the proportion of time used by each crop to the cumulative field time used by all crops.

The CPMS model was validated using the data gathered from field experiments carried out at Michigan State University and Clinton County, Michigan. The field experiments were carried out using a moldboard plow, chisel plow, field cultivator, disk harrow, row crop planter and grain drill at different operation speed and operation depth to determine the draft and fuel requirements. Regression analysis was performed between model outputs and experimental outputs. A student's *t* test was used to determine whether the intercept and the slope of the regression line were significantly different from zero. An F-Statistic was used to determine whether the relation expressed by the regression line was statistically significant. The model's prediction of the fuel consumption plotted against the actual fuel consumption gave a high correlation between measured and predicted values for all implements used.

A statistical analysis gave regression lines with high correlation coefficients for the draft requirements of the moldboard plow, chisel plow and field cultivator. The model draft equations for these implements were based on the implement width, operation

depth and operation speed. The correlation coefficients for the row crop planter and grain drill were lower compared to the above implements. The model draft equations for these implements were calculated based on the number of of rows or openers and independent of the operation speed. The correlation coefficient for the disk harrow was low, showing a low association between the experimental draft and the model draft. The model draft equation for the disk harrow was calculated based on the implement width and operation speed and does not include the operation depth.

The prediction of the model fuel consumption plotted against the actual fuel use gave a high correlation between measured and predicted values for all of the experiments with all of the implements used in these field tests. All experiments for each implement were combined and analyzed. The coefficient of correlation for the fuel consumption was low for the combined data of the row crop planter as compared to high coefficient of correlation from the individual row crop planter experiment. This variation probably was due to problems with the model draft equation.

In conclusion, the CPMS model predicts the sizes of tractors and implements for a given farm size. For a given tractor size, the model predicts the maximum implement size and the maximum area of operation. The model determines the compatibility of the tractor and machinery used to properly match the available power and to complete the farm operation within specified time constraint. The model recommends the implement size and the user has to select the commercial size implement to be used in the program. When a well-matched system is selected, the total annual cost of owning and operating the set of machines is then determined. Several well-matched systems can be found, thus the least cost should be selected. The concept of expert systems used for this program

will easily allow the user to carry out a sensitivity analysis. The model was also created to be used with external data files. The model was able to compare different farm sizes, tillage systems, and crop production system with respect to costs and machinery requirements. The machinery cost analysis was able to evaluate machinery costs when: (a) the use of machinery was shared in several enterprises; (b) the same machinery was used under different conditions (eg. speed, depth, field efficiency, tractive efficiency); and (c) machinery costs were compared for different situations such as farm size and production practices.

9. SUGGESTIONS FOR FUTURE WORK

At present, the CPMS program determines the machinery selection and cost of production based only on the tillage and planting operations. The program should be further developed to include the spraying and harvesting operation. The program should also be expanded to determine the break-even price and break-even yield for defender and challenger crops. It should be modified to add more implements, tractors and crops. Programs to be modified for Malaysia should include the rice crop, rotovator, tractive efficiency, field efficiency, and cost assumptions.

Further works should be carried out in the programming to ensure that the program could be used for various geographical locations and situations. It is suggested that equations which change with locations and situations are to be fed into the program as external files.

A statistical analysis showed a low correlation coefficient of the disk harrow draft requirements. It is recommended that more research be carried out to develop a disk harrow draft equation to include operation depth and operation speed. It is also recommended to carry out more experiments using the row crop planter to reduce the draft variations between the model and experimental results.

The author would like to suggest that the CPMS program be tested by extension agents and later be used by farmers. Their feedback should be used to further develop

or modified the CPMS program. Ultimately, the author would like the program to be automated for the advanced user. Automated CPMS program should include only the final outputs for the machinery sizes and costs.

APPENDIX

APPENDIX A

FIELD EXPERIMENTAL DATA

Tables A.1 to A.26 show the experiments carried out using the chisel plow, moldboard plow, disk harrow, field cultivator, row crop planter and grain drill at MSU and Clinton County. The experimental and model draft and fuel requirements were tabulated for each experiment. These data were analyzed using F-statistic and student's *t* test. The summary for regression analysis were as in Table 5.4 to 5.10 in Chapter 5.

APPENDIX A

Table A.1 Experimental and Model Draft and Fuel Requirements For Chisel Plow on Capac Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
3.68	25.00	22.06	13.32	15.97	14.28
5.26	25.00	16.37	10.92	13.88	13.27
5.39	25.00	20.56	16.31	17.47	14.81
4.69	25.00	22.26	17.86	16.86	15.04
5.01	20.00	16.92	11.03	13.71	13.24
5.34	20.00	17.47	11.86	13.94	14.00
6.82	20.00	18.38	16.23	14.98	13.78
8.44	13.00	11.39	12.84	10.47	10.92
8.20	10.00	8.44	8.43	7.97	9.58

Location: Michigan State University. Implement: Chisel Plow. Size: 8 tools of 2.2 m.

Table A.2 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Capac Loam Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.93	10.54	9.64	15.00	13.00
5.73	11.51	9.89	14.49	12.96
7.30	9.63	11.65	18.46	14.37
7.17	10.14	11.81	18.14	14.29
8.80	9.06	11.29	22.27	15.49
8.81	8.89	11.35	22.29	15.47
11.45	9.47	15.71	28.97	17.43
10.96	11.08	16.77	27.72	17.00

Location: Michigan State University. Implement: Disk Harrow of 4.27 m. No-Till

Table A.3 Experimental and Model Draft and Fuel Requirements for Field Cultivator on Capac Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.00	10.00	9.39	11.96	14.16	13.09
6.86	13.00	12.16	12.62	18.28	14.60
7.82	13.00	11.02	13.57	19.10	14.86
8.33	10.00	8.09	11.27	15.03	13.40
10.68	8.00	7.10	14.57	13.26	12.61
8.24	13.00	13.71	18.70	19.47	15.44
9.69	13.00	11.76	16.86	20.70	15.37
11.39	10.00	9.03	16.08	17.04	14.17
9.49	13.00	11.91	14.98	20.53	15.41

Location: Michigan State University.
Implement: Field Cultivator Size: 25-tool Width: 4.27 m
Condition: After Moldboard Plowed and Disk Harrowed.

Table A.4 Experimental and Model Draft and Fuel Requirements for Field Cultivator on Capac Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.73	8.00	4.37	10.24	11.71	12.82
6.68	13.00	13.95	16.93	18.13	14.51
8.76	8.00	5.74	11.12	12.25	13.92
8.26	13.00	12.99	19.01	19.48	14.88
11.11	8.00	5.33	13.72	13.48	14.11
10.18	10.00	12.60	19.37	16.25	13.72

Location: Michigan State University.
Implement: Field Cultivator Size: 25-tool Width: 4.27 m
Field Condition: No-Till Area.

Table A.5 Experimental and Model Draft and Fuel Requirements for Grain Drill on Capac Loam Soil After Moldboard Plowing.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.61	5.35	9.81	6.75	8.96
8.79	5.06	9.79	6.75	9.67
10.93	5.03	12.61	6.75	8.68
12.71	5.28	12.96	6.75	10.19

Location: Michigan State University.
Implement: Grain Drill Size: 15 Openers Width: 2.84 m
Field Condition: Previously Moldboard Plowed area.

Table A.6 Experimental and Model Draft and Fuel Requirements for Grain Drill on Capac Loam Soil After Chisel Plowing.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.77	5.00	8.53	6.75	8.59
8.54	5.50	9.03	6.75	8.74
11.01	4.87	10.23	6.75	8.28
12.71	5.28	11.48	6.75	8.87

Location: Michigan State University.
Implement: Grain Drill Size: 15 Openers Width: 2.84 m
Field Condition: Previously Chisel Plowed area.

Table A.7 Experimental and Model Draft and Fuel Requirements for Chisel Plow on Owosso-Marlette Sandy Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
6.56	20	19.24	19.29	13.48	13.19
3.75	20	15.50	19.70	11.19	12.30
4.02	15	13.69	19.26	8.56	11.17
8.54	15	15.36	19.86	11.33	11.73
9.19	15	16.46	20.10	11.72	12.04

Location: St.John, Michigan.
Implement: Chisel Plow Size: 7-tine Width: 2.5 m

Table A.8 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Granby Loamy Sand Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.59	10	7.15	8.89	8.33	10.42
5.59	15	7.25	9.09	8.33	10.42
7.89	10	7.73	10.57	11.76	12.63
8.03	15	8.71	11.19	11.97	12.74

Location: St.John, Michigan.
Implement: Disk Harrow Width: 3.96 m
Field Condition: No-Till area.

Table A.9 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Palms Muck Soil.

Speed, km/h	Number of passes	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.31	one	7.10	10.97	13.16	15.19
8.03	one	6.49	11.91	14.47	15.79
10.32	one	6.39	15.76	18.60	18.75
9.38	twice	4.71	14.29	16.89	16.91
7.45	twice	5.68	10.53	13.43	15.30
8.12	twice	2.78	10.94	14.63	15.83

Location: St.John, Michigan.
Implement: Disk Harrow Width: 3.04 m
Field Condition: Previously Moldboard plowed area.

Table A.10 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Metamora-Capac Sandy Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.03	13	6.42	9.94	13.21	14.77
8.12	13	7.49	12.34	15.25	16.50
8.06	13	8.34	12.17	15.15	16.45

Location: St.John, Michigan.
Implement: Disk Harrow Width: 3.17 m

Table A.11 Experimental and Model Draft and Fuel Requirements for Corn Planter on Palms Muck Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.22	8.51	10.95	9.3	10.37
6.88	8.54	10.63	9.3	10.29
7.88	7.43	11.49	9.3	10.40
7.91	7.61	11.62	9.3	10.39

Location: St.John, Michigan.
Implement: Corn Planter Size: 6-row Width: 3.83 m
Field Condition: No-Till area.

Table A.12 Experimental and Model Draft and Fuel Requirements for Corn Planter on Gilford Sandy Loam Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.59	9.69	9.79	9.30	11.33
7.04	9.40	12.33	9.30	11.30
7.85	8.78	12.39	9.30	11.24
8.05	7.65	12.02	9.30	11.16

Location: St.John, Michigan.
Implement: Corn Planter Size: 6-row Width: 3.83 m
Field Condition: No-Till area.

Table A.13 Experimental and Model Draft and Fuel Requirements for Corn Planter on Gilford Sandy Loam Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.72	6.74	8.44	9.30	12.85
7.09	6.95	9.58	9.30	12.99
8.14	6.46	10.65	9.30	13.01
8.35	6.61	11.15	9.30	13.06

Location: St.John, Michigan.
Implement: Corn Planter Size: 6-row Width: 3.83 m
Field Condition: Previously disk harrowed area.

Table A.14 Experimental and Model Draft and Fuel Requirements for Grain Drill on Granby Loamy Sand Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
6.02	4.56	7.89	2.34	5.23
6.06	4.46	7.80	2.34	5.28
7.71	3.82	8.72	2.34	5.86
8.77	3.72	9.31	2.34	6.26
8.41	3.07	8.81	2.34	6.23

Location: St.John, Michigan.
Implement: Grain Drill Size: 18 openers Width: 3.05 m
Field Condition: Previously moldboard plowed and disk harrowed.

Table A.15 Experimental and Model Draft and Fuel Requirements for Grain Drill on Palms Muck Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
6.17	3.62	6.99	5.22	7.14
6.01	3.67	6.86	5.22	7.15
7.68	2.47	7.86	5.22	7.02
7.61	3.17	7.94	5.22	7.04
8.64	2.38	7.19	5.22	6.97
8.42	3.09	7.97	5.22	7.03

Location: St.John, Michigan.
Implement: Grain Drill Size: 18 openers Width: 3.05 m
Field Condition: No-Till area.

Table A.16 Experimental and Model Draft and Fuel Requirements for Grain Drill on Palms Muck Soil. (Table A.15 cont)

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
6.01	3.67	6.86	5.22	7.15
7.61	3.17	7.94	5.22	7.04
8.42	3.09	7.97	5.22	7.03

Location: St.John, Michigan.
Implement: Grain Drill Size: 18 openers Width: 3.05 m
Field Condition: No-Till area.

Table A.17 Experimental and Model Draft and Fuel Requirements for Grain Drill on Granby Loamy Sand Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.64	3.63	4.09	2.90	4.54
7.88	3.57	4.03	2.90	4.49
7.50	2.92	3.29	2.90	4.22
8.95	3.16	3.56	2.90	4.30

Location: St.John, Michigan.
Implement: Seed Drill Size: 10 openers Width: 1.83 m
Field Condition: No-Till area.

Table A.18 Experimental and Model Draft and Fuel Requirements for Grain Drill on Granby Loamy Sand Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.60	4.26	7.42	2.90	4.42
7.27	3.24	8.53	2.90	4.71
7.17	4.31	8.65	2.90	4.71
8.99	3.16	8.36	2.90	4.85
8.35	3.12	8.35	2.90	4.87

Location: St.John, Michigan.
Implement: Grain Drill Size: 10 openers Width: 1.83 m
Field Condition: Previously moldboard plowed and disk harrowed.

Table A.19 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Granby Loamy Sand Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.38		7.71	8.70	8.44	11.70
7.09		8.75	10.82	8.11	11.45
8.10		9.58	9.88	9.26	12.24
7.81		9.81	11.07	8.93	12.20
10.11		11.48	12.96	11.57	14.09

Location: St.John, Michigan.
Implement: Disk Harrow Width: 3.04 m
Field Condition: Previously Moldboard plowed area.

Table A.20 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Palms Muck Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
6.90		8.19	12.16	10.28	16.68
7.85		7.21	12.13	11.70	16.47
7.53		7.73	12.46	11.22	15.56
9.73		8.33	15.75	14.49	16.14
9.55		9.38	16.00	14.23	15.54

Location: St.John, Michigan.
Implement: Disk Harrow Width: 3.96 m
Field Condition: No-Till area.

Table A.21 Experimental and Model Draft and Fuel Requirements for Chisel Plow on Metamora-Capac Sandy Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
4.05	16	10.68	7.90	9.15	11.53
3.94	16	11.09	8.59	9.08	11.42
5.70	20	14.58	12.89	12.78	13.39
7.26	16	13.16	13.54	11.25	12.69
7.24	18	14.58	14.18	12.63	13.46
6.90	20	16.96	16.65	13.76	13.98
9.44	18	16.25	19.82	14.25	14.28
7.36	18	14.80	17.03	12.72	13.54
9.44	18	16.25	19.82	14.25	14.28
7.36	18	14.80	17.03	12.72	13.52

Location: St.John, Michigan.
Implement: Chisel Plow Size: 7-tine Width: 2.5 m

Table A.22 Experimental and Model Draft and Fuel Requirements for Moldboard Plow on Metamora-Capac Sandy Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
4.47	25	21.79	17.06	20.65	16.69
5.15	15	14.78	11.79	12.87	12.41
6.99	13	12.92	12.63	12.56	12.34
6.62	20	16.98	16.29	18.84	15.99

Location: St.John, Michigan.
Implement: Moldboard Plow Size: 6-Bottom Width: 2.43 m

Table A.23 Experimental and Model Draft and Fuel Requirements for Field Cultivator on Capac Loam Soil.

Speed, km/h	Depth,cm	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
7.96	12.00	13.07	16.38	17.74	14.64
7.95	10.00	11.31	13.46	14.78	13.55
8.62	8.00	6.39	10.86	12.18	12.34
9.30	12.00	12.55	17.36	18.80	15.28
10.55	8.00	7.86	14.54	13.19	12.62
1.063	8.00	6.94	15.05	13.23	12.74
11.90	8.00	7.17	13.25	13.90	13.12

Location: Michigan State University.
Implement: Field Cultivator Size: 25-tool Width: 4.27 m
Field Condition: After Chisel Plowed and Disk Harrowed.

Table A.24 Experimental and Model Draft and Fuel Requirements for Disk Harrow on Capac Loam Soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.57	11.72	9.79	14.09	13.25
5.40	11.03	8.69	13.66	12.87
5.33	11.50	9.27	13.49	12.92
6.86	13.37	12.99	17.36	14.38
7.06	12.06	12.31	17.86	14.61
8.12	12.63	13.30	20.55	15.40
8.56	13.26	15.26	21.65	16.08
8.16	12.63	13.75	20.64	15.43
8.47	13.36	16.47	21.43	15.72

Location: Michigan State University.
Implement: Disk Harrow Width: 4.27 m
Field Condition: Previously Chisel Plowed area.

Table A.25 Experimental and Model Draft and Fuel Requirements for Corn Planter on Capac Loam soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.09	8.42	10.28	12.00	12.71
4.72	8.78	10.68	12.00	12.95
5.90	10.48	13.56	12.00	13.89
6.76	10.14	13.92	12.00	15.17
7.17	9.96	13.65	12.00	13.46
4.63	11.31	11.02	12.00	12.77
4.91	11.14	10.19	12.00	12.66

Location: St.John, Michigan.
Implement: Corn Planter Size: 6-row Width: 3.83 m
Field Condition: No-Till.

Table A.26 Experimental and Model Draft and Fuel Requirements for Grain Drill on Palms Muck soil.

Speed, km/h	Expt. Draft,KN	Expt. Fuel,L/h	Model Draft,KN	Model Fuel,L/h
5.62	4.25	6.80	5.22	8.30
5.88	5.25	7.59	5.22	8.33
7.44	4.80	8.83	5.22	8.44
7.17	4.31	8.65	5.22	8.42
8.45	4.86	9.25	5.22	8.54
8.65	5.78	9.75	5.22	8.52

Location: St.John, Michigan.
Implement: Grain Drill Size: 18 openers Width: 3.05 m
Field Condition: Previously moldboard plowed and disk harrowed.

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