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DEVELOPMENT OF A FIELD MACHINERY SELECTION MODEL

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Francis J. Wolak

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Thomas H Burkhardt
Major professor

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DEVELOPMENT OF A FIELD MACHINERY SELECTION MODEL

By

Francis J. Wolak

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ABSTRACT

DEVELOPMENT OF A FIELD MACHINERY SELECTION MODEL

By

Francis J. Wolak

Michigan's Saginaw Valley Farmers face problems of non-increasing navy bean yields and soil erosion. Many solutions have been proposed to these problems. A need exists for analysis of management strategies in production agriculture. A thorough analysis will hasten the adoption of socially and individually attractive production practices.

A major component of the farm is the machinery complement requirement. A computer model was developed which selects field machinery capable of satisfying the requirement. The model considers seven crops: alfalfa, corn, navy beans, oats, soybeans, sugar beets, and wheat. Labor supply can vary between 1 and 2 full time operators. Machinery technology includes self-propelled combines and four-wheel drive tillage tractors.

Model input includes: farm size, crop rotation, field operation date constraints, labor supply, and available workday data. The number and size of machines to complete all field work within prescribed date constraints is determined. The average annual cost of individual machines and total complement is determined. Average annual cost

includes aspects of: depreciation, interest, repairs, shelter, insurance, and fuel use.

The deterministic model uses standard engineering techniques to match machine productivity to available time. Available time is a function of available workday data, workday length, and labor supply. Machine productivity depends upon: assumed available machine sizes, allowable operating speeds, implement draft, and machine efficiencies.

The model increments machine complement productivity. For each productivity step a weekly work schedule is developed. The smallest machinery complement which produces a satisfactory work schedule is selected as the required machinery set.

Once a complete weekly work schedule is developed a second machinery complement is determined by oversizing the combine if possible. The harvester oversizing may allow more time for fall tillage to take place and thus allow a relatively smaller tractor-implement set to be chosen. The tractor-implement combination is resized. The smallest total cost determines which of the two developed machinery sets is designated as the required machinery set.

The model is unique in its measure of the risk associated with selected machinery complements. Using actual yearly available workday data, the model selects a machinery set for each year of data. The selected machinery sets are ranked on a cost per hectare basis. Risk issues can be addressed by analyzing the relative rankings of the selected machinery complements.

The model can, if desired, consider one available workday data set. Results show the use of one available workday data set, a statistical grouping of several yearly data sets, to be inferior in its measure of risk when compared to generation of machinery sets for each year of actual data.

Model results show rotations containing alfalfa and/or sugar beets to exhibit the highest machinery costs. A whole farm analysis of crop rotation shows the C-NB-NB-BT (corn-navy bean-navy bean-sugar beet) rotation to have the highest net return to land, for considered rotations.

Model results were sensitive to several model parameters and inputs. The deletion of fall cornstalk disking reduced required machinery cost $60.00 per hectare on a 162 hectare O/A-A-A-C-C-NB-C (oats/alfalfa-alfalfa-alfalfa-corn-corn-navy bean-corn) farm. Two extra spring field cultivations increased machinery cost $46.00 per hectare on a 162 hectare C-C-NB-W (corn-corn-navy bean-wheat) farm. Varying the available workday data set resulted in a $60.00 per hectare difference between data set extremes on a 162 hectare NB-C-SB (navy bean-corn-soybean) farm.

Approved by:

Thomas H Burkhardt
Major Professor

Donald M Edwards
Department Chairman

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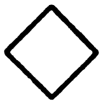
FLOW CHART SYMBOL	DESCRIPTION
	Decision - Branching along alternate paths
	Off-Page Connector
	On-Page Connector
	Terminal - The beginning or end of a subroutine
	Processing of Data
	Information Flow
	Loop Control

Crop Rotation Symbol	Description
A	Alfalfa
BT	Sugar beets
C	Corn
NB	Navy beans
O	Oats
SB	Soybeans
W	Wheat

Example: O/A-A-NB-BT; 4 year rotation where 25 percent of the total crop area is assigned to oats seeded with alfalfa, alfalfa, navy beans, and sugar beets, respectively.

1. INTRODUCTION

1.1 Problem

The Saginaw Valley is one of Michigan's most productive agricultural regions. But several agronomic problems have surfaced in the area. Navy bean yields have remained fairly constant in spite of introduction of superior navy bean varieties and continued yield increases of competing crops. In addition, environmentalists report declining water quality for Saginaw Bay and the surrounding lakes and streams. This decline is due partly to agricultural non-point source pollution. Finally, improved cultural practices are needed as energy supplies dwindle.

Many solutions to these problems have been proposed, including the use of different crop rotations and alternate tillage practices.

1.2 Conceptual Paradigm

The ability to advise farm operators in management activities lies with the advisor's skill in synthesizing the impact of proposed actions on farm operation. Farm operators will be more receptive to new ideas when accompanied by a thorough analysis of their impact on farm operation.

Beneficial solutions may be offset by their unfavorable impact on other farm areas. A new crop rotation could improve yields, but may require increased labor, machinery, and management skills. An alternate tillage practice designed to reduce soil and nutrient erosion could alter the material flow of the farm.

Any farm management solution requires analysis within the entire farm framework. To do this, it helps to think of the farm as a system comprised of interacting components. Each component can then be studied individually. The researcher should focus on one area. When sufficiently understood the component can be listed in an inventory for use in future whole farm analysis.

The systems approach requires expertise in several areas. Agronomic issues require input from crop and soil scientists. The physical relationship between machinery, energy, and labor necessitates agricultural engineering skills. Agricultural economists are needed to analyze price and risk issues. A group of members from the above fields has been formed at Michigan State University.

Crop rotation impact on farm operation was studied by the Michigan State University group. The objective of the investigators was to assess the component's inventory and develop a framework for presenting results to the farm community.

1.3 Machinery as a Subsystem

Field machinery, as a major component of the farm system, is selected to meet a set of interacting constraints, including: 1) weather conditions; 2) labor supply; 3) productive land area;

4) soil type; 5) available machinery; 6) crops to be grown; and 7) field operations. This dissertation focuses on the analysis and development of a field machinery system.

To analyze the impact of crop rotation on a particular farm, necessary field machinery and its cost must be determined. Further analysis can be undertaken for various management strategies. The absolute level of machinery cost is useful to show the farmer model results are "in the ballpark".

Naturally, differences will occur between the farmer's machinery complement and that generated in the model. These arise because management alternatives differ with each operation.

When probable differences in actual and generated machinery complements are rationalized, the difference in generated machinery complements can be studied. All generated complements are based on the same assumptions. A percentage difference in machinery cost for two generated systems can provide information to the farm operator after his specific management practices are accounted for.

In summary, the generated machinery complement must closely resemble actual machinery complements to give the farm operator confidence in further analysis. More importantly, accurate relationships between generated machinery complements must be established before the relative merits of different management strategies can be assessed.

1.4 Previous Investigation

Several approaches to machinery requirements and associated costs have been employed: 1) enterprise budgets and custom hire rates; 2) whole farm, profit maximizing linear programming models; 3) cost minimization models which seek a least cost machinery complement for a given management structure; and 4) heuristic models for selecting multiple enterprise machinery sets. The enterprise budget and custom hire approach is limited by failure to adequately address the interaction of labor supply, timeliness, weather patterns, operations schedule, and crop rotation.

Models which seek to maximize returns are generally linear programming models (International Harvester Pro-Ag, 1977). Models in this category account for the interaction of timeliness, labor constraints, crop rotation, and weather patterns.

Linear programming models are useful for organizing the enterprise mix to maximize returns given a current machinery complement. The models point out where bottlenecks occur in the present machinery complement and how much should be spent to alleviate them. Linear programming models are less effective for application to search strategies. Use of these models for machinery selection requires considerable user input and this is unacceptable for this current multidisciplinary study.

Models which seek minimum cost machinery sets for a given farm organization employ various selection criteria. Singh (1978) reviewed models in this category.

The economic minimization models select a minimum cost machinery set for a given farm size and crop rotation. The objective function includes machinery cost, labor cost, and timeliness cost terms. These models account for field operation schedules and weather conditions. Only a limited number of crop enterprises can be considered using cost minimization models. Current models of this type consider one or two crops at most. It is the author's opinion that expansion of cost minimization models to include the seven major crop enterprises of the Saginaw Valley would not be feasible for an easily understood multi-disciplinary model.

The heuristic machinery models developed at Michigan State University view timeliness as a constraint, rather than a penalty. This results in a less complicated model structure. Field operations must be completed within specific calendar periods. Thus, machine productivity is matched to available time during scheduled calendar periods such that all operations are completed.

The Singh (1978) machinery selection model was recently tested in the Saginaw Valley region by this author. The following problems were noted during its application and operation:

1) The number of crop enterprises considered required expansion to include sugar beets.

2) The unlimited labor supply assumption produced results unacceptable to Saginaw Valley farmers in light of their relatively limited and more discrete labor supply.

3) Model technology did not include 4-wheel drive tractors. A separate type of tractor, an alfalfa harvest tractor, was not well received by farm operators.

4) Initial results indicated a potential problem in the accounting for available workday data. (This problem is not limited to the Singh (1978) model, but is relevant to most machinery models developed to date.)

5) The model reflected soil and available workday conditions of central lower Michigan. The soil and workday parameters would need adjustment for studies of the Saginaw Valley. This represents a problem in application only.

1.5 Problem Statement

The problems associated with the Singh (1978) model were great enough to warrant development of a new model. The objectives associated with the new model were to:

1) Develop a multidisciplinary farm decision framework machinery selection model.

2) Develop a machinery selection model for both physical and economic prediction purposes. The model should consider operator labor constraints and the seven major Saginaw Valley field crops.

3) Compare model operation using actual workday data and employing chance-constraint techniques outlined in previous machinery selection models.

4) Develop a method of validating machinery and available workday generator parameters.

Machinery involved in crop transport, drying and/or processing is not considered by the model.

The new model boundaries include:

1) A 80 to 400 hectare farm size.

2) A 1 to 2 full time operator range.

3) Fine-textured lake plain soils of the Saginaw Valley.

4) Cash crop enterprises only.

5) Maximum of 1 combine, 1 tillage tractor, and 1 utility tractor.

6) Self-propelled combines and the availability of 4-wheel drive tillage tractors.

The objective of this dissertation is to develop a machinery selection model. The model must be designed such that nonengineers will be comfortable with its use and results. The developed model will be used by extension and research faculty for analysis purposes. The developed model may also play a role in classroom instruction.

The model is outlined in Chapter 2. Input data and methodology to determine their validity are presented in Chapter 3. Chapter 4 compares the use of the actual to probabilistic workday data. The crop rotation impact on machinery requirements and on the entire farm are presented in Chapter 5. A program listing, input data structure, and example output is contained in Appendicies A-E.

2. FIELD MACHINERY SELECTION MODEL

The machinery selection model developed at Michigan State University served as a starting point for developing the new machinery selection model. It is useful to review the heuristic model of Singh (1978) and contrast the new model with it. As stated previously, the Singh (1978) model matches machine productivity to available time. The smallest set of machinery, which enables required time to be less than or equal to available time, is selected as the required machinery complement. An iterative search technique is employed. The search proceeds in five steps: 1) combine sizing, 2) tillage tractor selection, 3) utility tractor selection, 4) alfalfa harvest tractor selection, and 5) tractor-drawn implement sizing.

The selected machinery complement is qualified with a design probability. This is the percentage of years for which the selected machinery complement could complete all field operations within the user specified field operation date constraints.

The design probability is determined by the available workday data set. This is a statistical grouping of many individual yearly workday records and is used as an indicator of the weather, soil, and crop condition impact on scheduling field work. The workday data of Singh (1978) are assigned a probability level. A workday data set at the 80 percent level implies that the weekly available field work time described there in would occur or be exceeded 8 out of 10 years. The machinery set developed for the 80 percent workday data set would, in theory, have a design probability of 80 percent.

Singh (1978) calculated a single machinery complement for a single workday data set. Correlations exist between the weekly values of available workdays. Singh (1978) attempted to capture the correlations by combining weekly means and standard deviations of available workdays over an operation's scheduled period and using areas under the normal curve to arrive at weekly available workday values.

The new model uses actual yearly workday records. Each year of data is used to develop a machinery complement. The collection of yearly machinery complements is inspected to arrive at any user specified design probability. This method of selecting the design probability is the major difference between the new model and that of Singh (1978).

Another change concerns the labor supply assumptions. Singh (1978) assumes an unlimited labor supply. This does not offer an accurate portrayal of management options available to Saginaw Valley farmers. The assumption is probably more realistic for large acreage farms where labor hire decisions may be more routine. A wide range of farm sizes can be considered simply by allowing selection of multiple machinery units.

The new model is developed for a limited labor supply. The maximum number of combines, tillage tractors, and utility tractors allowed is one each. Because of operation assignment to the combines and tractors, labor supply is restricted to a maximum of two operators. Seldom does a week occur when all three power units can be utilized. When this does happen, one man can generally do all work assigned to the combine and utility tractor. Because the labor supply is restricted the current model considers only a limited farm size.

Heuristic models cannot be judged absolutely correct or incorrect. The drawback associated with farm size restrictions due to the limited labor supply assumption is offset by superior accounting of labor and machinery interaction and the closer approximation of the real world decision making process. Hopefully, problems associated with the limited labor supply assumption can be resolved with future research.

The search procedure is modified in the new model. The Singh (1978) iterative search considers combines, tillage, utility, and alfalfa harvest tractors, in order. The implied field operation priority is the same as the order of power unit consideration. Within each power unit category, field operation priority is assigned by operation ending date constraints. A priority scheduling of this type is possible because no competition occurs between power units for drivers.

The new search procedure allocates machine productivity to available work time and operator time for each week during the year. Competition of power units for labor must be considered. In a limited labor mode the model cannot simply schedule tillage tractor operations and then utility tractor operations. The tillage tractor could utilize all available labor leaving the utility tractor unable to accomplish any work during the week.

The new iterative search is a two-step process. Combine size and sugar beet harvest capacity are determined first. Tractor size is determined second. Harvest operations receive priority during this process. Conceivably, all operator time in a week could be allocated to harvest operations.

Only two categories of tractors, tillage and utility, are considered. For tractor operations priority is based on ending date constraints only. In each week the model attempts to accomplish the maximum work for the priority operation regardless of which tractor does the field work. The work accomplished for lower priority operations must account for the tractor and labor assignments of operations already scheduled during the week.

The new model incorporates several other changes. It has the capacity to consider 4-wheel drive tillage tractors. Oats and sugar beets were added to the existing alfalfa, corn, navy bean, soybean, and wheat crops list. The model output can be given in English or SI units. An attempt is made to select two satisfactory machinery complements for a given year. The lower cost complement is selected as the required machinery complement.

In summary, for each year of available workday data a machinery complement is selected. The selection occurs in two steps. Combine and sugar beet harvest operations are considered first. Harvest capacity is increased stepwise until all operations are completed within their specified date constraints. Tractor sizes are selected after harvest capacity is selected. Tractor power level is increased stepwise until all field operations are completed within specified date constraints.

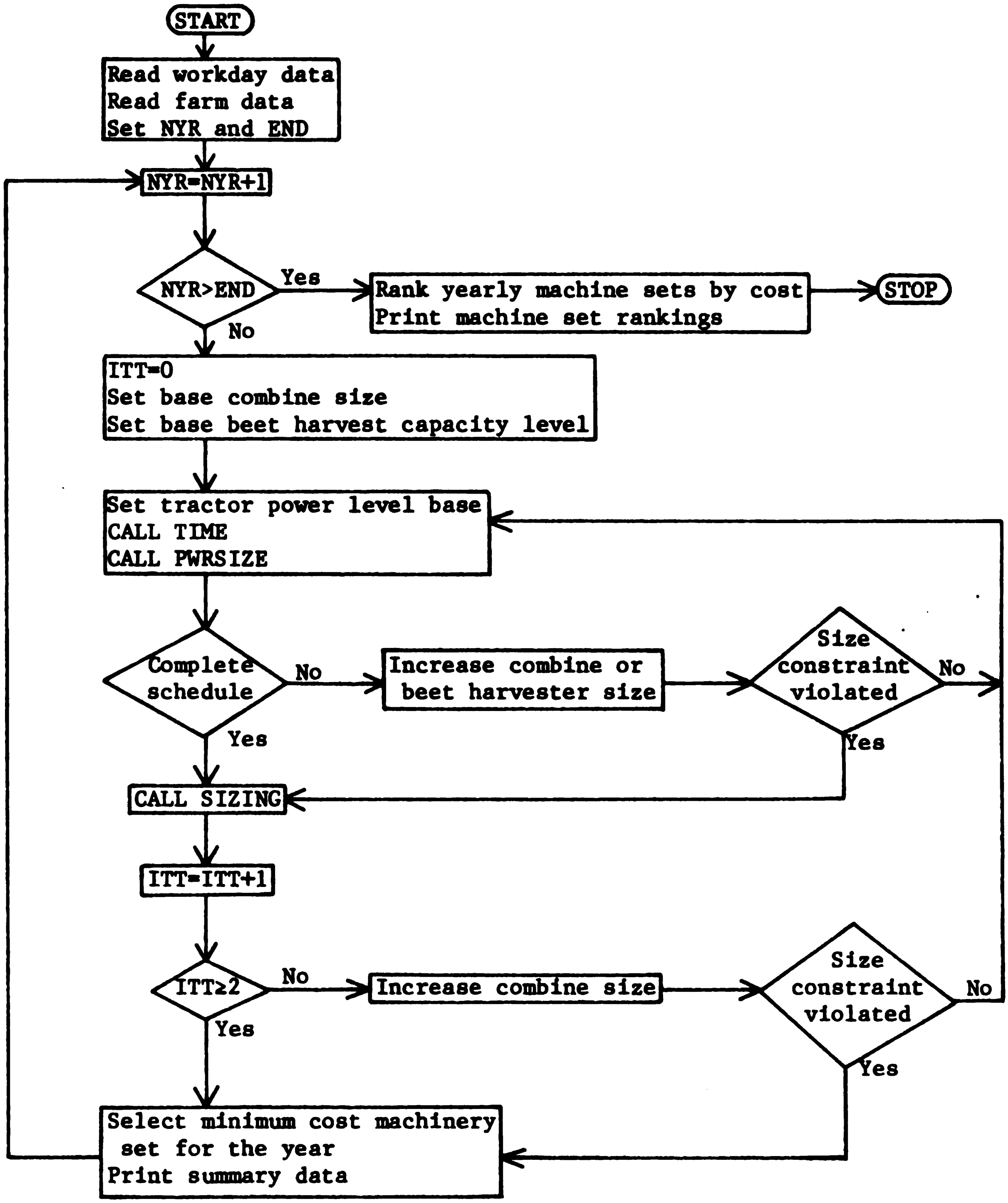
A weekly scheduling process determines the appropriateness of each step in harvest capacity and tractor size. If an operation is unfinished in the last week to schedule it, the current size is judged too small and the next step in size is considered. If work is completed or no date constraint occurs in a week, scheduling continues to the next week.

Once a combine and tractor size are selected to satisfy the weekly work schedule, the model is used to select implement size. Fuel use and cost of the selected machinery complement are predicted. If possible, a second machinery complement based on an oversized combine is determined. The oversized combine should complete its assigned operation sooner and therefore, allow more time for fall tillage. Increased time for fall tillage would enable use of a smaller tractor. The less expensive of the two possible machinery complements is designated the required machinery complement for the year. The required machinery complements for each year of workday data are ranked according to cost per hectare. A detailed presentation of the model follows.

2.1 FMSM Program

The field Machinery Selection Model (FMSM) of Figure 2.1 directs model information flow. Model input includes 28 years of weekly workday data. For each year, workday data were collected in four categories: 1) corn harvest; 2) alfalfa harvest; 3) tillage; and 4) combine operations (Section 3.2).

Farm input data subject to analysis include: 1) crop rotation; 2) farm size; 3) percentage of farm assigned to each crop; 4) labor supply; 5) alfalfa yield; and 6) operation date constraints. Model operation parameters and print control variables are listed at the end of the farm data input file. (Appendix B).



END = Last year
ITT = Counter for machinery sets selected per year (1-2)
NYR = Counter for year (1-28)

Figure 2.1. FMSM flow diagram.

The model can generate four output levels. These vary from summary statistics to detailed weekly work schedules and machinery sizing information.

A machinery set is generated using available workday data for one year. Because 28 years of available workday data exist, the model will generate 28 machinery sets for the input farm. Each machinery set reflects the unique workday availabilities of the year for which it was developed. The 28 selected machinery sets are used to calculate individual design probabilities.

The model can be run for less than 28 years of workday data. It is envisioned that 28-year runs have summary outputs only. Detailed output could be obtained for selected years if further analysis of a 28-year run is desired. A detailed output for only 1 year out of a possible 28 will lessen computing expense.

NYR and END variables control the number of years analyzed. Combine, sugar beet harvester, and tractor size are set at the start of each year. The arbitrarily chosen base settings are 2-row, level 1 (0.81 ha/h, 2 A/h) and 60 PTOkW (80 PTOHP), respectively.

The model operates in three major parts. A TIME routine is used to calculate available time for field operations. Using another routine, PWRSIZE, power and capacity needs are determined. A SIZING routine is then used to obtain the tractor-drawn machine size, fuel use and cost factors.

The FMSM program contains two sizing aspects. When a complete schedule cannot be found by PWRSIZE, FMSM attempts to utilize possible harvester-tractor trade-offs. Insufficient harvester capacity or inadequate tractor size for a given harvest capacity results in an incomplete schedule.

Generation of the first machinery set for each year may involve selection of combine and sugar beet harvest capacities greater than the minimum capacities required. When an incomplete schedule is detected an attempt is made to resize the harvest capacities. If inadequate harvester capacity is the cause of the incomplete schedule, the model moves on to the sizing of implements and the incomplete schedule is noted in the output file. If the incomplete schedule is due to insufficient tractor size, the over-sizing of harvest capacity may free up time for fall tillage and allow adequate tractor selection.

After SIZING is called, an attempt is made to generate a second machinery set. Sugar beet harvest capacity is held constant. Combine size is increased and a new tractor-implement set is selected. The year end results could show 0, 1 or 2 satisfactory machinery sets. The least expensive machinery set is chosen.

Sugar beet harvest capacity is held constant for the second machinery set for several reasons. Larger combine and sugar beet harvest capacities may entail increases in truck size or number. The model does not include economic aspects of transport vehicles.

The higher cost of the larger combine is included in the economic choice of machinery sets for the year. Although increased sugar beet harvest capacity will not necessarily require larger machinery, higher equipment operation speeds may be needed. In this case, little or no economic penalty is assigned to a system with an oversized beet harvest capacity; therefore, an oversized sugar beet harvest capacity is not considered when selecting the second machinery set.

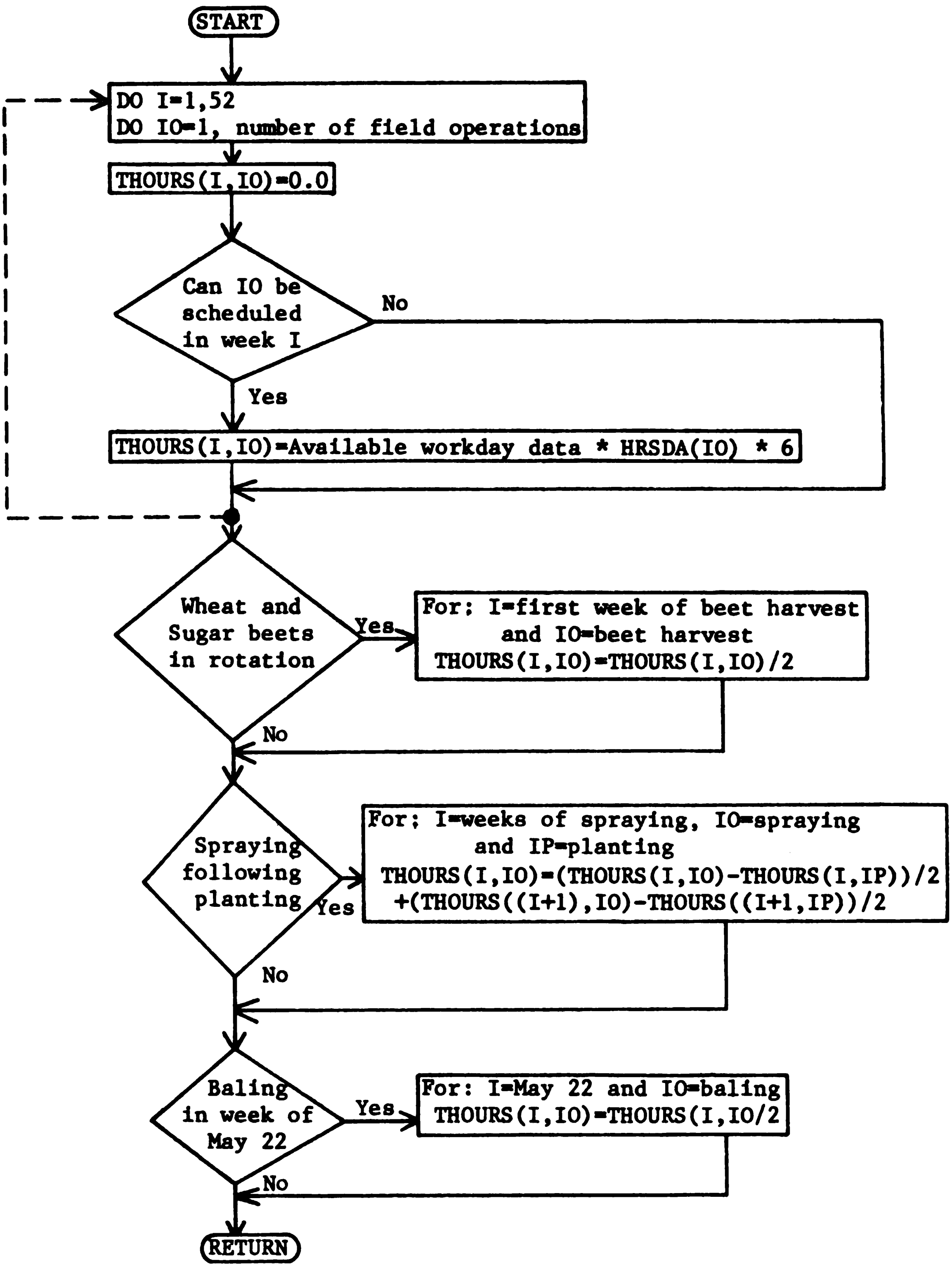
The model ranks the generated machinery sets based on average annual cost per hectare. The yearly cost and summary statistics of each machine set are recorded. The machine set corresponding to any design probability can be obtained directly from the machinery set rankings.

2.2 Subroutine TIME

The TIME subroutine (Figure 2.2) calculates the weekly hours available for each operation. For weeks when an operation cannot be scheduled because of time constraints, the available hours are set to 0.0. The available operation hours for a scheduled week depend on workday length (hr/day), work week length (days), and the weekly work-day data (percent of week available for work).

Harvest operations are considered first for each week. Tillage operations are scheduled once available harvester time is exhausted or harvest operations are completed. A problem in model operation may occur when a scheduled tillage or planting operation overlaps a harvest operation assigned a lower priority (later ending date constraint).

The problem relates to input data priority. By scheduling harvest operations first, the model implicitly gives priority to harvesting over tillage or planting, regardless of ending date constraint. The model will assign available time to harvest operations in the beginning of each week. As a result, the remaining time may be 0.0. Since



HRSDA(IO) = Assumed workday length of operation IO
THOURS(I,IO) = Available field workhours for operation IO in week I

Figure 2.2. Flow diagram for subroutine TIME.

a tractor cannot accomplish any work when there is no time, the model generates an incomplete schedule.

This problem occurs twice in the current field operation schedules for rotations containing wheat and sugar beets (see Table 3.10). It could occur whenever a tillage or planting operation overlaps harvesting in the fall and the harvest operation has a lower priority (later ending date constraint).

Because the problem solution would involve major rewriting of the machinery selection model, a simplifying assumption was made. Sugar beet harvest beginning date must be delayed 1.5 weeks when wheat is in the rotation (Christenson, 1979). One week of this delay can be accounted for by changing the starting date for sugar beet harvest. The rest of the 1.5 week delay is made up by reducing available sugar beet harvest hours by one-half in their first scheduled week. Wheat can then be planted for one-half of the week in question.

Cases may exist where wheat planting is completed before sugar beet harvesting begins. Generally, the weekly scheduling process would schedule some activity in this time slot. However, it is possible that half of the first sugar beet harvest week may go unused.

Any herbicide applied to crops after planting is considered a pre-emergence spray. Spraying must occur within several days of planting. Hours available for spraying always equal or exceed those available for planting since they were generated using a less restrictive C_3 value (Tulu moisture criteria, Section 3.2).

The available spraying hours in a week are adjusted to reflect the necessity of waiting until the crop is planted and the deadline of spraying before emergence. The adjustment incorporates the difference in planting and spraying hours. The available spraying hours in week I are one-half the difference in spraying and planting hours in weeks I and I+1. Thus, time available is that which occurs after planting is finished in week I and before it is scheduled in week I+1 for each week I spraying is scheduled.

Available alfalfa harvest time during the week of May 22 is reduced by one-half. The reduction simulates the desired May 25 starting date for harvesting (Helsel, 1979), since the model will schedule only one-half the maximum time available during May 22.

2.3 Power Unit Sizing

An iterative search procedure is used to determine power unit sizes. The model cannot consider multiple numbers of any individual power unit type, therefore power units are limited to a maximum of 1 combine, 1 tillage tractor and 1 utility tractor.

The search begins with a 2-row combine and 60 PTOkW (80 PTOHP) tillage tractor. A 2-row combine is the smallest size considered in the model. The 60 PTOkW tractor is used as a starting point only, since the model will select a tractor smaller than 60 PTOkW if necessary.

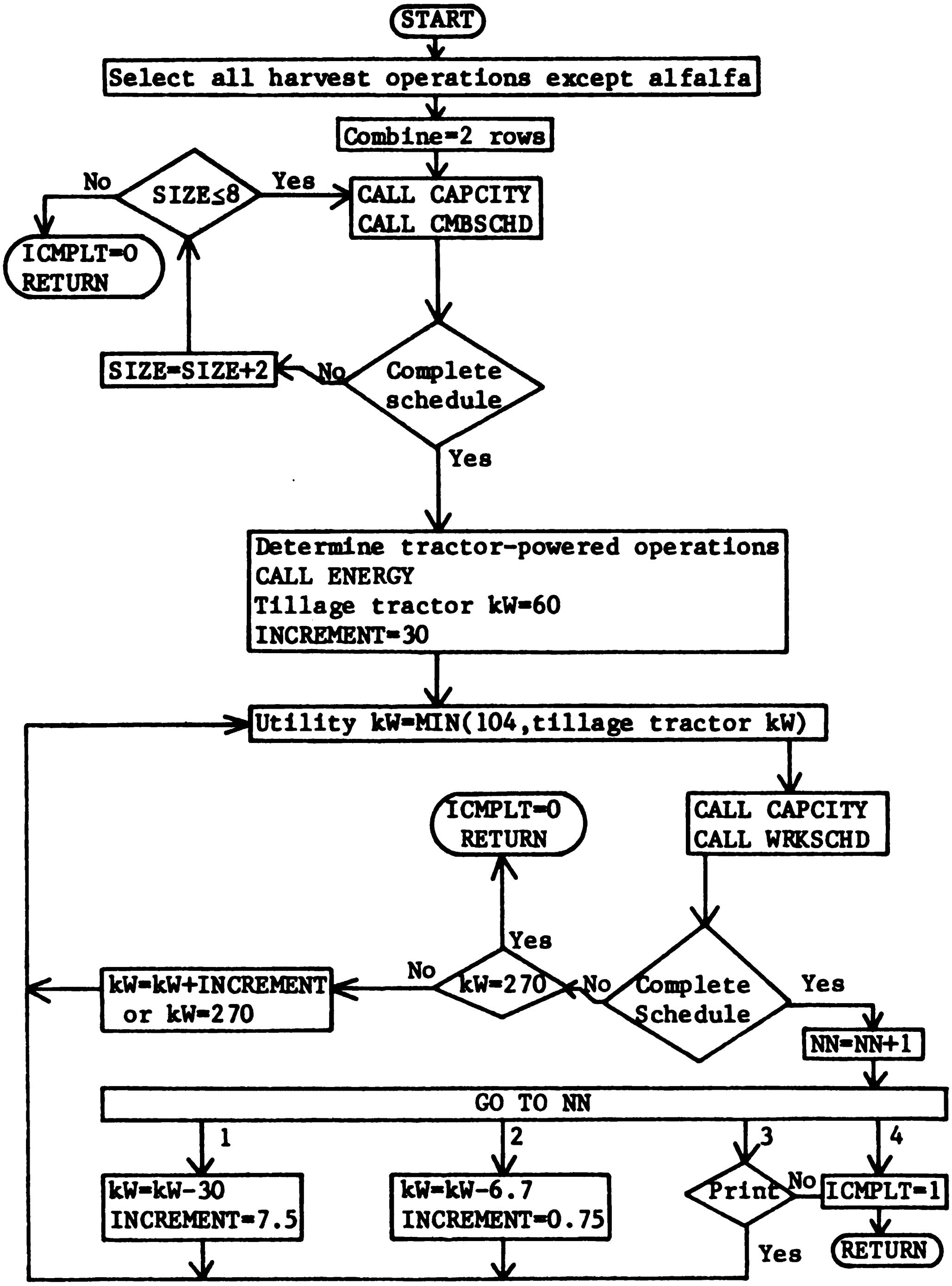
Power unit size is increased until all date constraints are met. If the maximum combine size of 8-rows or tillage tractor size of 201 PTOkW (270 PTOHP) is exceeded, selection stops and the inability to complete all operations is noted in the output file. The maximum power unit sizes were felt to be the maximum sizes generally found in the Saginaw Valley. The maximum values can be changed to reflect the views of the person using the model.

Figure 2.3 is a flow chart for determining power unit size. Harvest operations, except alfalfa, are considered first. Current combine capacity is determined using the CAPCITY subroutine. Subroutine CMBSCHD is used to calculate the amount of work accomplished per week. The CMBSCHD algorithm is also used to select the sugar beet harvest capacity.

A harvest schedule completion check follows. If any harvest operation is not completed by its end date, the schedule is incomplete and thus a larger combine is needed. When all harvest operations can be finished the schedule is complete. Tractor sizing begins when the harvest schedule is complete.

First, energy requirements (kW·h/ha, HP·hr/A) for tractor-powered operations are determined using the ENERGY subroutine. The base power sizing increment is 30 kilowatts (40 HP). The utility tractor size is the minimum of current tillage tractor size or the maximum available utility tractor size of 104 PTOkW (140 PTOHP).

The utility tractor size assumption is made for several reasons. The 104 PTOkW level is close to the breakpoint PTOkW of two- and four-wheel drive tractors (Implement and Tractor Red Book, 1979). Most tractors above this level are 4-wheel drive. It is assumed only a two-wheel drive unit can perform the row crop operations assigned to the utility tractor. Current ground speed assumptions prevent further power increases past the 104 PTOkW utility tractor level from increasing field capacity.



ICMPLT = Indicator of work schedule completeness (0=unfinished schedule, 1=finished schedule)
INCREMENT = Tractor power level step size
kW = Tillage tractor size in killowatts
NN = Counter used in tractor sizing
SIZE = Combine size in rows

Figure 2.3. Flow diagram for subroutine PWRSIZE.

A trade-off between tillage and utility tractor size may exist. The optimum size relationship between the two may depend on farm size, available labor, crops grown, yearly weather patterns, field operations needed for each crop rotation, and possibly other factors. The experimentation required to determine the quantitative effects of these factors was not undertaken.

A quick check of utility tractor maximum size was made. Maximum utility tractor sizes ranging from 52 PTOkW (70 PTOHP) to 112 PTOkW (150 PTOHP) were analyzed for a 162 hectare corn-navy bean farm. Table 2.1 gives results for four design probabilities on the example farm.

The results show an equal or smaller cost when the maximum utility tractor size is increased from 75 PTOkW. At the 25-year completion level, the 52 to 75 PTOkW utility tractors were unable to complete all field work. It appears, based upon Table 2.1 results, that oversizing the utility tractor has less effect on system cost than undersizing.

Equating utility tractor size to tillage tractor size could, in some cases, oversize the utility tractor and its associated equipment. But this effect is cancelled somewhat by the lower purchase price assigned to the utility tractor due to its increased age. For all the above reasons utility tractor size is equated to tillage tractor size until it's maximum productivity level of 104 PTOkW is reached.

The capacity of each tractor-powered operation is determined by CAPCITY. A weekly schedule is assigned using the WRKSCHD subroutine. Tractor power is increased by the initial 30 PTOkW increment until a

Table 2.1 Effect of Utility Tractor Maximum Power Level Upon Machinery Set Cost.*

Machine set ranking*** (years out of 28)	Machine set cost, $/ha.								
	Maximum utility tractor power level, PTOkW								
	112	104	97	89	82	75	67	60	52
25	238	238	238	246	259	**	**	**	**
23	211	211	211	212	230	238	238	236	**
21	206	206	206	206	206	206	209	199	198
15	177	177	177	177	177	177	177	176	175

*162 hectare, 1-operator C-NB farm.

**Unable to complete all field operations within specified date constraints.

***Ranking represents number of years for which machinery set completed all work within specified date constraints.

satisfactory schedule is developed. The power increment is then reset until the lowest satisfactory tractor size to the nearest 0.75 kilowatt is found. Weekly field operation schedules can be printed in the output file if desired.

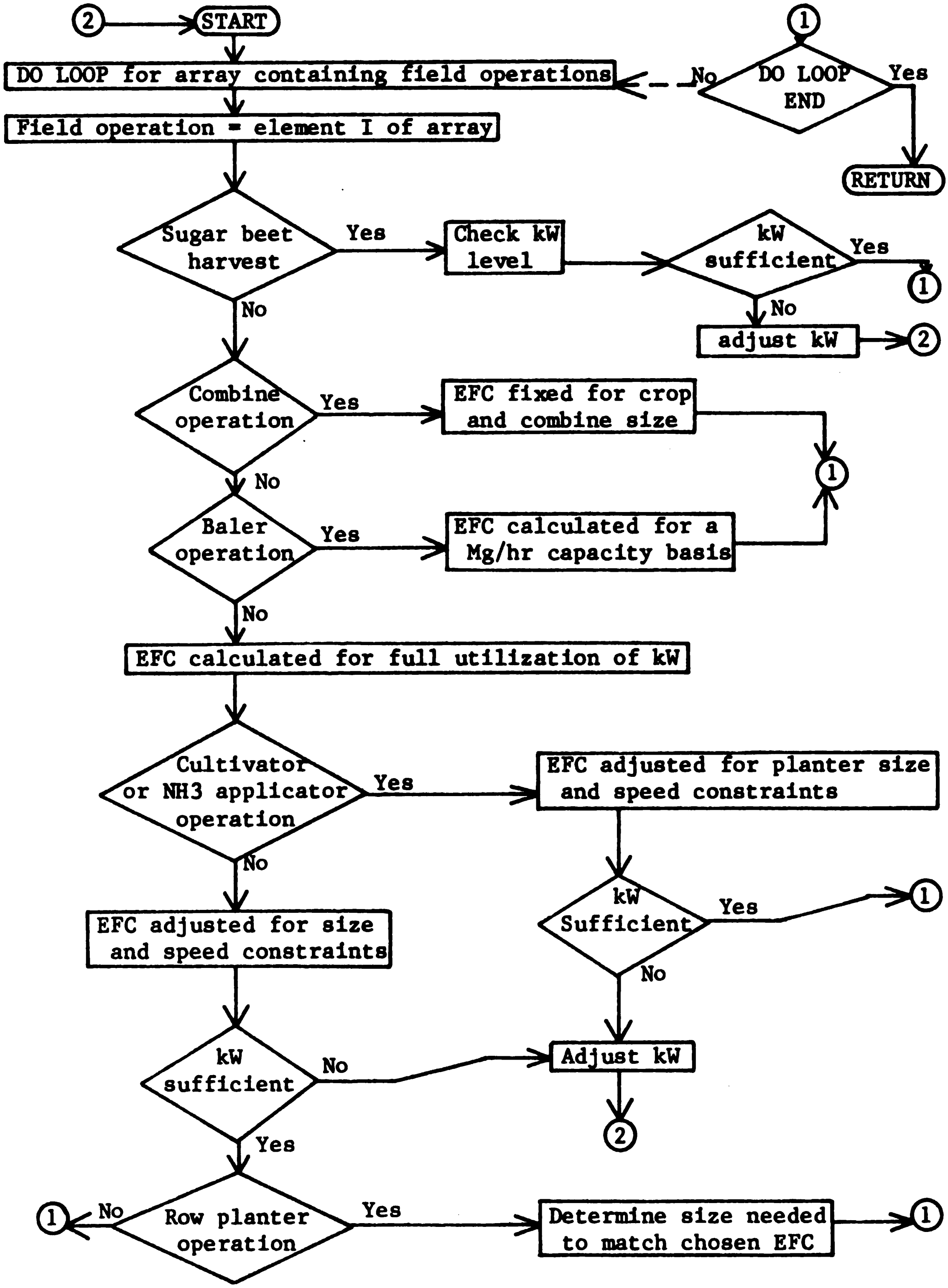
2.4 Subroutine CAPCITY

The CAPCITY subroutine (Figure 2.4) is used to determine effective field capacity (EFC) for various field operations. Field operation, implement required, and power source must be determined for each component in the figure. Table 2.2 lists the power source assignment for implements. For example, the moldboard plow is powered by the tillage tractor.

The EFC of sugar beet toppers and lifters can be calculated using the CMBSCHD subroutine. Then CAPCITY can be used to check the required utility and tillage tractor kilowatt levels against current levels. To find the required kilowatts the equations and parameters of section 3.1.1 are employed. If necessary, tractor kilowatt levels are increased and the routine is rerun from the beginning.

Based on data statements, model input also includes the capacities of the four navy bean combine sizes. The EFC of corn, wheat, soybean, and oat harvest can be calculated using Equation 3.2. Speed, width, and field efficiency of each crop are fixed for combine size; thus, EFC is fixed for crop and combine size.

By incorporating yield, cutting, and machine capacity data, baler EFC can be determined. The yields for first, second, and third



EFC = Effective field capacity
kW = Tractor size (kilowatt)

Figure 2.4. Flow diagram for subroutine CAPCITY.

Table 2.2 Operation Assignment to Power Source.

Operation/Implement	Power Unit: Tillage Tractor	Power Unit: Utility Tractor	Power Unit: Combine
Moldboard plow	X		
Moldboard plow & leveler	X		
Disk harrow**	X		
Disk**	X		
Chisel plow	X		
Field cultivator 1**	X		
Field cultivator 2**	X		
Sugar beet topper		X	
Sugar beet lifter	X		
No-till planter		X	
NH3 applicator		X	
Grain drill		X	
Row cultivator		X	
Rotary hoe		X	
Mower-conditioner*		X	
Row planter		X	
Baler		X	
Rotary cutter		X	
Fertilizer spreader		X	
Rake*		X	
Sprayer		X	
Windrower		X	
Navy bean puller		X	
Corn head			X
Wheat harvest			X
Soybean harvest			X
Navy bean harvest			X
Oat harvest			X

*May be assigned to tillage tractor on two-operator farms.

**Similar implements may have different draft force requirements due to different operating depths.

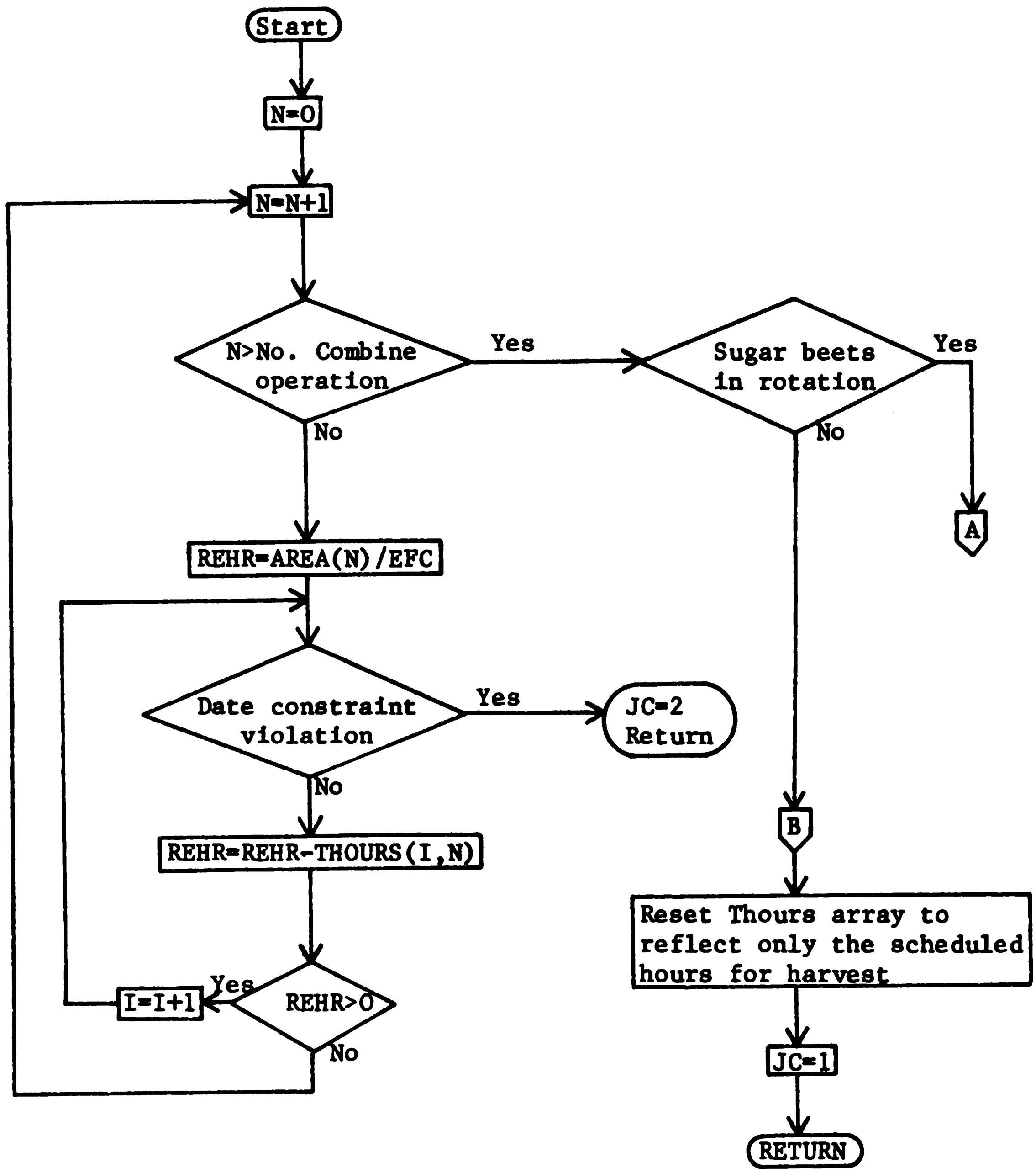
cuttings are assumed to be 50, 30, and 20 percent of the total alfalfa yield, respectively. Oats and/or wheat straw yield is assumed to be 3.4 Mg/ha (1.5 T/A). The EFC is simply the baler capacity (Mg/hr) divided by crop yield (Mg/ha).

For non-harvest operations, EFC is first calculated to fully utilize all tractor power. The EFC is then adjusted, if necessary, to fit in the range of allowable EFC for a particular implement. The allowable EFC range is determined by the maximum and minimum EFC boundaries. Maximum and minimum EFC are calculated using fastest and slowest ground speed and largest and smallest machine widths in Equation 3.2. If EFC is out of range on the high side, EFC is equated to the maximum allowable. If EFC is out of range on the low side, tractor power levels are adjusted to the required horsepower for the minimum EFC.

The EFC of cultivators and ammonia applicators is constrained not only by speed limits but also by planter size. Presumably, cultivator and ammonia applicator sizes match planter size exactly. The ammonia applicator is generally used only after planting. Use of the ammonia applicator for plow down or disk incorporation would not be possible unless model parameters were changed to analyze machinery designed specifically for that purpose.

2.5 Subroutine CMBSCHD

The CMBSCHD subroutine is used to determine the capacity of all harvest operations except alfalfa (Figure 2.5). Completion of all combine operations can be checked using the counter N mechanism. When



AREA(N) = Land area assigned to Nth combine operation
JC = Completeness of work schedule (JC=1 satisfactory schedule,
JC=2 unsatisfactory schedule)
K = Counter of beet harvest capacity
N = Counter for combine operations
REHR = Required hours for completion of Nth combine operation
THOURS(I,N) = Maximum available hours in week I for operation N

Figure 2.5. Flow diagram for subroutine CMBSCHD.

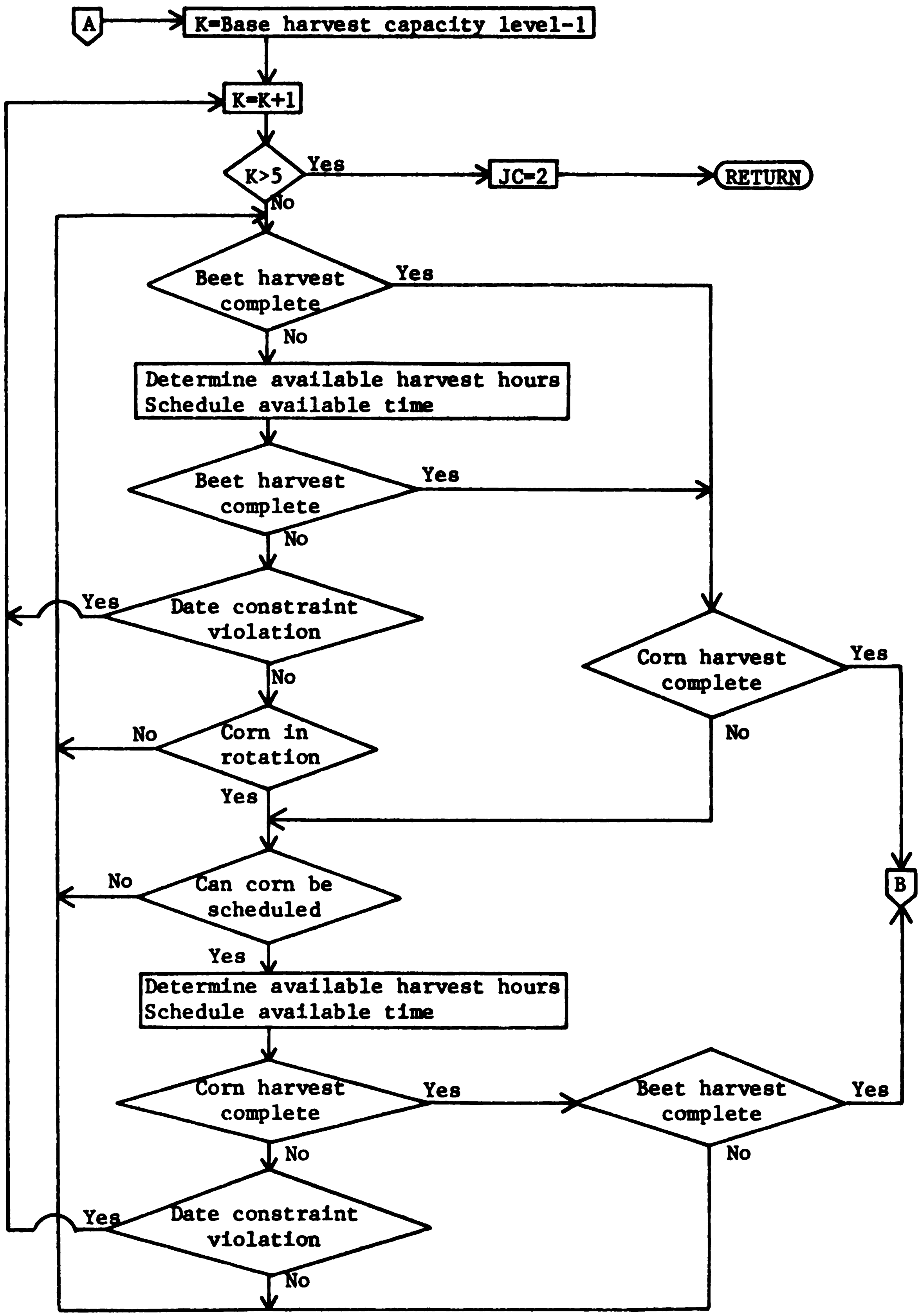


Figure 2.5. (continued).

all combine operations are completed, the subroutine sizes the beet harvester or proceeds directly to the summary section. To determine the required field time for the Nth combine operation, the land area to harvest is divided by current combine capacity. The calendar date is incremented in 1 week units. During each week the required field time will be reduced by the available hours in the week. If at the end of the week required hours are still positive, the date constraint is checked. If the ending date constraint is not violated the next week is considered. An ending date constraint violation implies a larger combine is needed. When required harvest hours become negative, the operation is completed and operation N+1 is considered.

The user-specified date constraints for sugar beet harvest may give it priority over corn harvest. Available work time previously allocated to corn harvest may now be given to sugar beet harvest.

Two machines, a topper and a lifter are required for sugar beet harvest. The potential harvest capacity is determined by machine size and labor supply. The machinery size which enables two-man operations to harvest at 1 megagram per hour would allow a one-man operation to harvest at one-half megagram per hour. The single operator must divide time equally between topping and lifting, thus reducing the capacity attainable for a given size of machinery.

With this model, sugar beet harvest capacity is based on the lifting operation only. Available work hours are adjusted to reflect the labor supply constraint on capacity as follows:

$$BTHR = \frac{THOURS\ (1+PCTHRD)}{2} \quad (2.1)$$

where:

BTHR = weekly available sugar beet lifting hours

THOURS = weekly available hours for both topping and lifting

PCTHRD = extra labor available over the one-man minimum (0.0 to 1.0 operators)

On a two-man farm (PCTHRD = 1.0) hours for lifting would equal the maximum available. On a one-man farm (PCTHRD = 0.0), one-half the maximum time would be available for lifting. After sugar beet harvest capacity is determined, time spent topping is equated to time spent lifting to facilitate full labor accounting.

The available hours adjustment simplifies the model since only one operation is considered. The adjustment also ensures the correct allocation of labor and available work time to both sugar beet harvest operations, since the amount of sugar beets harvested equals the amount topped.

Part A in Figure 2.5 can be summarized as follows: Sugar beet harvest is given priority in each week. Any time remaining in each week is allocated to corn combining for farms with corn in rotations. When all time in a week is allocated, the next week is considered until operations are completed. If a date constraint for corn or sugar beets is violated, larger sugar beet harvest capacity is selected.

This procedure does not investigate possible tradeoffs between sugar beet and corn harvest capacity. The smallest possible sugar beet harvest capacity is selected for the current combine size.

When a satisfactory harvest set is determined, available harvest hours are adjusted. The available hours array for harvest is equated to the exact time needed in each week for each harvest operation.

Unfinished operations in their last scheduled week indicate an unsatisfactory power level. If the unfinished operation is not alfalfa harvest, a return to PWRSIZE with JC=2 is made.

The model considers one size each of a baler, rake, and mower-conditioner. If alfalfa harvest cannot be completed within its date constraints, the integer multiple of required extra alfalfa harvest machinery is determined. The labor required to operate the extra machinery units is not included in model results. When the extra alfalfa harvest machinery sets are determined, weekly scheduling continues.

2.6 Subroutine WRKSCHD

The WRKSCHD subroutine (Figure 2.6) develops a weekly work schedule based on the tractor power level supplied to it by the PWRSIZE subroutine (Section 2.3). Field work is scheduled week-by-week until all operations are finished or a date constraint is violated. The main information WRKSCHD supplies to PWRSIZE is the status of the developed work schedule, either satisfactory or unsatisfactory.

An unsatisfactory work schedule indicates to the PWRSIZE subroutine that the tractor power level is too small. A satisfactory work schedule implies that the current tractor power level supplied by the PWRSIZE subroutine is adequate. WRKSCHD does not evaluate the possibility of a smaller tractor power level also being adequate.

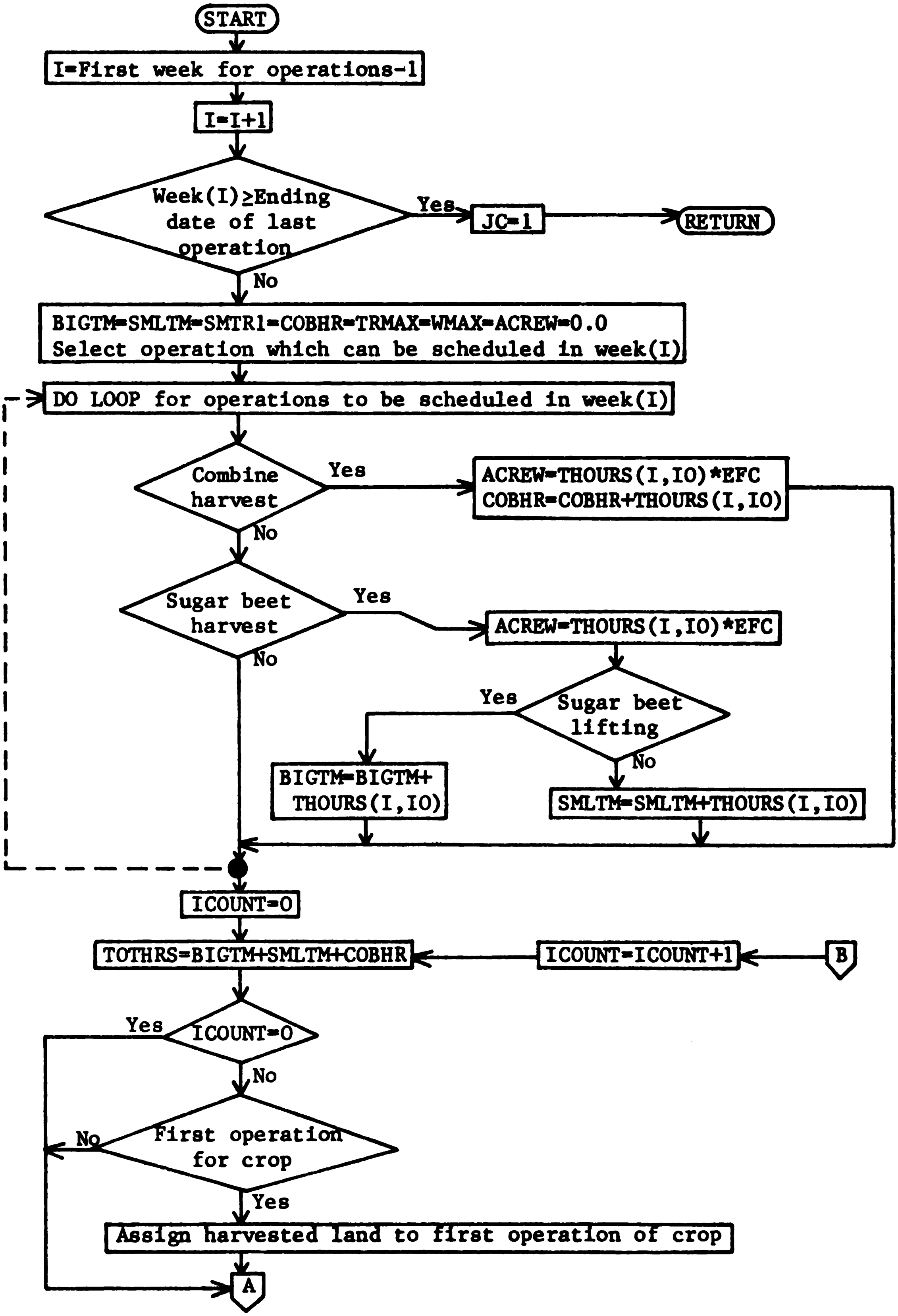
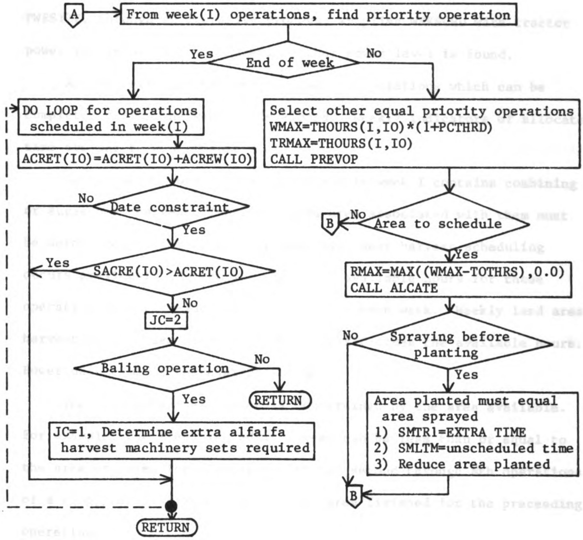


Figure 2.6. Flow diagram for subroutine WRKSCHD.



ACRET(IO) = Total area finished for operation IO
ACREW(IO) = Area of operation finished in week(I)
BIGTM = Allocated tillage tractor time
COBHR = Time allocated to combine
ICOUNT = Loop counter
JC = Schedule completion indicator (JC=1, satisfactory schedule;
JC=2, unsatisfactory schedule)
PCTHRD = Level of labor available from second worker (0.0 - 1.0)
RMAX = Remaining time in week, accounting for time previously allocated
SACRE(IO) = Maximum area to schedule for operation IO
SMLTM = Allocated utility tractor time
SMTR1 = Extra spraying time allocated to utility tractor
THOURS(I,IO) = Available hours for operation IO in week(I)
TOTHRS = Sum of labor time assigned to all power units
TRMAX = Maximum time for any power unit in week(I)
WMAX = Maximum hours available in week

Figure 2.6. (continued).

PWRSIZE, through an iterative process, supplies WRKSCHD with tractor power levels until the smallest tractor power level is found.

At the beginning of Week I, a set of operations which can be completed during the week is developed. Weekly indicators of allocated time are set to 0.0 (Figure 2.6).

If the set of operations considered in week I contains combining or sugar beet harvest, labor and land area associated with them must be determined. Since combining and sugar beet harvest scheduling occurs previously (Subroutine CMBSCHD), available hours for these operations are the exact amount needed in each week. Weekly land area harvested for these crops is simply the EFC times the available hours. Power unit time is the available time.

The area worked each week is constrained by the area available. For example, the area planted in a week can be less than or equal to the area prepared for planting. For the second through Nth operations of a crop, the available land is that area finished for the preceeding operation.

The available land for the first crop operation must come from the harvested land area of the preceeding crop. PREVOP determines the available area. WRKSCHD updates information used in PREVOP. After the first crop operation is scheduled in WRKSCHD, the harvested area it used is made unavailable for further use by any other crop.

The first operations for two or more crops may compete for a parcel of harvested ground. An example rotation is O/A-A-A-C-C-NB-C. After corn is harvested, the first operation for navy beans (NB) or corn (C) may be scheduled on the harvested land. The model matches supply (harvested ground) to demand (first crop operation). Priority is based on ending date constraint. Once a supply is used to satisfy a demand, it cannot be used to satisfy any other demand.

When the first operation for a crop can be scheduled WRKSCHD attempts to find harvested land which is used only for the crop in question. If no exclusive supplier of land is found or more land area is required, harvested land is matched to demand on a "first come, first serve" basis in accordance with the demand operations ending date constraint.

After supply and demand accounting, or for the first pass in the week I (ICOUNT=0, Figure 2.6), WRKSCHD searches the workable operations set for week I. The highest priority operation is selected. Priority is based on ending date constraint. If the priority operation has already been scheduled in week I, or if the operation is completed, the next highest priority operation is selected.

A subset of priority operations is then developed. Operations with the same ending date constraint and for the same crop as the above priority operation are included in the subset. An operation assigned to a different workday data set is not included in the subset. Subset operations are flagged such that they are considered only once in the current week.

The weekly maximum hours available are multiplied by the available labor supply. The maximum time a single tractor can use is the time available for the operations subset. PREVOP is called to determine the area which can be scheduled.

If land area is available, the remaining time is adjusted by the time already allocated in the week. ALCATE determines the land area worked in the week and assigns the remaining time to the subset field operations.

When the last operation of the subset is planting, a check is made to see if the following operation is spraying. Hectares planted in a week must equal the hectares sprayed in the week. Spraying belongs to a different workday data set than planting; thus, it has a lower priority than planting.

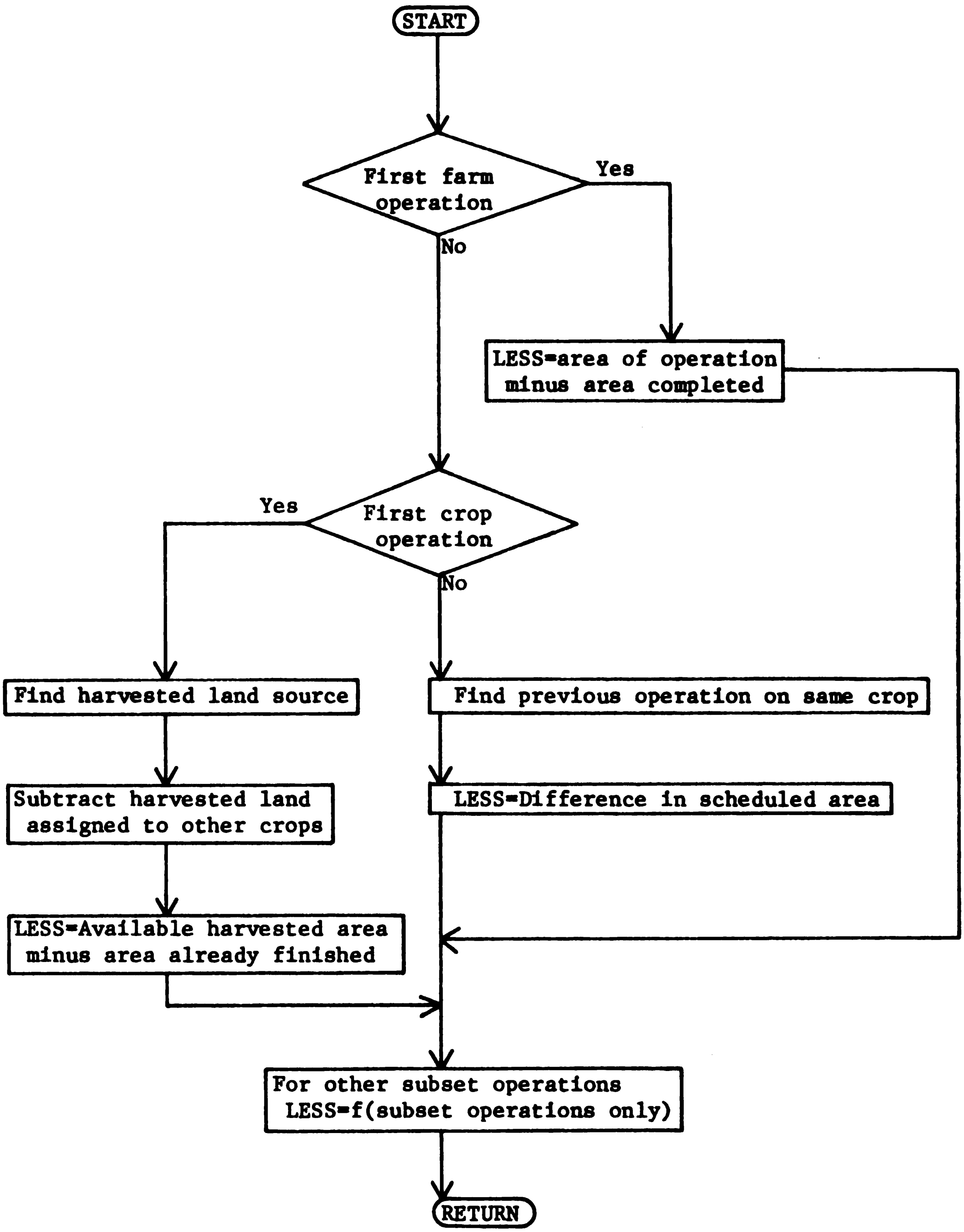
Spraying workday availability is based on a C_3 value of 1.00 (Section 3.2). Spraying hours will always equal or exceed planting hours (C_3=0.980: Section 3.2). Area sprayed in the week is equated to area planted by first assigning the extra available spraying time.

If the extra spraying hours are insufficient to complete spraying, any unused hours for planting are scheduled. Finally, if necessary, area of planted ground is reduced to allow more time for spraying.

When all operations for the week are considered or time is expired, end-of-week accounting occurs. The operations set for week I is inspected. Land area of each operation is totaled. If week I is the last week for scheduling the operation, a completion check is made.

2.7 Subroutine PREVOP

The PREVOP subroutine (Figure 2.7) determines which land areas can be scheduled at the beginning of the week. An operations subset from WRKSCHD is considered. All subset operations are for one crop (WRKSCHD). Once available land area for the first operation is determined, remaining subset operation areas can be identified.



LESS = Land area that can be scheduled for operation in the beginning of each week

Figure 2.7. Flow diagram for subroutine PREVOP.

The first farm operation can be scheduled in any quantity within its assigned area. The first crop operation is constrained by the harvested land area available. The land area available for second or later crop operations depends on the previous operation.

2.8 Subroutine ALCATE

The purpose of the ALCATE subroutine (Figure 2.8) is to assign tractor and labor time to field work and maximize hectares completed within constraints. ALCATE is called by WRKSCHD for subsets of operations with equal ending dates for one crop. The subsets may contain one or more field operations. Each operation is identified with a land area that could be scheduled in the beginning of the week. The initial queue is calculated using the PREVOP subroutine.

When the subset contains two or more operations the last operation is assumed to have the highest priority. As much of the last operation as possible will be scheduled first. It is possible with this assumption to plant previously tilled ground before all remaining tillage is completed. Delaying some tillage to allow early planting is believed to be a realistic farming practice. Often, with the exception of spring planting, the set contains only one field operation, and this assumption has little bearing on farm work assignment.

The land area available for the final operation is scheduled first if time permits. When all available land for the final operation is scheduled, the next-to-last operation is considered. Tasks scheduled for the hectares of the next-to-last operation could be simultaneously completed with the final operation of the subset. Thus,

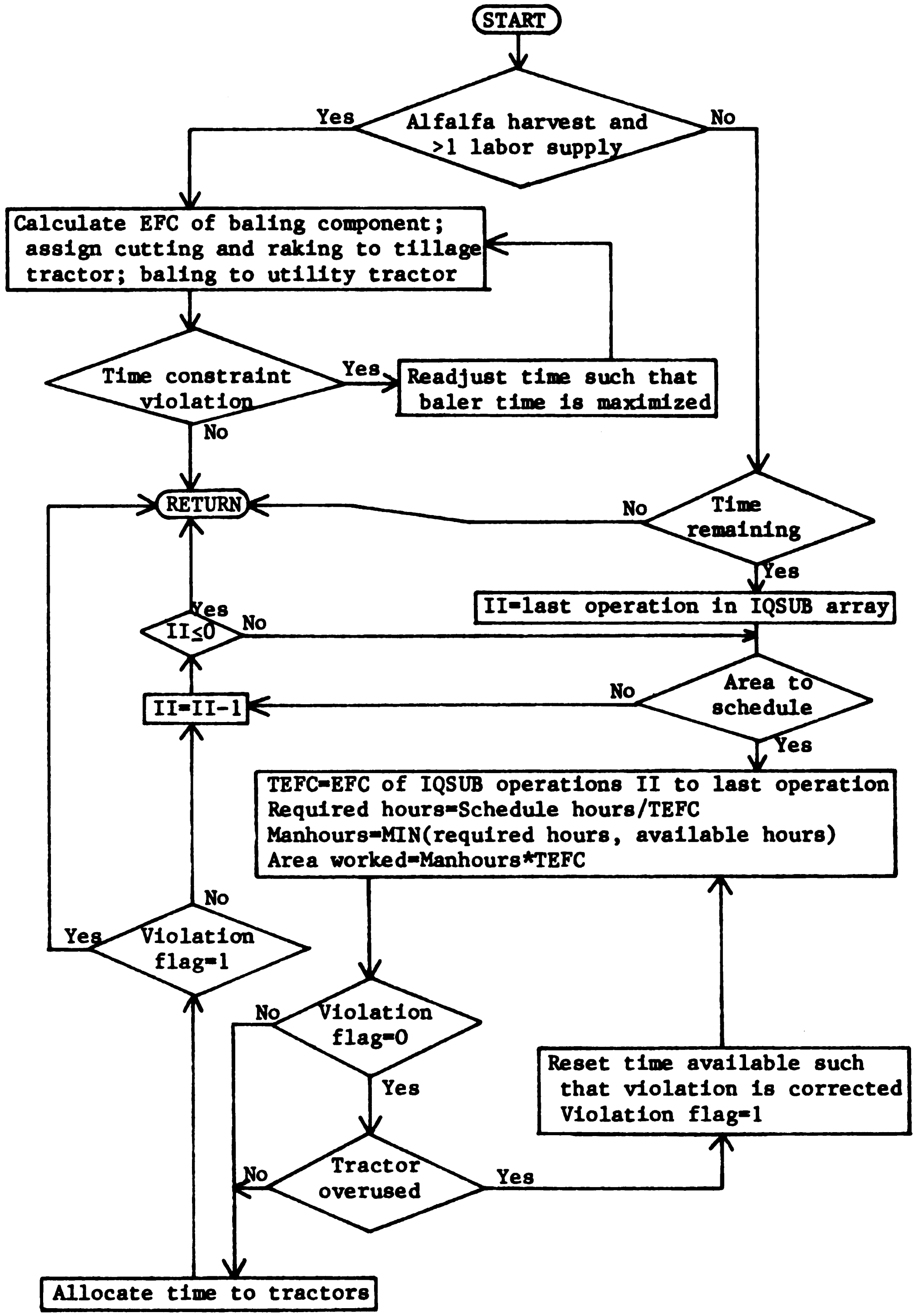


Figure 2.8. Flow diagram for subroutine ALCATE.

the last two operations are then considered one and as available time permits the hectares will be scheduled equally between the two. The allocation is expanded to include the final three operations and so on until all work operations in the subset are completed or available time is exhausted.

On farms with more than one operator, drivers may compete for power units. In cases of fixed tractor assignment, all available labor may not be used. As an example, the utility tractor cannot be used for plowing nor can the tillage tractor be used for row cultivation. Thus, a tractor operator may be idle because the model does not allow his tractor to switch from plowing to cultivation or vice versa. An exception is on farms where more than one man is available to harvest alfalfa. Once the combined capacity of the alfalfa harvest system is determined, mowing-conditioning and raking operations are assigned to the tillage tractor while baling is assigned to the utility tractor.

In some situations, an unusually large tractor may be designated for cutting or raking hay. On an actual farm, an older tractor would likely be assigned this task; since the model considers only two tractor sizes, this is not reflected in the output. From the standpoint of machinery requirements, the absence of an older tractor for cutting or raking would be the only model error. Tillage and utility tractor sizes would not be affected since a rake does not determine tractor size directly, but only consumes operator time.

Tillage tractor fuel use and expected life may be affected slightly. The addition of an older tractor would not affect average cost significantly; thus, it is reasonable to assume that the tillage tractor can perform cutting and raking tasks.

2.9 Subroutine SIZING

Some sizing occurs before the SIZING subroutine is called. Row crop planter size is determined in the CAPCITY subroutine. Combine size is selected in the CMBSCHD subroutine. The SIZING subroutine (Figure 2.9) finalizes the selection of width and speed for the remaining machinery. The EFC of each operation is known (see CAPCITY, Section 2.4). Model input also includes allowable operating speeds (see Section 3.1.1). Equation 3.2 is used to relate EFC to implement speed and width.

Each field operation is analyzed separately. Cultivators and ammonia applicator sizes are adjusted to correspond with planter size. The width of land into one windrow of the baler will depend on the crop grown or the alfalfa cutting. The navy bean combine must operate on a windrow that will facilitate bean puller and planter size matching. Combine speed and width for operations other than navy bean harvest are specified in the input data.

The remaining implements are incremented through available sizes. The speed is calculated using methods outlined in Section 3.1.1. The minimum machine size that will produce an allowable operating speed is selected. The tendency is to select operating speeds relatively close to the maximum allowable. For each operation, the annual implement use hours and fuel usage are determined. A bean puller must be selected for navy bean harvest. However, the puller is not scheduled for weekly use like other operations because combine operations are scheduled before tractors are considered. Instead, land area combined is considered pulled the same day. Labor and fuel

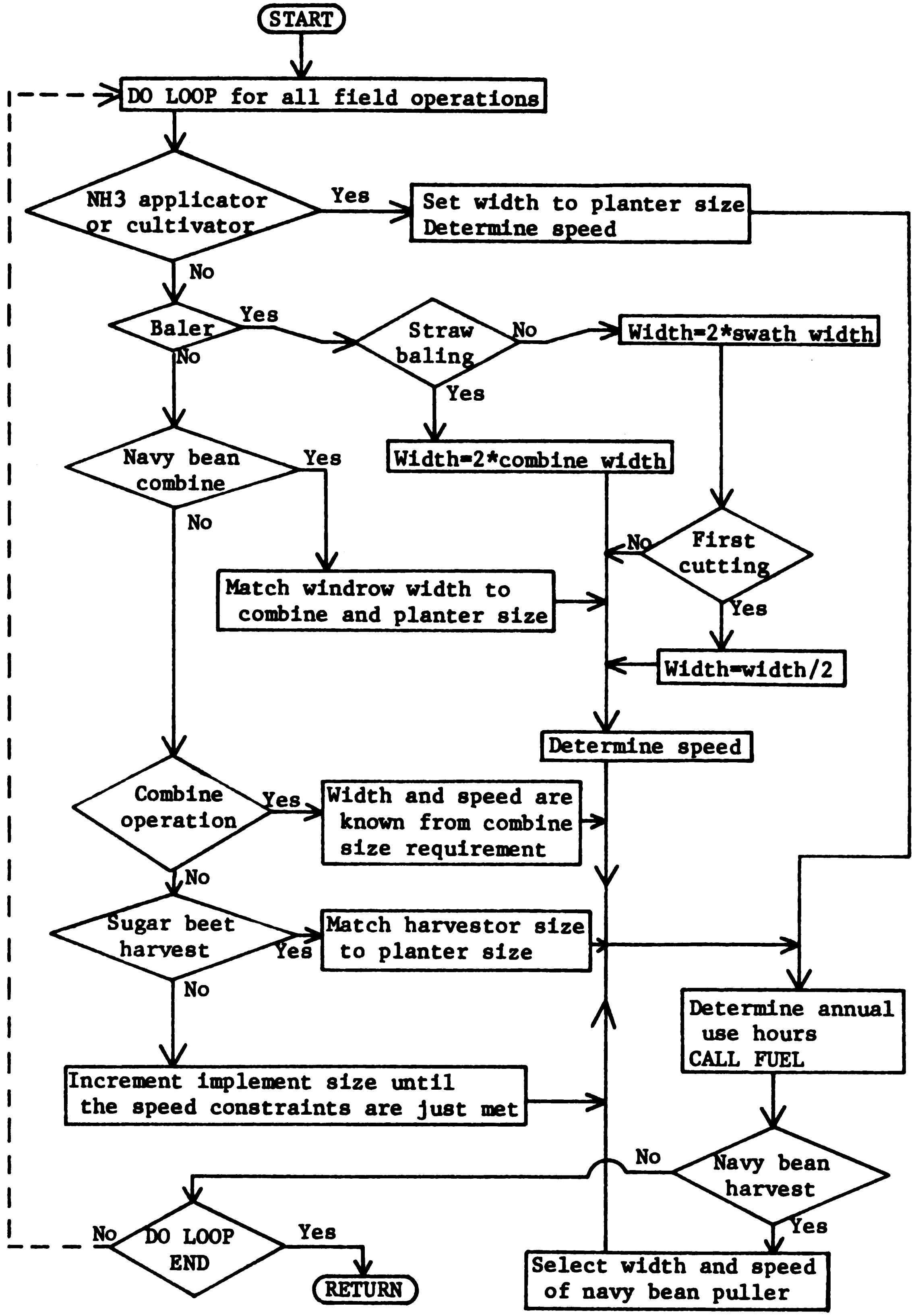


Figure 2.9. Flow diagram for subroutine SIZING.

use for navy bean pulling is considered in the summary. Planter width and combine capacity are used to arrive at a correct puller width. Given appropriate field patterns 4, 6, 8, and 12-row windrows are possible.

2.10 Subroutine FUEL

Diesel fuel usage can be calculated using the FUEL subroutine (Figure 2.10). FUEL is called by SIZING for each crop operation. The formula outlined in the ASAE YEARBOOK (1978) is used to calculate the fuel consumption of tractor-powered operations.

$$\text{Fueleff}=2.64*\text{RAT} + 3.91 - 0.20 *(738*\text{RAT} + 173)^{\frac{1}{2}} \quad (2.2)$$

Where: Fueleff = Fuel efficiency (L/kWhr)

Rat = Ratio of equivalent PTO power required to maximum available PTO power

Fuel consumption should be reported in litres per hectare units. The required conversion is:

Fueluse = Fueleff * EN/EFC

Where: Fueluse = Diesel fuel usage (L/ha)

EN = Required power for operation (PTOkW)

EFC = Effective field capacity (ha/hr)

The use of these equations was spot-checked against data in the literature (White, 1974). Model results were average to slightly higher than average. Implement drafts are higher than average for Saginaw Valley soils, thus a higher than average fuel use is expected.

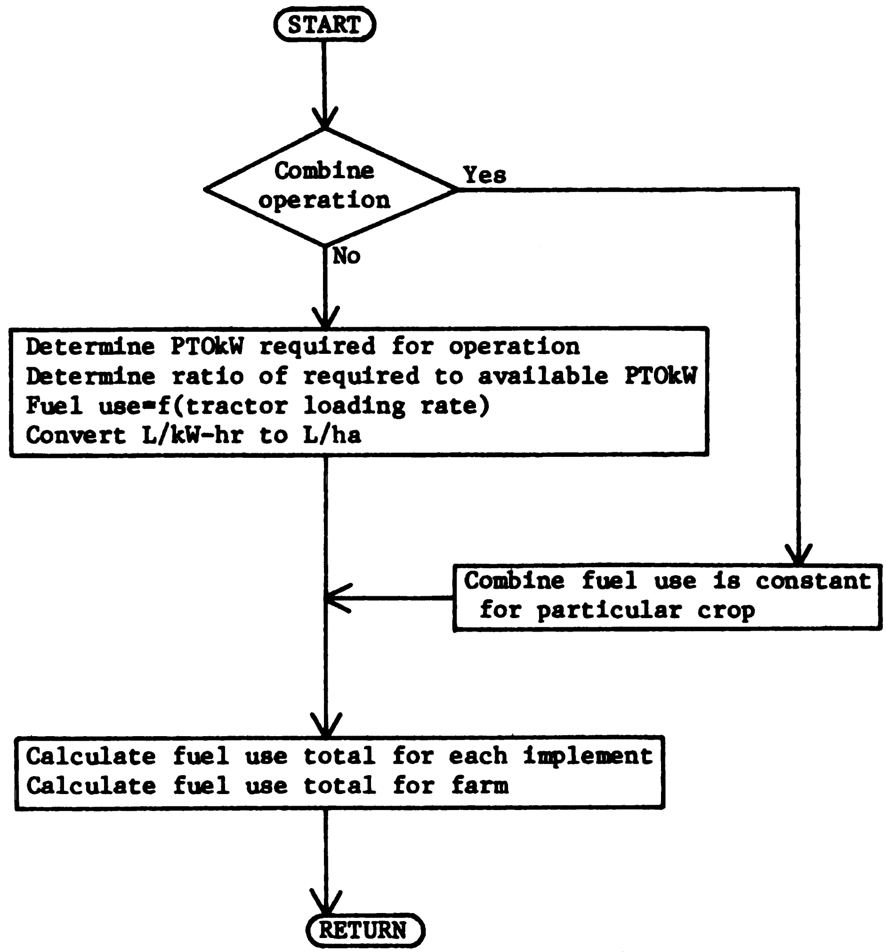


Figure 2.10. Flow diagram for subroutine FUEL.

Combine operation fuel usage is constant for each crop harvested. The usage figures taken from Singh (1978) are given in Table 2.3. The fuel subroutine also totals fuel usage for field operations and for all farm operations.

Table 2.3 Fuel Use of Combine Operations

Operation	Fuel Use,L/ha (gal/acre)
Corn harvest	15.0 (1.6)
Wheat harvest	13.6 (1.5)
Oat harvest	13.6 (1.5)
Soybean harvest	10.3 (1.1)
Navy bean harvest	13.6 (1.5)

2.11 Subroutine COST

The average yearly cost per hectare is computed for each selected machinery set. Depreciation, interest, repairs, insurance, shelter, and fuel cost are determined. Machinery cost is based on an 8-year service life for equipment. Techniques outlined by Bowers (1975) are used to calculate machinery cost. Depreciation based on a 10 percent salvage value is determined using a straight line formula. Average interest is found by multiplying the interest rate by one-half the sum of purchase and salvage prices. (A machine with a service life shorter than 8 years should be adjusted for purchase price, such that interest will be calculated for the 8-year period.) The interest rate used for this study was 0.13 (Black, 1979).

Repairs are calculated on an annual use basis. The average repair cost per machine per year is the purchase price multiplied by the total repairs factor over the service life of the machine and prorated to the annual machine usage.

Insurance and shelter costs are fixed percentages of the purchase price. (Insurance cost must be adjusted, if machine life is less than 8 years, to a 8-year basis). Shelter costs are calculated only on the initial price because a replacement machine would occupy the same shelter space as did the worn-out machine.

An algorithm for machinery cost calculation is presented in Figure 2.11. The routine contains a list of machines and widths required to complete all field operations. The annual use of each machine is assigned to the appropriate power source.

Some field operations use the same machine but operate at dissimilar drafts, and thus require different sizes for the same implement (see Table 2.2). An attempt is made to adjust speed and width for the heavy draft operation using the COST subroutine. The purpose of the adjustment is to equate machine size to that of the lighter draft operation without violating speed constraints.

The resizing technique will depend on the way machine sizes were initially chosen. Implement sizes are selected based on the minimum width that will satisfy the speed constraints of the machine (Section 2.9). Machine speeds tend toward the upper speed limit since that speed will allow the smallest implement width. A larger machine operated at a slower speed (but still within the prescribed speed range) could be chosen, but a smaller machine at a higher speed could never be used in the resizing procedure.

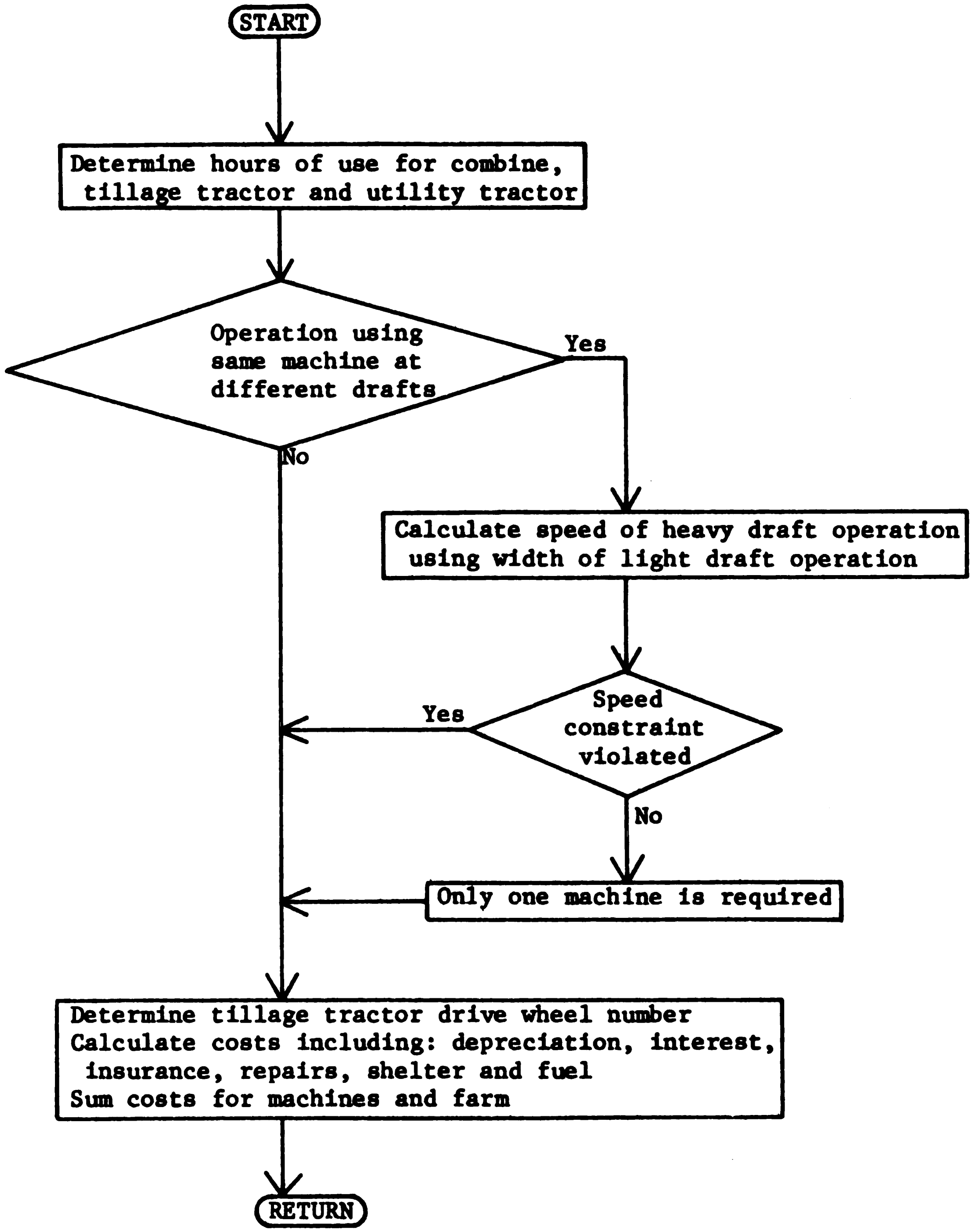


Figure 2.11. Flow diagram for subroutine COST.

If width is increased for the heavy draft operation machine, speed is necessarily lowered. If the width can be made equal to that of the lighter draft operation without violating speed constraints, then only one machine of the larger size will be required. If speed constraints are violated, two units of the same implement must be included in the cost computations.

Once the final list of machines and sizes is formulated, the purchase price of each machine is found from the data (Section 3.1.2). Costs are calculated as outlined previously. The results are recorded for the second through fourth output levels (Section 2.1).

2.12 Model Hierarchy

The model hierarchy is presented in Figure 2.12. The model begins by determining available worktime in TIME. Power unit size is determined in PWRSIZE.

PWRSIZE first determines harvester requirements by incrementing harvester size. Capacity of each increment is calculated in CAPCITY. Available time is matched to machine capacity in CMBSCHD.

The second task of PWRSIZE is to determine tractor power levels. ENERGY is called to determine the kW·h/ha levels of each tractor-powered field operation. The EFC for each tractor size increment is calculated. WRKSCHD matches available tractor time to EFC. PREVOP tells WRKSCHD how much work can be scheduled in the beginning of each week. ALCATE calculates field work completed and time used.

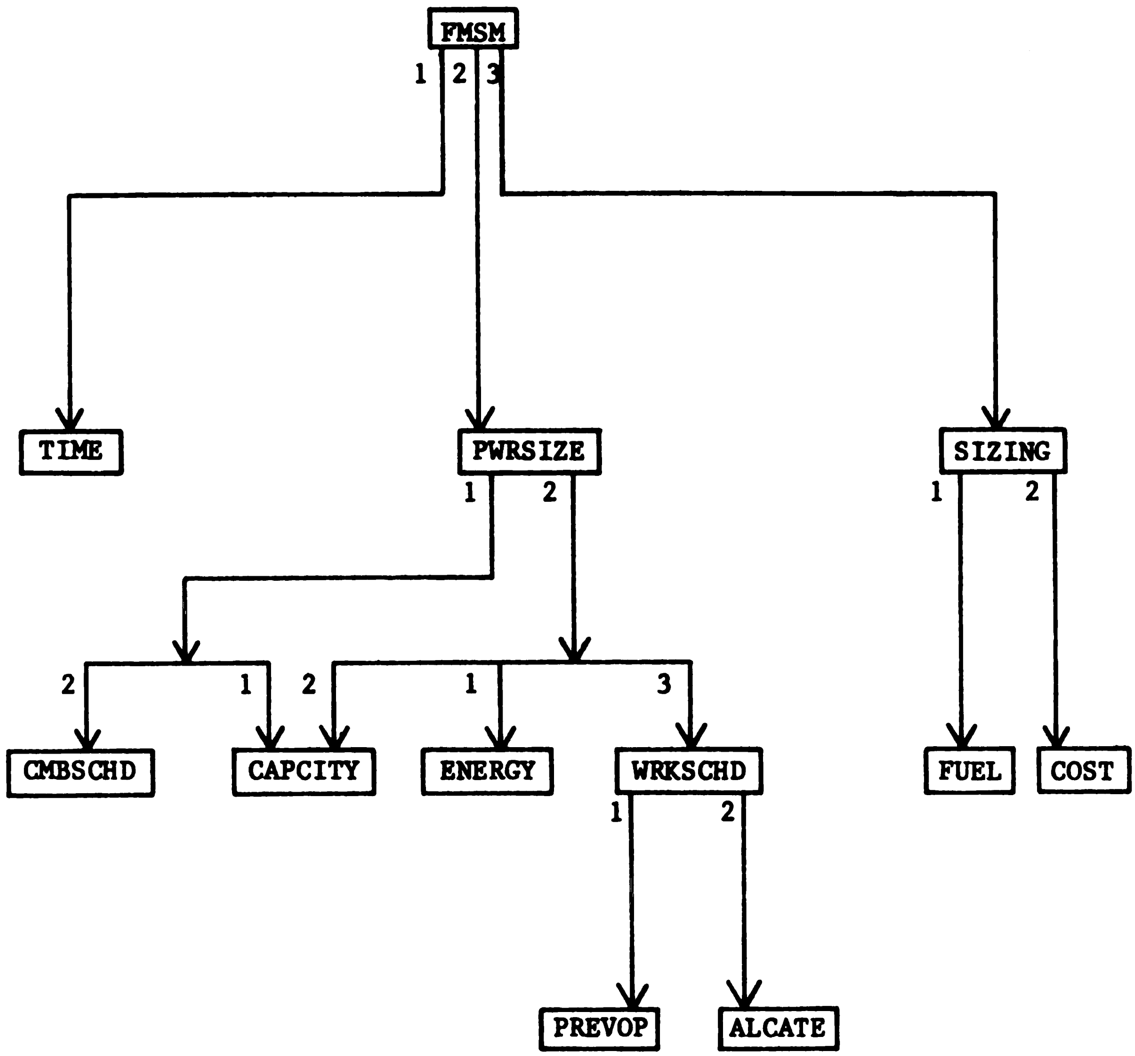


Figure 2.12. Field machinery selection model hierarchy.

Finally, FMSM calls SIZING to match implement speed and width to calculated EFC. Fuel use for each field operation is calculated in FUEL. The average annual cost of individual and total implements is calculated in the COST subroutine.

3. MODEL PARAMETER AND INPUT DEVELOPMENT

Parameter and input data fall into one of three categories: 1) machinery related; 2) available time related; and 3) farm identification. Machinery data determine the productivity of each step in machinery size during the selection process. These data are also used to size tractor-drawn implements and to compute costs. Available time data defines the portion of each week which can be scheduled for field operations. Farm data pertain to operation scheduling dates and workday length constraints.

Collection of input data can be accomplished by searching the literature or making field observations. Both sources are utilized in this study. The data collected become model input. Results using the collected data must be verified.

Validation is an important and time consuming process. The validation of the data used in the current study was accomplished by utilizing a "backwards" approach. In reality the validation is carried out first. Model parameters are then adjusted such that model results match those found in the validation. In developing the model parameters published reports were used as bench marks whenever possible. The "backwards" approach is useful because it forces the researcher to get first-hand field experience and it serves as a valuable tool in presenting model results. Listing validation results will quickly demonstrate to the audience the physical relationships of the model. Since all model results will be based on the relations listed, a degree of confidence is immediately given to the model results.

The "backwards" approach is used to determine the machinery draft-speed-width relations and the available workday parameters. Data collection is outlined in the following sections.

3.1 Machinery Parameters

Required machinery parameters of the newly developed model include:

a) draft

b) field efficiency

c) tractive efficiency

d) allowable operating speeds

e) theoretical harvest capacities

f) reliability

g) sizes available and list prices

h) service life and repair data

The collection of machinery data is discussed in two parts: 1) productivity parameters, and 2) parameters for determining machinery set fixed and variable costs.

3.1.1 Machine Productivity Parameters

Productivity data are required by two model equations developed from the ASAE YEARBOOK (1978):

$$PTOkW = \frac{D * S * W * RE}{LF * TE * CONV * C1} \qquad (3.1)$$

$$EFC = \frac{S * W * Eff}{C2} \qquad (3.2)$$

where:

PTOkW = Tractor power takeoff power (kW)

D = Implement draft (N/m)

S = Implement speed (km/h)

W = Implement width (m)

LF = Tractor load factor (decimal)

TE = Tractive efficiency (decimal)

CONV = Tractor PTO to axle power ratio (decimal)

C1 = Dimensionality constant (C1 = 3600)

EFC = Effective field capacity (ha/h)

Eff = Field efficiency (decimal)

C2 = Dimensionality constant (C2 = 10)

RE = Implement reliability (decimal)

Equation 3.1 provides a means of matching reported data to actual field conditions. A method to determine the data validity for Saginaw Valley conditions follows.

Table 3.1 lists the probable base point match of tractor power to implement speed and width. Data in Table 3.1 are synthesized from published reports (Benson, 1978); spot checks of Saginaw Valley farms; and conversations with tractor dealers, extension agents, and farm industry groups. Variables in Equation 3.1 are selected to meet the performance figures of Table 3.1.

When data are substituted from Table 3.1 into Equation 3.1, five unknowns remain. Load factor (LF) is the tractor design loading rate. It reduces tractor wear while providing extra power for difficult field conditions briefly encountered. LF is designated 0.80 (White, 1977).

Table 3.1. Base Point Match of Tractor Power Level to Implement Speed and Width.

Implement	Tractor Size		Implement Width		Implement Speed	
	PTOkW	PTOHP	m	ft	km/h	mph
Moldboard plow	97.0	130.0	2.0	6.7	6.4	4.0
Disk corn stalks	97.0	130.0	7.3	24.0	7.2	4.5
Disk harrow	97.0	130.0	6.3	20.7	6.4	4.0
Chisel plow	97.0	130.0	3.2	10.4	6.4	4.0
Field cultivate	97.0	130.0	5.9	19.4	8.9	5.5
Sugar beet topper	82.0	110.0	4.0^{+}	4.0^{+}	8.1	5.0
Sugar beet lifter	97.0	130.0	4.0^{+}	4.0^{+}	8.1	5.0
Row planter	75.0	100.0	12.0^{+}	12.0^{+}	7.2	4.5
Ammonia applicator	75.0	100.0	12.0^{+}	12.0^{+}	7.0	4.3
Row cultivator	75.0	100.0	12.0^{+}	12.0^{+}	7.4	4.6
Rotary hoe	75.0	100.0	12.0^{+}	12.0^{+}	10.1	6.3
Grain drill	44.0	59.0	3.7	12.0	9.7	6.0
Rotary cutter	47.0	63.0	3.7	12.0	9.7	6.0
Fertilizer spreader	58.0	78.0	18.3	60.0	8.1	5.0
Sprayer	22.0	30.0	9.1	30.0	8.1	5.0
Navy bean puller/ windrower	46.0	62.0	6.0^{+}	6.0^{+}	8.1	5.0
Mower-conditioner	47.0	63.0	3.7	12.0	9.7	6.0
Rake	16.0	21.0	3.7	12.0	8.1	5.0
Baler	49.0	66.0	5.4^{*}	6.0^{*}	**	**

$^{+}$Width in rows (0.76 m, 30 in.)

*Width in Mg/hr (T/hr)

**Ground speed is not a direct factor in power requirement

The PTO to axle power conversion (CONV) is 0.96 (ASAE YEARBOOK, 1978). For the sake of simplicity, reliability (RE) is assumed to be 1.0 for all machines considered. The remaining unknowns are draft (D) and tractive efficiency (TE).

Domier and Friesen (1969) report a slight tractive efficiency advantage for four-wheel drive tractors in tests on a clay stubble field. Osborne (1971) reported little difference between tractors when operated on firm soil, but a greater advantage for four-wheel drive tractors when operated in soft soil. Dwyer and Pearson (1976) reported a 14% advantage for four-wheel drive tractors over a range of surface conditions.

For simplicity of model operation, let us assume that tractive efficiencies are constant between two- and four-wheel drive units. Plowing requires more energy than other field operations and thus is a major factor in tillage tractor selection. Tractive efficiency is nearly equal for two- and four-wheel drive tractors when operated on firm soil, thus specification of different tractive efficiencies become less important when sizing tractor power levels.

Equation 3.1 cannot be solved until one of the remaining unknown variables, tractive efficiency or draft, is specified. Tractive efficiencies were selected to match reported data (Bowers, 1975, and White, 1977). Any error present in the tractive efficiency values (Table 3.2) will be offset when draft is calculated.

Substitution of power speed, and width data from Table 3.1; tractive efficiency data from Table 3.2; and the LF, RE and CONV parameters from above; into equation 3.1 results in one equation with one unknown. The unknown, draft, can be solved for each field

Table 3.2. Assumed Draft and Tractive Efficiencies.

Implement	Draft N/m	Draft lb/ft	Tractive Efficiency %
Moldboard plow	16,272	1,115	80
Moldboard plow/leveler	17,513	1,200	80
Disk harrow	4,962	340	75
Disk	3,794	260	75
Chisel plow	10,508	720	80
Field cultivator 1	3,794	260	75
Field cultivator 2	3,036	208	60
Sugar beet topper	5,284*	1,188*	75
Sugar beet lifter	6,245*	1,404*	75
No-till planter	2,402*	540*	72
Ammonia applicator	1,779*	400*	72
Grain drill	2,481	170	72
Row cultivator	1,668*	375*	72
Rotary hoe	1,223*	275*	72
Mower-conditioner	2,919	200	80
Row planter	1,713*	385*	72
Baler	5.5+	6.7+	80
Rotary cutter	2,919	200	80
Fertilizer spreader	876	60	80
Rake	1,168	80	80
Sprayer	584	40	72
Navy bean puller/windrower	2,113*	475*	80

*Draft per row (0.76 m, 30 in.)

+Drawbar kW/Mg (hp/T of alfalfa)

operation. The calculated drafts are listed in Table 3.2. The drafts resemble data reported by White (1977) except that: 1) moldboard plow draft is slightly higher; 2) calculated sugar beet topping draft is higher; and 3) sugar beet lifting draft is lower.

The draft discrepency of moldboard plowing may only be a function of soil type. White (1977) lists plowing drafts for sandy, loam, and clay loam soils. The soil associated with the calculated draft may contain more clay than the clay loam White (1977) lists.

Discrepency in sugar beet lifting draft may be a function of soil moisture content. A wetter soil tends to cling to the sugar beet root, increasing the work expended to uproot the plant and the weight of material lifted.

No justification could be found for the higher sugar beet topping draft. It is speculated that plant moisture differences may be a cause. The draft figures reported in the validation were assumed in the current model.

Table 3.3 outlines field efficiency and speed data (White, 1978). Operating speed ranges were adjusted to allow full use of tillage tractor horsepower. The drawbar power requirements of a given machine operated at its fastest speed overlap those of the next larger machine operated at its slowest speed. This adjustment eliminates the possibility of a tractor, at a given power level, to be too small for a particular size machine operating at its slowest speed and yet over-powered for the next smaller size machine operating at its fastest speed.

Harvest capacities cannot be determined entirely using machine productivity data. Material handling capability may play a larger

Table 3.3. Assumed Implement Operating Speeds and Field Efficiencies

Implement	Operating speed, km/h (mph) Minimum		Maximum		Field Efficiency %
Moldboard plow	5.5	(3.4)	7.2	(4.5)	80
Moldboard plow/leveler	5.5	(3.4)	7.2	(4.5)	80
Disk harrow	4.8	(3.0)	8.1	(5.0)	80
Disk	4.8	(3.0)	8.1	(5.0)	85
Chisel plow	6.4	(4.0)	9.7	(6.0)	85
Field cultivator 1	6.4	(4.0)	9.7	(6.0)	85
Field cultivator 2	6.4	(4.0)	9.7	(6.0)	85
Sugar beet topper	3.2	(2.0)	8.9	(5.5)	70
Sugar beet lifter	3.2	(2.0)	8.9	(5.5)	70
No-till planter	4.8	(3.0)	9.7	(6.0)	55
Ammonia applicator	4.8	(3.0)	9.7	(6.0)	65
Grain drill	4.0	(2.5)	9.7	(6.0)	70
Row cultivator	4.0	(2.5)	8.1	(5.0)	80
Rotary hoe	8.1	(5.0)	16.1	(10.0)	80
Mower-conditioner	4.8	(3.0)	9.7	(6.0)	75
Row planter	4.8	(3.0)	9.7	(6.0)	55
Baler	4.0	(2.5)	8.1	(5.0)	60
Rotary cutter	4.8	(3.0)	9.7	(6.0)	70
Fertilizer spreader	3.2	(2.0)	8.1	(5.0)	70
Rake	6.4	(4.0)	8.1	(5.0)	80
Sprayer	3.2	(2.0)	8.1	(5.0)	65
Navy bean puller/ windrower	3.2	(2.0)	8.1	(5.0)	80

role than harvester capacity. The current machinery model does not account for movement of harvested material. However, limiting effects of material handling are partially incorporated by assuming discreet step sizes in harvest capacity.

Harvest capacities are listed in Table 3.4. Presumably, the crop is loaded into transport vehicles in the field.

Combine capacities for corn, navy beans, soybeans, and wheat were obtained (Singh, 1978). It is assumed that oat harvest capacity will likely equal wheat harvest capacity. Wheat and oat plants have relatively similar characteristics although lodging would be a larger problem for oats.

Five sugar beet harvest capacities were developed with help from a sugar beet industry official (Brimhall, 1979). The capacities range between 0.8 to 1.9 hectares per hour for a two-operator farm. A 1.9 hectare per hour capacity would require a four-row lifter operating at 8.9 kilometer per hour.

Alfalfa baler capacity is approximately 5.4 Mg/h (Rider, 1976). Table 3.4 lists mower-conditioner, raking, and baling operations for a 4.5 megagram per hectare crop. The alfalfa harvest system capacity (cut, rake, bale) is also given.

3.1.2 Machinery Economic Data

Service life and repair data are obtained from Bowers (1975) and listed in Table 3.5. Available machinery sizes are from the National Farm and Power Equipment Dealer's Association (Fall 1979) and the Deere and Company Agricultural Sales Manual (1979).

Table 3.4. Assumed Harvest Capacities, Field Efficiencies, and Speed

Crop	Harvester Size	Speed, km/h	(mph)	Field Efficiency, %	Field Capacity, ha/hr	(A/hr)
Corn	2-row	5.3	(3.3)	70	0.6	1.4
	4-row	4.8	(3.0)	65	1.0	2.4
	6-row	4.5	(2.8)	63	1.3	3.2
	8-row	4.5	(2.8)	60	1.6	4.0
Wheat	2-row	4.5	(2.8)	75	1.0	2.5
	4-row	4.8	(3.0)	75	1.5	3.6
	6-row	5.6	(3.5)	75	1.7	4.1
	8-row	5.6	(3.5)	70	1.9	4.8
Oats	2-row	4.5	(2.8)	75	1.0	2.5
	4-row	4.8	(3.0)	75	1.5	3.6
	6-row	5.6	(3.5)	75	1.7	4.1
	8-row	5.6	(3.5)	70	1.9	4.8
Soybeans	2-row	4.0	(2.5)	70	0.8	2.1
	4-row	4.5	(2.8)	70	1.3	3.1
	6-row	5.3	(3.3)	70	1.5	3.6
	8-row	5.3	(3.3)	65	1.7	4.1
Navy beans	2-row	8.0	(5.0)	70	1.7	4.3
	4-row	8.0	(5.0)	67	2.1	5.3
	6-row	8.0	(5.0)	65	2.5	6.3
	8-row	8.0	(5.0)	63	3.1	7.7
Sugar beets	1*	*	*	70	0.8	2.0
	2	*	*	70	1.1	2.8
	3	*	*	70	1.4	3.5
	4	*	*	70	1.7	4.3
	5	*	*	70	1.9	4.7
Alfalfa	**	**	**	**	0.6	1.5

*Sugar beet harvest capacity is set at 5 levels. Speed ranges between 3.2 to 8.9 km/h (2.0 to 5.5 mph) depending upon harvester width.

**Alfalfa harvest consists of mower-condition, rake, and bale operations. Capacity listed is for a 3.7 m (12 ft) swath, 5.4 Mg/hr baler, and 4.5 Mg/ha crop. Speed and efficiency values are in Table 3.3.

Table 3.5. Assumed Repair and Service Life Data

Implement	Total Repairs % of Purchase Price	Service Life hrs
Moldboard plow	80.0	2,000
Disk	65.0	2,000
Chisel plow	65.0	2,000
Field cultivator	65.0	2,000
Sugar beet topper	60.0	2,000
Sugar beet lifter	80.0	2,000
No-till planter	75.0	1,000
Ammonia applicator	75.0	2,000
Grain drill	75.0	1,000
Row cultivator	65.0	2,000
Rotary hoe	65.0	2,000
Mower-conditioner	180.0	1,000
Row planter	75.0	1,000
Baler	80.0	2,000
Rotary cutter	60.0	2,000
Spin spreader	75.0	1,200
Rake	75.0	2,000
Sprayer	75.0	1,200
Navy bean puller	75.0	2,000
Corn head	33.0	2,000
Grain platform	33.0	2,000
Windrow pickup/platform	33.0	2,000
Combine	33.0	2,000
2-wheel drive tillage tractor	90.0	10,000
2-wheel drive utility tractor	90.0	4,800
4-wheel drive tillage tractor	90.0	10,000

Tractor and combine prices were obtained from the National Farm and Power Equipment Dealer's Association (Fall 1979). Prices were adjusted to August 15, 1979, levels using information compiled by the Statistical Reporting Service (1979).

Prices per PTOkW were determined for three tractor categories: four-wheel drive tillage; two-wheel drive tillage; and two-wheel drive utility. A linear regression of paired data (i.e., tractor size, PTOkW and price) was used. Where tractors were rated in drawbar or engine kilowatt, power takeoff kilowatt levels were calculated using data from the ASAE YEARBOOK (1978). Utility tractors were determined to be 4 years old (Singh, 1978). Utility tractor purchase price is assumed to be 48 percent of the new price (Hunt, 1977). The developed equations are:

Two-wheel drive purchase price = 302.51 * PTOkW: $r^2 = 0.94$

Four-wheel drive purchase price = 346.49 * PTOkW: $r^2 = 0.85$

Where r^2 = coefficient of determination

Combine prices were ranked from lowest to highest. The lowest and highest cost machines were $22,175 and $66,283, respectively. The price list was divided into four categories: $20,000; $30,000; $40,000 and $50,000 and above. The number of machines in each category were 5, 7, 7, and 6 respectively. The average price of each category was used as the purchase price for 2, 4, 6, and 8-row capacity machines, respectively.

Corn head prices were average for all manufactures (National Farm Power and Equipment Dealer's Association, Fall 1979). Prices of grain and pickup platforms and for tillage and planting equipment were obtained from Deere and Company (1979). Bean puller, bean windrower, ammonia applicator, and fertilizer spreader prices were obtained in dealer interviews and from previous studies (Benson, 1978 and Singh, 1978). Prices and sizes of equipment are given in Table 3.6.

3.2 Available Workdays

The literature reports two categories of workday data: 1) observed date for a location and year (e.g., Link, 1968), and 2) generated data using weather and soil parameter inputs (e.g., Kish and Privette, 1974). Singh (1978) reviewed the literature in this area.

No observed workday records exist for the Saginaw Valley, thus a workday generator (Tulu, 1973) is used in the present study. The workday simulator predicts daily work, no-work day sequences for tillage, crop maintenance, and corn combining operations. Workday sequences for harvest of crops other than corn are not explicitly developed in the simulation, thus a new method is developed to generate harvest workday sequences. The generation of harvest workday sequences will be discussed later in this section.

The Tulu (1973) simulation is based on soil moisture budgets. His model includes five weather and two soil parameters. The weather data are: 1) maximum daily temperature (^{o}F); 2) minimum daily temperature (^{o}F); 3) daily precipitation (hundredths of an inch); 4) daily open pan evaporation (hundredths of an inch); and 5) snow condition (0 = no snow, 1 = snow). The soil parameters are water-holding capacity (in./ft.) and a soil moisture level criterion.

Table 3.6. Assumed Machinery Sizes and Associated Prices

Implement	Unit of* Measure	Size/Price							
Moldboard plow	width (b)	3	4	5	6	7	8	9	10
	$	1,889	7,425	8,594	9,763	10,932	12,101	15,068	16,233
Disk	width (m)	3.48	4.34	5.21	6.50	7.80	9.17	10.97	12.19
	$	4,371	4,909	8,403	9,511	12,014	14,781	19,708	21,029
Chisel plow	width (m)	2.44	3.05	3.35	3.96	4.57	5.18	5.97	6.40
	$	1,987	2,189	3,082	3,284	3,543	3,818	7,010	7,212
Field cultivator	width (m)	3.81	4.72	5.64	6.55	7.77	8.69	10.38	12.34
	$	2,274	2,690	3,701	4,232	6,983	7,277	8,977	9,460
Sugar beet topper	width (r)	2	3	4					
	$	6,315	7,490	8,665					
Sugar beet lifter	width (r)	2	3	4					
	$	18,948	24,644	25,458					
Ammonia applicator	width (r)	2	4	6	8				
	$	2,000	2,400	2,800	3,200				
Grain drill	width (m)	3.05	6.10						
	$	4,011	8,391						
Row cultivator	width (r)	4	6	8	12				
	$	1,450	2,597	3,400	4,717				
Rotary hoe	width (m)	4	6	8	12				
	$	1,559	2,219	3,070	5,343				
Mower-conditioner	width (m)	3.66							
	$	7,950							
Row planter	width (r)	4	6	8	12				
	$	6,321	10,671	14,297	22,438				
Baler	capacity (c)	5.44							
	$	6,245							
Rotary cutter	width (m)	1.52	1.83	2.13	4.17	4.57			
	$	1,507	1,568	1,884	4,202	6,070			

Table 3.6. (cont'd.)

Implement	Unit of* Measure	Size/Price			
Spin spreader	width (m) / $	18.3 / 2,500			
Rake	width (m) / $	3.66 / 1,754			
Sprayer	width (m) / $	9.14 / 2,640			
Navy bean puller	width (r) / $	4 / 6,235	6 / 7,996	8 / 11,616	
Corn head	width (r) / $	2 / 4,248	4 / 9,037	6 / 12,740	8 / 16,114
Grain platform	width (m) / $	3.05 / 5,300	3.96 / 5,700	4.88 / 6,124	
Platform & pickup	width (m) / $	3.05 / 7,455	3.96 / 7,855	4.88 / 8,549	
Combine	width (r) / $	2 / 24,898	4 / 36,179	6 / 45,641	8 / 57,124
2-wheel tillage tractor	PTOkW / $/PTOkW	45 to 112 / 302.50			
2-wheel utility tractor	PTOkW / $/PTOkW	45 to 104 / 151.25			
4-wheel tillage tractor	PTOkW / $/PTOkW	112 to 201 / 346.49			

*b = 41 cm (16 in) bottom, r = 76 cm (30 in) row, m = meter, c = Mg/hr

The soil moisture criterion describes the available water in a soil layer as a percentage of the maximum available water in the layer. Maximum available moisture is defined as field capacity minus wilting point. Tulu (1973) divided the soil profile into three layers. The first layer occupies the 0.0-to 1.2-inch region. Second and third layers are at the 1.2-to 3.0-and 3.0-to 6.0-inch depths, respectively. Each layer is assigned a moisture criterion (C_i) = The top two layers are assigned a value of 0.985 ($C_1 = C_2 = 0.985$). The third layer criterion will depend on soil type, drainage conditions, and field operation performed (Tulu, et al., 1974). A brief summary of the Tulu model follows.

Heat units are accumulated from the beginning of the year to determine the date of soil thaw. At spring thaw, the soil presumably is at the saturation point. The date of spring thaw triggers the moisture budget. If, on any day, the budget indicates a moisture level lower than the criterion set for each level, then a workday is said to have occurred. Conversely, if the budget indicates a higher moisture level than the criterion for at least one level, then a non-workday is recorded. The model continues in this fashion until the soil freezes in the fall. The model results produce a daily workday record for the tillage, crop maintenance, and corn harvest operation categories.

Tulu (1973) ran the model for northern Indiana where actual workday data existed on three farms for 1 year each. The model gave good results for spring tillage and fall corn harvest using the C_3 values of 0.985 and 1.0, respectively. No validation was undertaken for fall tillage operations.

A technique to determine workday availability for harvest of all crops was needed. Two conditions must exist before harvest can begin: 1) the ability to adequately propel a harvester across the field, and 2) crop moisture should be at an acceptable level.

Von Bargen (1966) describes an open haying day as a day for which hay-harvesting operations can take place. Three factors: rainfall on the date, percentage of possible sunshine on the date, and rainfall on the previous date, determine whether an open haying date occurs.

Using the Tulu (1973) model and the idea of an open haying day (Von Bargen, 1966) a procedure was developed to predict workday sequences for soybean, navy bean, wheat, oat and alfalfa harvest. Tulu (1973) model results for $C_3 = 1.00$ predict the ability to propel a machine over a field. With the help of extension agronomists (Helsel, 1979) rainfall levels conducive to harvest were hypothesized.

It is hypothesized harvest workdays can be predicted using Tulu (1973) model results and rainfall data. A summary of the hypothesized procedure follows. An alfalfa harvest workday would occur on any day that: 1) is part of a 3-day workday sequence for $C_3 = 1.00$; 2) it does not rain; and 3) less than 0.20 inch rain was recorded for the other days in the $C_3 = 1.0$ workday sequence.

A harvest day for soybeans, navy beans, wheat and oat harvest is established provided: 1) there is no rain that day; 2) less than 0.20 inch rain was recorded the previous day; and 3) it is a workday according to the data generated using $C_3 = 1.0$.

The number and distribution of harvest workdays for sugar beets are equated to the usable days available for tillage during the same period. This assumption was drawn after conversations with several Michigan sugar beet farmers.

It is hoped that the hypothesized method of determining harvest workdays will be investigated in future studies.

As previously mentioned, the Tulu (1973) model was validated for Northern Indiana. A new validation was needed for the Saginaw Valley area. The validation would confirm the correctness of the C_3 value selected. The selection of the C_3 parameter for the Saginaw Valley and the validation were carried out hand in hand.

While farmers and extension personnel cannot produce workday records, they can identify a reasonable machinery complement for a given area. This is the key point to this validation procedure.

Using a water-holding capacity of 1.9 inches per foot (Meints, 1979), several work/no-work day tillage sequences are generated for different C_3 values. The Bad Axe weather station provided weather data for the years 1949 to 1977. Open pan evaporation for these years was obtained from the East Lansing station.

Actual data for each of the 28 years are used as input by the machinery selection model (Chapter 2). The model selects the machinery complement which accomplishes all work in each of the 28 years for the given farm and operation date constraints. The selected machinery sets are ranked from highest to lowest for cost per hectare.

A 162 hectare C-NB farm was selected for study. The operations schedule for the farm is presented in Table 3.7. Four machinery sequences were developed for C_3 parameters of 0.970, 0.975, 0.980, and 0.985. Harvest workdays as developed previously are identical for all comparisons. Results are given in Table 3.8.

Table 3.7. Operations Schedule for a C-NB Farm*

Operation	Crop	Starting Date	Finishing Date	Field Work hrs/day
Harvest	Navy beans	8/28**	10/01	6
Harvest	Corn	10/09	11/12	10
Disking	Navy beans	10/09	11/26	12
Fertilizer spreading	Corn	8/28	11/26	12
Moldboard plowing	Corn	8/28	5/14	12
Field Cultivation 1	Corn	4/24	5/14	12
Planting	Corn	4/24	5/14	12
Spraying	Corn	4/24	5/14	12
Moldboard plowing	Navy beans	10/09	6/18	12
Disk harrowing	Navy beans	4/10	6/18	12
Field cultivation 1	Navy beans	5/15	6/18	12
Field cultivation 2	Navy beans	5/22	6/18	12
Planting	Navy beans	5/22	6/18	12
Cultivation	Corn	5/29	6/18	12
NH3 application	Corn	5/29	6/18	12
Cultivation	Navy beans	6/19	7/09	12

*162 hectare, 1-operator

**Month/day

Table 3.8. Machinery Sets for a C-NB Farm Under Four Workday Data Sets+

	C_3(Tulu moisture criterion)											
	0.985			0.980			0.975			0.970		
Rank	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows
28	*	*	*	*	*	*	*	*	*	*	*	*
27	*	*	*	*	*	*	*	*	*	*	*	*
26	205	87	2	*	*	*	*	*	*	*	*	*
25	202	83	2	248	69	8	*	*	*	*	*	*
24	195	69	2	241	123	2	289	116	8	*	*	*
23	184	56	4	219	78	4	254	80	8	*	*	*
22	184	66	2	216	99	2	241	123	2	*	*	*
21	184	55	4	215	70	4	239	85	6	*	*	*
20	183	54	4	214	69	4	224	87	4	255	138	2
19	181	50	4	205	87	2	221	81	4	255	80	8
18	165	56	2	192	64	4	216	99	2	241	123	2
17	164	54	2	187	62	4	216	74	4	241	123	2
16	163	52	2	184	57	4	205	87	2	235	78	6
15	163	51	2	184	66	2	204	85	2	230	96	4
14	162	50	2	170	49	4	203	66	4	229	93	4
13	162	50	2	166	59	2	201	83	2	219	78	4
12	150	49	2	164	55	2	184	66	2	205	87	2
11	150	49	2	164	55	2	181	50	4	204	85	2
10	150	49	2	164	54	2	170	49	4	186	60	4
9	150	49	2	164	54	2	170	49	4	181	50	4
8	150	49	2	164	54	2	168	63	2	173	65	2

Table 3.8. (cont'd.)

	C_3 (Tulu moisture criterion)											
	0.985			0.980			0.975			0.970		
Rank	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows	Cost $/ha	Tractor PTOkW	Combine Rows
7	150	49	2	162	51	2	166	60	2	170	49	4
6	150	49	2	150	49	2	165	57	2	168	63	2
5	150	49	2	150	49	2	163	52	2	165	57	2
4	150	49	2	150	49	2	150	49	2	162	50	2
3	150	49	2	150	49	2	150	49	2	150	49	2
2	150	49	2	150	49	2	150	49	2	150	49	2
1	150	49	2	150	49	2	150	49	2	150	49	2

+162-hectare, 1-operator

*Unable to complete all field work within specified date constraints

The appropriate moisture criterion for tillage is selected by identifying the sequence of machine sets most likely to appear for the given farm and study area. The C_3 parameter of 0.980 was selected because it generated the sequence of machinery sets most likely to be found on the example farm as judged by extension specialists at Michigan State University. The selection criterion was based on the relative ranking of machinery set costs for the four C_3 parameters and personal observations of farms.

3.3 Farm Identification

Data concerning the farm pertain to crop rotation, length of workday, and scheduled field operations. Crop rotations with alfalfa, corn, navy beans, oats, soybeans, sugar beets, and wheat are common.

Probable workday lengths for field operations are given in Table 3.9. Field operation sequence and scheduled periods are obtained from Christenson et al. (1980) and reported in Table 3.10.

Table 3.9. Estimated Workday Lengths

Operation	Field Work, hr/day
Corn harvest	10.0
Soybean harvest	8.0
Alfalfa harvest	9.0
Navy bean harvest	6.0
Wheat harvest	8.0
Oat harvest	7.0
Sugar beet harvest	11.0
Tillage	12.0

Table 3.10. Assumed Timing of Field Operations

	Crop							
Operation	Corn	Navy Beans	Soybeans	Sugar Beets	Wheat	Alfalfa	Oats	Oats/Alfalfa
Harvest	10/09-11/13+	8/28-10/02	9/25-10/23	9/25-11/13	7/17-8/07	7/10-7/24 8/21-9/04 5/22-6/12	7/24-8/14	7/24-8/14
Fertilize	A-11/27++	w/plant	w/plant	w/plant	A-10/16 3/20-4/24	5/22-6/12	A-11/27	A-11/27
Fall disk*	10/09-11/27	10/09-11/27	10/09-11/27	10/09-11/27	A-10/16		10/09-11/27	10/09-11/07
Plowing	A-5/15	A-6/19	A-6/05	A-11/27			A-11/27	A-11/27
Spring disk		4/10-6/19 5/15-6/19	4/10-6/05	4/10-5/15			4/10-5/08	4/10-5/08
Field cult.	4/24-5/15	5/22-6/19	5/15-6/05	4/10-5/15	9/25-10/16		4/10-5/08	4/10-5/08
Planting	4/24-5/15	5/22-6/19	4/10-6/05	4/10-5/15	9/25-10/16		4/10-5/08	4/10-5/08
Spraying	4/24-5/15	5/22-6/19	5/15-6/05		5/01-5/08			
Cultivate	5/29-6/19	6/19-7/10	6/12-7/03	5/22-6/19 6/12-7/03				
NH3 applic.	5/29-6/19			6/05-6/26				
Bale straw								7/24-8/21

+10/19-11/13 indicates that corn harvest starts October 9 and ends November 13.

++A beginning date of A means this operation would start after harvest of the previous crop.

*Fall disking after corn or before wheat only.

4. ANALYSIS OF DESIGN PROBABILITY CALCULATION METHODS

Selected machinery complements must be qualified with a design probability. The design probability indicates the number of years out of 10 for which the selected machinery set could complete all field work. A design probability of 0.70 would indicate that for 7 out of 10 years, the selected machinery complement would complete all field work for the given farm, within the specified date constraints.

The design probability allows unbiased comparison of machinery requirements for different rotations. An unequal design probability would undersize one machinery set relative to the other, without accounting for lower productivity of the smaller set. Equal design probabilities assure that the selected machinery sets are equal in productive ability.

The best way to determine the design level is to develop machinery complements for each year's weather data. This is the same procedure used to determine the workday simulator parameters. From an economic standpoint, inspection of Table 3.8 shows that a 78 PTOkW tractor and a 4-row combine would complete all field work on the C-NB farm 23 years out of the sampled 28, for C_3=0.980.

The physical design probability may not be that machinery complement corresponding to cost number 23. The twenty-third largest tillage tractor is 87 PTOkW. The twenty-third largest combine is 4-rows. Because the model investigates combine-tractor trade-offs (Section 2.1), a 4-row combine and less than 87 PTOkW tractor may have been adequate in year 19 but may have cost more than set No. 19 in Table 3.8.

The physical design probability must account for tractor size, combine size, and sugar beet and alfalfa harvest capacity requirements. Because the model prints only the lowest cost machinery set for each year and not all satisfactory machine sets, the economic design probability is used in the following discussion.

The development of machinery sets for each year of available workday data, while giving good results, has a drawback. Analysis of labor vs. machinery, and number of operations vs. machinery requirements, would necessitate generation of many yearly machinery complements for the same farm.

Attempts have been made to statistically group workday data. Burrows and Siemens (1974) determined the 80 percent level of time available in each work period; these data are then used in their machinery model. Tulu (1973) developed a unique distribution to describe generated workday data. Using this distribution function, he inputted the probability of workdays in each period for his machinery model.

Singh (1978) considered weekly workday data to be normally distributed and independent from week to week. By grouping weekly means and standard deviations together over an operation's scheduled period, and using areas under the normal curve, a percentage of time available for work on the given operation can be found. The weekly number of hours available is a proportion of weekly mean to the sum of means over the period.

For each method reviewed, the choice of a probability level for each period translates to an equal design probability level for the machinery set chosen. Fulton et al. (1976) point out that a probability level assigned to periods does not necessarily imply that the given probability level will be correct for the entire season. Correlations may exist between periods during a season.

The computational advantages of using statistically grouped data are great enough that an unbiased estimation technique was sought. For comparison, model performance using actual data is determined first. Three 162 hectare farms, C-NB, C-NB-W-BT, and C-NB-NB-BT were selected for study. Operations scheduled for the farms are shown in Tables 3.7, 4.1 and 4.2. Machinery complements for the three farms were developed for the 28 years of daily workday data.

Cost per hectare for generated machinery sets are given in Table 4.3. The machinery set cost figure is used as an indication of the machinery set field capacity. Field capacity is a function of tractor, implement, combine, alfalfa baler, and sugar beet harvester size. An analysis utilizing the physical capacity of each implement using 28 machinery sets would be unwieldy. Using the machinery complement cost simplifies the analysis procedure, while still giving the reader a feel for the relative field capacities involved.

A C-NB farm (Table 4.3) would require a machinery set costing 248 $/ha to complete all field work within specified data constraints 25 out of 28 years. For three of the 28 years no machinery set could be found to complete the field work within the specified data constraints. The inability to complete the field work for the 3 years out of 28 may be due to the 1 man labor supply, maximum tractor size of 201 PTOkW or maximum combine size of 8 rows (Section 2.3).

Analysis of crop rotation is made by inspecting machinery set cost for a single ranking and for the highest rank obtainable. A probability

Table 4.1. Operations Schedule for a C-NB-W-BT Farm[+]

Operation	Crop	Starting Date	Finishing Date	Field Work hrs/day
Harvest	Wheat	7/17[*]	8/06	8
Harvest	Navy beans	8/28	10/01	6
Fertilize	Wheat	8/28	10/08	12
Disk harrow	Wheat	8/28	10/08	12
Field cult.	Wheat	9/25	10/08	12
Plant	Wheat	9/25	10/08	12
Topping	Sugar beets	10/02	11/12	11
Lifting	Sugar beets	10/02	11/12	11
Harvest	Corn	10/09	11/12	10
Fertilize	Sugar beets	8/28	11/26	12
Plow	Sugar beets	8/28	11/26	12
Disk	Navy beans	10/09	11/26	12
Fertilize	Corn	9/25	11/26	12
Fertilize	Wheat	3/20	4/23	12
Spray	Wheat	5/01	5/07	12
Field cult. 1	Sugar beets	4/10	5/14	12
Field cult. 2	Sugar beets	4/10	5/14	12
Plant	Sugar beets	4/10	5/14	12
Spray	Sugar beets	4/10	5/14	12
Plow	Corn	9/25	5/14	12
Field cult. 1	Corn	4/24	5/14	12
Plant	Corn	4/24	5/14	12
Spray	Corn	4/24	5/14	12
Plow	Navy beans	10/09	6/18	12
Disk harrow	Navy beans	4/10	6/18	12
Field cult. 1	Navy beans	5/15	6/18	12
Field cult. 2	Navy beans	5/22	6/18	12
Plant	Navy beans	5/22	6/18	12
Cultivate	Sugar beets	5/22	6/18	12
NH3 applic.	Corn	5/29	6/18	12
Cultivate	Corn	5/29	6/18	12
NH3 applic.	Sugar beets	6/05	6/25	12
Cultivate	Sugar beets	6/12	7/02	12
Cultivate	Navy beans	6/19	7/09	12

[+]162 hectare, 1-operator

[*]Month/day

Table 4.2. Operations Schedule for a C-NB-NB-BT Farm[+]

Operation	Crop	Starting Date	Finishing Date	Field Work hrs/day
Harvest	Navy beans	8/28[*]	10/01	6
Topping	Sugar beets	9/25	11/12	11
Lifting	Sugar beets	9/25	11/12	11
Harvest	Corn	10/09	11/12	10
Fertilize	Sugar beets	8/28	11/26	12
Plow	Sugar beets	8/28	11/26	12
Disk	Navy beans 1	10/09	11/26	12
Fertilize	Corn	9/25	11/26	12
Field cult. 1	Sugar beets	4/10	5/14	12
Field cult. 2	Sugar beets	4/10	5/14	12
Plant	Sugar beets	4/10	5/14	12
Spray	Sugar beets	4/10	5/14	12
Plow	Corn	9/25	5/14	12
Field cult. 1	Corn	4/24	5/14	12
Plant	Corn	4/24	5/14	12
Spray	Corn	4/24	5/14	12
Plow	Navy beans 2	8/28	6/18	12
Disk harrow	Navy beans 2	4/10	6/18	12
Field cult. 1	Navy beans 2	5/15	6/18	12
Field cult. 2	Navy beans 2	5/22	6/18	12
Plant	Navy beans 2	5/22	6/18	12
Plow	Navy beans 1	10/09	6/18	12
Disk harrow	Navy beans 1	4/10	6/18	12
Field cult. 1	Navy beans 1	5/15	6/18	12
Field cult. 2	Navy beans 1	5/22	6/18	12
Plant	Navy beans 1	5/22	6/18	12
Cultivate	Sugar beets	5/22	6/18	12
NH3 applic.	Corn	5/29	6/18	12
Cultivate	Corn	5/29	6/18	12
NH3 applic.	Sugar beets	6/05	6/25	12
Cultivate	Sugar beets	6/12	7/02	12
Cultivate	Navy beans 1	6/19	7/09	12
Cultivate	Navy beans 2	6/19	7/09	12

[+]162 hectare, 1-operator

[*]Month/day

Table 4.3. Required Machinery Complement Cost for Twenty Eight Years of Available Workday Data**

Ranking+	Machinery complement cost, $/ha		
	C-NB	C-NB-W-BT	C-NB-NB-BT
28	*	*	*
27	*	*	*
26	*	*	319
25	248	*	282
24	241	*	277
23	219	326	243
22	216	299	232
21	215	284	231
20	214	264	231
19	205	257	229
18	192	252	228
17	187	251	220
16	184	251	216
15	184	236	198
14	170	227	197
13	166	218	197
12	164	207	196
11	164	206	196
10	164	205	196
9	164	201	195
8	164	190	184
7	162	190	184
6	150	190	184
5	150	190	184
4	150	190	184
3	150	190	184
2	150	190	184
1	150	190	184

+Ranking is based on cost per hectare
*Unable to select a machinery complement capable of completing all field operations within specified date constraints
**162 hectare, one-operator

of 0.69 corresponding to the 20th year out of 28 (20/28+1=0.69, Thom 1966) would require machinery sets with costs of 214, 264 and 231 $/ha for C-NB, C-NB-W-BT, and C-NB-NB-BT farms respectively.

Model performance using the Singh (1978) method of available time determination is compared to performance using actual data. Weekly means and standard deviations were calculated from the daily workday records. The means and standard deviations were combined over each field operation's scheduled calendar period. Using area under the normal curve and an 80 percent level (i.e., for 8 out of 10 years at least the calculated amount or more worktime occurs), the total time for each field operation was determined. Weekly available time is the ratio of weekly mean to total of means over the scheduled period.

Available hours were inputted to the machinery model. Cost per hectare for the selected machinery sets are given in Table 4.4 under the normal distribution heading. The table ranks the cost per hectare in terms of the Table 4.3 results using actual yearly data. Note the unequal nature of the rankings. Using the Singh (1978) method an equal 0.80 design probability level is assumed for each of the three farms. Comparison to Table 4.3 results show the design probabilities are actually 0.62, 0.52 and 0.59 for the C-NB, C-NB-W-BT, and C-NB-NB-BT farms respectively.

The normal distribution method of Singh (1978) overstates the design probability for the three example farms. Further, the normal distribution method misleads one to believe the three farms have an equal design probability when in reality these design probabilities vary. Using the normal distribution would bias results in favor of the

Table 4.4. Model Results for Assumed Available Workday Data Distributions and Probability Distributions*

Workday probability level	Farm size=162 hectares, one operator labor supply					
	C-NB		C-NB-W-BT		C-NB-NB-BT	
	$/ha	rank+	$/ha	rank+	$/ha	rank+
			Normal Distribution			
0.800	192	18	242	15	221	17
			Beta Distribution			
0.525	185	16	276	20	235	22
0.550	203	18	308	22	253	23
0.575	215	21	344	23	285	25
0.600	219	23	341	23	315	25

*Field operations for each crop are given in Tables 3.7, 4.1, 4.2.

+Rank is in relation to Table 4.3 results, No. out of 28.

C-NB-W-BT rotation since its machinery set costs ranking (actual design probability) indicates a performance rating lower than the C-NB or C-NB-NB-BT farms for the same normal curve parameters.

Because of the shortcomings associated with the normal distribution method a second probability distribution was tested. The weekly mean and standard deviations for workday data were fit to the beta distribution parameters k_1 and k_2 (Naylor et al., 1966). Areas under the beta curve were calculated using the MDBETI subroutine of the International Mathematical and Statistical Library (1979).

The 80 percent design level was sought. Specifying the 80 percent workday probability level for each week's data is more restrictive than specifying that level for an operation's scheduled period. The beta distribution technique was used in a trial and error setting to discover a beta percentage level for individual weeks which would develop an 80 percent design probability for the entire farm.

The selection of beta parameters first focused on harvest operations to be followed by tillage and planting operations. From inspection of the actual available harvest workday data, the minimum hours available 8 out of 10 years were selected (Table 4.5). An iterative search yielded the weekly beta parameters which recreate the actual data of Table 4.5.

After the weekly harvest time was found, non-harvest operation time availability was determined. Since non-harvest operations can occur over relatively long periods of time and since various non-harvest field operations compete for the same time, the procedure used for selection of harvest beta parameters is not applicable to finding non-harvest beta parameters.

Through trial and error four weekly beta percentages were selected to be presented in this section. The beta percentages are 52.5, 55.0, 57.5 and 60.0. A beta percentage of 55.0 denotes the value of the random variable which occurs or is exceeded 55 percent of the time.

It was desired to select the weekly beta percentage such that the chosen machinery set exhibited an 80 percent design probability. Failing the first test it was hoped that the design probability would be equal among example farms, when comparison was made to design probabilities generated by selection of machinery sets for each of the 28 years of available workday data.

The work time available for harvest was combined with each non-harvest available workday data set. The combined time set was

Table 4.5. Available Harvest Hours at 80 Percent Level**

Harvest Operation	Beginning Date	Ending Date	Work Hours Per Day	Total Hours in Period
Navy beans	8/28*	10/01	6.0	82.3
Soybeans	9/25	10/22	8.0	75.4
Wheat	7/14	8/06	8.0	61.7
Oats	7/24	8/13	7.0	60.0
Sugar beets	9/25	11/12	11.0	132.0
Corn	10/09	11/12	10.0	162.9
Alfalfa first	5/22+	6/11	9.0	88.7
Alfalfa second	7/10	7/23	9.0	54.0
Alfalfa third	8/21	9/03	9.0	61.8

*Month/day

+Usable hours during week 5/22 are reduced by one-half to approximate a starting date of 5/25.

**8 out of 10 years at least the listed harvest hours would occur, based upon the 28 year available workday data set developed in Section 3.2.

processed as input for the machinery model. Results appear in Table 4.4 under the beta distribution heading.

It is hypothesized that a beta percentage can be found to recreate any design probability. The 52.5 to 60.0 beta percentage range produced actual design probabilities of 0.55 to 0.79 for the C-NB farm. A beta percentage of 52.5 recreates the 55 percent design level for a C-NB farm. However, the 52.5 percent beta level does not produce equal design probabilities for all farms in Table 4.4.

Thus the beta distribution technique can be used, in all likelyhood, to find an 80 percent design probability for a particular farm. The beta percentages selected for a particular crop rotation could not be used to analyze other crop rotations, since the results in

Table 4.4 show unequal design probabilities between crop rotations for any given beta percentage level.

One final test of the beta and normal distribution methods was made. Since the beta and normal distribution methods could be used to find a particular design probability on a single given crop rotation, they were tested for the case where the field operation schedule was modified. Deletion of one operation was arbitrarily selected for the test.

The results shown for the three farms listed in Tables 3.7, 4.1, and 4.2 were adjusted by deleting fall disking. Model results for actual data use are given in Table 4.6, probability distributions are presented in Table 4.7.

The deletion of fall corn stalk disking lowered the machinery set cost associated with a given design probability Table 4.6 vs. Table 4.3. Focusing on the 0.69 design probability (rank=20), cost reductions were 48, 5, and 11 $/ha for the C-NB, C-NB-W-BT, and C-NB-NB-BT farms respectively. The reduction in cost is expected as the workload is reduced on the farm.

Inspection of Tables 4.7 and 4.4 show the model results for both normal and beta distribution methods to have changed. The beta distribution method utilizing a 52.5 percentage yielded a C-NB farm with a rank of 16. Deletion of fall disking changed the rank on the C-NB farm to 19 for the same 52.5 beta percentage. As in the previous discussion a given probability level generated unequal design probabilities between the example farms. Thus, work with statistically

Table 4.6. Required Machinery Complement Cost for Twenty Eight Years of Available Workday Data++

Ranking+	Machinery complement cost, $/ha		
	C-NB	C-NB-W-BT	C-NB-NB-BT
28	*	*	*
27	233	*	*
26	224	*	317
25	210	*	262
24	202	*	241
23	193	289	235
22	186	280	226
21	167	259	223
20	166	259	220
19	164	246	200
18	164	242	199
17	163	240	196
16	162	231	195
15	162	217	195
14	161	208	195
13	161	206	195
12	160	205	195
11	160	204	194
10	160	189	194
9	149	189	183
8	149	189	183
7	149	189	183
6	149	189	183
5	149	189	183
4	149	189	183
3	149	189	183
2	149	189	183
1	149	189	183

+Ranking is based on cost per hectare of each machinery complement.
*Unable to select a machinery complement capable of completing all field operations within specified date constraints.

++162 hectare, one-operator farm, and deletion of corn stalk disking operation.

Table 4.7. Model Results for Assumed Available Workday Data Distributions and Probability Distributions Under a Modified Operations Schedule*

Workday probability level	Farm size=162 hectare, one operator labor supply					
	C-NB		C-NB-W-BT		C-NB-NB-BT	
	$/ha	rank+	$/ha	rank+	$/ha	rank+
			Normal Distribution			
0.800	167	21	231	16	201	19
			Beta Distribution			
0.525	165	19	257	19	221	20
0.550	184	21	290	23	242	24
0.575	190	22	323	23	266	25
0.600	193	23	316	23	298	25

*Field operations are given in Tables 3.7, 4.1, 4.2, except fall disking of corn stalks is excluded.

+Rank is in relation to Table 4.6 results, No. out of 28.

grouped data was halted. Design probabilities are found by generating machinery sets for each year and selecting the appropriate set from the ranking.

In summary, design probabilities must be determined by using actual yearly data in the machinery model. Statistically grouped data, for normal and beta distributions, were unsatisfactory for use in design probability determinations. Comparison of machinery sets using statistically grouped data may lead to biased conclusions because machine set productivity may not be equal between complements.

5. RESULTS

Results for farm size, labor supply, and design probability are discussed. A sensitivity analysis of machinery cost and fuel use is provided. Results for net return to land, including crop receipts, operating costs, machinery and labor costs are also provided.

5.1 Net Returns to Land

Sixteen crop rotations are considered for analysis. For each rotation, 28 machinery complements corresponding to each year of workday data were developed. For illustrative purposes the machinery set with the 20th highest cost (0.69 design probability) was used in the comparison. Equally valid net return to land comparisons could be made for design probabilities other than 0.69. Labor supply was restricted to one full-time operator. Farm size was set at 162 hectares.

Machinery expenditure is only one aspect of the farm's total cost. The gross income, operating expenses, crop hauling and drying costs, and labor expenses must be known. Expected-yield relationships among crops for the Saginaw Valley region are shown in Table 5.1 (Christenson et al., 1980). Crop prices, seed, fertilizer, herbicides, insecticides, crop hauling and drying, and labor costs are obtained from Christenson et al. (1980). Crop prices are listed in Table 5.2.

Table 5.3 summarizes income and expenses for each farm. Substantial variations in net returns per hectare to land exist. The

Table 5.1. Expected Yields Under Alternate Rotations[+]

Sequence	Corn, kg/ha 1st	Corn, kg/ha 2nd	Corn, kg/ha 3rd	Soybeans, kg/ha	Navy Beans kg/ha 1st	Navy Beans kg/ha 2nd	Wheat kg/ha	Oats kg/ha	Sugar Beets Mg/ha	Alfalfa, Mg/ha Seeding	Alfalfa, Mg/ha 1st	Alfalfa, Mg/ha 2nd	Alfalfa, Mg/ha 3rd	Alfalfa, Mg/ha 4th
C-NB	7218				1457									
C-SB	7218			2354										
C-C-SB	7218	6904		2354										
C-NB-BT	6904				1345				47					
C-SB-BT	6904			2354					47					
C-NB-W-BT	6904				1569		4035		45					
C-SB-W-BT	6904			2354			3699		45					
C-NB-NB-BT	6904				1457	1233			45					
O/A-A-A-C-C-SB-C	7407	7218	7218*	2354				2869		2.2	10.3	9.9		
O/A-A-A-A-A-C-C-C	7407	7218	6904					2869		2.2	10.3	9.9	9.0	8.5
C-C-NB-W	6904	6904			1569		4035							
NB-C-SB	7218			2354	1345									
C-C-NB-BT	6904	6904			1569				47					
O/A-A-NB-BT					1793			2869	49	2.2	10.3			
O-NB-BT					1233			3587	45					
O/A-A-A-C-C-NB-C	7407	7218	7218*		1569			2869		2.2	10.3	9.9		

[+]Given fine-textured lake plain soils, adequate tile and surface drainage, and recommended cultural practices.

*Corn following navy beans or soybeans.

Table 5.2. Estimated Crop Prices

Crop	Price, $
Corn	0.09/kg
Navy beans	0.44/kg
Soybeans	0.23/kg
Sugar beets	25.90/Mg
Wheat	0.12/kg
Oats	0.10/kg
Alfalfa	60.63/Mg

Source: Christenson et al. (1980)

Table 5.3. Income-Expense Summary for 162 Hectare, 1-Operator Farm+

Crop Rotation	Gross Income	Seed, Fertilizer, Herbicides & Insecticides	Hauling & Drying	Family Labor***	Machinery Cost:++ Depreciation, Interest, Fuel, & Repairs	Returns to* Land
C-NB-NB-BT	741.32	136.30	53.99	80.31	230.85	239.87
C-NB-BT	810.51	143.07	81.50	80.31	272.04	233.59
C-NB-W-BT	738.85	136.28	61.41	80.31	263.83	197.02
O/A-A-NB-BT	778.38	147.89	58.71	80.31	297.74	193.73
C-C-NB-BT	788.27	149.10	84.56	80.31	292.40	181.89
NB-C-SB	593.05	127.90	36.72	80.31	179.92	168.20
C-SB-BT	793.21	127.31	80.93	80.31	338.11	166.55
C-NB	644.95	143.91	52.24	80.31	213.94	154.54
C-NB-BT	689.42	127.51	52.09	80.31	300.06	129.46
C-SB-W-BT	691.90	128.20	61.88	80.31	305.08**	117.05
C-SB	595.52	124.24	52.76	80.31	221.65	116.56
C-C-NB-W	605.41	144.58	51.50	80.31	236.08	92.94
O/A-A-A-C-C-NB-C	670.31	146.04	61.28	80.31	310.44	72.24
C-C-SB	605.41	138.58	69.19	80.31	256.54	60.79
O/A-A-A-C-C-SB-C	595.52	142.26	61.73	80.31	297.71	13.52
O/A-A-A-A-A-C-C-C	583.17	139.39	62.44	80.31	308.91	-7.88

+Interest on operating is included in each category; values reported as $/ha.

++Machine design probability is 0.69.

*Gross income minus nonland costs; property taxes are not deducted.

**Machine design probability is 0.55 since this was the highest level attainable for the given labor and farm size assumptions.

***One operator is paid at the rate of $13,000 per year.

O/A-A-A-A-C-C-C rotation produces a negative net return, -$7.88 per hectare. The C-NB-NB-BT rotation offers the highest net return at $239.87 per hectare. Of the top 10 rotations, 8 contain sugar beets. Forty percent of the Saginaw Valley farms surveyed in 1974 had continuously, either 3 years of navy beans or navy beans and beets (Christenson et al., 1980). The C-NB-NB-BT rotation, which fits this category provides the highest net return to land.

Rotations containing only navy beans, corn, soybeans, and wheat generally produced average net returns. Rotations containing more than 1 year of alfalfa were usually the poorest performers.

The net returns exhibit a $247.75 per hectare range between C-NB-NB-BT and O/A-A-A-A-C-C-C rotations. The gross return differences between the two farms account for $158.15. Hauling, drying, and input costs account for a difference of $11.54 in net returns; machinery expenditure account for another $78.06 of the net return difference.

When conducting a crop rotation analysis the reliability of the rotation must be addressed. The probability of a crop failure may be higher for navy beans than for soybeans. Weather influences not only the machinery complement required but also crop yield. The risk issues involved in determining the gross income and cost figures other than machinery cost are beyond the scope of this dissertation. The reader should consult Hoskin (1981) for further details on risk issues of crop rotations.

5.2 Crop Rotation Impact on Machinery Requirements ✓

A more detailed look at machinery costs for the 16 rotations follows. Machinery expenditures are ranked from highest to lowest in Table 5.4. The highest cost machinery set is for C-SB-BT farm at $338.11 per hectare. The high cost for the C-SB-BT farm is due partly to the fall harvest competition. All three crops must be harvested between September 25th and November 13th. The sugar beet ground must be plowed in the fall (Table 3.10) and plowing can not begin until soybeans are harvested.

The O/A-A-A-C-C-SB-C and C-C-NB-BT farms have similar machinery costs. The rotations involving alfalfa have relatively high machinery costs for several reasons. The mower-conditioner, rake, and baler are specialized equipment not needed for farms where alfalfa is not included in rotation. The alfalfa rotations need the special equipment plus combine, tillage and utility tractors, etc. Alfalfa harvest is in direct conflict with soybean and navy bean planting, cultivation, and ammonia application. With only one operator, large machinery is needed to accomplish the large work load that falls between May 22 to June 12 -- the scheduled time for alfalfa harvest.

Sugar beets also require specialized equipment, e.g. beet topper and lifter; therefore, their costs are relatively high. Sugar beet ground must be plowed in the fall and a large tractor may be needed for the task. The sugar beet lifter is a heavy draft implement and tends to require a large tractor.

The remaining machinery costs can be rationalized by the demand for time by field operations. The C-SB and C-NB farms differ in cost

Table 5.4. Summary of Machinery Complements at a 0.69 Design Probability[+]

Crop Rotation	Tillage Tractor PTOkW	Utility Tractor PTOkW	Combine, Rows	Sugar Beet Harvest Capacity, ha/hr	Extra Alfalfa Harvest Machine Sets Required[**]	Diesel Fuel L/ha	Machinery Cost[++] $/ha
C-SB-BT	137	104	8	0.71	0	87.7	338.11
O/A-A-A-C-C-NB-C	111	104	8	0.00	0	82.6	310.44
O/A-A-A-A-A-C-C-C	85	85	8	0.00	1	76.2	308.91
C-SB-W-BT	97	97	8	0.86	0	74.6	305.08*
O-NB-BT	156	104	2	0.40	0	94.2	300.06
O/A-A-NB-BT	99	99	2	0.40	1	92.7	297.74
O/A-A-A-C-C-SB-C	111	104	8	0.00	0	80.5	297.71
C-C-NB-BT	73	73	8	0.56	0	86.7	292.40
C-NB-BT	67	67	6	0.56	0	88.5	272.04
C-NB-W-BT	97	97	2	0.86	0	79.4	263.83
C-C-SB	98	98	8	0.00	0	76.9	256.54
C-C-NB-W	95	95	4	0.00	0	71.5	236.08
C-NB-NB-BT	74	74	2	0.40	0	89.5	230.85
C-SB	98	98	4	0.00	0	75.2	221.65
C-NB	68	68	4	0.00	0	81.1	213.94
NB-C-SB	49	49	4	0.00	0	76.7	179.92

[+]162 hectare, one-operator farm.

++Includes: depreciation, interest, fuel, and repairs.

*C-SB-W-BT farm is at a 0.55 design probability, since this was the highest level attainable for the given labor and farm size assumptions.

**Extra labor would be required to drive the tractor operating the extra alfalfa harvest machinery.

because the harvest date is earlier and the planting date is later for the navy beans on the C-NB farm. Harvest begins a month earlier for navy beans, thus bean harvest competition with corn is less and more time is available for fall tillage. The later planting date for navy beans increases the time for spring tillage.

Machinery costs for the NB-C-SB farm are less than for either C-SB or C-NB farms because of the advantage of the earlier harvest and later planting dates for navy beans, and in any week the required work is less, so the work load is more evenly distributed. On equal-sized farms less work is required during corn planting on the NB-C-SB farm than on a C-NB or C-SB farm because corn acreages are larger on those farms.

5.3 Labor Supply, Farm Size, and Design Probability Analysis

Labor supply, farm size, and design probability analyses are outlined in Tables 5.5 through 5.8. Three farm sizes (182, 283, and 404 hectare), three labor supplies (1.0, 1.5, and 2.0), and four design probability levels are studied. Design probability ranges between 0.48 and 0.79.

Table 5.5 gives results for the 0.79 design probability. A satisfactory machine set was selected for fewer than one-third of the farm size/labor supply combinations. While one could expect a machinery set for a one-operator, 162 hectare farm to be satisfactory for a two-man, 283 hectare farm, this is not always the case (Table 5.5). Often the extra labor may not be fully utilized because constraints exist on operation assignment to tractors.

Table 5.5. Selected Machinery Sets for a 0.79 Design Probability**

Crop Rotation	Farm Size								
	162			283			404		
	Labor Supply			Labor Supply			Labor Supply		
	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0
C-NB	219	181	170	*	*	*	*	*	*
C-C-SB	*	219	215	*	*	*	*	*	*
C-NB-W-BT	326	254	238	*	*	*	*	*	*
C-SB-W-BT	*	*	340	*	*	*	*	*	*
O/A-A-A-C-C-NB-C	*	273	268	*	*	*	*	*	*
C-C-NB-BT	318	254	248	*	*	*	*	*	*
NB-C-SB	195	169	163	181	160	155	*	*	*
C-C-NB-W	253	219	191	*	*	*	*	*	*
O/A-A-NB-BT	391	298	290	*	*	232	*	*	*
O/A-A-A-A-A-C-C-C	332	289	259	*	*	*	*	*	*
O-NB-BT	*	330	309	*	*	*	*	*	*
C-SB-BT	*	284	267	*	*	*	*	*	*
C-NB-NB-BT	243	203	199	*	180	165	*	*	*
O/A-A-A-C-C-SB-C	*	261	255	*	*	*	*	*	*
C-SB	223	202	202	*	*	*	*	*	*
C-NB-BT	287	238	230	*	*	215	*	*	*

*Unable to complete all field operations within specified date constraints.

**Machinery set cost is presented $/ha.

Table 5.6. Selected Machinery Sets for a 0.69 Design Probability**

	Farm Size								
	162			283			404		
	Labor Supply			Labor Supply			Labor Supply		
Crop Rotation	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0
C-NB	214	170	162	188	167	161	*	*	*
C-C-SB	257	211	203	*	*	*	*	*	*
C-NB-W-BT	264	218	202	*	217	187	*	*	*
C-SB-W-BT	*	332	291	*	*	*	*	*	*
O/A-A-A-C-C-NB-C	310	234	219	*	217	186	*	*	*
C-C-NB-BT	292	244	204	*	*	218	*	*	*
NB-C-SB	180	149	149	166	141	140	*	*	*
C-C-NB-W	236	176	176	*	183	183	*	*	*
O/A-A-NB-BT	298	232	232	267	218	213	*	*	*
O/A-A-A-A-A-C-C-C	309	233	229	*	*	286	*	*	*
O-NB-BT	300	245	245	*	*	*	*	*	*
C-SB-BT	338	257	224	*	*	206	*	*	*
C-NB-NB-BT	231	184	184	215	174	156	*	175	166
O/A-A-A-C-C-SB-C	298	221	202	*	204	179	*	*	*
C-SB	222	185	167	*	*	*	*	*	*
C-NB-BT	272	219	200	*	196	179	*	*	*

*Unable to complete all field operations within specified date constraints.

**Machinery set cost is presented $/ha.

Table 5.7. Selected Machinery Sets for a 0.59 Design Probability**

	Farm Size								
	162			283			404		
	Labor Supply			Labor Supply			Labor Supply		
Crop Rotation	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0
C-NB	187	165	150	174	147	142	*	*	150
C-O-SB	227	203	170	*	*	186	*	*	*
C-NB-W-BT	251	205	190	*	192	172	*	*	*
C-SB-W-BT	*	282	224	*	*	*	*	*	*
O/A-A-A-C-C-NB-C	259	218	200	*	200	176	*	*	*
C-C-NB-BT	279	220	200	*	214	193	*	*	*
NB-C-SB	164	149	149	154	140	128	*	134	126
C-C-NB-W	200	171	156	*	150	144	*	*	*
O/A-A-NB-BT	248	225	208	242	191	186	*	210	194
O/A-A-A-A-A-C-C-C	278	229	215	*	225	231	*	*	*
O-NB-BT	284	204	204	*	197	194	*	*	*
C-SB-BT	323	244	219	*	227	196	*	*	*
C-NB-NB-BT	220	184	184	195	159	151	*	154	147
O/A-A-A-C-C-SB-C	246	207	188	*	199	169	*	*	*
C-SB	211	167	157	*	177	163	*	*	*
C-NB-BT	256	200	185	*	182	176	*	*	161

*Unable to complete all field operations within specified date constraints.

**Machinery set cost is presented $/ha.

Table 5.8. Selected Machinery Sets for a 0.48 Design Probability**

	Farm Size								
	162			283			404		
	Labor Supply			Labor Supply			Labor Supply		
Crop Rotation	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0
C-NB	170	150	150	164	142	130	*	142	133
C-C-SB	218	176	167	*	186	154	*	*	*
C-NB-W-BT	227	190	190	211	166	152	*	*	162
C-SB-W-BT	283	206	186	*	197	192	*	*	*
O/A-A-A-C-C-NB-C	231	206	180	237	189	167	*	*	206
C-C-NB-BT	256	203	184	*	193	178	*	*	*
NB-C-SB	162	149	150	151	134	121	152	126	124
C-C-NB-W	179	156	156	176	143	124	*	*	*
O/A-A-NB-BT	236	208	208	223	179	171	*	184	176
O/A-A-A-A-A-C-C-C	255	199	182	274	220	202	*	*	*
O-NB-BT	250	201	187	214	188	192	*	*	162
C-SB-BT	298	230	196	*	222	184	*	*	*
C-NB-NB-BT	197	184	184	187	155	142	*	151	138
O/A-A-A-C-C-SB-C	223	194	168	237	181	160	*	*	*
C-SB	204	157	157	*	159	152	*	*	*
C-NB-BT	238	197	185	205	174	166	*	161	147

*Unable to complete all field operations within specified date constraints.

**Machinery set cost is presented $/ha.

Smaller tractor power levels than currently exhibited in 1.5 or 2.0 operator farms may result if the extra labor could be fully utilized each week. Smaller power units are associated with lower cost. However, the decreased cost would be somewhat offset by the multiple units of implements required to fully occupy the second laborer. Since the model cannot be used to analyze implement assignment to more than one power unit, this area was not investigated.

Results for the 0.69 design probability show a higher rate of satisfactory machinery complement selection than at the 0.79 level (Table 5.6). The 0.10 drop in design probability caused a $93.00 per hectare drop in machinery system cost for a 162 hectare, one-man O/A-A-NB-BT farm.

The results for the 162 hectare, one-man farm at 0.69 design probability are identical to those in Section 5.1. The additional labor supply results in a machinery cost per hectare reduction for the 162 hectare C-NB farm. Employing an additional half-time worker would reduce the machinery cost per hectare by $44.00. Adding a second half-time worker reduces machinery cost by only $8.00.

The $44.00 per hectare cost reduction translates to a total reduction of $7,128.00 for the farm. The extra labor could be paid up to $7,128.00 per year and the net returns to land would exceed that on a one-man farm. The labor-machinery trade-off at a 0.69 design probability ranged from a low of $31.00 per hectare for a 162 hectare NB-C-SB farm to $81.00 per hectare for a 162 hectare C-SB-BT farm. The cost reduction of $81.00 per hectare translates to a $13,122.00 total annual reduction for the farm or $122.00 more than that estimated for the family labor cost (see Table 5.3).

Other cost comparisons are possible using data from Table 5.6. The machinery set cost reduction for a move from a 162 hectare, one-operator to a 283 hectare, two-operator O/A-A-A-C-C-SB-C farm is $119.00 per hectare.

Tables 5.7 and 5.8 show results for the 0.59 and 0.48 design probability levels, respectively. Even at the 0.48 design probability, all of the work would not be completed on many of the 404 hectare farms. As design probability increases, so do machine costs (see Table 5.5 through 5.8). A 162 hectare, one-operator O/A-A-NB-BT rotation ranges from $236.00 to $391.00 per hectare for the 0.48 to 0.79 design probabilities, respectively. Similar ranges exist for the other 15 crop rotations. The cost of different design probabilities point out the flexibility a farmer has when investigating machinery vs. timeliness costs.

Looking at machinery set costs for different design probabilities allows one to see how costly a relative change would be from a machinery standpoint. If a decision is made that 69 percent of the years all field tasks should be completed within certain time periods, a quick check can be made to see what impact a 79 or 59 percent level might make.

The technique in reality is allowing the investigator to put a machinery cost figure alongside different risk levels of field work completion. For a more complete discussion of risk issues including yield and price issues the reader is referred to Hoskin (1981).

5.4 Sensitivity Analysis

Tables 5.9 through 5.12 list eight sensitivity tests under four design probabilities. For illustrative purposes and because the results are similar for all cases, the discussion will focus on the 0.69 design probability (Table 5.10).

Sensitivity analysis allows the farmer to investigate individual machinery system questions. Model output is studied for a single given change in input value or model parameter. The farmer, by looking at a single management option for his operation, can see the relative impact the alternative makes on the entire system.

The first test was to limit planter size to an 8-row maximum. The results of this test (run No. 2) show a system cost reduction for O/A-A-A-C-C-NB-C and a cost increase for C-C-NB-W, C-NB-W-BT, and C-SB-BT farms. Two factors, the reduced cost of the 8-row planter and the increased tillage capacity needed to offset the loss in planting capacity, are responsible for the cost differences.

The results indicate that the NB-C-SB farm machinery set described in run number 1 used an 8-row planter since its cost is exactly equal to the machinery set described in run number 2. For the cases where total cost decreased, the additional expense associated with the increased tillage capacity was more than offset by the reduced expense of the lowered planting capacity. Conversely for the cases where machinery set cost increased, the additional expense associated with increased tillage capacity was more than the reduction in expense due to reduced planting capacity.

Table 5.9. Sensitivity Analysis at a 0.79 Design Probability++

Crop Rotation	1+	2	3	4	5	6	7	8	9
C-NB-W-BT	326	322	299	289	328	334	*	*	247
O/A-A-A-C-C-NB-C	*	*	286	*	*	*	*	*	251
NB-C-SB	195	187	182	176	209	242	312	214	165
C-C-NB-W	253	282	236	225	297	*	*	*	207
C-SB-BT	*	*	340	375	*	*	*	*	308

+Description of model runs:

1 = Base run using input data of Chapter 3.
2 = Row planter width limited to 8-row maximum.
3 = Spring planting periods expanded by one week for each crop.
4 = No fall disking of corn stalks.
5 = One extra spring field cultivation for each crop.
6 = Two extra spring field cultivations for each crop.
7 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.970
8 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.975
9 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.985

*Unable to complete all field operations within specified date constraints.

++162 hectare, 1-operator farm, machinery set cost reported as $/ha.

Table 5.10. Sensitivity Analysis at a 0.69 Design Probability[++]

Crop Rotation	1[+]	2	3	4	5	6	7	8	9
C-NB-W-BT	264	266	259	259	286	307	*	*	218
O/A-A-A-C-C-NB-C	310	304	251	250	312	314	*	357	241
NB-C-SB	180	180	166	162	202	211	240	201	162
C-C-NB-W	236	239	221	209	256	282	*	282	190
C-SB-BT	338	340	333	314	351	373	*	*	291

[+]Description of model runs:

1 = Base run using input data of Chapter 3.
2 = Row planter width limited to 8-row maximum.
3 = Spring planting periods expanded by one week for each crop.
4 = No fall disking of corn stalks.
5 = One extra spring field cultivations for each crop.
6 = Two extra spring field cultivations for each crop.
7 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.970
8 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.975
9 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.985

*Unable to complete all field operations within specified date constraints.

[++]162 hectare, 1-operator farm, machinery set cost reported as $/ha.

Table 5.11. Sensitivity Analysis at a 0.59 Design Probability++

Crop Rotation	1+	2	3	4	5	6	7	8	9
C-NB-W-BT	251	255	218	240	265	288	*	306	207
O/A-A-A-C-C-NB-C	259	251	231	241	274	298	*	337	231
NB-C-SB	164	164	162	161	186	206	199	183	149
C-C-NB-W	200	193	189	178	227	267	*	255	172
C-SB-BT	323	321	318	302	331	343	*	*	268

+Description of model runs:

1 = Base run using input data of Chapter 3.
2 = Row planter width limited to 8-row maximum.
3 = Spring planting periods expanded by one week for each crop.
4 = No fall disking of corn stalks.
5 = One extra spring field cultivations for each crop.
6 = Two extra spring field cultivations for each crop.
7 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.970
8 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.975
9 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.985

*Unable to complete all field operations within specified date constraints.

++162 hectare, 1-operator farm, machinery set cost reported as $/ha.

Table 5.12. Sensitivity Analysis at a 0.48 Design Probability++

Crop Rotation	1+	2	3	4	5	6	7	8	9
C-NB-W-BT	227	227	206	208	249	265	*	284	201
O/A-A-A-C-C-NB-C	231	231	224	230	260	279	296	268	211
NB-C-SB	162	162	161	160	174	200	185	166	149
C-C-NB-W	179	179	170	168	209	225	280	228	168
C-SB-BT	298	303	273	285	319	328	*	338	259

+Description of model runs:

1 = Base run using input data of Chapter 3.
2 = Row planter width limited to 8-row maximum.
3 = Spring planting periods expanded by one week for each crop.
4 = No fall disking of corn stalks.
5 = One extra spring field cultivations for each crop.
6 = Two extra spring field cultivations for each crop.
7 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.970
8 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.975
9 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.985

*Unable to complete all field operations within specified date constraints.

++162 hectare, 1-operator farm, machinery set cost reported as \$/ha.

Model run No. 3 is for an extension of all spring planting dates by one week. Comparison to the base run shows a range in cost decreases from $5.00 per hectare for C-NB-W-BT to $59.00 per hectare for O/A-A-A-C-C-NB-C rotations.

The large cost decrease for the O/A-A-A-C-C-NB-C farm is due to the reduced competition between alfalfa harvest and navy bean planting. The expanded spring planting period had a relatively smaller impact on crop rotations whose planting is spread more uniformly throughout the year. One could expect the expanded spring planting periods to have a greater impact as farm size is increased.

For the O/A-A-A-C-C-NB-C rotation the cost of the yield reduction for the delayed planting on the whole farm must be less than $59.00 per hectare to make the expanded planting period profitable. Only the portion of the crop planted in the extra week would be included in the timeliness penalty. In reality a yield reduction greater than $59/hectare would be acceptable for the crop planted in the extra week since the portion of the crop planted within the original date constraints would have no relative yield reduction.

Fall disking of corn stalks is excluded in model run No. 4. Cost differences ranged from $5.00 to $60.00 per hectare for the C-NB-W-BT and O/A-A-A-C-C-NB-C rotations, respectively.

Three factors account for the cost decreases associated with the elimination of fall disking. Fewer field operations mean less tractor power is needed on the farm as a whole. Removal of a fall tillage operation allows more fall plowing to take place. As more plowing is accomplished in the fall, less tillage tractor power is needed since the workload is spread more evenly throughout the year. Finally, the elimination of fall disking could free up enough labor time such that a smaller combine, operated for a longer period, might be feasible. It is not known whether disking corn stalks will effect yields of the following crops. Using 46 centimeter plow bottoms or keeping a 40-centimeter plow adjusted such that fall disking is not required could return as much as $60.00 per hectare for the O/A-A-A-C-C-NB-C rotation.

One and two extra spring field cultivations for each crop are considered in model run No's. 5 and 6, respectively. The cost increase ranged from $2.00 per hectare for the O/A-A-A-C-C-NB-C farm to $22.00 per hectare for the C-NB-W-BT farm in run No. 5. Cost increases for two extra field cultivations ranged between $4.00 per hectare for the O/A-A-A-C-C-NB-C farm to $46.00 per hectare for the C-C-NB-W rotation.

Several items account for cost increases associated with extra field cultivations. The crop rotation in question plays a significant role. Wheat and alfalfa require no spring field cultivations. Crops with relatively early planting dates (i.e. corn, sugar beets, and oats) find less good weather per week for planting than crops with later planting dates (i.e. navy beans and soybeans). Finally, the ability to shift plowing to the fall is a factor. As tractor size is increased not only will the field cultivation capacity increase but the time available might also rise. The extra time would occur because the increased tractor size allowed more fall plowing, thus freeing up previously allocated time in the spring for field cultivation.

The results for model run No's. 7 through 9 are not applicable to the farmers case directly. The tests are designed to analyze different available workday data sets. The person putting the model into practice is cautioned to study the results to get a feel for the impact available workday data sets have on model performance.

The base run is for C_3 (Tulu moisture criterion) = 0.980. Cost reductions for the less restrictive C_3 value of 0.985 ranged from \$18.00 per hectare for NB-C-SB to \$69.00 per hectare for the O/A-A-A-C-C-NB-C rotation. At the more restrictive C_3 values of 0.970 and 0.975, cost increases ranged from \$21.00 to \$60.00 per hectare for NB-C-SB in tests 7 and 8. For the case of C_3 = 0.970 no satisfactory machinery set could be found on any farm except for the NB-C-SB rotation.

The results point out the care which must be taken when selecting the available workday data set. The requirement of available workday data validation is obvious after looking at the results.

5.5 Fuel Use

Diesel fuel usage is calculated for each selected machinery set (Table 5.14). Inspection of the C-C-NB-BT farm (Table 5.13) shows fuel use varies for each of the 23 selected machinery sets.

One could expect machinery sets in Table 5.13 to consume equal fuel amounts, since each accomplishes the same work. However, fuel use per hectare generally increases with tractor size. Minimum fuel use occurs with a tractor loading rate of 0.82 (Equation 2.2). As tractor size increases, loading rate decreases because of the speed constraints for many implements. When the loading rate moves away from 0.82, fuel efficiency decreases.

Table 5.13. Model Output for 28 Years of Available Workday Data on a C-C-NB-BT Farm+

Rank	Year	Cost $/ha	Large Tractor (PTOkW)	Small Tractor (PTOkW)	Combine Rows	Planter Rows	Beet Capacity ha/hr	Alfalfa Men (Extra)	Fuel Use L/ha
28	60-61++		Date Constraint Violated for Row Plant of Corn Two*						
27	67-68		Date Constraint Violated for Disking of Corn Two						
26	68-69		Date Constraint Violated for Field Cult. 1 of Corn Two						
25	70-71		Date Constraint Violated for Toping Beet of Sugar Beets						
24	72-73		Date Constraint Violated for Field Cult. 1 of Corn One						
23	65-66	318	138	104	4	12	0.94	0	88.1
22	73-74	317	175	104	2	12	0.40	0	94.3
21	71-72	299	129	104	4	12	0.40	0	93.1
20	62-63	292	74	74	8	12	0.56	0	86.7
19	52-53	290	136	104	2	12	0.40	0	93.3
18	61-62	285	87	87	6	12	0.56	0	88.0
17	53-54	279	112	104	4	12	0.40	0	92.6
16	57-58	266	95	95	4	12	0.40	0	91.1
15	51-52	262	81	81	4	12	0.71	0	86.4
14	64-65	256	81	81	4	12	0.40	0	89.3
13	74-75	250	73	73	4	12	0.40	0	88.3
12	69-70	250	97	97	2	12	0.40	0	91.3
11	59-60	245	84	84	2	12	0.56	0	87.6
10	55-56	240	87	87	2	12	0.40	0	90.0
9	66-67	220	60	60	4	8	0.40	0	86.7
8	58-59	220	59	59	4	8	0.40	0	86.6
7	54-55	213	63	63	2	8	0.56	0	85.9
6	75-76	201	61	61	2	8	0.40	0	86.9
5	50-51	201	60	60	2	8	0.40	0	86.7
4	63-64	200	59	59	2	8	0.40	0	86.6
3**	49-50	184	49	49	2	6	0.40	0	85.8

+162 hectare, 1-operator ++The actual crop year of fall 1960 to spring 1961

*Operation and crop causing date constraint violation.

**Results for rank numbers 1 and 2 (Years 56-57 and 76-77) equal rank number 3 values.

Table 5.14. Average Diesel Fuel Use of Field Operations+

Crop Rotation	Diesel Fuel Use, L/ha
C-NB-NB-BT	88.0
C-NB-BT	90.9
C-NB-W-BT	78.3
O/A-A-NB-BT	83.8
C-C-NB-BT	88.7
NB-C-SB	77.1
C-SB-BT	88.7
C-NB	80.8
O-NB-BT	87.7
C-SB-W-BT	77.1
C-SB	70.2
C-C-NB-W	70.2
O/A-A-A-C-C-NB-C	75.9
C-C-SB	76.4
O/A-A-A-C-C-SB-C	73.9
O/A-A-A-A-C-C-C	72.4

+162 hectare, 1-operator farms. Does not include transport.

To eliminate variability between individual machinery sets, fuel use was averaged over all satisfactory machinery sets for each rotation. Fuel consumption results are shown in Table 5.14. Rotations described in Table 5.14 are listed in the same order as the net returns to land analysis offered in Table 5.3.

It was noted previously that crop rotations with sugar beets have the highest net returns to land; they also use the most diesel fuel. Usage ranges between 70.2 liters and 90.9 liters for C-C-NB-W and C-NB-BT farms, respectively. The 20.7 liter difference is significant from a physical standpoint. The economic significance of this difference decreases when the cost of the 20.7 liters (20.7 liters X 0.20 $/liter = $4.14) is compared to the net returns differential of $140.65 per hectare between the two farms (Table 5.3).

Only diesel fuel usage is analyzed. Direct energy for fertilizer, crop transport, insecticides, herbicides, and crop drying is not included in the research study. A complete energy analysis would also require measures of indirect energy use for each rotation.

Fuel use sensitivity is investigated in Table 5.15. The same model runs are used as in Section 5.4. In general only slight variations occurred between runs. The major changes occurred when the amount of field work changed.

The most significant changes occurred for model run No's. 4 through 6. Run No. 4 (deletion of fall corn stalk disking) caused a slight reduction in fuel use. One or two extra field cultivations added enough work to make a noticeable difference in fuel use per hectare.

Table 5.15. Diesel Fuel Use Sensitivity Analysis*

Crop Rotation	1+	2	3	4	5	6	7	8	9
C-NB-W-BT	78.3	79.4	77.7	76.1	84.2	90.1	78.3	79.0	77.9
O/A-A-A-C-C-NB-C	75.9	76.2	79.2	71.9	81.8	88.4	77.0	77.3	75.1
NB-C-SB	77.0	77.1	76.9	74.7	84.0	91.1	77.4	77.0	76.9
C-C-NB-W	70.2	70.7	70.0	66.6	75.7	81.2	70.4	70.6	70.0
C-SB-BT	88.7	91.5	87.8	85.9	96.0	103.1	89.2	88.3	87.2

+Description of model runs:

1 = Base run using input data of Chapter 3.
2 = Row planter width limited to 8-row maximum.
3 = Spring planting periods expanded by one week for each crop.
4 = No fall disking of corn stalks.
5 = One extra spring field cultivations for each crop.
6 = Two extra spring field cultivations for each crop.
7 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.970
8 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.975
9 = Workday data generated for a C_3 (Tulu moisture criterion) = 0.985

*162 hectare, 1-operator farm, fuel use figures reported as L/ha.

For all other model runs the fuel use variations are due to the loading rate of the tractors as discussed previously in this section. The amount of field work accomplished for sensitivity tests 2,3,7,8, and 9 does not vary and thus the fuel use does not vary except due to the tractor loading rate influence.

6. SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

The following conclusions are made:

1) The machinery selection model is useful in a farm decision framework because:

    a) The model predicts the number and size of the machinery required for a given enterprise organization.

    b) The model provides an estimate of annual machinery cost.

    c) The model points out relative differences in management strategies. While an absolute answer from a model is always open to debate, the relative difference between management strategies is believed accurate.

    d) Model logic is simple; therefore, it has relatively more value in an interdisciplinary study. The straight forward logic is also easily understood by audiences unfamiliar with computer modeling.

    e) The model can easily be part of an experimental design. Alternative management strategies can be studied by operating the model for each alternative and analyzing the output.

    f) Tillage methods employed in the current model can be easily modified.

    g) Custom hire of non-harvest field operations can be simulated by excluding the operation in the input data list.

2) The results show:

a) Actual workday data use is superior to probabilistic workday data use. Probabilistic workday data cannot capture the correlations between calendar periods in a single year. Use of actual workday data does not pose a computing expense problem when only yearly summary statistics are printed in the output file.

b) Crop rotation has a significant impact on machinery complement requirements. The results show a $247.75 per hectare difference between the extreme machinery complement costs for C-NB-NB-BT and O/A-A-A-A-A-C-C-C farms (Table 5.3).

c) Crop rotation affects field machine fuel usage. The difference between the C-NB-BT and C-C-NB-W farms was 20.7 liters per hectare (Table 5.14). The fuel use figure, while being significant physically, accounts for only 3 percent of the net returns differential between the same rotation (fuel cost = 0.20 $/L, net returns differential = $140.65/ha (Table 5.3)). Field machinery fuel usage is generally highest in crop rotations containing sugar beets.

d) The number of tillage operations effects both fuel use and machinery complement size requirements. This result could easily be presented to farm operators in a farmer workshop setting. The addition of two extra spring field cultivations would necessitate their being worth $46.00 per hectare in increased yields for a 162 hectare, one-operator C-C-NB-W farm (Table 5.10).

e) Model results can be sensitive to specification of field operation date constraints. An expansion of spring planting period by one week decreased cost significantly. The increased planting periods reduced machinery cost $59.00 per hectare for a O/A-A-A-C-C-NB-C farm (Table 5.10).

f) The model results were sensitive to changes in available workday generator parameters. A $60.00 per hectare difference was found for the extreme workday data generator parameters on a NB-C-SB farm (Table 5.10). This result points out the necessity of collecting available workday data in the field for validation purposes.

3) The "backwards" approach to parameter validation (Chapter 3.1.1) is a quick and effective method.

4) The model and use of the "backwards" approach should be useful to check current data bases.

5) The model results should be helpful to farm operators. In particular the model addresses: machinery cost associated with design probabilities; choice of date constraints; impact of enterprise mix; and effect of tillage equipment and practice.

Research should proceed in the following areas:

1) Set up stations to check the workday generator parameters.

2) Include a crop transport, drying and storage component in the model.

3) Combine and four-wheel drive tractor selection parameters may need more study. Combine technology is dynamic; capacity rates may be different from those currently predicted. The literature points out a tractive efficiency advantage for four-wheel drive tractors; this may require incorporation into the present model.

4) The model should be modified to allow excess labor to do the same field work as the primary labor (i.e. both operators could row cultivate or disk at the same time). At present the fixed tractor assignment to operations could lower productivity by idling one tractor and laborer in multi-operator farms.

5) Using an experimental design procedure, an investigation should be made to determine the optimum planting and harvest periods. The effect and cost of timeliness could be a study itself.

6) The model should be expanded to include labor supplies greater than two operators. This change would involve use of multiple combines; tillage and utility tractors. The change would allow consideration of larger hectare production units.

7) The model, as part of a whole farm analysis, should be presented to farm operators in a workshop setting.

APPENDICES

APPENDIX A

FIELD MACHINERY SELECTION MODEL FORTRAN LISTING

APPENDIX A
FIELD MACHINERY SELECTION MODEL FORTRAN LISTING

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      PROGRAM FMSM(INPUT,OUTPUT,TAPE1)
C
C*****    FIELD MACHINERY SELECTION MODEL  MICH ST UNIV  E LANSING MI
C*****    WRITTEN BY FRANCIS J WOLAK  1980
C*****     DESCRIBED IN: DEVELOPMENT OF A FIELD MACHINERY SELECTION
C*****      MODEL, PHD THESIS 1980, MICHIGAN STATE UNIVERSITY
C
C*****     BASED UPON EARLIER WORK: SINGH 1980, FIELD MACHINERY SYSTEM
C*****      MODELING AND REQUIREMENTS FOR SELECTED MICHIGAN CASH CROP
C*****      PRODUCTION SYSTEMS, PHD THESIS, M.S.U., E.LANSING
C
C*****    COMMON BLK VARIABLE DESCRIPTIONS
C A        ALFALFA HARVEST AVAILABLE WORKDAY CATEGORY
C ACRE     ACRES OF OPERATION TO BE SCHEDULED
C ACRET    TOTAL ACRES OF OPERATION COMPLETED TO DATE
C ACREW    ACRES OF OPERATION COMPLETED IN WEEK I
C ALFYLD   AVERAGE ALFALFA YIELD (TONS/ACRE)
C AN       ALPHANUMERIC UNITS FOR MACHINE SIZE
C ANDRAFT  ALPHANUMERIC UNITS FOR MACHINE DRAFT
C ASSIGN   MATRIX ACCOUNTING FOR LAND PASSED FROM HARVEST TO NEXT CROP
C B        COMBINE HARVEST AVAILABLE WORKDAY CATEGORY
C BTCAP    HARVEST CAPACITY FOR SUGAR BEETS (ACRES/HR)
C C        CORN COMBINING, STALK CHOP, & FERT SPREAD AVAIL. WORKDAY CLASS
C CBEFF    COMBINE FIELD EFFICIENCY (DECIMAL)
C CBSPEED  COMBINE SPEED (MILES/HOUR)
C COSTPA   AVERAGE MACHINERY COMPLIMENT COST ($/ACRE)
C CROP1    ALPHANUMERIC NAME FOR EACH CROP IN ROTATION
C DRAFT    IMPLEMENT DRAFT (LB/FT, LB/ROW, TON/HR)
C EFC      EFFECTIVE FIELD CAPACITY (ACRES/HR)
C EFF      FIELD EFFICIENCY (DECIMAL)
C EPA      IMPLEMENT ENERGY REQUIREMENT (HP-HR/ACRE)
C FAST     MAXIMUM IMPLEMENT SPEED (MPH)
C FUELFRM  TOTAL DIESEL FUEL USE FOR FARM (GALLONS)
C FUELRT   DIESEL FUEL COST ($/GALLON)
C FUELTOT  SUM OF DIESEL FUEL COST ($/GALLON)
C HARVEST  IDENTIFICATION OF HARVEST FIELD OPERATION FOR EACH CROP
C HPINCT   TRACTOR HORSEPOWER SIZE INCREMENT (HP)
C HPMAXT   MAXIMUM TILLAGE TRACTOR HORSEPOWER
C HPTRACL  CHOSEN TILLAGE TRACTOR SIZE (HP)
C HPTRACS  CHOSEN UTILITY TRACTOR SIZE (HP)
C HRSDA    WORKDAY LENGTH (HRS)
C HSRT     HOUSING COST, DECIMAL FRACTION OF PURCHASE PRICE
C IALF     REQUIRED EXTRA ALFALFA HARVEST MACHINERY SETS
C ICMPLT   NUMBER OF COMPLETE MACHINERY SETS SELECTED FOR YEAR (0-2)
C ICROP    ARRAY CONTAINING CROP ASSIGNMENETS FOR EACH FIELD OPERATION
C IDATE    BEGINNING DATE OF EACH CALENDAR WEEK
C IEND     ENDING WEEK OF EACH USER INPUT FIELD OPERATION
C IEND2    SECOND ENDING DATE FOR OPERATION WHICH MUST STOP DURING WINTER
C IENDFY   ENDING DATE OF LAST OPERATION ON FARM
C IENDY    ENDING DATE OF OPERATIONS WITH YEAR INCLUDED (YEAR=1 OR 2)
C IFIRST   ARRAY CONTAINING FIRST FIELD OPERATION FOR EACH CROP
C IGROUP   CLASSIFICATION OF IMPEMENTS FOR COMPUTING PURPOSES
C IM       NUMBER OF SIZES OF EACH IMPLEMENT
C INSR     INSURANCE COST (DECIMAL FRACTION OF PURCHASE PRICE)
C IOPER    ARRAY CONTAINING FIELD OPERATION ASSIGNMENT OF INPUT DATA
C IQ       ARRAY OF FIELD OPERATIONS WHICH CAN BE SCHEDULED IN WEEK
C IQSUB    SUBSET OF IQ ARRAY, OPERATIONS WITH EQUAL PRIORITY
C IQUIT    FIELD OPERATION WHICH WASN'T COMPLETED FOR YEAR IN QUESTION
C IR       INTEREST RATE (DECIMAL)
C IROW     ROW PLANTER WIDTH (ROWS)
C ISIU     INDICATOR OF UNIT SYSTEM (0=ENGLISH, 1=SI METRIC)
C ISTART   BEGINNING DATE OF INPUT FIELD OPERATIONS
C ISTARTY  BEGINNING DATE OF FIRST FIELD OPERATION FOR FARM
C ITRACI   ASSIGNMENT OF FIELD OPERATION TO WORKDAY LENGTH CATEGORIES
C IZBEET   SUGAR BEET HARVESTING CAPACITY
C I7COMB   COMBINE SIZE (ROWS)
C KWEEK    FIRST WEEK FOR WHICH WORK CAN BE SCHEDULED (1-52)
C LESS     LAND AREA WHICH CAN BE SCHEDULED IN BEGINNING OF WEEK FOR CROP
C N        NUMBER OF FIELD OPERATIONS FOR FARM
C NF       PRINT CONTROL (INTERNAL)
C NFF      PRINT CONTROL (INTERNAL)
C NPRINT   PRINT CONTROL (USER SUPPLIED)
C OPER     ALPHANUMERIC OF IMPLEMENT NAMES
C OPERTN   ALPHANUMERIC OF FIELD OPERATION NAMES
C ORDER    MATRIX ASSIGING HARVESTED LAND TO 1ST OPERATION ON NEXT CROP
C PCTHRD   EXTRA LABOR SUPPLY (0.0 TO 1.0)
C PRICE    PRICE OF EACH IMPLEMENT SIZE ($/UNIT SIZE)
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C RA1      FIRST TEN CHARACTERS OF ROTATION NAME
C RA2      LAST 4 CHARACTERS OF ROTATION NAME (11 TO 14)
C RE       MACHINE RELIABILITY (DECIMAL)
C ROWCOM1  COMBINE SIZE (ROWS)
C RWD      ROW WIDTH (FT)
C SACRE    LAND AREA TO SCHEDULE FOR EACH FIELD OPERATION (ACRES)
C SIDRUNT  SI UNITS OF IMPLEMENT DRAFT
C SISIZE   SI UNITS OF IMPLEMENT SIZE
C SIZE     SIZE OF EACH IMPLEMENT (FT, ROWS, OR BOTTOMS)
C SL       SERVICE LIFE OF EACH MACHINE (HRS)
C SLOW     SLOWEST ALLOWABLE IMPLEMENT OPERATION SPEED (MPH)
C SPEED    OPERATING SPEED FOR EACH IMPLEMENT (MPH)
C T        TILLAGE, BEET HARVEST, AND PLANTING AVAILABLE WORKDAY CLASS
C TACRE    TOTAL LAND AREA OF FARM (ACRES)
C TE       TRACTIVE EFFICIENCY (DECIMAL)
C THOURS   TIME AVAILABLE IN EACH WEEK FOR EACH FIELD OPERATION (HRS)
C TOTRP    TOTAL REPAIRS OVER LIFE OF MACHINE (DECIMAL OF PURCHASE PRICE)
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     +ISTARTY,IEND2Y,IENDY(55)
      COMMON/BLK2/ HRSDA(11),RF(33),BTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITPAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK7/OPER(33),CROP1(30),AN(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,RWWD,DFR,TACRE
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK15/IR,TR,INSR,HSRT,FUELRT,LABORRT
      COMMON/BLK16/RA1,RA2
      COMMON/BLK17/IQUIT
      COMMON/BLK18/NPRINT,ISIU
      COMMON/BLK19/HPMAXT,HPENCT
      COMMON/BLK41/ORDER(7,14),ASSIGN(7,14)
      COMMON/BLK43/THOURS(52,55)
      COMMON/BLK50/KBEEP
      COMMON/BLK51/IOSUE(10),ACRET(55),LESS(55),ACREW(55),IG(20)
      COMMON/BLK52/FUELTOT(33),FUELFRM
      COMMON/BLK53/IFIRST(30),HARVEST(7)
      COMMON/BLK60/IZBEET,IZCOMB,ICPPLT,IALF,IROW
      COMMON/BLK61/COSTPA
      COMMON/BLK44/A(52,28),T(52,28),B(52,28),C(52,28)
      DIMENSION HPL(4),HPS(4),CMB(4),BTS(4),SYSCOST(4),ROW(4),
     +YRHPL(28),YRHPS(28),YRCMB(28),YRBTS(28),YRCST(28),YRROW(28)
     +,YRALF(28),YFUEL(28),TRFUL(4),IQT(4),IYKQT(28),IYRALF(4)
      DIMENSION SIACRT(55)
      DATA DISCON1,DISCON2/10H          ,10H1127T0-40*/
C*****   READ YEARLY WORKDAY DATA, YEAR STARTS JULY 10, SO 28 YEARS OUT
C*****     OF 29 YEARS DATA CAN BE USED
      READ(1,101)  ((T(I,J),J=1,28),I=1,27)
      READ(1,102)  ((T(I,J),J=1,28),I=28,52)
      READ(1,101)  ((B(I,J),J=1,28),I=1,27)
      READ(1,102)  ((B(I,J),J=1,28),I=28,52)
      READ(1,101)  ((A(I,J),J=1,28),I=1,27)
      READ(1,102)  ((A(I,J),J=1,28),I=28,52)
      READ(1,101)  ((C(I,J),J=1,28),I=1,27)
      READ(1,102)  ((C(I,J),J=1,28),I=28,52)
C*****   READ: 1)CROP ROTATION 2)FARM SIZE 3)ACRES OF EACH CROP
C*****     4)SOURCE OF LAND MATRIX
      READ 300,RA1,RA2
      READ 105,ISIU, TACRE
      IF(ISIU.EQ.1)TACRE=TACRE/0.4046856
      DO 134 I=1,21
  134 ACRE(I)=0.0
  135 READ 136,I,ACRE(I)
      IF(I.EQ.0)GO TO 146
      GO TO 135
  146 DO 258 IA=1,7
      DO 258 IB=1,14
  258 ORDER(IA,IB)=0.0
  133 READ 131,I,J,ORDER(I,J)
      IF(I.EQ.0)GO TO 132
      GO TO 133
C*****   CONVERT PERCENTAGES TO ACRES
  132 DO 56 IA=1,21
   56 ACRE(IA)=ACRE(IA)*TACRE
      DO 57 IA=1,7
      DO 57 IB=1,14
   57 ORDER(IA,IB)=ORDER(IA,IB)*TACRE
```

```
C*****    READ EXTRA LABOR AVAILABILITY (0,0.5,1) AND ALFALFA YIELD
      READ 104, PCTHRD,ALFYLD
      IF(ISIU.EQ.1)ALFYLD=ALFYLD/2.24170245
      N=0
C*****    READ OPERATION DATE CONSTRAINTS
      DO 10 IO=1,55
      READ 100, ISTART(IO),IEND(IO),IOPER(IO),ICROP(IO),IEND2(IO)
      IF(ISTART(IO) .EQ. 0) GO TO 11
      N=N+1
   10 CONTINUE
C*****    FIND FIRST OPERATION FOR EACH CROP
   11 DO 137 I=1,14
      DO 138 J=1,N
      IF(ICROP(J).EQ.I)GO TO 139
  138 CONTINUE
      IFIRST(I)=0.0 $ GO TO 137
  139 IFIRST(I)=J
  137 CONTINUE
      IALFCT=0
C*****    SPECIFY WHICH OPERATION NUMBERS(1-55) ARE HARVEST OPERATIONS
      DO 140 I=1,N
      IF(ICROP(I).EQ.13.AND.IOPER(I).EQ.17)IALFCT=IALFCT+1
      IF(ICROP(I).LE.12)GO TO 140
      IF(ICROP(I).EQ.15)HARVEST(1)=I
      IF(ICROP(I).EQ.16)HARVEST(2)=I
      IF(ICROP(I).EQ.17)HARVEST(3)=I
      IF(ICROP(I).EQ.18)HARVEST(4)=I
      IF(ICROP(I).EQ.19)HARVEST(5)=I
      IF(ICROP(I).EQ.20)HARVEST(6)=I
      IF(ICROP(I).EQ.13.AND.IALFCT.EQ.2.AND.IOPER(I).EQ.17)HARVEST(7)=I
  140 CONTINUE
      DO 141 I=1,N $ IC=ICROP(I)
  141 SACRE(I)=ACRE(IC)
      ISTARTY=410
C*****    FIND FIRST STARTING DATE FOR NEXT SPRING, SPECIFY 2ND END DATES
      DO 615 L=1,N
      ISTARTY=MIN0(ISTARTY,ISTART(L))
      IF(IEND2(L).GT.0)GO TO 615
      IEND2(L)=IEND(L)
  615 CONTINUE
      ISTARTY=20000+ISTARTY
C*****    FIND KWEEK (FIRST WEEK OF WORK 1-52)
      DO 614 L=1,52
      IF(IDATE(L).EQ.ISTART(1))GO TO 611
  614 CONTINUE
  611 KWEEK=L
C*****    CONVET MON-DAY DATE TO YR-MON-DAY DATE
      DO 612 L=1,N
      IF(IEND(L).GT.ISTART(1))GO TO 613
      IENDY(L)=20000+IEND(L) $ GO TO 612
  613 IENDY(L)=10000+IEND(L)
  612 CONTINUE
      IEND2Y=IENDY(N)
C*****    PRINT FARM DATA
      PRINT 204,RA1,RA2
      PRINT 202
      DO 122 IO=1,N
      IENDS=IEND(IO)-1
      DISCONT=DISCON1  $  IF(IEND(IO) .NE. IEND2(IO)) DISCONT=DISCON2
      IOPERA=IOPER(IO) $ LA=ICROP(IO)  $  K=ITRAC1(IOPERA)
  122 PRINT 203,IO,OPEPTN(IOPERA),CROP1(LA),ISTART(IO),IENDS,HRSDA(K),
     +DISCONT
      IF(ISIU.EQ.0)GO TO 60
      SITACRE=TACRE*0.4046856
      PRINT 61,PCTHRD,SITACRE
      GO TO 62
   60 PRINT 207,PCTHRD,TACRE
C*****    READ PRINT CONTROL VARIABLES
   62 READ 107,NPRINT,NFF,IBEGIN,IFINSH,ICMPLT,IZCOMP,IZREET,TRHP316
      LPSTRT=1 $ LPEND=28
      IF(NFF.EQ.0)GO TO 108
C*****    NFF SAYS SHORTER RUN THAN 28 YEARS
      LPSTRT=IBEGIN $ LPEND=IFINSH
  108 NYR=LPSTRT-1
C
C*****    YEARLY LOOP FOR MACHINE SELECTION  NYR IS THE COUNTER
  410 NYR=NYR+1 $ ITT=0 $ IF(NYR.GT.LPEND)GO TO 417
```

```
C*****    SELECTING A MACHINE SET  OR TESTING A SPECIAL CASE ?
      IF(NFF.LE.1)GO TO 109
      HPTRACL=TRHPBIG $ IALF=0 $ IROW=0 $ HPENCT=40. $ HPMAXT=270
      GO TO 110
  109 IZBEET=IZCOMB=ICMPLT=IALF=IROW=0
   20 HPTRACL=90.0 $ HPENCT=40.0 $ HPMAXT=270.0
C*****    CONSTRUCT THE THOURS MATRIX
  110 CALL TIME(ITT,NYR)
C*****    START SELECTION PROCESS
      CALL P.RSIZE
C*****    1)IF COMPLETE SCHEDULE
      IF(ICMPLT.GE.1) GO TO 21
C*****    NOT A COMPLETE SCHEDULE
C*****    INCREMENT SUGAR BEET HARVESTER OR COMBINE SIZES IF POSSIBLE
      IF(IZBEET.EQ.0)GO TO 22
      IF(IZBEET.LT.(IZCOMB/2))GO TO 23
   22 IZCOMB=IZCOMB+2 $ IF(IZCOMB.LE.8)GO TO 20
      IZCOMB=IZCOMB-2
      IF(IZBEET.EQ.0)GO TO 21
      IF(IZBEET.GE.5.AND.IZCOMB.GE.8)GO TO 21
   23 IZBEET=IZBEET+1 $ IF(IZBEET.LE.5)GO TO 20
      IF(IZCOMB.LE.6)GO TO 22
C*****    SELECT IMPLEMENT SIZES
   21 CALL SIZING
C*****    STORE MACHINE SET DATA IN TEMPORARY ARRAYS
      ITT=ITT+1
      HPL(ITT)=HPTRACL $ HPS(ITT)=HPTRACS $ CMB(ITT)=ROWCOM1
      BTS(ITT)=IZBEET $ SYSCOST(ITT)=COSTPA $ ROW(ITT)=IROW
      TRFUL(ITT)=FUELFRM/TACRE
      IQT(ITT)=IQJIT  $ IYRALF(ITT)=IALF
      IF(IZBEET.EQ.0)GO TO 47
      BTS(ITT)=BTCAP(BTS(ITT))/2.+BTCAP(BTS(ITT))/2.*PCTHPD
C*****    IF TWO SETS HAVE BEEN GENERATED CALCULATE LOWEST COST SET
   47 IF(ICMPLT.EQ.2)GO TO 27
C*****    USE BIGGER COMBINE AND FIND NEW MACHINERY SET
      IZCOMB=IZCOMB+2 $ IF(IZCOMB.LE.8)GO TO 20
   27 RMIN=999999999.0
C*****    FIND MIN COST
      DO 29 KK=1,ITT
   29 RMIN=AMIN1(RMIN,SYSCOST(KK))
C*****    WHICH SET IS THE MIN COST SET
      DO 30 KK=1,ITT
      IF(RMIN.GT.(SYSCOST(KK)+.1))GO TO 30
      IF(RMIN.LT.(SYSCOST(KK)-.1))GO TO 30
      GO TO 31
   30 CONTINUE
C*****    STORE MIN SET DATA IN YEARLY ARRAY
   31 YRHPL(NYR)=HPL(KK) $ YRHPS(NYR)=HPS(KK) $ YRCMB(NYR)=CMB(KK)
      YRBTS(NYR)=BTS(KK) $ YRCST(NYR)=SYSCOST(KK)
      YRALF(NYR)=IYRALF(KK) $ YRROW(NYR)=ROW(KK) $ YFUEL(NYR)=TRFUL(KK)
      IYRQT(NYR)=IQT(KK)
      IPT=0 $ N2=0 $ IPTCT=0
      IYEAR=48+NYR $ IY2=IYEAR+1
C*****    PRINT SUMMARY OF YEARLY DATA
      IF(ISIU.EQ.0)GO TO 70
      SICST=YRCST(NYR)/0.4046856 $ SITKW=YRHPL(NYR)*0.7456999
      SIUKW=YRHPS(NYR)*0.7456999 $ SIBT=YRBTS(NYR)*0.4046856
      SIFUEL=YFUEL(NYR)*3.785412
      PRINT 66,IYEAR,IY2,SICST,SITKW $ GO TO 71
   73 PRINT 67,SIUKW $ IF(IPT.EQ.0)GO TO 71
   74 PRINT 35,YRCMB(NYR) $ IF(IPT.EQ.0)GO TO 71
   75 PRINT 68,SIBT $ IF(IPT.EQ.0)GO TO 71
   76 PRINT 37,YRROW(NYR) $ IF(IPT.EQ.0)GO TO 71
   77 PRINT 38,YRALF(NYR) $ IF(IPT.EQ.0)GO TO 71
   78 PRINT 63,SIFUEL $ IF(IPT.EQ.0)GO TO 71
      GO TO 633
   70 PRINT 33,IYEAR,IY2,YRCST(NYR),YRHPL(NYR) $ GO TO 46
   50 PRINT 34,YRHPS(NYR) $ IF(IPT.EQ.0)GO TO 46
   51 PRINT 35,YRCMB(NYR) $ IF(IPT.EQ.0)GO TO 46
   52 PRINT 36,YRBTS(NYR) $ IF(IPT.EQ.0)GO TO 46
   53 PRINT 37,YRROW(NYR) $ IF(IPT.EQ.0)GO TO 46
   54 PRINT 38,YRALF(NYR) $ IF(IPT.EQ.0)GO TO 46
   55 PRINT 39,YFUEL(NYR) $ IF(IPT.EQ.0)GO TO 46
C*****    IS THIS A COMPLETE SCHEDULE
  633 DO 634 KK=1,M
      IF(ACRET(KK).LT.(SACRE(KK)-0.1))GO TO 637
  634 CONTINUE
```

```
C*****    GO TO BEGINNING OF YEARLY LOOP
      GO TO 410
  637 YRCST(NYR)=100000. $ GO TO 410
   46 N1=N2+1 $ N2=AMIN0((N1+7),N)
      IF(N2.EQ.N)IPT=1
      PRINT 45,(ACRET(IJ),IJ=N1,N2)
      IPTCT=IPTCT+1
      GO TO(50,51,52,53,54,55,633)IPTCT
   71 N1=N2+1   $   N2=AMIN0((N1+7),N)
      IF(N2.EQ.N)IPT=1
      DO 72 KLM=N1,N2
   72 SIACRT(KLM)=ACRET(KLM)*0.4046856
      PRINT 45,(SIACRT(IJ),IJ=N1,N2)
      IPTCT=IPTCT+1
      GO TO(73,74,75,76,77,78,633)IPTCT
C*****    PRINT YEARLY STATS IN HIGHEST TO LOWEST FASHION
  417 RLABOR=1.0*PCTHRU
      IF(ISIU.EQ.0)GO TO 80
      SIHCTR=TACRE*0.4046856
      PRINT 81,RLABOR,SIHCTR,RA1,RA2
      GO TO 83
   80 PRINT 660,RLABOR,TACRE,RA1,RA2
   83 DO 630 M=LPSTRT,LPEND
      BIG=YRCST(LPSTRT) $ ICNT=LPSTRT
      DO 635 L=LPSTRT,LPEND
      IF(YRCST(L).LE.BIG)GO TO 635
      BIG=YRCST(L) $ ICNT=L
  635 CONTINUE
      IYEAR=48+ICNT $ IY2=IYEAR+1 $ MPRT=29-M
      IF(BIG.GT.999)GO TO 631
      IF(ISIU.EQ.0)GO TO 82
C*****    SI UNIT OUTPUT
      SIBIG=BIG/0.4046856  $ SITT=YRHPL(ICNT)*0.7456999
      SIUT=YRHPS(ICNT)*0.7456999 $ SIBT=YRBTS(ICNT)*0.4046856
      SIFUEL=YFUEL(ICNT)*3.785412
      PRINT 636,MPRT,IYEAR,IY2,SIBIG,SITT,SIUT,YRCMB(ICNT),YRROW(ICNT),
     *SIBT,YRALF(ICNT),SIFUEL
      GO TO 630
C*****    ENGLISH UNIT OUTPUT
   82 PRINT 636,MPRT,IYEAR,IY2,BIG,YRHPL(ICNT),YRHPS(ICNT),YRCMB(ICNT),
     *YRROW(ICNT),YRBTS(ICNT),YRALF(ICNT),YFUEL(ICNT)
      GO TO 630
  631 IOP=IOPER(IYRCT(ICNT)) $ IOPC=ICROP(IYRAT(ICNT))
      PRINT 632,MPRT,IYEAR,IY2,OPERTN(IOP),CROP1(IOPC)
  630 YRCST(ICNT)=0.0
   33 FORMAT(*- YEAR=*,I3,*-*,I2,*   COST=*,F6.2,7H $/ACRE,*   TILLAGE*,
     ** TRACTOR=*,F17.2,* HP*)
   34 FORMAT(* *,36X,*UTILITY TRACTOR=*,F17.2,* HP*)
   35 FORMAT(* *,36X,*COMBINE SIZE=*,F20.2,* ROWS*)
   36 FORMAT(* *,36X,*BEET HARVEST CAPACITY=*,F11.2,8H ACRE/HR)
   37 FORMAT(* *,36X,*ROW PLANTER SIZE=*,F16.2,* ROWS*)
   38 FORMAT(* *,36X,*EXTRA ALFALFA MEN REQUIRED=*,F6.2,* DRIVERS*)
   39 FORMAT(* *,36X,*DIESEL FUEL USEAGE=*,F14.2,13H GALLONS/ACRE)
   45 FORMAT(* *,82X,8F6.0)
  660 FORMAT(*1*,29X,*RANKED MACHINERY SETS FOR A *,F5.1,*  OPERATOR  *,
     *F6.0,*  ACRE  *,
     *A10,A4,* FARM*//19X,*  RANK   YEAR   COST    LARGE    SMALL    COMBI
     *NE *
     *,*   PLANTER  BEET CAPACITY  ALFALFA MEN     FUEL USE*/33X,6HS/ACRE
     *,*   TRACTOR  TRACTOR   *,6H(ROWS),3X,6H(ROWS),3X,12H(ACRES/HOUR),
     *4X,7H(EXTRA),4X,14H(GALLONS/ACRE)/)
  636 FORMAT(* *,14X,I4,I4,*-*,I2,F8.2,F8.0,F9.0,F8.0,F9.0,F13.2,
     *F13.0,F15.2)
  632 FORMAT(* *,19X,I4,I4,*-*,I2,10X,*DATE CONSTRAINT VIOLATED FOR *,
     *A10,* OF *,A10)
  101 FORMAT(14X,14F8.4/8X,14F8.4)
  102 FORMAT(6X,15F8.4/8X,13F8.4)
  103 FORMAT(2I5)
  300 FORMAT(2A10)
  136 FORMAT(I2,F10.2)
  131 FORMAT(2I2,F10.2)
  202 FORMAT(18X,*OPERATION     OPERATION*,8X,*CROP*,10X,*STARTING*,7X,*
     1FINISHING      FIELD WORK    DISCONTINUE FOR*/20X,*NUMBER*,
     *40X,*DATE*,11X,*DATE*,8X,*HOURS/DAY*,5X,*THE PERIOD OF*/)
  203 FORMAT(22X,I2,6X,A10,5X,A10,8X,I4,11X,I4,11X,F4.1,8X,A10)
  109 FORMAT(2F10.2)
  107 FORMAT(7I3,F10.2)
```

```
207 FORMAT(*-*,23X,*PERCENTAGE OF EXTRA LABOR AVAILABLE PER WEEK*,
   *F7.2,15X,*TOTAL CROP ACRES=*,F6.1)
204 FORMAT(*1*,51X,*ROTATION=*,A10,A4//)
100 FORMAT(2I5,2I3,I5)
 61 FORMAT(*-*,20X,*PERCENTAGE OF EXTRA LABOR AVAILABLE PER WEEK*,
   *F7.2,15X,*TOTAL CROP HECTARES=*,F7.1)
 66 FORMAT(*- YEAR=*,I3,*-*,I2,*   COST=*,F6.2,7H $/HA  ,
   **   TILLAGE TRACTOR=*,F17.2,* KW*)
 67 FORMAT(* *,36X,*UTILITY TRACTOR=*,F17.2,* KW*)
 68 FORMAT(* *,36X,*BEET HARVEST CAPACITY=*,F11.2,11H HECTARE/HR)
 63 FORMAT(* *,36X,*DIESEL FUEL USEAGE=*,F14.2,15H LITERS/HECTARE)
 81 FORMAT(*1*,28X,*RANKED MACHINERY SETS FOR A *,F5.1,*  OPERATOR*,
   *F7.1,*  HECTARE *,A10,A4,* FARM*//19X,*  RANK  YEAR   COST    LARG
   *E    SMALL   COMBINE  PLANTER  BEET CAPACITY  ALFALFA MEN      *,
   **FUEL USE*/34X,*$/HA   TRACTOR  TRACTOR   (ROWS)    (ROWS)*,
   **      (HA/HR)         (EXTRA)        (LITER/HA)*/)
105 FORMAT(I1,F10.2)
    END
```

```
      SUBROUTINE TIME(ITT,NYR)
C
C*****    CONSTRUCTS THOURS ARRAY FROM WEEKLY DATA
C*****    WRITTEN BY F.J. NOLAN 1980
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     +ISTARTY,IEND2Y,IENDY(55)
      COMMON/BLK2/ HRSDA(11),RF(33),BTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK6/I,NF,NFF,RWJF,DPR,TACRE
      COMMON/BLK18/NPRINT,ISIU
      COMMON/BLK43/THOURS(52,55)
      COMMON/BLK44/A(52,28),T(52,28),B(52,28),C(52,28)
      DO 401 ID=1,52
      DO 401 IOP=1,N
C*****    ITC=USEABLE WORKDAY IDENTIFER (1-11)
      THOURS(ID,IOP)=0.0 $ ITC=ITRAC1(IOPER(IOP))
C*****    IF SUGAR BEET HARVEST IST=FIRST WEEK OF HARVEST
      IF(IOPER(IOP).EQ.8.AND.ISTART(IOP).EQ.IDATE(ID))IST=ID
C*****    IF OPERATION IS DISCONTINUED OVER WINTER
      IF(IEND2(IOP).NE.IEND(IOP))GO TO 402
C*****    IF OPERATION CANNOT BE SCHEDULED THIS WEEK
      IF(IDATE(ID).LT.ISTART(IOP).OR.IDATE(ID).GE.IEND(IOP))GO TO 401
C*****    1)IF TILLAGE GO TO 406   2)IF COMBINING GO TO 407
C*****     3)IF ALFALFA HARVEST GO TO 408
  404 IF(ITC.EQ.2.OR.ITC.EQ.11)GO TO 406
      IF(ITC.EQ.4.OR.ITC.EQ.5.OR.ITC.EQ.7.OR.ITC.EQ.10)GO TO 407
      IF(ITC.EQ.6)GO TO 408
C*****    COMBINE CORN, FERTILIZE, STALK CHOP
      THOURS(ID,IOP)=6.0*C(ID,NYR)*HRSDA(ITC) $ GO TO 401
  406 THOURS(ID,IOP)=6.0*T(ID,NYR)*HRSDA(ITC) $ GO TO 401
  407 THOURS(ID,IOP)=6.0*B(ID,NYR)*HRSDA(ITC) $ GO TO 401
  408 THOURS(ID,IOP)=6.0*A(ID,NYR)*HRSDA(ITC)
C*****    WEEK OF MAY 22 IS CUT ONE HALF FOR ALFALFA HARVEST TO
C*****     SIMULATE STARTING DATE OF MAY 25
      IF(ID.EQ.21)THOURS(ID,IOP)=THOURS(ID,IOP)/2.0 $ GO TO 401
C*****    FOR OPERATIONS STOPPED IN WINTER CHECK DATE CONSTRAINTS
  402 IF(IDATE(ID).GE.410.AND.IDATE(ID).LT.IEND(IOP))GO TO 404
      IF(IDATE(ID).GE.ISTART(IOP).AND.IDATE(ID).LT.IEND2(IOP))
     +GO TO 404
  401 CONTINUE
      IWHT=IBT1=IBT2=0
C*****    CHECK FOR WHEAT, BEET TOPPING, BEET LIFTING
      DO 766 KK=1,N
      IF(IOPER(KK).EQ.26)IWHT=KK
      IF(IOPER(KK).EQ.8)IBT1=KK
      IF(IOPER(KK).EQ.9)IBT2=KK
  766 CONTINUE
C*****    AVAILABLE BEET HOURS ARE HALVED TO GIVE MORE TIME TO
C*****     WHEAT PLANTING
      IF(IBT1.EQ.0)GO TO 767
      IF(IWHT.EQ.0)GO TO 767
      THOURS(IST,IBT1)=THOURS(IST,IBT2)=THOURS(IST,IBT1)/2.0
  767 CONTINUE
C*****    ADJUST SPRAYING HOURS TO REFLECT TIME AVAILABLE NEXT WEEK
C*****    SPRAYING HAS MORE HOURS BUT MUST WAIT FOR PLANTING THEREFORE
C*****    IT CAN USE ONLY THE LAST HALF OF WEEK I AND THE FIRST HALF
C*****    OF WEEK I+1
      DO 768 KK=1,N
C*****    IF NOT SPRAYING
      IF(IOPER(KK).NE.22)GO TO 768
      IF(KK.EQ.1)GO TO 768
C*****    IF PREVIOUS OPERATION WASN'T ROW PLANTING
      IF(IOPER(KK-1).NE.16)GO TO 768
C*****    SHR=SPRAY HRS/DAY  PHR=PLANTING HRS/DAY
      SHR=HRSDA(ITRAC1(IOPER(KK))) $ PHR=HRSDA(ITRAC1(IOPER(KK-1)))
C*****    LOOP TO ADJUST SPRAYING HOURS  1/2 OF WEEK J & 1/2 OF WEEK J+1
      DO 769 J=15,28
      IF(IDATE(J).LT.ISTART(KK).OR.IDATE(J).GE.IEND(KK))GO TO 769
      THOURS(J,KK)=(C(J,NYR)*SHR-T(J,NYR)*PHR)*6./2.0+
     +(C((J+1),NYR)*SHR-T((J+1),NYR)*PHR)*6./2.+T(J,NYR)*PHR*6.
  769 CONTINUE
  768 CONTINUE
C*****    1)IF 2ND OR HIGHER TRIP THRU LOOP 2)PRINT SAYS NO. SKIP OUT
      IF(ITT.GT.0)GO TO 44
      IF(NPRINT.LE.3)GO TO 44
C*****    PRINT THOURS ARRAY
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      PRINT 43
      PRINT 42,(IDATE(I),I=15,47)
      DO 40 J=1,N
   40 PRINT 41,J,(THOURS(I,J),I=15,47)
   44 CONTINUE
   42 FORMAT(/4X,33I4)
   41 FORMAT(I3,1X,33F4.0)
   43 FORMAT(*1*,51X,*HOURS AVAILABLE FOR ALL OPERATIONS*/)
      END
```

```
      SUBROUTINE PWRSIZE
C
C*****    SERVES AS THE CONTROLLER FOR SIZING OF COMBINE AND TRACTORS
C*****    WRITTEN BY D. SINGH  REWRITTEN BY F. J. WOLAK (1990)
C
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/N,NF,NFF,HJJD,DPR,TACRE
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK18/NPRINT,ISIU
      COMMON/BLK19/HPMAXT,HPENCT
      COMMON/BLK60/IZFEET,IZCOMB,ICMPLT,IALF,IROW
      DIMENSION IQ(55)
C*****    SET EFC TO 0.0
      DO 70 IO=1,N
   70 EFC(IO)=0.0
C
C*****    SELECT ALL HARVEST OPERATIONS EXCEPT ALFALFA HARVEST
C*****    IP=COUNTER FOR HARVEST OPERATIONS
C*****    IBT=THE BEET HARVEST FIELD OPERATION NUMBER 1 THRU N
C*****    IQ=ARRAY OF HARVEST FIELD OPERATONS
      IP=IBT=0
      DO 1 IO=1,N
C*****    1)IF BEET HARVEST  2)IF NOT A COMBINE OPERATION
      IF(IOPER(IO).EQ.9)IBT=IO
      IF(IOPER(IO) .LT.25 ) GO TO 1
      IP=IP+1  $  IQ(IP)=IO
    1 CONTINUE
C*****    PRINT INFO FOR HIGHEST OUTPUT LEVEL
      IF(NPRINT.LE.3)GO TO 110
      PRINT 302
C*****    START WITH A 2-ROW COMBINE
  110 ROWCOM1=2.0
C*****    IF THIS IS A SECOND RUN FOR YEAR OR SIZE IS USER SPECIFIED
      IF(IZCOMB.GT.0)ROWCOM1=IZCOMB
C*****    PRINT INFO FOR HIGHEST OUTPUT LEVEL ONLY
  411 IF(NPRINT.LE.3)GO TO 119
      PRINT 300,ROWCOM1
C*****    DETERMINE EFC OF COMBINE OPERATIONS
  119 CALL CAPCITY(IP,IQ,SMLHP,HPTRAC)
C*****    COMPARE TIME AVAILABLE, ACRES TO HARVEST &  EFC
      CALL CMBSCHD(IP,IQ,JC,IBT)
C*****    IS THE SCHEDULING JOB COMPLETE  JC=1 YES, JC=2 NO
      IF(JC.EQ.1) GO TO 4
C*****    JC=2 THUS MORE HARVEST CAPACITY IS NEEDED
C*****    8-ROW COMBINE IS LARGEST AVAILABLE
      IF(ROWCOM1.GE.8.)GO TO 4
C*****    INCREASE SIZE AND CALL SUBROUTINES AGAIN
      ROWCOM1=ROWCOM1+2.0 $ GO TO 411
    4 IZCOMB=ROWCOM1
C
C*****    SELECT OPERATIONS WHICH RELY ON TRACTOR POWER
C*****    PRINT CONTROL: NF=1 WEEKLY SCHEDULE IS PRINTED: NF=2 NO PRINT
C*****    NN=HORSEPOWER INCREMENT CONTROLLER
      IP=NF=NN=0
      DO 11 IO=1,N
      IF(IOPER(IO).GE.25) GO TO 11
      IP=IP+1  $  IQ(IP)=IO
   11 CONTINUE
      IF(NPRINT.LE.3)GO TO 112
      PRINT 303
C*****    DETERMINES HP-HR/ACRE OF EACH OPERATON
  112 CALL ENERGY
C*****    INITIALIZE TRACTOR SIZE AND INCREMENT
      HPTRAC=HPTRACL $ HPENC=HPENCT
C*****    SECOND TRACTOR IS CONSTRAINED TO 2-WHEEL DRIVE(WOLAK 1990)
   20 SMLHP=AMIN1(140.0,HPTRAC) $ GO TO 33
C*****    IF INSTRUCTED A WEEKLY SCHEDULE WILL BE PRINTED
   30 NF=NF+1 $ PRINT 2
C*****    FOR HIGHEST OUTPUT LEVEL PRINT INFO AFTER IF STATEMENT
   33 IF(NPRINT.LE.3)GO TO 401
      IF(ISIU.EQ.0)GO TO 60
      SITTKW=HPTRAC*0.7456999 $ SIUTKW=SMLHP*0.7456999
      PRINT 61,SITTKW,SIUTKW
      GO TO 401
   60 PRINT 304,HPTRAC,SMLHP
C*****    IF THIS IS A COMPLETE SIZING RUN
```

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  401 IF(NFF.LE.1)GO TO 400
C******   THIS RUN IS FOR A SPECIFIC MACHINERY SET, CHANGE INCREMENT
      NN=3
C******   PRINT WEEKLY SCHDEDULE FOR 2 HIGHEST OUTPUT LEVELS
      IF(NPRINT.LT.3)GO TO 400
      PRINT 2 $ NF=NF+1
C******   DETERMINE EFC OF TWO TRACTORS
  400 CALL CAPCITY(IP,IQ,SMLHP,HPTRAC)
C******   ALLOCATE TIME TO WORK GIVEN EFC, ALSO COMPUTE SCHEDULE OF WORK
      CALL WRKSCHD(JC)
C******   IF COMPLETE SCHEDULE
      IF(JC.EQ.1) GO TO 15
C******   IF TRACTOR SIZE IS ALREADY AT MAXIMUN SKIP OUT
      IF(HPTRAC.GE.(HPMAXT-0.01)) GO TO 21
C******   1)INCREMENT TRACTOR SIZE  2)MAXIMUN HP CONSTRAINT (WOLAK 1980)
      HPTRAC=HPTRAC+HPENC
      IF(HPTRAC.GT.HPMAXT)HPTRAC=HPMAXT
      GO TO 20
C
C******   INCREMENT IS LOWERED EACH TIME A COMPLETE SCHEDULE IS FOUND
C******    UNTIL TRACTOR SIZE IS LOWEST HP WHICH ACCOMPLISHES WORK
C******    INCREMENTS ARE 40,10 & 1 HP
C******   FOR EACH OVERSHOOT OF TRACTOR SIZE THE HP IS REDUCED AND
C******    INCREMENT IS RESET
   15 NN=NN+1  $  GO TO (16,17,18,19) NN
   16 HPTRAC=HPTRAC-30.  $  HPENC=10.  $  GO TO 20
   17 HPTRAC=HPTRAC-9.0 $ HPENC=1. $ GO TO 20
   18 IF(NPRINT.GE.5)GO TO 30
   19 CONTINUE
   21 CONTINUE
      HPTRACL=HPTRAC $ HPTRACS=SMLHP
C******   IF SCHEDULE IS A COMPLETE ONE
      IF(JC.EQ.1)ICMPLT=ICMPLT+1
      RETURN
    2 FORMAT(*1*,61X,*WORK SCHEDULE*)
  300 FORMAT(/59X,F4.0,* ROW COMBINE*)
  303 FORMAT(*-*,55X,*SELECTION OF TRACTOR SIZE*//)
  304 FORMAT(/32X,*TILLAGE TRACTOR HORSEPOWER= *,F4.0,10X,
     +*SECOND TRACTOR HORSEPOWER= *,F4.0)
  302 FORMAT(*1*,53X,*SELECTION OF COMBINE CAPACITY*//)
   61 FORMAT(/31X,*TILLAGE TRACTOR KILOWATT= *,F6.1,10X,
     +*SECOND TRACTOR KILOWATT= *,F6.1)
      END
```

```
      SUBROUTINE CAPCITY (M,IQ,SMLHP,HPTRAC)
C
C*****   DETERMINES EFC OF COMBINE AND DRAWN IMPLEMENT
C*****   READJUSTMENT OF PTOHP WILL OCCUR IF CONSTRAINTS ARE VIOLATED
C*****   WRITTEN BY D. SINGH  REWRITTEN BY F.J. WOLAK 1980
C
C*****   M=NUMBER OF FIELD OPERATIONS FOR WHICH EFC IS TO BE DETERMINED
C*****   IQ=ARRAY OF FIELD OPERATIONS TO CONSIDER IN THIS CALL
C*****   SMLHP=PTOHP OF UTILITY TRACTOR
C*****   HPTRAC=PTOHP OF TILLAGE TRACTOR
C*****   EFC=EFFECTIVE FIELD CAPACITY OF EACH OPERATION IN ACRES/HOUR
C*****   IROW=PLANTER SIZE, SERVES AS A DETERMINING FACTOR IN SIZING OF
C*****    CULTIVATOR, NH3 APPLICATOR  **CAUTION**  NH3 APPLICATOR CANNOT
C*****    BE USED BEFORE PLANTER SINCE IT'S SIZE IS A FUNCTION OF IROW
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     *ISTARTY,IEND2Y,IENDY(55)
      COMMON/BLK2/HRSDA(11),RE(33),BTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,8),
     1PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK7/OPER(33),CROP1(30),AF(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,RWD,DPR,TACRE
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK18/NPRINT,ISIJ
      COMMON/BLK21/CREFF(5,4),CRSPEED(5,4)
      COMMON/BLK60/IZELFT,IZCOMB,ICMPLT,IALF,IROW
      DIMENSION IQ(55)
      REAL MINB(33),MAXB(33)
C*****   LOOP FOR CURRENT ARRAY OF FIELD OPERATIONS
C*****   J=IMPLEMENT NUMBER 1 THRU 33
C*****   IO=FIELD OPERATION 1 THRU N
      EFM=0.0
   17 DO 16 L=1,M $ IO=IQ(L) $ J=IOPER(IO)
C*****   DEPENDING UPON IMPLEMENT FIND HP LEVEL AVAILABLE FOR OPERATION
      IF(J.GT.9.OR.J.EQ.8)PTOHP=SMLHP
      IF(J.LT.10.AND.J.NE.8)PTOHP=HPTRAC
C*****   1)IF IMPLEMENT IS A BEET HARVEST IMPLEMENT  2)IF IMPLEMENT IS A
C*****    COMBINE  3)IF IMPLEMENT IS A BALER
      IF(J.EQ.8.OR.J.EQ.9) GO TO 40
      IF(J.GE.25) GO TO 8
      IF(J.EQ.17)GO TO 41
C*****   ACRE/HOUR=PTOHP*FIELD EFFICIENCY/((HP-HR)/ACRE)
      EFC(IO)=PTOHP*RE(J)*EFF(J)/EPA(J)
C*****   IF IMPLEMENT IS A CULTIVATOR OR NH3 APPLICATOR
      IF(J.EQ.11.OR.J.EQ.13.OR.J.EQ.14) GO TO 30
C*****   FIND MAX AND MIN SIZE OF IMPLEMENT IN FEET
      GO TO (1,2,3,2,2,4,4)IGROUP(J)
    1 MAXB(J)=SIZE(J,IM(J))
      MINB(J)=SIZE(J,1)
      GO TO 4
    2 MAXB(J)=SIZE(J,IM(J))*RWD
      MINB(J)=SIZE(J,1)*RWD
      GO TO 4
    3 MAXB(J)=SIZE(J,IM(J))*16.0/12.0
      MINB(J)=SIZE(J,1)*16.0/12.0
    4 CONTINUE
C*****   IF SIZE AND SPEED CONSTRAINTS ARE MET GO TO 36
      EFCMAX=MAXB(J)*RE(J)*FAST(J)*EFF(J)/8.25
      EFC(IO)=AMIN1(EFC(IO),EFCMAX)
      EFCMIN=MINB(J)*RE(J)*SLOW(J)*EFF(J)/8.25
      IF(EFC(IO) .GE. EFCMIN) GO TO 36
C*****   TRACTOR HP IS TOO SMALL FOR SMALLEST IMPLEMENT AT SLOWEST SPEED
C*****   PRINT INFORMATION IF PRINT LEVEL IS 4 (HIGHEST OUTPUT LEVEL)
  100 IF(NPRINT.LE.3)GO TO 19
      IF(ISIJ.EQ.0)GO TO 60
      SIKW=PTOHP*0.7456999 $ SIWIDTH=MINB(J)*0.3048
      PRINT 61,SIKW,SIWIDTH,OPER(J)
      GO TO 19
   60 PRINT 400,PTOHP,MINB(J),OPER(J)
C*****   INCREMENT TRACTOR HP AND GO TO BEGINING OF THE LOOP
   19 TEMHP=EFCMIN*EPA(J)/(EFF(J)*RE(J))
      PTOHP=IFIX(TEMHP+1.0)
      SMLHP=HPTRAC=PTOHP
      GO TO 17
```

```
C
C*****    COMBINE SECTION  DETERMINE COMBINE SIZE (JX) AND CROP (JB)
        6 IF(ROWCOM1 .EQ. 2) JX=1
          IF(ROWCOM1 .EQ. 4) JX=2
          IF(ROWCOM1 .EQ. 6) JX=3
          IF(ROWCOM1 .EQ. 8) JX=4
          JB=J-24
C*****    JB: 1=CORN  2=WHEAT  3=SOYS  4=NAVIES  5=OATS
          EFC(IO)=SIZE(J,JX)*RE(J)*CBSPEED(JB,JX)*CBEFF(JB,JX)/8.25
C*****    NAVY BEAN CAPACITY  INDEPENDENT OF PLANTER SIZE,  WINDROW SIZE
C*****     IS ALTERED TO ARRIVE AT THE CAPACITY FOR 2 TO 8 ROW COMBINES
          IF(IOPER(IO).EQ.28)EFC(IO)=SIZE(J,JX)*RE(J)
          GO TO 16
C
C*****    PLANTER SIZE DEPENDENT SECTION
C*****    NH3 APPLICATOR AND CULTIVATOR ARE A FUNCTION OF PLANTER SIZE
C*****     AND MUST OBEY THE SPEED LIMITS SET IN BLKDATA
       30 EFCMAX=2.5*RE(J)*IROW*FAST(J)*EFF(J)/8.25
          EFC(IO)=AMIN1(EFC(IO),EFCMAX)
          EFCMIN=RWWD*RE(J)*IROW*SLOW(J)*EFF(J)/8.25
          IF(EFCMIN.GT.EFC(IO))GO TO 100
C*****     IF IMPLEMENT ISN'T A PLANTER
       36 IF(J.NE.16.AND.J.NE.10) GO TO 16
C
C*****    IROW DETERMINATION SECTION
C*****    RWSZ=A COMBINATION OF SPEED AND PLANTER SIZE IN ROWS
          RWSZ=EFC(IO)*8.25/(RE(J)*EFF(J)*RWWD)
C*****    DETERMINE WHICH PLANTER SIZE IS NEEDED TO SATISFY PLANTER EFC
          IBIG=IM(J)
          DO 32 IJ=1,IBIG
C*****    IF SUGAR BEETS ARE HARVESTED GREATER THAN 3.6 ACRES/HR
C*****     THEN A 4 ROW HARVESTER IS REQUIRED AND THUS A SIX ROW PLANTER
C*****     CAN'T BE USED ON FARM
          IF(EFB.GT.3.6.AND.SIZE(J,IJ).EQ.6)GO TO 32
C*****    IF CURRENT LOOP THRU SIZES IS OK GO TO 33
          IF((SIZE(J,IJ)*FAST(J)).GE.RWSZ) GO TO 33
       32 CONTINUE
C*****      PLANTER SIZE COULDN'T BE FOUND  STOP 1
          PRINT 5
          STOP
C*****    ACCOUNT FOR POSSIBLE ROUNDING ERROR
       33 IROW=SIZE(J,IJ)+0.1
          GO TO 16
C
C*****    SUGAR BEET HARVEST SECTION
C*****    CHECK THE HP REQUIRED TO PULL SUGAR BEET HARVEST EQUIPTMENT
       40 BTPTOHP=EFC(IO)*8.25*DRAFT(J)/(RE(J)*EFF(J)*.8*.96*TE(J)*375.
         **RWWD)
          EFB=EFC(IO)
C*****     IF REQUIRED HP IS LESS THAN AVAILABLE HP
          IF(BTPTOHP.LE.PTOHP) GO TO 16
C*****    READJUST HP, PRINT INFO IF HIGHEST OUTPUT LEVEL IS SPECIFIED
          PTOHP=IFIX(BTPTOHP+1.0)
          HPTRAC=SMLHP=PTOHP
          IF(NPRINT.LE.3)GO TO 17
          IF(ISIU.EQ.0)GO TO 62
          SIKW=PTOHP*0.7456999 $ SIEFC=EFC(IO)*0.4046856
          PRINT 63,SIKW,SIEFC
          GO TO 17
       62 PRINT 70,PTOHP,EFC(IO)
          GO TO 17
C
C*****    BALER SECTION
C*****    DETERMINE BALER EFC,  FIRST,SECOND,THIRD CUTTINGS ARE .5,.3,
C*****         .2 OF TOTAL YIELD RESPECTIVELY  BALER CAPACITY IS TON/HR
C*****          SIZE ARRAY CONTAINS CAPACITY  STRAW YIELD IS 1.5 TON/ACRE
       41 ID=ISTART(IO)/100
          IF(ID.EQ.5)TPA=ALFYLD*0.5
          IF(ID.EQ.7)TPA=ALFYLD*0.3
          IF(ID.GE.8)TPA=ALFYLD*0.2
          EFC(IO)=SIZE(17,1)*RE(J)/TPA
C*****       IF PREVIOUS OPER IS COMBINE THEN THIS IS STRAW BALE
          IF(IOPER(IO-1).GE.25)EFC(IO)=SIZE(17,1)*RE(J)/1.5
       16 CONTINUE
      400 FORMAT(42X,F6.2,* HP TRACTOR CANNOT PULL *,F6.2,2X,*FEET OF *,A10)
       70 FORMAT(38X,F6.2,* HP TRACTOR NEEDED TO PULL BEET EQPT AT EFC=*
         *,F10.3)
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    5 FORMAT(*  STOP 1  PLANTER SIZE AND CAPACITY MISMATCH*)
   61 FORMAT(42X,F6.1,* KW TRACTOR CANNOT PULL *,F6.2,2X,*METER OF *,A10
     *)
   63 FORMAT(38X,F6.1,* KW TRACTOR NEEDED TO PULL BEET EQPT AT EFC=*,
     *F10.3)
      END
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      SUBROUTINE CMBSCHD(M,IG,JC,IBT)
C
C*****   SELECTS COMBINE AND SUGAR BEET HARVEST CAPACITY
C*****   WRITTEN BY F.J. WOLAK  1980
C
C*****   COMBINE OPS ARE TAKEN IN ORDER SUPPLIED BY INPUT, CURRENT
C*****   COMBINE SIZE IS SCHEDULED IF A DATE CONSTRT IS VIOLATED A
C*****   RETURN TO PWRSIZE FOR LARGER SIZE COMBINE IS MADE.  BEET LIFTER
C*****   IS CHOSEN FOR THE GIVEN SIZE OF COMBINE.  TRADE OFFS OF COMBINE
C*****   AND BEET LIFTER SIZE ARE NOT MADE DIRECTLY IN THIS SUB.
C*****
C*****   HARVESB=THE PERCENTAGE OF WEEK REMAINING FOR COMBINE ACTIVITY
C*****   FBHR=THE HOURS PER WEEK USED FOR SOY AND NAVY BEAN HARVEST
C*****   REHR=REQUIRED HOUR TO COMPLETE AN OPERATION
C*****   BTACRE=TOTAL BEET ACRES COMPLETED TO DATE WITH CURRENT SIZE
C*****   CORN=HOURS LEFT FOR CORN COMBINING (LOWEST PRIORITY)
C*****   EFB=EFFECTIVE FIELD CAPACITY OF BEET HARVESTOR
C*****   WBTHR=HOURS AVAIL FOR BEET HARVEST (SECOND LOWEST PRIORITY)
C*****   IBT=OPERATION NUMBER OF BEET HARVESTING
C*****   CMB=ARRAY OF SCHEDULED WORK FOR HARVEST OPERATION AND WEEK
C*****   JC=COMPLETION RECORD, JC=1 WORK COMPLETED, JC=2 WORK NOT DONE
C*****   IG=ARRAY OF COMBINE HARVEST OPERATIONS ONLY
C*****   M=NUMBER OF OPERATIONS IN IG ARRAY
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     +ISTARTY,IEND2Y
      COMMON/BLK2/HRSDA(11),RE(33),BTCAP(5)
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK7/OPER(33),CROP1(30),AN(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK18/NPRINT,ISIU
      COMMON/BLK60/IZBEET,IZCOMB,ICMPLT,IALF,IROW
      COMMON/BLK43/THOURS(52,55)
      DIMENSION HARVESB(52),IG(55),CMB(52,55),FBHR(52)
      DO 1 I=1,52
      HARVESB(I)=1.0 $ FBHR(I)=0.0
      DO 1 J=1,55
    1 CMB(I,J)=0.0
C*****   N=COUNTER OF OPERATIONS IN IG ARRAY
      N=K=0
    2 N=N+1
C*****   IF ALL COMBINE OPERATIONS HAVE BEEN CONSIDERED LOOK FOR BEETS
      IF(N.GT.M) GO TO 30
C*****   IO=FIELD OPERATION 1 THRU N
C*****   REHR=REQUIRED TIME FOR FIELD OPERATION IO
      IO=IG(N) $ REHR=SACRE(IO)/EFC(IO)
C*****   DETERMINE STARTING DATE FOR OPERATION IO
      DO 4 I=26,52
      IF(ISTART(IO).EQ.IDATE(I)) GO TO 5
    4 CONTINUE
    7 I=I+1
C*****   IF DATE CONSTRAINT ISN'T VIOLATED, GO TO 11
    5 IF(ISTART(IO).LE.IDATE(I).AND.IDATE(I+1).LE.IEND(IO)) GO TO 11
C*****   DATE CONSTRAINT HAS BEEN VIOLATED, PRINT REMAINING ACRES
C*****     RETURN TO PWRSIZE
      IF(NPRINT.LE.3)GO TO 12
      ACRLFT=REHR*EFC(IO)
      IF(ISIU.EQ.0)GO TO 70
      SIACRLF=ACRLFT*0.4046856
      PRINT 71,OPER(IOPER(IO)),CROP1(ICROP(IO)),IDATE(I),SIACRLF
      GO TO 12
   70 PRINT 10,OPER(IOPER(IO)),CROP1(ICROP(IO)),IDATE(I),ACRLFT
   12 JC=2
      IF(ROWCOM1.GE.8.AND.IBT.EQ.0)GO TO 3
      IF(ROWCOM1.GE.8.AND.IBT.GT.0)GO TO 45
      RETURN
C*****   UPDATE REQUIRED HOURS
   11  REHR=REHR-THOURS(I,IO)*HARVESB(I)
C*****   IF MORE TIME IS NEEDED GO TO 6
      IF(REHR.GT.0.) GO TO 6
C*****   IF CORN & BEETS ARE IN ROTATION CMB CANNOT BE SET YET
      IF(IOPER(IO).EQ.25.AND.IBT.GT.0)GO TO 8
C*****   CALCULATE HOURS SPENT IN WEEK I FOR OPERATION IO
      CMB(I,IO)=THOURS(I,IO)*HARVESB(I)+REHR
C*****   HARVEST OPERATION HAS BEEN COMPLETED
C*****   CALCULATE FRACTION OF WEEK REMAINING & BEAN HARVEST FOR WEEK
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    8 HARVESB(I)=-REHR/THOURS(I,IO)
      IF(IOPER(IO).EQ.27.OR.IOPER(IO).EQ.28)FBHR(I)=FBHR(I)+CMB(I,IO)
      GO TO 2
C*****   HARVEST OPERATION ISN'T COMPLETED
C*****   IF CORN & BEETS ARE IN ROTATION CMP CANNOT BE SET YET
    6 IF(IOPER(IO).EQ.25.AND.IBT.GT.0)GO TO 40
C*****   ALLOCATE TIME TO RUNNING TOTALS AND GO TO NEXT WEEK
      CMB(I,IO)=THOURS(I,IO)*HARVESB(I)
      IF(IOPER(IO).EQ.27.OR.IOPER(IO).EQ.28)FBHR(I)=FBHR(I)+CMB(I,IO)
   40 HARVESB(I)=0.0 $ GO TO 7
C
C*****   SUGAR BEET SECTION
C*****   TRIES TO SELECT BEET HARVEST CAPACITY GIVEN ABOVE COMBINE
C*****   IF NO BEET IN ROTATION, SKIP OUT
   30 K=0 $ IF(IBT.EQ.0) GO TO 3
C*****   K=SIZE OF BEET HARVEST CAPACITY 1 THRU 5 IN ACRES/HOUR
C*****   ICN=CORN HARVEST FIELD OPERATION NUMBER
      ICN=0
      DO 39 KJ=1,M $ IO=IQ(KJ)
      IF(IOPER(IO).EQ.25)ICN=IO
   39 CONTINUE
C*****   INCREMENT BEET HARVEST CAPACITY
C*****   IF BEET HARVESTER IS USER SPECIFIED REDIFINE K
C*****   IBTDN=FLAG FOR COMPLETION OF BEET HARVEST
C*****   BTACRE=ACRES OF BEET HARVEST COMPLETED
C*****   CORN=HOURS AVAILABLE IN WEEK FOR CORN HARVEST
C*****   CNAR=ACRES OF CORN HARVESTED
      IF(IZBEET.GT.0)K=IZBEET-1
   31 K=K+1 $ IBTDN=0 $ BTACRE=0.0 $ CNAR=0.0  $ CORN=0.0
C*****   IF CAPACITY IS LESS OR EQUAL TO MAX CONTINUE
      IF(K.LE.5)GO TO 62
C*****   COULDN'T FINISH RETURN TO PWRSIZE
   45 JC=2 $ K=IZBEET=5
      IF(ROWCOM1.GE.8.AND.K.GE.5)GO TO 38
      RETURN
C*****   INITIALIZE VARIABLES FOR CURRENT HARVEST CAPACITY
   62 DO 32 II=26,52
      IF(IDATE(II+1).EQ.ISTART(IBT)) I=II
      HARVESB(II)=1.0
      CMB(II,IBT)=CMB(II,(IBT-1))=0.0
      IF(ICN.NE.0)CMB(II,ICN)=0.0
   32 CONTINUE
C*****   SET I TO FIRST WEEK
   37 I=I+1
C*****   IF BEET HARVEST IS COMPLETE
      IF(IBTDN.EQ.1) GO TO 34
C*****   AVAILABLE HOURS IS ADJUSTED FOR TIME SPENT COMBINING BEANS
      WBTHR=AMAX1((THOURS(I,IBT)-FBHR(I)),0.0)
C*****   BEET HARVEST IS TWO OPERATIONS (TOPPING&LIFTING) HOURS
C*****     AVAILABLE IS DIVIDED EQUALLY BETWEEN THE TWO, THUS A HARVEST
C*****     CAPACITY OF 4 ACRE/HR IS 4 ACRE/HR IN A TWO MAN FARM BUT ONLY
C*****     2 ACRE/HR IN A ONE MAN FARM SINCE AVAILABLE HOURS ON A 2 MAN
C*****     FARM IS ONE HALF THAT ON A 4 MAN FARM
      BTHR=WBTHR/2.0+WBTHR/2.0*PCTHRD
C*****   RUNNING TOTAL OF ACRES COMPLETED
      BTACRE=BTHR*BTCAP(K)*PL(4)+BTACRE
C*****   1)CHECK ACRE CONSTRAINT  2)ASSIGN HOURS TO TWO OPERATIONS
      IF(SACRE(IBT).LE.BTACRE) GO TO 35
C*****   BEET HARVEST IS TWO OPERATIONS, TOPPING AND LIFTING
      CMB(I,IBT)=CMB(I,(IBT-1))=BTHR
C*****   IF DATE CONSTRAINT GO TO A BIGGER SIZE OF HARVESTER
      IF(IDATE(I+1).EQ.IEND(IBT)) GO TO 31
C*****   IF CORN IS ABSENT OR FINISHED GO TO NEXT WEEK
      IF(ICN.EQ.0)GO TO 37
      IF(SACRE(ICN).LT.(CNAR+0.1))GO TO 37
C*****   IF CORN CANNOT BE SCHEDULED THIS WEEK, GO TO NEXT WEEK
   43 IF(IDATE(I).LT.ISTART(ICN).OR.IDATE(I).GE.IEND(ICN))
     +  GO TO 37
C*****   AVAILABLE CORN HARVEST HRS ARE ADJUSTED BY HRS ALREADY SPENT
      CORN=AMAX1((THOURS(I,ICN)-WBTHR-FBHR(I)),0.0)
C*****   RUNNING TOTAL OF CORN ACRES COMPLETED
      CNAR=CNAR+CORN*EFC(ICN)*HARVESB(I)
C*****   1)CHECK ACRES COMPLETED  2)ASSIGN HOURS THIS WEEK  3)IF DATE
C*****     CONSTRAINT A BIGGER HARVESTER IS NEEDED
      IF(SACRE(ICN).LE.CNAR) GO TO 51
      CMB(I,ICN)=CORN*HARVESB(I) $ HARVESB(I)=0.0
      IF(IDATE(I+1).EQ.IEND(ICN)) GO TO 31
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      GO TO 37
C*****    CORN CROP IS COMPLETED
C*****    1)CALCULATE THE HOURS LEFT IN WEEK  2)ADJUST ASSIGNED HOURS BY
C*****     THE HOURS LEFT
   51 HRLFT=(CNAR-SACRE(ICN))/EFC(ICN)
      CMB(I,ICN)=CORN*HARVES(I)-HRLFT
C*****    ADJUST HOURS REMAINING FRACTION
      HARVES3(I)=HRLFT/CORN
C*****    ARE BEETS FINISHED
      IF(IBTDN.EQ.0) GO TO 37
C*****    BEETS & CORN ARE FINISHED, SET BEET EFC, GO TO SUMMARY SECTION
   38 EFC(IBT)=EFC(IBT-1)=BTCAP(K)*RE(9)
      GO TO 3
C*****    SINCE BEETS ARE DONE, HRS=0.0, CHECK FOR CORN
   34 WBTHR=0.0 $ GO TO 36
C*****    FOLLOWING SECTION IS FOR COMPLETED BEET HARVEST
C*****    1)SET COMPLETION INDICATOR  2)ADJUST HOURS SPENT  3)ASSIGN HRS
C*****     4)ADJUST HOURS SPENT FOR EXTRA HELP
   35 IBTDN=1
      BTHR=BTHR-(BTACRE-SACRE(IBT))/(BTCAP(K)*RE(9))
      CMB(I,IBT)=CMB(I,(IBT-1))=BTHR
      WBTHR=BTHR/(.5+.5*PCTHRD)
C*****    IS CORN FINISHED
   36 IF(ICN.EQ.0)GO TO 38
      IF(SACRE(ICN).LT.(CNAR+0.1))GO TO 39
      GO TO 43
C*****    SUMMARY SECTION
C*****    ASSIGN TO THE HOURS ARRAY THE HARVEST HRS FOUND IN THIS SUB
    3 JC=1 $ IZBEET=4
      DO 60 I=26,32
      DO 65 JK=1,M $ IO=IO(JK)
   65 THOURS(I,IO)=CMB(I,IO)
      IF(IBT.EQ.0) GO TO 60
      THOURS(I,(IBT-1))=THOURS(I,IBT)=CMB(I,IBT)
   60 CONTINUE
   10 FORMAT(* *,23X,*NOT ABLE TO FINISH OPERATION = *,A10,
     +* FOR CROP = *,A10,* BY *,I5,* ACRES LEFT=*,F7.2)
   71 FORMAT(* *,22X,*NOT ABLE TO FINISH OPERATION = *,A10,
     +* FOR CROP = *,A10,* BY *,I5,* HECTARES LEFT=*,F7.2)
      RETURN
      END
```

```
      SUBROUTINE ENERGY
C
C*****     DEVELOPED BY DEVINDAR SINGH  1978
C
C*****     EPA=ENERGY REQUIRED PER ACRE  (HP-HR/ACRE)
C
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,8),
     1PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK8/N,NF,NFF,RWWD,DPR,TACRE
C*****     LOOP FOR TRACTOR POWERED OPERATIONS
C*****     CALCULATE EPA ACCOUNTING FOR DIFFERENT UNITS ON DRAFT
      DO 5 K=1,24
      GO TO (1,2,1,1,2,5,5)IGROUP(K)
    1 EPA(K)=DRAFT(K)*(43560.0/(33000.0*60.0))
      GO TO 10
    2 EPA(K)=DRAFT(K)*(43560.0/(33000.0*60.0))/RWWD
C*****     0.96 IS AXLE TO PTO POWER RATIO, 0.8 IS TRACTOR LOADING RATE
   10 EPA(K)=EPA(K)/(0.96*0.80*TE(K))
    5 CONTINUE
      RETURN
      END
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```
      SUBROUTINE WRKSCHD(JC)
C
C*****   DEVELOPS A WEEKLY SCHEDULE OF FIELD WORK
C*****   SERVES AS THE SIZING MECHANISM FOR TILLAGE TRACTORS
C*****   WRITTEN BY F.J. WOLAK 1980
C
C*****   JC=COMPLETION CHECK, JC=1 WORK DONE, JC=2 UNFINISHED SCHEDULE
C*****   ALLOCATES TIME AMONG OPERATIONS, TRACTORS, COMBINES, AND MEN
C*****   POWER UNITS COMPETE FOR LABOR, LABOR IS CONSTRAINED BY NUMBER
C*****    OF MEN AVAILABLE AND TIME AVAILABLE FOR PARTICULAR OPERATION
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     *ISTARTY,IEND2Y,IENDY(55)
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK7/OPER(33),CROF1(30),AN(33),ADRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,RWD,DPR,TACRE
      COMMON/BLK17/IQUIT
      COMMON/BLK18/NPRINT,ISIJ
      COMMON/BLK41/CRDER(7,14),ASSIGN(7,14)
      COMMON/BLK43/THOURS(52,55)
      COMMON/BLK50/KWEEK
      COMMON/BLK51/IGSUB(10),ACRET(55),LESS(55),ACREW(55),IQ(20)
      COMMON/BLK53/IFIRST(30),HARVEST(7)
      COMMON/BLK60/IZFLET,IZCOMB,ICMPLT,IALF,IROW
      DIMENSION IDATEY(53),FLAG(20)
      INTEGER FLAG
      REAL LESS,MAYASGN
C*****   KWEEK=FIRST WEEK OF WORK
C*****   ACRET=TOTAL ACRES OF EACH FIELD OPERATION ALREADY SCHEDULED
      DO 8 JI=1,N
    8 ACRET(JI)=0.0
      DO 65 IA=1,7
      DO 65 IB=1,14
   65 ASSIGN(IA,IB)=0.0
      I=KWEEK-1 $ IAF=0 $ IYEAR=1
C*****   I=COUNTER FOR WEEK
    2 I=I+1
      IF(I.LE.52) GO TO 3
      I=1 $ IYEAR=2
    3 IDATEY(I)=IYEAR*10000+IDATE(I)
      IDATEY(I+1)=IYEAR*10000+IDATE(I+1)
C*****   ISTARTY=FIRST OP, IEND2Y=LAST OP, CHECK WEEKLY BOUNDARY
      IF(IDATEY(I).GE.11127.AND.IDATEY(I).LT.ISTARTY)GO TO 2
      IF(IDATEY(I+1).GT.IEND2Y) GO TO 4
C*****   BIGTM=TIME ALLOCATED TO TILLAGE TRACTOR
C*****   SMLTM=TIME ALLOCATED TO UTILITY TRACTOR
C*****   SMTR1=UTILITY TRACTOR TIME FOR WHICH NO OTHER UNIT CAN USE
C*****   COBHR=TIME ALLOCATED TO COMBINE OPERATION
C*****   TRMAX=MAXIMUM SCHEDULEABLE TIME FOR ANY ONE TRACTOR
C*****   RMAX=REMAINING UNSCHEDULED TIME IN WEEK
C*****   WMAX=MAXIMUM TIME WHICH CAN BE SCHEDULED
C*****   ACREW=ACRES SCHEDULED IN CURRENT WEEK
C*****   LESS=ACRES WHICH CAN BE SCHEDULED AT BEGINNING OF WEEK
      BIGTM=SMLTM=SMTR1=COBHR=TRMAX=RMAX=WMAX=0.0
      DO 5 JI=1,N
    5 ACREW(JI)=LESS(JI)=0.0
C*****   IQ=ARRAY OF OPERATION WHICH CAN BE DONE IN WEEK I
      L=0
      DO 6 IO=1,N
      IF(THOURS(I,IO).LE.0.0) GO TO 6
      L=L+1 $ IQ(L)=IO
    6 CONTINUE
      IF(L.EQ.0) GO TO 20
C
C*****   COMBINE AND BEET HARVEST SECTION
C*****   THESE OPERATIONS HAVE ALREADY BEEN SIZED THEY ARE NOW SCHEDULED
C*****    SO THAT HOURS AVAILABLE FOR TRACTOR DRIVING IS CORRECT
C*****    THEY ARE THE HIGHEST PRIORITY OPERATIONS IN THE WEEK
      DO 90 K=1,L $ IO=IQ(K)
      IF(IOPER(IO).EQ.8.OR.IOPER(IO).EQ.9) GO TO 70
      IF(IOPER(IO).LT.25) GO TO 90
   70 ACREW(IO)=THOURS(I,IO)*EFC(IO)
      IF(IOPER(IO).GE.25)COBHR=COBHR+ACREW(IO)/EFC(IO)
      IF(IOPER(IO).EQ.9)BIGTM=BIGTM+ACREW(IO)/EFC(IO)
      IF(IOPER(IO).EQ.8)SMLTM=SMLTM+ACREW(IO)/EFC(IO)
   90 CONTINUE
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C*****    FLAG=INDICATION OF ATTEMPT TO SCHEDULE OPERATION ALREADY
      DO 9 JI=1,L
    9 FLAG(JI)=0
C*****    TOTHRS=HOURS ALREADY ALLOCATED IN WEEK
      ICOUNT=0
   30 TOTHRS=BIGTM+SMLTM+COBHR
C*****    ACCOUNT FOR HARVESTED ACRES USED BY FIRST OPER OF NEXT CROP
C*****    IF FIRST TRIP THRU LOOP SKIP OUT
      IF(ICOUNT.EQ.0)GO TO 53
      IO=IQSUB(1)
      IC=ICROP(IO)
C*****    IF FIRST OPER FOR CROP IC ISN'T IO SKIP OUT
      IF(IFIRST(IC).NE.IO)GO TO 53
      ALEFT=ACREW(IO)
C*****    DO LOOP FOR SEVEN HARVEST OPERATIONS
      DO 51 K=1,7
      IF(ORDER(K,IC).LE.0.0)GO TO 51
C*****    DO LOOP FOR FOURTEEN CROPS
      DO 52 M=1,14
      IF(M.EQ.IC)GO TO 52
C*****    IF CROP K GROUND IS PASSED TO MORE THAN ONE OTHER CROP
      IF(ORDER(K,M).GT.0.0)GO TO 51
   52 CONTINUE
C*****    MAX=THE MIN OF ACRES TO SCHEDULE OR THOSE AVAILABLE
      MAXASGN=AMIN1(ALEFT,(ACRET(HARVEST(K))+ACREW(HARVEST(K))-
     +ASSIGN(K,IC)))
      ALEFT=ALEFT-MAXASGN
      ASSIGN(K,IC)=ASSIGN(K,IC)+MAXASGN
      IF(ALEFT.LE.0.01)GO TO 53
   51 CONTINUE
C*****    THE FIRST OPERATION COMPETES WITH OTHERS FOR HARVESTED LAND
      DO 54 K=1,7
      IF(ORDER(K,IC).LE.0.0)GO TO 54
C*****    MAX ACRES HARVESTED
      HARAVL=ACRET(HARVEST(K))+ACREW(HARVEST(K))
C*****    ACCOUNT FOR ACRES ALL READY USED
      DO 55 M=1,14
   55 HARAVL=HARAVL-ASSIGN(K,M)
C*****    MAX=MIN(ACRES TO SCHED, HARVESTED, AVAILABLE-ASSIGNED)
      MAXASGN=AMIN1(ALEFT,HARAVL,(ORDER(K,IC)-ASSIGN(K,IC)))
      ASSIGN(K,IC)=ASSIGN(K,IC)+MAXASGN
      ALEFT=ALEFT-MAXASGN
      IF(ALEFT.LT.0.01)GO TO 53
   54 CONTINUE
C*****    DO LOOP TO DETERMINE PRIORITY OF OPERS AND START SCHEDULING
   53 DO 10 JI=1,L $ IO=IQ(JI)
C*****    IF CROP ACRES ARE LESS OR EQUAL TO SCHEDULED ACRES
      IF(SACRE(IO).LT.(ACRET(IO)+ACREW(IO)+.01))GO TO 10
C*****    1)IF OPERATION IS COMBINE  2)IF OPERATION IS BEET HARVEST
      IF(IOPER(IO).GE.25) GO TO 10
      IF(IOPER(IO).EQ.8.OR.IOPER(IO).EQ.9)GO TO 10
C*****    HAVE WE ALREADY CONSIDERED THIS OPERATION
      IF(FLAG(JI).EQ.1) GO TO 10
C*****    ARE HOURS AVAILABLE FOR OPER GREATER THAN THOSE ALREADY USED
      IF((THOURS(1,IO)+THOURS(I,IO)*PCTHPD).GT.TOTHRS)GO TO 11
   10 CONTINUE
C
C*****    END OF WEEK
C*****    CHECK COMPLETNESS OF SCHEDULE, PRINT INFO IF REQUESTED
C*****    ADD THE TIME FOR WHICH ONLY SMALL TRACTOR COULD OPERATE
      SMLTM=SMLTM+SMTR1
C*****    SKIP PRINTING AS INSTRUCTED BY PWRSIZE SUBROUTINE
      IF(NF.EQ.0) GO TO 80
      PRINT 12,IDATE(I),COBHR,BIGTM,SMLTM
C*****    LOOP FOR SUMMARY, CHECKS FOR ENDING DATE CONSTRAINTS, PRINTS
   80 IPRT=0
      IF(NF.EQ.0) IPRT=1
      DO 13 JI=1,L $ IO=IQ(JI) $ IOP=IOPER(IO) $ ICP=ICROP(IO)
      IF(ACREW(IO).LE.0.0) GO TO 13
C*****    PRINT HEADER ONLY ONCE IF PRINT IS CALLED FOR
      IF(IPRT.EQ.0.AND.ISIU.EQ.0)PRINT 102
      IF(IPRT.EQ.0.AND.ISIU.EQ.1)PRINT 125
      IPRT=1
C*****    RUNNING TOTAL OF ACRES SCHEDULED
      ACRET(IO)=ACRET(IO)+ACREW(IO)
C*****    1)IS MORE TIME AVAILABLE FOR OPERTATION  2)ARE ALL ACRES DONE
      IF(IDATE(I+1).NE.IEND(IO)) GO TO 1000
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      IF(ACRET(IO).GE.(SACRE(IO)-.1)) GO TO 1000
C******    PRINT INFO FOR HIGHEST OUTPUT LEVEL, JC=2 UNFINISHED SCHEDULE
      IF(NPRINT.LE.3)GO TO 23
      IF(ISIU.EQ.0)GO TO 120
      SIACRT=(SACRE(IO)-ACRET(IO))*0.4046856
      PRINT 121,OPER(IOPER(IO)),CROP1(ICROP(IO)),IDATE(I),SIACRT
      GO TO 23
  120 ACRUNF=SACRE(IO)-ACRET(IO)
      PRINT 111,OPER(IOPER(IO)),CROP1(ICROP(IO)),IDATE(I),ACRUNF
   23 JC=2 $ IQUIT=IO
C
C******    IF BALEING OPERATION ALLOW USE OF MORE MACHINES AND DRIVERS
      IF(IOP.EQ.15.OR.IOP.EQ.17.OR.IOP.EQ.21)GO TO 21
      RETURN
C
C******    DETERMINE EXTRA ALFALFA MEN AND MACHINES NEEDED
C******    ACR=ACRES ONE MACHINERY SET COULD ACCOMPLISH
   21 ACR=ACRET(IO)/(1.0+PCTHRD)
C******    IALF=THE INTEGER NUMBER OF EXTRA MACHINE SETS REQUIRED
      IALF=IFIX((SACRE(IO)-ACRET(IO))/ACR+.99)
C******    CHANGE ACRES COMPLETED AND COMPLETION INDICATOR
      ACRET(IO)=SACRE(IO) $ JC=1
C******    IALF=EXTRA MEN/MACHINE SETS REQUIRED
      IALF=MAX0(IALF,IAF)
      IAF=IALF
C******    PRINT FOR HIGHEST OUTPUT LEVEL ONLY
      IF(NPRINT.LE.3)GO TO 1000
      PRINT 22,IALF
C******    PRINT SUMMARY INFO IF INSTRUCTED BY PWRSIZE
 1000 WHR=ACREW(IO)/EFC(IO)
      IF(NF.EQ.0)GO TO 13
      IF(ISIU.EQ.0)GO TO 126
      SIHAWK=ACREW(IO)*0.4046856 $ SIHAT=ACRET(IO)*0.4046856
      SIEFC=EFC(IO)*0.4046856
      PRINT 127,CROP1(ICP),OPER(ICP),SIHAWK,SIHAT,WHR,SIEFC,THOURS(I,IO)
      GO TO 13
  126 PRINT 14,CROP1(ICP),OPER(IOP),ACREW(IO),ACRET(IO),WHR,EFC(IO)
     *,THOURS(I,IO)
   13 CONTINUE
C
C******    COMPLETION CHECK,  AN OPERATION MAY END IN WEEK I BUT NOT BE
C******     CONSIDERED BECAUSE NO HOURS WERE AVAILABLE FOR IT
   20 DO 110 IK=1,N
C******    1)CHECK FOR ENDING DATE  2)CHECK ACRES  3)CHECK PRINT LEVEL
      IF(IDATE(I+1).NE.IEND(IK)) GO TO 110
      IF(ACRET(IK).GE.(SACRE(IK)-0.1)) GO TO 110
      IF(NPRINT.LE.3)GO TO 103
      IF(ISIU.EQ.0)GO TO 122
      SIACRT=(SACRE(IK)-ACRET(IK))*0.4046856
      PRINT 121,OPER(IOPER(IK)),CROP1(ICROP(IK)),IDATE(I),SIACRT
      GO TO 103
  122 ACRUNF=SACRE(IK)-ACRET(IK)
      PRINT 111,OPER(IOPER(IK)),CROP1(ICROP(IK)),IDATE(I),ACRUNF
  103 GO TO 112
  110 CONTINUE
      GO TO 2
C******    IF OPERATION IS ALFALFA HARVEST DO THE SAME AS IN ABOVE SECTION
  112 IF(IOPER(IK).EQ.15.OR.IOPER(IK).EQ.17.OR.IOPER(IK).EQ.21)
     *GO TO 25
C******    OPERATON ISN'T ALFALFA OP, UNSATISFACTORY SCHEDULE
      JC=2 $ IQUIT=IK $ RETURN
   25 ACR=ACRET(IK)/(1.0+PCTHRD)
      IALF=IFIX((SACRE(IK)-ACRET(IK))/ACR+.99)
      ACRET(IK)=SACRE(IK)
      IALF=MAX0(IALF,IAF)
      IAF=IALF
      IF(NPRINT.LE.3)GO TO 20
      PRINT 22,IALF
      GO TO 20
C
C******    DETERMINE IF A GROUP OF OPERATIONS ON THE SAME CROP CAN BE
C******     SCHEDULED  (EXAMPLE: PLOW-DISK-PLANT CORN)
C******    ITRAC=CLASS OF OPERATION BASED UPON HRS AVAILABLE & DAY LENGTH
C******    J=NUMBER OF OPERATIONS IN SUBSET
C******    IQSUB=SUBSET OF OPERATIONS WITH SAME ENDING DATE FOR SAME CROP
   11 ITRC=ITRAC1(IOPER(IO)) $ J=1 $ IX=JI+1 $ IQSUB(1)=IO
      ISUBEND=IENDY(IO)
```

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      CHR=THOURS(I,IO) $ ICRP=ICROP(IO)
      IF(IX.GT.L) GO TO 31
C*****   LOOP THRU ALL OPERATIONS IN IG
      DO 15 JJ=IX,L $ IO=IG(JJ)
C*****   1)IF DIFFERENT CROPS  2)IF COMBINE OPERATION  3)IF PREVIOUSLY
C*****   CONSIDERED  4)IF ENDING DATES ARE DIFFERENT  5)IF UNEQUAL CLASS
      IF(ICRP.NE.ICROP(IO)) GO TO 15
      IF(IOPER(IO).GT.25) GO TO 15
      IF(FLAG(JJ).EQ.1) GO TO 15
      IF(ISUBEND.LT.IENDY(IO)) GO TO 15
      IF(ITRC.NE.ITRAC1(IOPER(IO))) GO TO 15
      J=J+1 $ IQSUB(J)=IQ(JJ)
   15 CONTINUE
C*****   UPDATE FLAG
   31 DO 18 JJ=1,J
      DO 19 II=1,L
      IF(IQSUB(JJ).NE.IQ(II)) GO TO 19
      FLAG(II)=1 $ GO TO 18
   19 CONTINUE
   18 CONTINUE
C*****   WEEKLY MAXIMUN & MAXIMUN FOR ONE TRACTOR
      WMAX=CHR+CHR*PCTHRD $ TRMAX=CHR
C*****   DETERMINE ACRES OF CROPS IN IQSUB WORKABLE AT BEGINNING OF WEEK
      CALL PREVOP(IQSUB(1),J)
C*****   IF NONE CAN BE SCHEDULED TO TO 30
      DO 200 JK=1,J
      IF(LESS(IQSUB(JK)).GT.0.01) GO TO 60
  200 CONTINUE
      ICOUNT=ICOUNT+1 $ GO TO 30
C*****   REMAINING TIME IN WEEK CALCULATION  THIS MAY CHANGE IN WEEK
C*****    DUE TO DIFFERENT TIME AVAILABILITIES FOR OPERATIONS
   60 RMAX=AMAX1((WMAX-TOTHRS),0.0)
C*****   ALLOCATE TIME TO OPERATIONS
      CALL ALCATE(J,RMAX,TRMAX,SMLTM,BIGTM,PCTHRD)
      IJK=IQSUB(J)
C*****   IF PLANTING AND SPRAYING ARE BACK TO BACK
      IF(IOPER(IJK).EQ.16.AND.IOPER(IJK+1).EQ.22)GO TO 16
      ICOUNT=ICOUNT+1 $ GO TO 30
C
C*****   SPRAYER SECTION
C*****   SPRAYING HAS EQUAL OR MORE AVAILABLE HOURS THAN PLANTING
C*****   ACRES PLANTED MUST EQUAL ACRES SPRAYED IN WEEK
C*****   CALCULATE EXTRA TIME AVAILABLE FOR SPRAYING
   16 EXTRA=AMAX1((THOURS(I,(IJK+1))-THOURS(I,IJK)-SMTR1),0.0)
C*****   SCHEDULE THE EXTRA TIME
      ACREW(IJK+1)=EXTRA*EFC(IJK+1)
C*****   IF ACRES SPRAYED ARE MORE THAN ACRES PLANTED GO TO 26
      IF(ACREW(IJK+1).GE.(ACREW(IJK)-.01))GO TO 26
C*****   ASSIGN EXTRA TIME TO SMALL TRACTOR
      SMTR1=SMTR1+EXTRA
C*****   DETERMINE TIME REMAINING FOR PLANTING CLASS OPERATION
      EXTRA2=AMAX1((WMAX-BIGTM-SMLTM),0.0)
      EXTRA2=AMIN1((TRMAX-SMLTM),EXTRA2)
C*****   ACRLFT=PLANTED-SPRAYED ACRES (SPRAYING USED EXTRA TIME ONLY)
      ACRLFT=ACREW(IJK)-ACREW(IJK+1)
C*****   IF UNSCHEDULED PLANTING TIME IS ENOUGH TO FINISH SPRAYING
      IF((EXTRA2*EFC(IJK+1)).GE.(ACRLFT-.01))GO TO 40
C*****   ACRES PLANTED MUST BE REDUCED
C*****   FIRST SCHEDULE THE EXTRA TIME
      ACREW(IJK+1)=ACREW(IJK+1)+EXTRA2*EFC(IJK+1)
C*****   DETERMINE COMBINED CAPACITY OF PLANTER AND SPRAYER
      EFCT=1.0/(1.0/EFC(IJK)+1.0/EFC(IJK+1))
C*****   DETERMINE HOW MUCH TIME MUST BE TAKEN FROM PLANTING
      TIME=(ACREW(IJK)-ACREW(IJK+1))/EFC(IJK)
C*****   ALOCATE TIME AMONG PLANTING AND SPRAYING
      ACREW(IJK)=ACREW(IJK+1)=ACREW(IJK+1)+TIME*EFCT
C*****   CREDIT UTILITY TRACTOR WITH WORK TIME
      SMLTM=SMLTM+EXTRA2
      GO TO 27
C*****   EXTRA2 WAS SUFFICIENT, SPRAYING=PLANTING, CREDIT SMALL TRACTOR
   40 ACREW(IJK+1)=ACREW(IJK)
      SMLTM=SMLTM+ACRLFT/EFC(IJK+1)
      GO TO 27
C*****   EXTRA1 WAS SUFFICIENT, SPRAYING=PLANTING, CREDIT SMALL TRACTOR
   26 ACREW(IJK+1)=ACREW(IJK)
      SMTR1=SMTR1+ACREW(IJK+1)/EFC(IJK+1)
   27 DO 29 II=1,L $ IO=IQ(II)
```

```
C*****    FLAG SPRAYING OPERATION
      IF(IO.EQ.(IJK+1))FLAG(II)=1
   29 CONTINUE
      ICOUNT=ICOUNT+1 $ GO TO 30
C*****    COMPLETE SCHEDULE WAS FOUND. RETURN
    4 JC=1 $ IQUIT=0 $  RETURN
   12 FORMAT(*-*,31X,*WEEK OF*,I5,*  COMBINE=*,F5.1,*  TILLAGE TRACTOR=*
     *,F5.1,*  UTILITY TRACTOR=*,F5.1)
  102 FORMAT(*0*,34X,*CROP     OPERATION   ACREWEEK  ACRETOTAL  TIME  *,
     *25HACRES/HOUR  MAXIMUN HOURS)
   22 FORMAT(* *,24X,*EXTRA ALFALFA CAPACITY IS NEEDED*,I4,
     ** EXTRA OF THE FOLLOWING MACHINE AND DRIVER IS NEEDED*)
   14 FORMAT(* *,31X,A10,1X,A10,F8.1,F11.1,F8.2,F9.2,F14.2)
  111 FORMAT(* *,23X,*NOT ABLE TO FINISH OPERATION = *,A10,
     ** FOR CROP = *,A10,* BY *,I5,* ACRES LEFT =*,F7.2)
  121 FORMAT(* *,22X,*NOT ABLE TO FINISH OPERATION = *,A10,
     ** FOR CROP = *,A10,* BY *,I5,* HECTARES LEFT =*,F7.2)
  125 FORMAT(*0*,30X,*CROP     OPERATION   HECTAREWK  HECTARETOT  TIME *,
     *27H HECTARES/HR  MAXIMUM HOURS)
  127 FORMAT(* *,27X,A10,1X,A10,F8.1,F12.1,2F9.2,F15.2)
      END
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      SUBROUTINE PREVOP(IO,J)
C
C*****    DETERMINE THE ACRES WHICH CAN BE SCHEDULED FOR EACH CROP IN
C*****     THE IQSUB ARRAY AT THE BEGINNING OF WEEK, THIS FIGURE MAY
C*****     CHANGE LATER IN THE WEEK AS ACRES ARE SCHEDULED
C*****    WRITTEN BY F.J. WOLAK  1980
C
C*****    IO=FIELD OPERATION NUMBER (1 THRU N) OF FIRST OPER IN IQSUB
C*****    J=NUMBER OF OPERATIONS IN IQSUB
C*****    HARAVL=AVAILABLE HRAVESTED ACRES
C*****    MAXAVL=MAXIMUN ACRES AVAILABLE FOR USE BY FIRST OPERATION
C*****     OF NEXT CROP
C
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK8/N,NF,NFF,RWWC,OPR,TACRE
      COMMON/BLK41/ORDER(7,14),ASSIGN(7,14)
      COMMON/BLK51/IQSUB(10),ACRET(55),LESS(55),ACREW(55),IQ(20)
      COMMON/BLK53/IFIRST(30),HARVEST(7)
      REAL LESS,MAXAVL
C*****    IF THIS IS THE FIRST OPERATION FOR FARM
      IF(IO.EQ.1) GO TO 31
C*****    IF THIS FIRST OPERATION FOR CROP
      DO 40 KL=1,14
      IF(IO.EQ.IFIRST(KL))GO TO 41
   40 CONTINUE
C*****    DETERMINE THE PRECEEDING OPERATION FOR THE CONSIDERED CROP
      DO 1 JK=1,IO
      IK=IO-JK
C*****    IF OPERATIONS IO & JK ARE ON THE SAME FARM
      IF(ICROP(IK).EQ.ICROP(IO)) GO TO 2
    1 CONTINUE
C*****    THIS IS THE FIRST OPERATION FOR CROP
   31 LESS(IO)=SACRE(IO)-ACRET(IO) $ GO TO 30
    2 LESS(IO)=ACRET(IK)+ACREW(IK)-ACRET(IO) $ GO TO 30
C*****    FIRST OPERATION FOR CROP, WHAT GROUND DOES IT USE
   41 MAXAVL=0.0 $ IC=ICROP(IO)
C*****    DO LOOP FOR THE SEVEN CROP HARVESTS
      DO 4 I=1,7
C*****    DOES CROP IC USE HARVESTED LAND I, IF YES CONTINUE
      IF(ORDER(I,IC).LE.0.0)GO TO 4
      HARAVL=ACRET(HARVEST(I))+ACREW(HARVEST(I))
      IF(HARAVL.LE.0.0)GO TO 4
C*****    SUBTRACT HARVESTED ACRES ALL READY ASSIGNED TO ANOTHER CROP
      DO 3 JK=1,14
      IF(IC.EQ.JK)GO TO 3
      HARAVL=HARAVL-ASSIGN(I,JK)
    3 CONTINUE
      MAXAVL=MAXAVL+AMIN1(HARAVL,ORDER(I,IC))
    4 CONTINUE
      LESS(IO)=MAXAVL-ACRET(IO)
   30 IF(J.LT.2) GO TO 20
C*****    CALCULATE SCHEDULEABLE ACRES FOR OTHER OPS IN IQSUB
      DO 21 IJ=2,J $ IN=IQSUB(IJ) $ IN2=IQSUB(IJ-1)
   21 LESS(IN)=ACRET(IN2)+ACREW(IN2)-ACRET(IN)
   20 RETURN
      END
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      SUBROUTINE ALCATE(J,RMAX,TRMAX,SMLTM,BIGTM,PCTHR)
C
C******   ALLOCATES TIME AVAILABLE TO OPERATIONS FOR ONE CROP AT A TIME
C******   WRITTEN BY F.J. WOLAK  1980
C
C******   J=NUMBER OF OPERATIONS IN IQSUB ARRAY
C******   RMAX=AMOUNT OF TIME REMAINING IN WEEK ACCOUNTING FOR EXTRA HELP
C******   TRMAX=MAX HRS ONE TRACTOR CAN BE DRIVEN (EQUALS AVAILABLE HRS)
C******   SMLTM=TIME ALLOCATED TO UTILITY TRACTOR
C******   BIGTM=TIME ALLOCATED TO TILLAGE TRACTOR
C******   PCTHR=PERCENTAGE OF EXTRA HELP AVAILABLE ON FARM
C******   IQSUB=ARRAY OF FIELD OPERATIONS FOR ONE CROP WHICH CAN BE
C******    SCHEDULES AND HAVE EQUAL ENDING DATES  (EQUAL PRIORITY)
C
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/N,NF,NFF,R,JD,DPP,TACHE
      COMMON/BLK51/IQSUB(10),ACRET(55),LESS(55),ACREW(55),IG(20)
      REAL LESS,MANHR,MAX
C******    IF GREATER THAN ONE OPERATOR FARM AND ALFALFA HARVEST
      IF(ITRAC1(IOPER(IQSUB(1))).EQ.6.AND.PCTHR.GE..01)GO TO 21
C
C******   FOR THE ARRAY OF EQUAL PRIORITY OPERATIONS PASSED TO ALCATE IN
C******    IQSUB, AN ATTEMPT WILL BE MADE TO START WITH LAST OPERATION
C******    AND SCHEDULE AS MUCH AS POSSIBLE, NEXT THE LAST TWO OPERATIONS
C******    ARE TAKEN AS A GROUP AND SCHEDULED, THIS CONTINUES UNTIL ALL
C******    OPERATIONS ARE FINISHED OR TIME CONSTRAINT IS VIOLATED
      KK=0 $ MAX=RMAX $ II=J
C******    IF REMAINING TIME IS 0.0, RETURN
      IF(MAX.LT.0.01) GO TO 8
C******    IO=OPERATION II OF IQSUB ARRAY (IO=1 THRU N)
    6 IO=IQSUB(II)
      IF(LESS(IO).LE..01) GO TO 1
C******    DETERMINE COMBINED EFC OF OPERATIONS II TO J  OF IQSUB
      TEFC=0.0
      DO 2 JI=II,J $ IO=IQSUB(JI)
    2 TEFC=TEFC+1.0/EFC(IO)
      TEFC=1.0/TEFC
C******    RESET IO, DETERMINE HOURS NEEDED TO DO ALL WORK
    3 IO=IQSUB(II)
      RHR=LESS(IO)/TEFC
C******    HOURS IS THE MINIMUN OF HOURS AVAILABLE & HOURS NEEDED
      MANHR=AMIN1(MAX,RHR)
C******    ACR=ACRES COMPLETED OF IQSUB(II TO J)
      ACR=MANHR*TEFC
C******    ALLOCATE TIME OF EACH OPERATION (IQSUB(II-J)) TO BIG(TILLAGE)
C******     AND SMALL(UTILITY) TRACTORS
      BIG=SMALL=0.0
      DO 4 JI=II,J $ IO=IQSUB(JI)
      IF(IOPER(IO).GT.10) GO TO 5
      BIG=BIG+ACR/EFC(IO) $ GO TO 4
    5 SMALL=SMALL+ACR/EFC(IO)
    4 CONTINUE
C******    IF THE TRMAX CONSTRAINT HASN'T BEEN ADJUSTED FOR, CHECK IT NOW
      IF(SMALL.GT.0.01.AND.BIG.GT.0.01)GO TO 14
      IF(BIG.GT.0.01)GO TO 70
      IF((TRMAX+.01).GE.(SMLTM+SMALL))GO TO 11
      MAX=TRMAX-SMLTM $ GO TO 3
   70 IF((TRMAX+.01).GE.(BIGTM+BIG))GO TO 11
      MAX=TRMAX-BIGTM $ GO TO 3
   14 IF(KK.EQ.0) GO TO 13
C******    ASSIGN ACRES COMPLETED TO ARRAY(ACREW) LOCATION
   11 DO 7 JI=II,J $ IO=IQSUB(JI)
    7 ACREW(IO)=ACREW(IO)+ACR
C******    UPDATE TILLAGE AND UTILITY TRACTOR TIME, UPDATE TIME REMAINING
      BIGTM=BIGTM+BIG $ SMLTM=SMLTM+SMALL
      MAX=MAX-BIG-SMALL
C******    IF ADJUSTMENT WAS MADE BECAUSE OF TRMAX CONSTRAINT, RETURN
      IF(KK.EQ.1) GO TO 8
C******    IF THERE IS TIME REMAINING, CONTINUE
      IF(MAX.GT.0.01) GO TO 1
    8 RETURN
C******    GO TO NEXT OPERATION (REMEMBER ORDER IS LAST TO FIRST)
    1 II=II-1
      IF(II.LE.0) GO TO 8
      GO TO 6
C******    TRMAX CONSTRAINT CHECK
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C******    1)IF TILLAGE TRACTOR   2)IF UTILITY TRACTOR
   13 IF((BIGTM+BIG).GT.(TRMAX+.01)) GO TO 9
      IF((SMLTM+SMALL).GT.(TRMAX+.01)) GO TO 10
      GO TO 11
C******    TILLAGE TRACTOR: TIME AVAILABLE(MAX) WILL BE ADJUSTED SUCH THAT
C******      TILLAGE TRACTOR TOTAL JUST EQUALS TRMAX
    9 CNUM=BIG $ CDENOM=SMALL $ CMAX=TRMAX-BIGTM $ GO TO 12
C******    UTILITY TRACTOR: ADJUST(MAX) SUCH TAHAT UTILITY TRACTOR IS OK
   10 CNUM=SMALL $ CDENOM=BIG $ CMAX=TRMAX-SMLTM
C******    MAXIMUM TIME IS THE DIFFERENCE BETWEEN TRACTOR MAXIMUN(TRMAX)
C******      AND THE CONSTRAINT VIOLATING TRACTOR TIME PLUS THIS SAME
C******      DIFFERENCE MULTIPLIED BY THE RATIC OF TRACTOR TIMES FOR THE
C******      EFC OF THE IOSUB(II TO J) GROUP
C******    KK=1 TO SIGNIFY THAT THIS IS AS MUCH AS WE CAN SCHEDULE
   12 MAX=CMAX+CMAX*CDENOM/CNUM $ KK=1 $ GO TO 3
C
C******    ALFALFA WITH EXTRA HELP SECTION
C******    THIS SECTION MAKES BOTH DRIVERS WORK ON ALFALFA HARVEST THEY
C******      USE ONLY ONE SET OF EQUIPTMENT THUS ON TRACTOR MAY BE IDLE
C******      FOR SHORT PERIODS IF ONE MACHINE IS CRITICAL
C******    STORE ORIGINAL VALUES FOR POSSIBLE USE LATER
   21 ORGBIG=BIGTM $ ORGSML=SMLTM
C******    CALCULATE EFC OF ALFALFA HARVEST COMPONET (BALER,HAYBINE,RAKE)
   26 TEFC=0.0
      DO 22 JK=1,J $ IO=IOSUB(JK)
   22 TEFC=TEFC+1.0/EFC(IO)
C******    CALCULATE ACR (MAX ACRES POSSIBLE IN GIVEN TIME)
      TEFC=1.0/TEFC $ ACR=RMAX*TEFC
C******    ALLOCATION OF TIME LOOP
      DO 23 JK=1,J $ IO=IOSUB(JK)
C******    ACRES ARE CONSTRAINED BY TOTAL TO SCHEDULE
      ACREW(IO)=AMIN1((SACRE(IO)-ACRET(IO)),ACR)
C******    CALCULTAE HOURS FOR OPERATION IO
C******    IF OPERATION IS BALEING SCHEDULE SMALL TRACTOR
      HR=ACREW(IO)/EFC(IO)
      IF(IOPER(IO).EQ.17)GO TO 24
C******    BHR=TILLAGE TRACTOR REMAINING HOURS
      BHR=TRMAX-BIGTM
C******    TILLAGE TRACTOR HOURS ARE CONSTRAINED BY MAX AVAILABLE
      BIGTM=AMIN1((BIGTM+HR),TRMAX)
C******    IF HOURS ARE LESS THAN WHAT IS AVAILABLE TO TILLAGE TRACTORS
      IF(HR.LE.BHR)GO TO 23
C******    FIND HRS NOT ASSIGNABLE TO TILLAGE TRACTOR AND GIVE TO UTILITY
      HR=HR-BHR
   24 SMLTM=SMLTM+HR
C******    IF NO TIME CONSTRAINT IS VIOLATED
      IF(TRMAX.GE.(SMLTM-.01))GO TO 23
C******    BALER COULDN'T KEEP UP WITH OTHER MACHINES, RESET TIME TO THAT
C******      WHICH FULLY UTILIZES BALER BUT UNDER UTILIZES HAYBINE, ETC.
C******      RESET BIG & SMALL TRACTOR TIMES AND RESCHEDULE
      RMAX=(TRMAX-ORGSML)*EFC(IO)/TEFC
      BIGTM=ORGBIG $ SMLTM=ORGSML $ GO TO 26
   23 CONTINUE
   25 RETURN
      END
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      SUBROUTINE SIZING
C
C*****   SELECTS EQUIPTMENT GIVEN MACHINERY PARAMETERS, EFC,
C*****    AND INTERFACE CONSTRAINTS OF SEPERATE MACHINES
C*****   WRITTEN BY F.J. WOLAK    1980
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     +ISTARTY,IEND2Y,IENDY(55)
      COMMON/BLK2/HRSDA(11),RE(33),HTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,6),
     +PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK7/CPER(33),CROP1(30),AN(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,ROWD,DPR,TACRE
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK15/NPRINT,ISIU
      COMMON/BLK21/CBEFF(5,4),CBSPEED(5,4)
      COMMON/BLK51/IQSUP(10),ACRET(55),LESS(55),ACREW(55),IO(20)
      COMMON/BLK52/FUELTOT(33),FULLFRM
      COMMON/BLK60/IZBFET,IZCOMB,ICMPLT,IALF,IROW
      COMMON/BLK65/SISIZE(33),SIDRUNT(33)
      DIMENSION WIDTH(33),ANHRS(33)
      NBNSZ=0 $ FUELFRM=0.0
C*****   INITIALIZE MACHINERY ANNUAL USE HOURS & FUEL CONSUMPTION
      DO 25 I=1,33
   25 ANHRS(I)=FUELTOT(I)=0.0
C*****   IF LOWEST PRINT LEVEL
      IF(NPRINT.EQ.1)GO TO 30
      IF(ISIU.EQ.0)GO TO 60
      SITT=HPTRACL*0.7456999 $ SIUT=HPTRACS*0.7456999
      PRINT 61,SITT,SIUT,ROWCOM1
      GO TO 30
   60 PRINT 100,HPTRACL,HPTRACS,ROWCOM1
C*****   LOOP TO SIZE EQUIPTMENT FOR EACH FIELD OPERATION
C*****   I=FIELD OPERATION 1 THRU N
C*****   IO=IMPLEMENT(OPERATION) 1 THRU 33
C*****   IE=NUMBER OF SIZES TO CHOOSE FROM FOR IMPLEMENT IO
   30 DO 15 I=1,N $ IO=IOPER(I) $ IE=IM(IO)
C*****   IF IMPLEMENT IS NH3 APPLICATOR OR CULTIVATER
      IF(IO.EQ.11.OR.IO.EQ.13.OR.IO.EQ.14) GO TO 10
C*****   IF IMPLEMENT IS A BALER
      IF(IO.EQ.17)GO TO 33
      GO TO 11
C*****   CULTIVATOR & NH3 APPLICATER WIDTH ARE FIXED BY PLANTER SIZE
   10 WIDTH(IO)=IROW
      SPEED(IO)=EFC(I)*8.25/(WIDTH(IO)*ROWD*RE(IO)*EFF(IO))
      GO TO 1
C*****   BALER SECTION
C*****   DETERMINE PREVIOUS IMPLEMENT
   33 IOL=IOPER(I-1)
C*****   IF STRAW BALLING, WIDTH IS TWICE THE COMBINE HEADER WIDTH
      IF(IOL.GE.25)WIDTH(IO)=SIZE(IOL,(IFIX(ROWCOM1/2.)))*2.
C*****   IF HAY BALEING, WIDTH IS TWICE THE SWATH WIDTH
      IF(IOL.LT.25)WIDTH(IO)=WIDTH(IO)=WIDTH(IOL)*2.0
C*****   FOR FIRST CUTTING WIDTH IS ONE SWATH
      IF(IEND(I).LT.710)WIDTH(IO)=WIDTH(IO)/2.0
      SPEED(IO)=EFC(I)*8.25/(WIDTH(IO)*RE(IO)*EFF(IO))
      GO TO 1
C*****   IF COMBINE, IJ=COUNTER FOR COMBINE PARAMETERS
   11 IF(IO.GT.24) IJ=IO-24
C*****   IF NAVY BEANS, SPEED & WIDTH ARE FUNCTION OF PLANTER SIZE
      IF(IO.EQ.28) GO TO 21
      IF(IO.GE.25)GO TO 32
C*****   LOOP THRU IMPLEMENT SIZES
      DO 2 J=1,IE
C*****   1)IF NOT MEETS  2)3-ROW LIFTER CANNOT MATCH 4 OR 8-ROW PLANTER
      IF(IO.NE.8.AND.IO.NE.9) GO TO 20
      IF(J.EQ.2.AND.(IROW.EQ.4.OR.IROW.EQ.8))GO TO 2
C*****   IF COMBINE OPERATION  WIDTH AND SPEED ARE ALREADY KNOWN
   20 IF(IO.GT.24) GO TO 32
C*****   CALCULATE SPEED FOR CURRENT WIDTH
      WIDTH(IO)=SIZE(IO,J)
      SPEED(IO)=EFC(I)*8.25/(WIDTH(IO)*RE(IO)*EFF(IO))
C*****   IF SIZE IS ROWS NOT FEET, ADJUST SPEED
      IF(IGROUP(IO).EQ.2.OR.IGROUP(IO).EQ.5)SPEED(IO)=SPEED(IO)/ROWD
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C*****    IF SIZE IS BOTTOMS, ADJUST SPEED TO 16 INCH BOTTOMS
      IF(IGROUP(IO).EQ.3)SPEED(IO)=SPEED(IO)*0.75
C*****    IF SPEED OBEYS THE LIMITS SKIP OUT
      IF((SLOW(IO)-.01).LE.SPEED(IO).AND.SPEED(IO).LE.(FAST(IO)+.01))
     *GO TO 1
    2 CONTINUE
      GO TO 1
C*****    COMBINE SIZE AND SPEED ARE KNOWN
   32 JK=ROWCOM1/2. $ WIDTH(IO)=SIZE(IO,JK) $ SPEED(IO)=CBSPEED(IJ,JK)
      GO TO 1
C
C*****    NAVY BEAN SECTION
C*****    NAVY BEAN HEADER SIZE IS FIXED, DETERMINE WINDROW SIZE
C*****    1)START WITH PLANTER SIZE  2)BACK OFF 12 ROW WIDTH
C*****     3)IF 6 OR 12-ROW AND 6 OR 12-ROW COMBINE, THEN DOUBLE SIX
C*****     4)IF 4 OR 8-ROW AND 4+ROW COMBINE, WIDTH IS 8 ROWS
C*****     5)IF 8-ROW PLANTER AND 2-ROW COMBINE, WIDTH IS 4 ROWS
   21 WIDTH(IO)=IROW
      IF(IROW.EQ.12)WIDTH(IO)=6.0
      IF((IROW.EQ.6.OR.IROW.EQ.12).AND.EFC(I).GT.6.)WIDTH(IO)=12.
      IF(IROW.EQ.4.OR.IROW.EQ.8.AND.EFC(I).GT.5.)WIDTH(IO)=8.
C*****    NBNSZ=SIZING MECHANISM FOR BEAN PULLER
      NBNSZ=WIDTH(IO)
C*****    DETERMINE SPEED OF NAVY BEAN COMBINE
      JK=ROWCOM1/2.
      EFF(IO)=CBEFF(IJ,JK)
      SPEED(IO)=EFC(I)*8.25/(WIDTH(IO)*RWWD*RE(IO)*EFF(IO))
C*****    IF CORN HEADER REPORT SIZE IN ROWS NOT FEET
    1 IF(IO.EQ.25)WIDTH(IO)=WIDTH(IO)/2.5
C*****    CALCULATE SUM HOURS OF USE FOR IMPLEMENT
      ANHRS(IO)=ANHRS(IO)+ACRET(I)/EFC(I)
C*****    CALCULATE THE FUEL USE OF FIELD OPERATION
      CALL FUEL(IO,I,FUELUSE)
C*****    PRINT INFO FOR 3 HIGHEST OUTPUT LEVELS
      IF(NPRINT.EQ.1)GO TO 31
      IF(ISIU.EQ.0)GO TO 62
      SISPEED=SPEED(IO)*1.609344 $ SIEFC=EFC(I)*0.4046856
      SIFUEL=FUELUSE*3.785412
      SIDRAFT=DRAFT(IO)
      IF(IGROUP(IO).EQ.1.OR.IGROUP(IO).EQ.3)SIDRAFT=SIDRAFT*14.593904
      IF(IGROUP(IO).EQ.2.OR.IGROUP(IO).EQ.5)SIDRAFT=SIDRAFT*4.448222
      IF(IO.EQ.17)SIDRAFT=DRAFT(IO)*4.90332564
      SIWIDTH=WIDTH(IO)
      IF(IGROUP(IO).EQ.1)SIWIDTH=SIWIDTH*0.3048
      PRINT 101,OPER(IO),SIWIDTH,SISIZE(IO),SIDRAFT,SIDRUNT(IO),EFF(IO),
     *TE(IO),SISPEED,SIEFC,SIFUEL
      GO TO 31
   62 PRINT 101,OPER(IO),WIDTH(IO),AN(IO),DRAFT(IO),ANDRAFT(IO),EFF(IO),
     *TE(IO),SPEED(IO),EFC(I),FUELUSE
C*****    IF OPERATION JUST CONSIDERED WAS NOT NAVY BEAN HARVEST
   31 IF(NBNSZ.EQ.0)GO TO 15
C*****    1)SELECT BEAN PULLER  2)WIDTH=PLANTER SIZE  3)NO 12-ROW PULLER
C*****      4)PULL AT FASTEST SPEED  5)RESET NBNSZ AND PRINT INFO
      IO=24 $ WIDTH(IO)=IROW
      IF(IROW.EQ.12)WIDTH(IO)=6.0
      SPEED(IO)=FAST(IO)
      EFC(I)=FAST(IO)*RE(IO)*RWWD*WIDTH(IO)*EFF(IO)/8.25
      NBNSZ=0
      GO TO 1
   15 CONTINUE
C*****    SIZING IS COMPLETE DETERMINE COST
      CALL COST(WIDTH,ANHRS)
      RETURN
  101 FORMAT(* *23X,A10,F10.2,1X,A5,F9.2,1X,A6,F7.2,F10.2,2F9.2,F10.2)
  100 FORMAT(*1*,62X,*MACHINERY SET*//28X,*TILLAGE TRACTOR HORSEPOWER=*,
     *F5.0,* SECOND TRACTOR HORSEPOWER=*,F5.0,* COMBINE SIZE=*,F3.0,/
     */24X,*OPERATION*,9X,*SIZE*,11X,*DRAFT*,6X,*FLD EFF    TR EFF*,
     *3X,*SPEED    FLD CAP   FUEL CSPN*/87X,*(MPH)      (ACR/HR)  (GAL/ACR)*/
     *)
   61 FORMAT(*1*,62X,*MACHINERY SET*//29X,*TILLAGE TRACTOR KILOWATT=*,
     *F6.1,* SECOND TRACTOR KILOWATT=*,F6.1,* COMBINE SIZE=*,F3.0,/
     */23X,*OPERATION*,10X,*SIZE*,9X,*DRAFT*,8X,*FLD EFF    TR EFF*,
     *3X,*SPEED    FLD CAP   FUEL CSPN*/86X,*(KM/HR)    (HA/HR)      (L/HA)*/)
      END
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      SUBROUTINE FUEL(IOP,I,FUELUSE)
C
C*****    DETERMINES DIESEL FUEL USEAGE  WRITTEN BY F.J. WOLAK 1980
C*****    USES FORMULA OUTLINED IN ASAE YEARBOOK 1978
C
C*****    IOP=IMPLEMENT NUMBER 1 THRU 33  IDENTIFIES A PARTICULAR MACHINE
C*****    I=OPERATION NUMBER 1 THRU N  IDENTIFIES A PARTICULAR FIELD OF
C*****    FUELUSE=DIESEL FUEL USE FOR OPERATION I, IMPLEMENT IOP, GAL/ACR
C*****    FUELFRM=RUNNING TOTAL OF FUEL USE FOR FARM  GALLONS
C
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,8),
     *PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK8/N,NF,NFF,RWWD,DPH,TACRE
      COMMON/BLK13/HPTRACS,HOWCOM1,HPTRACL
      COMMON/BLK51/IGSUE(10),ACRET(55),LESS(55),ACREW(55),IQ(20)
      COMMON/BLK52/FUELTOT(33),FUELFRM
C*****    1)IF IMPLEMENT IS A COMBINE  2)IF IMPLEMENT ISN'T A BALER
      IF(IOP.GE.25)GO TO 4
      IF(IOP.NE.17)GO TO 11
C*****    PTOHP REQUIRED FOR BALEING USING 6 TON/HOUR CAPACITY
C*****    DRAFT OF BALER IS IN DBHP/TON
      EN=DRAFT(IOP)*6.0/(TE(IOP)*.96) $ GO TO 5
C*****    DETERMINE PTOHP FOR TRACTOR DRAWN IMPLEMENTS  DRAFT TO LB/FT
   11 GO TO(2,3,2,2,3,2)IGROUP(IOP)
    2 EN=0.022*DRAFT(IOP)*EFC(I)/(0.96*TE(IOP)*EFF(IOP))
      GO TO 5
    3 EN=0.022*DRAFT(IOP)/RWWD*EFC(I)/(0.96*TE(IOP)*EFF(IOP))
      GO TO 5
    4 IMP=IOP-24
      GO TO (6,7,8,9,7)IMP
C*****    FUEL USE OF COMBINE IS CONSTANT FOR A PARTICULAR CROP
    6 FUELUSE=1.60 $ GO TO 10
    7 FUELUSE=1.45 $ GO TO 10
    8 FUELUSE=1.10 $ GO TO 10
    9 FUELUSE=1.45 $ GO TO 10
C*****    HP IS SMALL OR LARGE TRACTOR HP DEPENDING UPON IMPLEMENT
    5 HP=HPTRACS
      IF(IOP.LE.10.AND.IOP.NE.8)HP=HPTRACL
C*****    RATIO OF REQUIRED TO AVAILABLE PTOHP FOR USE IN ASAE FORMULA
      RAT=EN/HP
      FUELEFF=0.52*RAT+0.768-0.04*SQRT(738.5*RAT+173.0)
C*****    1)CONVERT GAL/HP-HR TO GAL/ACRE  2)SUM FOR IMPLEMENT & FARM
      FUELUSE=FUELEFF*EN/EFC(I)
   10 FUELTOT(IOP)=FUELUSE*ACRET(I)+FUELTOT(IOP)
      FUELFRM=FUELFRM+FUELUSE*ACRET(I)
      RETURN
      END
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      SUBROUTINE COST(WIDTH,ANHRS)
C
C******   CALCULATES AVERAGE ANNUAL TOTAL COST OF FIELD MACHINERY
C******   WRITTEN BY F. J. WOLAK  1980
C
C******   WIDTH=ARRAY CONTAINING REQUIRED MACHINE SIZES
C******   ANHRS=THE ANNUAL HOURS OF USE FOR EACH MACHINE
C
      COMMON/BLK2/HRSLA(11),RE(33),HTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,8),
     *PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK5/SACRE(55),EFC(55)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK7/OPER(33),CROP1(30),AN(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,RWWD,OPR,TACRE
      COMMON/BLK12/SL(33),TOTRF(33)
      COMMON/BLK13/HPTRACS,ROWCOM1,HPTRACL
      COMMON/BLK18/NPRINT,ISIU
      COMMON/BLK15/IR,TR,INSR,HRST,FUELRT,LABORRT
      COMMON/BLK52/FUELTOT(33),FUELFRM
      COMMON/BLK60/IZBEET,IZCOMB,ICMPLT,IALF,IROW
      COMMON/BLK61/COSTPA
      DIMENSION WIDTH(33),ANHRS(33),NUNIT(33)
      REAL IINT,INTT,ISHT,INSR,IR,ISH
      DO 1 I=1,33
    1 NUNIT(I)=0
C******   ASSIGN IMPLEMENT(OPERATION) HOURS TO TRACTORS AND COMBINE
      DO 23 IO=1,29
C******   IF NOT A COMBINE OPERATION  GO TO 24
      IF(IO.LT.25)GO TO 24
C******   COMBINE OPERATION  CALCULATE RUNNING TOTAL OF COMBINE TIME
      ANHRS(30)=ANHRS(30)+ANHRS(IO) $ GO TO 23
C******   IF OPERATION IS ASSIGNED TO UTILITY TRACTORS  GO TO 25
   24 IF(IO.EQ.8.OR.IO.GT.10)GO TO 25
C******   TILLAGE TRACTOR HOURS CALCULATION
      ANHRS(31)=ANHRS(31)+ANHRS(IO) $ GO TO 23
C******   UTILITY TRACTOR HOUR CALCULATION
   25 ANHRS(32)=ANHRS(32)+ANHRS(IO)
   23 CONTINUE
C******   ATTEMPT TO REDUCE THE NUMBER OF IMPLEMENTS BY COMBINING FIELD
C******     OPERATIONS TO ONE IMPLEMENT
      DO 2 I=1,N $ IO=IOPER(I)
C******   I=FIELD OPERATION 1 THRU N
C******   IO=IMPLEMENT(OPERATION) 1 THRU 33
C******   1)IF IMPLEMENT IS DISK HARROWS  2)IF IMPLEMENT IS PLOW&PACKER
C******    3)IF IMPLEMENT IS FIELD CULTIVATER FIRST PASS
      IF(IO.EQ.3)EFC3=EFC(I)
      IF(IO.EQ.2)EFC2=EFC(I)
      IF(IO.EQ.6)EFC6=EFC(I)
C******   IF NAVY BEANS ARE HARVESTED THEN A PULLER/WINDROWER IS NEEDED
C******   THE PULLER ISN'T SCHEDULED IN THE WEEKLY FASHION
      IF(IO.EQ.29)NUNIT(24)=1
C******   DETERMINE NUMBER OF UNITS REQUIRED
      NUNIT(IO)=1
C******   HAYBINE, RAKE, & BALER NUMBER MAY BE GREATER THAN 1
      IF(IO.EQ.15.OR.IO.EQ.17.OR.IO.EQ.21.AND.IALF.GT.0)NUNIT(IO)=1+IALF
    2 CONTINUE
C******   IF BOTH DISK HARROW & DISK ARE REQUIRED
      IF(NUNIT(3).GT.0.AND.NUNIT(4).GT.0)GO TO 3
C******   IF BOTH PLOW AND PLOW&PACKER ARE REQUIRED
    6 IF(NUNIT(1).GT.0.AND.NUNIT(2).GT.0)GO TO 4
C******   IF BOTH FIRST AND SECOND PASS FIELD CULTIVATIONS ARE NEEDED
    7 IF(NUNIT(6).GT.0.AND.NUNIT(7).GT.0)GO TO 8
      GO TO 5
C
C******   MULTIPLE DISK SECTION
C******   WHAT SPEED IS NEEDED IF THE POSSIBLY LARGER DISK IS USED
    3 SPD=EFC3*8.25/(WIDTH(4)*PE(3)*EFF(3))
C******   IF SPEED(SPD) IS OUT OF BOUNDS TWO SEPERATE DISKS ARE NEEDED
      IF(SLOW(3).GT.SPD)GO TO 6
C******   ADD HOURS AND FUEL USE OF THE TWO DISKING OPERATIONS
      ANHRS(4)=ANHRS(4)+ANHRS(3) $ NUNIT(3)=0
      FUELTOT(4)=FUELTOT(4)+FUELTOT(3) $ GO TO 6
C
C******   MULTIPLE PLOW SECTION
C******   WHAT SPEED IS NEEDED IF THE POSSIBLY LARGER PLOW IS USED
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    4 SPD=EFC2*8.25/(WIDTH(1)*RE(2)*EFF(2))
C*****     IF THE SPEED CONSTRAINT IS VIOLATED TWO PLOWS ARE NEEDED
      IF(SLOW(2).GT.SPD)GO TO 7
C*****     ADD HOURS AND FUEL OF TWO PLOWING OPERATIONS
      ANHRS(1)=ANHRS(1)+ANHRS(2) $ NUNIT(2)=0
      FUELTOT(1)=FUELTOT(1)+FUELTOT(2) $ GO TO 7
C
C*****     FIELD CULTIVATER SECTION
C*****     CALCULATE SPEED OF THE POSSIBLY LARGER 2ND PLOW
    6 SPD=EFC6*8.25/(WIDTH(7)*RE(6)*EFF(6))
C*****     IF THE SPEED CONSTRAINT IS VIOLATED 2 FLD CULT ARE NEEDED
      IF(SLOW(6).GT.SPD)GO TO 5
C*****     ADD HOURS AND FUEL USE OF TWO FIELD CULTIVATORS
      ANHRS(7)=ANHRS(7)+ANHRS(6) $ NUNIT(6)=0
      FUELTOT(7)=FUELTOT(6)+FUELTOT(7)
C*****     IF HP IS GREATER THAN 150 A 4 WHEEL DRIVE IS USED (WOLAK 1980)
    5 IF(HPTRACL.GT.150)GO TO 33
C*****     TILLAGE TRACTOR IS A TWO WHEEL DRIVE
      NUNIT(31)=1 $ GO TO 34
C*****     TILLAGE TRACTOR IS A FOUR WHEEL DRIVE
   33 NUNIT(31)=0 $ NUNIT(33)=1 $ ANHRS(33)=ANHRS(31)
C*****       1)IS A COMBINE NEEDED 2)IS A UTILITY TRACTOR NEEDED
   34 NUNIT(30)=NUNIT(32)=0
      IF(ANHRS(30).GT.0.0)NUNIT(30)=1
      IF(ANHRS(32).GT.0.0)NUNIT(32)=1
C*****     DEPRECIATION, INTEREST, INSURANCE, HOUSING, REPAIRS, PRICE,
C*****       AND FUEL TOTALS ARE SET TO ZERO
      DPRCT=INTT=ISHT=REPT=PRCT=FUELT=0
C*****     WHEAT, SOYBEANS, AND OATS USE THE SAME COMBINE HEAD
      IF(NUNIT(26).EQ.0.AND.NUNIT(27).EQ.0.AND.NUNIT(29).EQ.0)GO TO 36
      ANHRS(26)=ANHRS(26)+ANHRS(27)+ANHRS(29)
      NUNIT(26)=1 $ NUNIT(27)=NUNIT(29)=0
      FUELTOT(26)=FUELTOT(26)+FUELTOT(27)+FUELTOT(29)
C*****     PRINT INFO FOR 3 HIGHEST OUTPUT LEVELS
   36 IF(NPRINT.EQ.1)GO TO 30
      IF(ISIU.EQ.0)GO TO 60
      SIFULRT=FUELRT/3.785412
      PRINT 61,IR,SIFULRT $ PRINT 26
      GO TO 30
   60 PRINT 27,IR,FUELRT $ PRINT 26
C*****     DO LOOP TO COST EACH PIECE OF EQUIPTMENT
   30 DO 10 I=1,33
C*****     IF IMPLEMENT(OPERATION) IS NOT USED
      IF(NUNIT(I).EQ.0)GO TO 10
      IF(ANHRS(I).EQ.0)GO TO 10
C*****     IF IMPLEMENT ISN'T A COMBINE OR TRACTOR
      IF(I.LT.30)GO TO 17
C*****     IF IMPLEMENT ISN'T A COMBINE
      IF(I.GT.30)GO TO 20
C*****     DETERMINE PRICE OF COMBINE
      J=ROWCOM1/2.0 $ PRC=PRICE(I,J) $ FUEL=0.0 $ GO TO 21
C*****     IF IMPLEMENT ISN'T A TILLAGE TRACTOR
   20 IF(I.GT.31)GO TO 22
C*****     PRICE THE 2-WHEEL DRIVE TILLAGE TRACTOR (WOLAK 1980)
      PRC=HPTRACL*225.575 $ FUEL=0.0 $ GO TO 21
C*****     IF IMPLEMENT ISN'T A UTILITY TRACTOR
   22 IF(I.GT.32)GO TO 35
C*****     PRICE UTILITY TRACTOR  (WOLAK 1980)
      PRC=HPTRACS*225.575*0.48 $ FUEL=0.0 $ GO TO 21
C*****     PRICE 4-WHEEL DRIVE TILLAGE TRACTOR  (WOLAK 1980)
   35 PRC=HPTRACL*258.376 $ FUEL=0.0 $ GO TO 21
C*****     IF IMPLEMENT(OPERATION) ISN'T A COMBINE HARVEST
   17 IF(I.LE.24)GO TO 11
C*****     J=COMBINE SIZE 1 THRU 4 (SIZES IN ARRAY)
      J=ROWCOM1/2.0 $ GO TO 13
C*****     FIND POSITION IN SIZE ARRAY OF CHOSEN WIDTH  THEN MATCH
C*****       LOCATION TO THE CORRESPONDING PRICE
C*****         IF ONE AVAILABLE SIZE IMPLEMENT GO TO PRICE DETER
   11 IEND=IM(I)
      IF(IEND.GT.1)GO TO 40
      J=IEND $ GO TO 13
   40 DO 12 J=1,IEND
      IF(WIDTH(I).LE.(SIZE(I,J)+.01))GO TO 13
   12 CONTINUE
   13 PRC=PRICE(I,J)*NUNIT(I)
C*****     IF IMPLEMENT(OPERATION) ISN'T NAVY BEAN HARVEST
      IF(I.NE.28)GO TO 32
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C*****     IF NAVY BEANS ARE HARVESTED AND A GRAIN HEAD ISN*T USED THEN
C*****      THE FULL PRICE OF NACVY BEAN HEAD IS USED  IF A GRAIN HEAD HAS
C*****      BEEN PURCHASES THEN ONLY THE WINDROW PICKUP IS NEEDED
      IF(NUNIT(26).EQ.0)GO TO 32
      PRC=PRC-PRICE(26,J)*NUNIT(I)
   32 FUEL=FUELTOT(I)*FUELRT $ FUELT=FUELT+FUEL
C*****     RUNNING TOTAL OF PRICE
   21 PRCT=PRCT+PRC
C*****     LIFE OF MACHINE IS 8 YAERS OR WHEN WORN OUT
      RLIFE=AMIN1(8.,(SL(I)/ANHRS(I)))
C*****     DEPRECIATION IS STRAIGHT LINE  10 SALVAGE  MAXIMUM 8 YEARS OR
C*****      SERVICE LIFE  RUNNING TOTAL IS CALCULATED
      DPRC=0.9*PRC/RLIFE $ DPRCT=DPRCT+DPRC
C*****     AVERAGE INTERFST ACCOUNTING FOR EQUIPTMENT WHICH IS USED UP
C*****      IN LESS THAN 8 YEARS
      IINT=AMAX1(1.,(8./RLIFE))*1.1*PRC*IR/2. $ INTT=INTT+IINT
C*****     INSURANCE ACCOUNTING FOR FAST WEAR OUT
      RINSUR=AMAX1(1.,(8./RLIFE))*PRC*INSR $ ISHT=ISHT+RINSUR
C*****     HOUSING IS BASED UPON INITIAL PRICE ONLY
      HOUSE=PRC*HRST $ ISHT=ISHT+HOUSE
C*****     ADD INSURANCE AND HOUSING
      ISH=RINSUR+HOUSE
C*****     REPAIRS BASED UPON YEARLY USE ONLY
      RREP=ANHRS(I)/SL(I)*PRC*TOTRP(I) $ REPT=REPT+RREP
C*****     AVERAGE YEARLY TOTAL COST FOR MACHINE
      SUM=DPRC+IINT+ISH+RREP+FUEL
C*****     PRINT INFO FOR 3 HIGHEST OUTPUT LEVELS
      IF(NPRINT.EQ.1)GO TO 10
      PRINT 15,OPER(I),NUNIT(I),ANHRS(I),PRC,DPRC,IINT,ISH,RREP,FUEL,SUM
   10 CONTINUE
C*****     CALCULATE FARMS AVERAGE YEARLY TOTAL MACHINERY COST & COST/ACR
      SUM=DPRCT+INTT+ISHT+REPT+FUELT
      COSTPA=SUM/TACRE
C*****     PRINT INFO FOR 3 HIGHEST OUTPUT LEVELS
      IF(NPRINT.EQ.1)GO TO 31
      PRINT 28
      PRINT 16,PRCT,DPRCT,INTT,ISHT,REPT,FUELT,SUM
   15 FORMAT(* *,19X,A10,I6,3X,8F10.2)
   16 FORMAT(* *,48X,7F10.2)
   27 FORMAT(*1*,57X,*MACHINERY COST ANALYSIS*//31X,*INTEREST RATE=*,
     +F5.2,*  FUEL COST=*,F5.2,9H $/GALLON,*  8 YEAR DEPRECIATION*,
     +* SCHEDULE*//)
   26 FORMAT(* *,20X,*IMPLEMENT QUANTITY    USE HRS   PRICE    DEPRCTN*,
     +2X,*INTEREST   INS&HOUS  REPAIRS      FUEL      TOTAL*/)
   28 FORMAT(* *,48X,7(10H ---------))
   61 FORMAT(*1*,57X,*MACHINERY COST ANALYSIS*//32X,*INTEREST RATE=*,
     +F5.2,*  FUEL COST*,F5.2,8H $/LITER,*  8 YEAR DEPRECIATION*,
     +* SCHEDULE*//)
   31 RETURN
      END
```

```
      BLOCK DATA
C
C*****    SETS MACHINERY PARAMETERS
C*****    WRITTEN BY DEVINDAR SINGH 1978
C*****    MODIFIED AN NEW DATA SUPPLIED BY FJ WOLAK 1980
C
      COMMON/BLK1/ISTART(55),IEND(55),IEND2(55),IDATE(55),PCTHRD,
     +ISTARTY,IEND2Y
      COMMON/BLK2/ HRSDA(11),RL(33),BTCAP(5),ALFYLD
      COMMON/BLK3/IOPER(55),ICROP(55),ITRAC1(33),ACRE(55)
      COMMON/BLK4/SLOW(33),FAST(33),SPEED(33),SIZE(33,8),
     1PRICE(33,8),IGROUP(33),IM(33)
      COMMON/BLK6/DRAFT(33),EFF(33),TE(33),EPA(33)
      COMMON/BLK7/OPER(33),CROP1(30),AN(33),ANDRAFT(33),OPERTN(33)
      COMMON/BLK8/N,NF,NFF,RWWD,DPR,TACRE
      COMMON/BLK12/SL(33),TOTRP(33)
      COMMON/BLK15/IR,TR,INSP,HSRT,FUELRT,LABORRT
      COMMON/BLK16/RA1,RA2
      COMMON/BLK21/CBEFF(5,4),CBSPEED(5,4)
      COMMON/BLK65/SISIZE(33),SICRUNT(33)
      REAL INSP,IR,LABORRT
C
C  1=MOLDBOARD PLOW        12=GRAIN DRILL          23=WINDROWER
C  2=MF PLOW AND PACKER    13=ROW CULTIVATOR       24=BEAN PULLER
C  3=DISK HARROW           14=ROTARY HOE           25=CORN HARVEST
C  4=DISK                  15=HAYBNE               26=WHEAT HARVEST
C  5=CHISEL PLOW           16=PLANTER              27=SOYBEAN HARVEST
C  6=FIELD CULT DEEP       17=BALER                28=NAVYBEAN HARVEST
C  7=FIELD CULT/SPRAYER    18=BLANK                29=OAT HARVEST
C  8=BEET TOPPER           19=ROTARY CUTTER        30=COMBINE
C  9=BEET LIFTER           20=FERTILIZER SPRDR     31=TILLAGE TRACTOR
C 10=NO TILL PLANTER       21=RAKE                 32=UTILITY TRACTOR
C 11=NH3 APPLICATOR        22=SPRAYER              33=4-WHEEL DRIVE TRACTOR
C
C*****    BEGINNING DATES OF EACH WEEK  ONLY THESE DATES MAY BE USED
      DATA(IDATE(J),J=1,52)/102,109,116,123,130,206,213,220,227,306,313,
     +320,327,403,410,417,424,501,508,515,522,529,605,612,619,626,703,
     +710,717,724,731,807,814,821,828,904,911,918,925,1002,1009,1016,
     +1023,1030,1106,1113,1120,1127,1204,1211,1218,1225/
C*****    DRAFT DATA
      DATA(DRAFT(J),J=1,33)/1115.,1200.,340.,260.,720.,260.,208.,1188.,
     +1404.,540.,400.,170.,375.,275.,200.,385.,6.72,0.,200.,60.,80.,
     +40.,0.,475.,9*0.00/
C*****    FIELD EFFICIENCIES
      DATA(EFF(J),J=1,24)/.80,.80,.80,.85,.85,.85,.85,.70,.70,.55,.65,
     +.70,.80,.80,.75,.55,.65,.0,.70,.70,.80,.65,.0,.80/
C*****    TRACTIVE EFFICIENCIES
      DATA(TE(J),J=1,24)/.8,.8,.75,.75,.8,.75,.6,.75,.75,.72,.72,
     +.72,.72,.72,.8,.72,.8,0.00,.8,.8,.8,.72,.8,.8/
C*****    MINIMUM ALLOWABLE OPERATING SPEEDS
      DATA(SLOW(J),J=1,24)/3.4,3.4,3.,3.,4.,4.,4.,2.,2.,3.,3.,2.5,2.5,
     +5.0,3.,3.,2.0,0.0,3.,2.,4.,2.,0.0,2./
C*****    MAXIMUN ALLOWABLE OPERATING SPEEDS
      DATA(FAST(J),J=1,24)/4.5,4.5,5.,5.,6.,6.,6.,5.5,5.5,6.,6.,6.,5.,
     +10.,6.,6.,5.,0.,6.,5.,5.,5.,0.,5./
C*****    ROW SPACING
      DATA RWWD/2.5/
C*****    BEET HARVEST SYSTEM CAPACITY (ACRES/HR)
      DATA(BTCAP(K),K=1,5)/2.0,2.75,3.5,4.25,4.65/
C*****    COMBINE FIELD EFFICIENCY
      DATA CBEFF/0.70,.75,.70,.70,.75,.65,.75,.70,.67,.75,.63,.75,.70,
     +.65,.75,.60,.70,.65,.63,.70/
C*****    COMBINE SPEED
      DATA CBSPEED/3.25,2.75,2.5,5.0,2.75,3.0,3.0,2.75,5.00,3.0,
     + 2.75,3.5,3.25,5.00,3.5,2.75,3.5,3.25,5.0,3.5/
C
C*****    TYPES OF OPERATIONS
C      K  TYPE OF OPERATION
C      1  STALK SHREDDING, FERTILIZER SPREADING AND SPRAYING OPERATIONS
C      2  TILLAGE, PLANTING, CULTIVATION AND AMMONIA APPLICATION OPERATIO
C      3  NILL
C      4  SOYBEANS HARVESTING
C      5  WHEAT HARVESTING
C      6  ALFALFA HARVESTING
C      7  FIELD BEAN HARVESTING
C      8  CORN HARVESTING, EQUIVALENT TO 1
C      9  WINTER OPERATIONS, EQUIVALENT TO 1
```

```
C     10  OAT HARVESTING
C     11  SUGAR BEET HARVESTING
C
C*****    IDENTIFICATION OF IMPLEMENTS FOR OPERATION TYPE
      DATA(ITRAC1(J),J=1,33)/7*2,2*11,5*2,6,2,2*6,2*1,6,2*1,
     * 7,8,5,4,7,10,4*2/
C*****    HOURS AVAILABLE FOR EACH TYPE OF OPERATION
      DATA(HRSDA(K),K=1,11)/3*12.,8.,8.,9.,6.,10.,12.,7.,11./
C*****     MACHINE RELIABILITY
      DATA(RE(K),K=1,33)/33*1.00/
C
C*****    MACHINE SIZE AND DRAFT UNITS
C*****    IGROUP(1) SIZE IN FEET       DRAFT IN LB/FT
C*****    IGROUP(2) SIZE IN ROWS       DRAFT IN LB/ROW
C*****    IGROUP(3) SIZE IN BOTTOMS    DRAFT IN LB/FT
C*****    IGROUP(5) SIZE IN ROWS       DRAFT IN LB/ROW
C*****    IGROUP(7) SIZE IN FEET
C*****    IDENTIFY THE GROUP FOR EACH OPERATION
      DATA(IGROUP(K),K=1,29)/3,3,1,1,1,1,1,2,2,5,5,1,5,5,1,5,1,1,1,1,1,
     11,5,5,7,7,7,7,7/
C*****    IM=THE NUMBER OF SIZES AVAILABLE FOR EACH IMPLEMENT
      DATA(IM(J),J=1,30)/8,8,8,8,8,8,8,3,3,4,4,2,4,4,1,4,1,0,5,1,1,1,
     1 0,3,4,4,4,4,4,4/
C*****    SIZE OF EACH IMPLEMENT AVAILABLE
      DATA(SIZE(1,K),K=1,8)/3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0/
      DATA(SIZE(2,K),K=1,8)/3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0/
      DATA(SIZE(3,K),K=1,8)/11.42,14.25,17.08,21.33,25.58,30.08,36.,40./
      DATA(SIZE(4,K),K=1,8)/11.42,14.25,17.08,21.33,25.58,30.08,36.,40./
      DATA(SIZE(5,K),K=1,8)/8.,10.,11.,13.,15.,17.,19.,21./
      DATA(SIZE(6,K),K=1,8)/12.5,15.5,18.5,21.5,25.5,28.5,34.5,40.5/
      DATA(SIZE(7,K),K=1,8)/12.5,15.5,18.5,21.5,25.5,28.5,34.5,40.5/
      DATA(SIZE(12,K),K=1,2)/13.,20./
      DATA(SIZE(13,K),K=1,4)/4.0,6.0,8.0,12.0/
      DATA(SIZE(14,K),K=1,4)/4.,6.,8.,12./
      DATA SIZE(15,1)/12./
      DATA(SIZE(16,K),K=1,4)/4.0,6.0,8.0,12.0/
      DATA(SIZE(10,K),K=1,4)/4.0,6.0,8.0,12.0/
      DATA(SIZE(11,K),K=1,4)/4.,6.,8.,12./
      DATA SIZE(17,1)/6./
      DATA(SIZE(19,K),K=1,5)/5.,6.,7.,13.67,15./
      DATA SIZE(20,1)/60.0/
      DATA SIZE(21,1)/12.0/
      DATA SIZE(22,1)/30.0/
      DATA(SIZE(24,K),K=1,3)/4.0,6.0,8.0/
      DATA(SIZE(25,K),K=1,4)/5.0,10.0,15.0,20.0/
      DATA(SIZE(26,K),K=1,4)/10.0,13.0,13.0,16.0/
      DATA(SIZE(27,K),K=1,4)/10.0,13.0,13.0,16.0/
      DATA(SIZE(28,K),K=1,4)/4.25,5.25,6.30,7.65/
      DATA(SIZE(30,K),K=1,4)/2.0,4.0,6.0,8.0/
      DATA(SIZE(8,K),K=1,3)/2.,3.,4./
      DATA(SIZE(9,K),K=1,3)/2.,3.,4./
      DATA(SIZE(29,K),K=1,4)/10.0,13.0,13.0,16.0/
C*****    SERVICE LIFE OF EACH MACHINE IN HOURS
      DATA(SL(K),K=1,33)/9*2000.,1000.,2000.,1000.,2*2000.,2*1000.,
     *3*2000.,1200.,2000.,1200.,8*2000.,10000.,4800.,10000./
C*****    TOTAL REPAIRS OVER SERVICE LIFE OF MACHINE ( OF PRICE)
      DATA(TOTRP(K),K=1,33)/2*.8,5*.65,.6,.8,3*.75,2*.55,1.8,.75,
     *2*.6,.6,5*.75,6*.33,3*.9/
C*****    INTEREST,TAX,INSURANCE,HOUSING,FUEL COST
      DATA IR,TP,INSR,HSRT,FUELRT/.13,0.0,.0025,.0075,.75/
C*****    PRICE OF EACH AVAILABLE MACHINE SIZE
      DATA(PRICE(1,K),K=1,8)/1889.,7425.,8594.,9763.,10932.,12101.,
     *15068.,16233./
      DATA(PRICE(2,K),K=1,8)/1889.,7425.,8594.,9763.,10932.,12101.,
     *15066.,16233./
      DATA(PRICE(3,K),K=1,8)/4371.,4909.,8403.,9511.,12014.,14781.,
     *19708.,21029./
      DATA(PRICE(4,K),K=1,8)/4371.,4909.,8403.,9511.,12014.,14781.,
     *19708.,21029./
      DATA(PRICE(5,K),K=1,8)/1987.,2189.,3082.,3284.,3543.,3818.,
     *7010.,7212./
      DATA(PRICE(6,K),K=1,8)/2274.,2690.,3701.,4232.,6983.,7277.,
     *8977.,9460./
      DATA(PRICE(7,K),K=1,8)/2274.,2690.,3701.,4232.,6983.,7277.,
     *8977.,9460./
      DATA(PRICE(8,K),K=1,3)/6315.,7490.,8665./
      DATA(PRICE(9,K),K=1,3)/18948.,24644.,25458./
```

```
      DATA(PRICE(11,K),K=1,4)/2000.,2400.,2800.,3200./
      DATA(PRICE(12,K),K=1,2)/4011.,8391./
      DATA(PRICE(13,K),K=1,4)/1450.,2597.,3400.,4717./
      DATA(PRICE(14,K),K=1,4)/1559.,2219.,3070.,5343./
      DATA PRICE(15,1)/7950./
      DATA(PRICE(16,K),K=1,4)/6321.,10671.,14297.,22438./
      DATA PRICE(17,1)/6245./
      DATA(PRICE(19,K),K=1,5)/1507.,1568.,1884.,4202.,6070./
      DATA PRICE(20,1)/2500./
      DATA PRICE(21,1)/1754./
      DATA PRICE(22,1)/2640./
      DATA(PRICE(24,K),K=1,3)/6235.,7996.,11616./
      DATA(PRICE(25,K),K=1,4)/4248.,9037.,12740.,16114./
      DATA(PRICE(26,K),K=1,4)/5300.,5700.,5700.,6124./
      DATA(PRICE(27,K),K=1,4)/5300.,5700.,5700.,6124./
      DATA(PRICE(28,K),K=1,4)/7455.,7855.,7855.,8549./
      DATA(PRICE(29,K),K=1,4)/5300.,5700.,5700.,6124./
      DATA(PRICE(30,K),K=1,4)/24898.,36179.,45641.,57124./
C*****    ALPHANUMERIC DATA IMPLEMENT NAMES
      DATA(OPER(K),K=1,33)/10HMB PLOW   ,10HPLOW+PCKR ,10HDISK HRRW ,
     +10HDISK      ,10HCHISEL PLW,10HFLD CULT 1,10HFLD CULT 2,
     +10HBEET TPPER,10HBEET LFTR ,10HNOTILL PLT,10HNH3 APPLIC,
     +10HGRAIN DRLL,10HROW CULT  ,10HROTARY HOE,10HHAYBINE   ,
     +10HPLANTER   ,10HBALER FRST,10HBALER SCND,10HROTRY CUT ,
     +10HFERT SPRDR,10HRAKE      ,10HSPRAYER   ,10HWINDROWER ,
     +10HBEAN PULLR,10HCORN HEAD ,10HGRAIN HEAD,10HGRAIN HEAD,
     +10HPCKUP HEAD,10HGRAIN HEAD,10HCOMBINE   ,10HTILL TRCTR,
     +10HUTIL TRCTR,10H4 WHEEL TR/
C*****    OPERATION NAMES
      DATA(OPERTN(K),K=1,33)/10HMB PLOWING,10HPLOW+PACK ,10HDISK HAROW,
     +10HDISKING   ,10HCHISL PLOW,10HFLD CULT 1,10HFLD CULT 2,
     +10HTOPNG BEET,10HLFT BEETS ,10HNT ROW PLT,10HNH3 APPLIC,
     +10HPLANT GRN ,10HROW CULT  ,10HROTARY HOE,10HALFA HRVST,
     +10HROW PLANT ,10HBALE FRST ,10HBALE SCND ,10HROTARY CUT,
     +10HFERT SPRD ,10HRAKE      ,10HSPRAY     ,10HWINDROW   ,
     +10HBEAN PULLR,10HHRVST CORN,10HHRST WHEAT,10HHRVST SOYS,
     +10HHRVST NAVY,10HHRVST OATS,4*10H          /
C
C******   INPUT CROP MATRIX
C******   COLUMNS
C******    1=CORN ONE               8=NAVY BEANS TWO
C******    2=CORN TWO               9=SUGAR BEETS ONE
C******    3=WHEAT ONE             10=SUGAR BEETS TWO
C******    4=WHEAT TWO             11=SOY BEANS ONE
C******    5=OATS ONE              12=SOY BEANS TWO
C******    6=OATS TWO              13=ALFALFA ONE (7)
C******    7=NAVY BEANS ONE        14=ALFALFA TWO (FIRST YEAR SEEDING)
C******   ROWS
C******   15=CORN HARVEST (1)     18=NAVY BEAN HARVEST (4)
C******   16=WHEAT HARVEST (2)    19=SUGAR BEET HARVEST (5)
C******   17=OAT HARVEST (3)      20=SOY BEAN HARVEST (6)
C
C*****    CROP NAMES
      DATA(CROP1(K),K=1,21)/10HCORN ONE  ,10HCORN TWO  ,10HWHEAT ONE ,
     +10HWHEAT TWO ,10HOATS ONE  ,10HOATS TWO  ,10HNAVY BNS 1,
     +10HNAVY BNS 2,10HSGR BTS 1 ,10HSGR BTS 2 ,10HSOY BNS 1 ,
     +10HSOY BNS 2 ,10HALFALFA 1 ,10HALFALFA 2 ,10HCORN      ,
     +10HWHEAT     ,10HOATS      ,10HNAVY BEANS,10HSUGAR BEET,
     +10HSOY BEANS ,10HALFALFA   /
C*****    ALPHANUMERIC OF IMPLEMENT SIZE
      DATA(AN(K),K=1,33)/4HBOTM,4HBOTM,4HFEET,4HFEET,4HFEET,4HFEET,
     +4HFEET,4HROWS,4HROWS,4HROWS,4HROWS,4HFEET,4HROWS,4HROWS,4HFEET,4HR
     +OWS,4HFEET,4H    ,4HFEET,4HFEET,4HFEET,4HFEET,4HFEET,4HROWS,4HROWS
     +,4HFEET,4HFEET,4HROWS,4HFEET,4HROWS,3*4H HP /
C*****    ALPHANUMERIC OF DRAFT UNITS
      DATA(ANDRAFT(K),K=1,33)/7*6HLB/FT ,4*6HLB/ROW,6HLB/FT ,
     +2*6HLB/ROW,6HLB/FT ,6HLB/ROW,6HHP/TON,6H      ,4*6HLB/FT ,
     +2*6HLB/ROW,9*6H      /
      DATA(SISIZE(K),K=1,33)/2*5HBOTM ,5*5HMETER,4*5HROWS ,5HMETER,
     +2*5HROWS ,5HMETER,5HROWS ,5HMETER,5H     ,5*5HMETER,2*5HROWS ,
     +2*5HMETER,5HROWS ,5HMETER,5HROWS ,3*5H KW  /
      DATA(SIDRUNT(K),K=1,33)/7*5HN/M  ,4*5HN/ROW,5HN/M  ,2*5HN/ROW,
     +5HN/M  ,5HN/ROW,5HN/MG ,5H     ,4*5HN/M  ,2*5HN/ROW,9*5H     /
      END
```

APPENDIX B

INPUT DATA FORMAT

Table A.1 Input Data Format

Line Number	Variable	Format
1	RA1,RA2	2A10
2	ISIU, TACRE	I1,F10.2
3-1+	I,ACRE(I)	I2,F10.2
1+1-m+	I,J,ORDER(I,J)	2I2,F10.2
m+1	PCTHRD,ALFYLD	2F10.2
m+2-n+	ISTART,IEND,IOPER,ICROP,IEND2	2I5,2I3,I5
n	NPRINT,NFF,IBEGIN,IFINSH,ICMPLT,IZCOMB, IZBEET,TRHPBIG	7I3,F10.2
Tape 1*	T,B,A,C	F8.4

+Last line of data must equal zero to signal the end of section.

*Available workday data. Data is read from Tape 1 input file.

T: % of week available for tillage, planting or sugar beet harvest
B: % of week available for combine operations except corn harvest
A: % of week available for alfalfa harvest operations
C: % of week available for corn harvest, fertilization and spraying

Farm input data.

RA1,RA2: Crop rotation name
ISIU: Unit Indicator (0-English, 1-SI)
TACRE: Total crop area considered
I,ACRE(I): Percentage of total area in each crop I (see BLKDATA subroutine)
I,J,ORDER(I,J): Supply-Demand matrix for harvested ground (see section 2.6, BLKDATA subroutine, and Figure A.1)
PCTHRD: Percentage of extra laborer available
ALFYLD: Alfalfa yield (t/acre or Mg/ha)
ISTART: Starting date of field operation (month/day)
IEND: Ending date of field operation (month/day)
IOPER: Field operation number (see BLKDATA subroutine)
ICROP: Crop number (see BLKDATA subroutine)
IEND2: Date for which field work must be halted in the fall
NPRINT: Output print control variable (1-summary statistics, 2-#1 plus, machinery set and cost tables; 3-#2 plus, weekly work schedule; 4-#3 plus, combine and tractor sizing information
NFF: Output print control variable (0-28 year run, selecting 0-2 machinery sets; 1-less than 28 year run, selecting 0-2 machinery sets; 2-less than 28 year run, testing a specific machinery set
IBEGIN: Starting year of weather data to be considered by model
IFINSH: Ending year of weather data to be considered by model
ICMPLT: 0-selection of machinery set, 1-testing of specific machinery set
IZCOMB: Combine size (rows)
IZBEET: Sugar beet harvest capacity (level 1-5, see Table 3.4)
TRHPBIG: Tillage tractor power level

Figure A.1 Supply (harvested crop land) - Demand (first field operation) Matrix+

Demand(j) \ Supply(i)	1 Corn	2 Wheat	3 Oats	4 Navy beans	5 Sugar beets	6 Soybeans	7 Alfalfa
1 Corn 1							
2 Corn 2							
3 Wheat 1							
4 Wheat 2							
5 Oats 1							
6 Oats 2							
7 Navy beans 1							
8 Navy beans 2							
9 Sugar beets 1							
10 Sugar beets 2							
11 Soybeans 1							
12 Soybeans 2							
13 Alfalfa 1							
14 Alfalfa 2							

+Used to determine values for data variable ORDER(I,J), see Table A.1 I=Supply number (1-7), J=Demand number (1-14), ORDER(I,J) = value in matrix cell (i,j), (0.0-1.0). Value in each cell represents a percent of the total crop acres.

APPENDIX C

MODEL OUTPUT FOR A C-NB-W-BT FARM; USING 28 YEARS OF AVAILABLE WORKDAY DATA, SUMMARY STATISTICS ONLY

APPENDIX C

MODEL OUTPUT FOR A C-NB-W-BT FARM: USING 28 YEARS OF AVAILABLE WORKDAY DATA, SUMMARY STATISTICS ONLY

```
C-NB-W-BT
1   161.87
 1    0.25
 7    0.25
 3    0.25
 9    0.25
15    0.25
16    0.25
18    0.25
19    0.25
00
 1 7    0.25
 4 3    0.25
 2 9    0.25
 5 1    0.25
0000
  0.5
  717   807 26 16
  828  1002 28 18
  828  1004 20  3
  828  1009  3  3
  925  1009  0  3
  925  1009 12  3
 1002  1113  8 19
 1002  1113  9 19
 1009  1113 25 15
  828  1127 20  9
  828  1127  1  9
 1004  1127  4  7
  925  1127 20  1
  320   424 20  3
  501   508 22  3
  410   515  6  9
  410   515  7  9
  410   515 16  9
  410   515 22  9
  925   515  1  1  1127
  424   515  6  1
  424   515 16  1
  424   515 22  1
 1009   619  1  7  1127
  410   619  3  7
  515   619  6  7
  522   619  7  7
  522   619 16  7
  522   619 13  9
  529   619 11  1
  529   619 13  1
  605   626 11  9
  612   703 13  9
  619   710 13  7

  1
```

ROTATION=C-NB-W-BT

OPERATION NUMBER	OPERATION	CROP	STARTING DATE	FINISHING DATE	FIELD WORK HOURS/DAY	DISCONTINUE FOR THE PERIOD OF
1	HRST WHEAT	WHEAT	717	806	8.0	
2	HRVST NAVY	NAVY BEANS	828	1001	6.0	
3	FERT SPRD	WHEAT ONE	828	1008	12.0	
4	DISK HAROW	WHEAT ONE	828	1008	12.0	
5	FLD CULT 1	WHEAT ONE	925	1008	12.0	
6	PLANT GRN	WHEAT ONE	925	1008	12.0	
7	TOPNG BEET	SUGAR BEET	1002	1112	11.0	
8	LFT BEETS	SUGAR BEET	1002	1112	11.0	
9	HRVST CORN	CORN	1009	1112	10.0	
10	FERT SPRD	SGR BTS 1	828	1126	12.0	
11	MB PLOWING	SGR BTS 1	828	1126	12.0	
12	DISKING	NAVY BNS 1	1009	1126	12.0	
13	FERT SPRD	CORN ONE	925	1126	12.0	
14	FERT SPRD	WHEAT ONE	320	423	12.0	
15	SPRAY	WHEAT ONE	501	507	12.0	
16	FLD CULT 1	SGR BTS 1	410	514	12.0	
17	FLD CULT 2	SGR BTS 1	410	514	12.0	
18	ROW PLANT	SGR BTS 1	410	514	12.0	
19	SPRAY	SGR BTS 1	410	514	12.0	
20	MB PLOWING	CORN ONE	925	514	12.0	1127TO-409
21	FLD CULT 1	CORN ONE	424	514	12.0	
22	ROW PLANT	CORN ONE	424	514	12.0	
23	SPRAY	CORN ONE	424	514	12.0	
24	MB PLOWING	NAVY BNS 1	1009	618	12.0	1127TO-409
25	DISK HAROW	NAVY BNS 1	410	618	12.0	
26	FLD CULT 1	NAVY BNS 1	515	618	12.0	
27	FLD CULT 2	NAVY BNS 1	522	618	12.0	
28	ROW PLANT	NAVY BNS 1	522	618	12.0	
29	ROW CULT	SGR BTS 1	522	618	12.0	
30	NH3 APPLIC	CORN ONE	529	618	12.0	
31	ROW CULT	CORN ONE	529	618	12.0	
32	NH3 APPLIC	SGR BTS 1	605	625	12.0	
33	ROW CULT	SGR BTS 1	612	702	12.0	
34	ROW CULT	NAVY BNS 1	619	709	12.0	

PERCENTAGE OF EXTRA LABOR AVAILABLE PER WEEK .50 TOTAL CROP HECTARES= 161.9

YEAR= 49-50 COST=189.69 $/HA

TILLAGE TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
UTILITY TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
COMBINE SIZE=	2.00 ROWS	40.	40.	40.	40.	40.	40.	40.	40.
BEET HARVEST CAPACITY=	.61 HECTARE/HR	40.	40.	40.	40.	40.	40.	40.	40.
ROW PLANTER SIZE=	6.00 ROWS	40.	40.						
EXTRA ALFALFA MEN REQUIRED=	0.00 DRIVERS								
DIESEL FUEL USEAGE=	30.99 LITERS/HECTARE								

YEAR= 50-51 COST=189.69 $/HA

TILLAGE TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
UTILITY TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
COMBINE SIZE=	2.00 ROWS	40.	40.	40.	40.	40.	40.	40.	40.
BEET HARVEST CAPACITY=	.61 HECTARE/HR	40.	40.	40.	40.	40.	40.	40.	40.
ROW PLANTER SIZE=	6.00 ROWS	40.	40.						
EXTRA ALFALFA MEN REQUIRED=	0.00 DRIVERS								
DIESEL FUEL USEAGE=	30.99 LITERS/HECTARE								

YEAR= 51-52 COST=213.09 $/HA

TILLAGE TRACTOR=	64.13 KW	40.	40.	40.	40.	40.	40.	40.	40.
UTILITY TRACTOR=	64.13 KW	40.	40.	40.	40.	40.	40.	40.	40.
COMBINE SIZE=	2.00 ROWS	40.	40.	40.	40.	40.	40.	40.	40.
BEET HARVEST CAPACITY=	.61 HECTARE/HR	40.	40.	40.	40.	40.	40.	40.	40.
ROW PLANTER SIZE=	8.00 ROWS	40.	40.						
EXTRA ALFALFA MEN REQUIRED=	0.00 DRIVERS								
DIESEL FUEL USEAGE=	31.57 LITERS/HECTARE								

YEAR= 52-53 COST=189.69 $/HA

TILLAGE TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
UTILITY TRACTOR=	49.22 KW	40.	40.	40.	40.	40.	40.	40.	40.
COMBINE SIZE=	2.00 ROWS	40.	40.	40.	40.	40.	40.	40.	40.
BEET HARVEST CAPACITY=	.61 HECTARE/HR	40.	40.	40.	40.	40.	40.	40.	40.
ROW PLANTER SIZE=	6.00 ROWS	40.	40.						
EXTRA ALFALFA MEN REQUIRED=	0.00 DRIVERS								
DIESEL FUEL USEAGE=	30.99 LITERS/HECTARE								

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YEAR= 53-54   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 54-55   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 55-56   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 56-57   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 57-58   COST=203.66 $/HA   TILLAGE TRACTOR=                  54.44 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  54.44 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  8.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               31.06 LITERS/HECTARE

YEAR= 58-59   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 59-60   COST=169.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 60-61   COST=205.86 $/HA   TILLAGE TRACTOR=                  58.91 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  58.91 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  8.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               31.28 LITERS/HECTARE

YEAR= 61-62   COST=[illegible] $/HA   TILLAGE TRACTOR=             67.11 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  67.11 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                 12.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               31.69 LITERS/HECTARE
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YEAR= 62-63   COST=253.57 $/HA   TILLAGE TRACTOR=                  63.38 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  63.38 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      6.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .83 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  8.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 63-64   COST=189.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 64-65   COST=189.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 65-66   COST=258.09 $/HA   TILLAGE TRACTOR=                 201.34 KW              40.  40.  40.  40.  24.   0.   0.   0.
                                 UTILITY TRACTOR=                 104.40 KW               0.  40.  40.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                      8.00 ROWS             0.   0.   0.   0.   0.   0.   0.   0.
                                 BEET HARVEST CAPACITY=             1.41 HECTARE/HR       0.   0.   0.   0.   0.   0.   0.   0.
                                 ROW PLANTER SIZE=                 12.00 ROWS             0.   0.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=                8.33 LITERS/HECTARE

YEAR= 66-67   COST=189.69 $/HA   TILLAGE TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  49.22 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .61 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  6.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 67-68   COST=304.51 $/HA   TILLAGE TRACTOR=                 106.64 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                 106.64 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      6.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=             1.41 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                 12.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               31.88 LITERS/HECTARE

YEAR= 68-69   COST=258.09 $/HA   TILLAGE TRACTOR=                 201.34 KW              40.  40.  40.  40.  24.   0.   0.   0.
                                 UTILITY TRACTOR=                 104.40 KW               0.  40.  40.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                      8.00 ROWS             0.   0.   0.   0.   0.   0.   0.   0.
                                 BEET HARVEST CAPACITY=             1.41 HECTARE/HR       0.   0.   0.   0.   0.   0.   0.   0.
                                 ROW PLANTER SIZE=                 12.00 ROWS             0.   0.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=                8.33 LITERS/HECTARE

YEAR= 69-70   COST=218.16 $/HA   TILLAGE TRACTOR=                  63.38 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 UTILITY TRACTOR=                  63.38 KW              40.  40.  40.  40.  40.  40.  40.  40.
                                 COMBINE SIZE=                      2.00 ROWS            40.  40.  40.  40.  40.  40.  40.  40.
                                 BEET HARVEST CAPACITY=              .83 HECTARE/HR      40.  40.  40.  40.  40.  40.  40.  40.
                                 ROW PLANTER SIZE=                  8.00 ROWS            40.  40.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               30.99 LITERS/HECTARE

YEAR= 70-71   COST=246.41 $/HA   TILLAGE TRACTOR=                 201.34 KW              40.  40.  40.  40.   0.   0.   0.   0.
                                 UTILITY TRACTOR=                 104.40 KW               0.  40.  40.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                      8.00 ROWS             0.   0.   0.   0.   0.   0.   0.   0.
                                 BEET HARVEST CAPACITY=             1.41 HECTARE/HR       0.   0.   0.   0.   0.   0.   0.   0.
                                 ROW PLANTER SIZE=                 12.00 ROWS             0.   0.
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=                7.52 LITERS/HECTARE
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YEAR= 71-72   COST=204.75 $/HA     TILLAGE TRACTOR=              56.67 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=              56.67 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  2.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=              8.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           31.17 LITERS/HECTARE

YEAR= 72-73   COST=344.77 $/HA     TILLAGE TRACTOR=             144.19 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=             104.40 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  4.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=             12.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           34.55 LITERS/HECTARE

YEAR= 73-74   COST=221.89 $/HA     TILLAGE TRACTOR=              51.45 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=              51.45 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  4.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=              8.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           30.95 LITERS/HECTARE

YEAR= 74-75   COST=189.69 $/HA     TILLAGE TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  2.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=              6.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           30.99 LITERS/HECTARE

YEAR= 75-76   COST=189.69 $/HA     TILLAGE TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  2.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=              6.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           30.99 LITERS/HECTARE

YEAR= 76-77   COST=189.69 $/HA     TILLAGE TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   UTILITY TRACTOR=              49.22 KW             40.  40.  40.  40.  40.  40.  40.  40.
                                   COMBINE SIZE=                  2.00 ROWS           40.  40.  40.  40.  40.  40.  40.  40.
                                   BEET HARVEST CAPACITY=          .61 HECTARE/HR     40.  40.  40.  40.  40.  40.  40.  40.
                                   ROW PLANTER SIZE=              6.00 ROWS           40.  40.
                                   EXTRA ALFALFA MEN REQUIRED=    0.00 DRIVERS
                                   DIESEL FUEL USEAGE=           30.99 LITERS/HECTARE
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RANKED MACHINERY SETS FOR A 1.5 OPERATOR 161.3 HECTARE C-NB-W-BT FARM

RANK	YEAR	COST $/HA	LARGE TRACTOR	SMALL TRACTOR	COMBINE (ROWS)	PLANTER (ROWS)	BEET CAPACITY (HA/HR)	ALFALFA MEN (EXTRA)	FUEL USE (LITER/HA)
28	65-66		DATE CONSTRAINT VIOLATED FOR FLD CULT 1 OF WHEAT ONE						
27	68-69		DATE CONSTRAINT VIOLATED FOR FLD CULT 1 OF WHEAT ONE						
26	70-71		DATE CONSTRAINT VIOLATED FOR FLD CULT 1 OF WHEAT ONE						
25	72-73	344.77	184.	104.	4.	12.	.61	0.	34.55
24	67-68	304.51	107.	107.	6.	12.	1.41	0.	31.88
23	62-63	253.57	63.	63.	6.	8.	.83	0.	30.99
22	61-62	232.38	67.	67.	2.	12.	.61	0.	31.69
21	73-74	221.89	51.	51.	4.	8.	.61	0.	30.95
20	69-70	218.16	63.	63.	2.	6.	.83	0.	30.99
19	51-52	213.09	64.	64.	2.	8.	.61	0.	31.57
18	60-61	205.86	59.	59.	2.	8.	.61	0.	31.28
17	71-72	204.75	57.	57.	2.	8.	.61	0.	31.17
16	57-58	203.66	54.	54.	2.	8.	.61	0.	31.06
15	49-50	189.69	49.	49.	2.	6.	.61	0.	30.99
14	50-51	189.69	49.	49.	2.	6.	.61	0.	30.99
13	52-53	189.69	49.	49.	2.	6.	.61	0.	30.99
12	53-54	189.69	49.	49.	2.	6.	.61	0.	30.99
11	54-55	189.69	49.	49.	2.	6.	.61	0.	30.99
10	55-56	189.69	49.	49.	2.	6.	.61	0.	30.99
9	56-57	189.69	49.	49.	2.	6.	.61	0.	30.99
8	58-59	189.69	49.	49.	2.	6.	.61	0.	30.99
7	59-60	189.69	49.	49.	2.	6.	.61	0.	30.99
6	63-64	189.69	49.	49.	2.	6.	.61	0.	30.99
5	64-65	189.69	49.	49.	2.	6.	.61	0.	30.99
4	66-67	189.69	49.	49.	2.	6.	.61	0.	30.99
3	74-75	189.69	49.	49.	2.	6.	.61	0.	30.99
2	75-76	189.69	49.	49.	2.	6.	.61	0.	30.99
1	76-77	189.69	49.	49.	2.	6.	.61	0.	30.99

APPENDIX D

MODEL OUTPUT FOR A C-NB FARM; USING 28 YEARS OF AVAILABLE WORKDAY DATA, SUMMARY STATISTICS ONLY

APPENDIX D
MODEL OUTPUT FOR A C-NB FARM; USING 28 YEARS OF AVAILABLE WORKDAY DATA, SUMMARY STATISTICS ONLY

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C-NB
1   161.87
 1   0.50
 7   0.50
15   0.50
18   0.50
00
 1 7    0.50
 4 1    0.50
0000
   0.0
   828  1002 28  18
  1009  1113 25  15
  1009  1127  4   7
   828  1127 20   1
   828   515  1   1  1127
   424   515  6   1
   424   515 16   1
   424   515 22   1
  1009   619  1   7  1127
   410   619  3   7
   515   619  6   7
   522   619  7   7
   522   619 16   7
   529   619 13   1
   529   619 11   1
   619   710 13   7

   1
```

ROTATION=C-NB

OPERATION NUMBER	OPERATION	CROP	STARTING DATE	FINISHING DATE	FIELD WORK HOURS/DAY	DISCONTINUE FOR THE PERIOD OF
1	HRVST NAVY	NAVY BEANS	828	1001	6.0	
2	HRVST CORN	CORN	1009	1112	10.0	
3	DISKING	NAVY BNS 1	1009	1126	12.0	
4	FERT SPRD	CORN ONE	828	1126	12.0	
5	MB PLOWING	CORN ONE	828	514	12.0	1127TO-409
6	FLD CULT 1	CORN ONE	424	514	12.0	
7	ROW PLANT	CORN ONE	424	514	12.0	
8	SPRAY	CORN ONE	424	514	12.0	
9	MB PLOWING	NAVY BNS 1	1009	618	12.0	1127TO-409
10	DISK HAROW	NAVY BNS 1	410	618	12.0	
11	FLD CULT 1	NAVY BNS 1	515	618	12.0	
12	FLD CULT 2	NAVY BNS 1	522	618	12.0	
13	ROW PLANT	NAVY BNS 1	522	618	12.0	
14	ROW CULT	CORN ONE	529	618	12.0	
15	NH3 APPLIC	CORN ONE	529	618	12.0	
16	ROW CULT	NAVY BNS 1	619	709	12.0	

PERCENTAGE OF EXTRA LABOR AVAILABLE PER WEEK 0.00 TOTAL CROP HECTARES= 161.9

YEAR	COST	ITEM	VALUE	UNIT								
YEAR= 49-50	COST=150.32 $/HA	TILLAGE TRACTOR=	49.22	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	49.22	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	6.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.65	LITERS/HECTARE								
YEAR= 50-51	COST=164.06 $/HA	TILLAGE TRACTOR=	54.44	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	54.44	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	8.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.56	LITERS/HECTARE								
YEAR= 51-52	COST=183.65 $/HA	TILLAGE TRACTOR=	66.37	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	66.37	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	8.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.75	LITERS/HECTARE								
YEAR= 52-53	COST=165.85 $/HA	TILLAGE TRACTOR=	58.91	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	58.91	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	8.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.61	LITERS/HECTARE								
YEAR= 53-54	COST=164.35 $/HA	TILLAGE TRACTOR=	55.18	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	55.18	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	8.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.56	LITERS/HECTARE								
YEAR= 54-55	COST=150.32 $/HA	TILLAGE TRACTOR=	49.22	KW	81.	81.	81.	81.	81.	81.	81.	81.
		UTILITY TRACTOR=	49.22	KW	81.	81.	81.	81.	81.	81.	81.	81.
		COMBINE SIZE=	2.00	ROWS								
		BEET HARVEST CAPACITY=	0.00	HECTARE/HR								
		ROW PLANTER SIZE=	6.00	ROWS								
		EXTRA ALFALFA MEN REQUIRED=	0.00	DRIVERS								
		DIESEL FUEL USEAGE=	32.65	LITERS/HECTARE								

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YEAR= 55-56   COST=204.92 $/HA   TILLAGE TRACTOR=               86.50 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               86.50 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   2.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=              12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            33.11 LITERS/HECTARE

YEAR= 56-57   COST=150.32 $/HA   TILLAGE TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   2.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=               6.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.65 LITERS/HECTARE

YEAR= 57-58   COST=219.40 $/HA   TILLAGE TRACTOR=               78.30 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               78.30 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   4.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=              12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.96 LITERS/HECTARE

YEAR= 58-59   COST=150.32 $/HA   TILLAGE TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   2.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=               6.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.65 LITERS/HECTARE

YEAR= 59-60   COST=196.69 $/HA   TILLAGE TRACTOR=               61.89 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               61.89 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   4.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=               8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.66 LITERS/HECTARE

YEAR= 60-61   COST=215.97 $/HA   TILLAGE TRACTOR=               99.18 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               99.18 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   2.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=              12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            33.38 LITERS/HECTARE

YEAR= 61-62   COST=169.80 $/HA   TILLAGE TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   4.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=               6.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.65 LITERS/HECTARE

YEAR= 62-63   COST=248.24 $/HA   TILLAGE TRACTOR=               68.60 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               68.60 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   9.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=              12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.81 LITERS/HECTARE

YEAR= 63-64   COST=150.32 $/HA   TILLAGE TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=               49.22 KW              81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                   2.00 ROWS
                                 BEET HARVEST CAPACITY=          0.00 HECTARE/HR
                                 ROW PLANTER SIZE=               6.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=     0.00 DRIVERS
                                 DIESEL FUEL USEAGE=            32.65 LITERS/HECTARE
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YEAR= 64-65   COST=161.99 $/HA   TILLAGE TRACTOR=                 50.71 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                 50.71 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     2.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                 8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              32.55 LITERS/HECTARE

YEAR= 65-66   COST=213.95 $/HA   TILLAGE TRACTOR=                 68.60 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                 68.60 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     4.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              32.81 LITERS/HECTARE

YEAR= 66-67   COST=163.78 $/HA   TILLAGE TRACTOR=                 53.69 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                 53.69 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     2.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                 8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              32.55 LITERS/HECTARE

YEAR= 67-68   COST=248.15 $/HA   TILLAGE TRACTOR=                201.34 KW                 81.  81.   0.  81.  81.   0.   0.   0.
                                 UTILITY TRACTOR=                104.40 KW                  0.   0.   0.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                     8.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              13.71 LITERS/HECTARE

YEAR= 68-69   COST=241.33 $/HA   TILLAGE TRACTOR=                123.04 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                104.40 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     2.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              33.53 LITERS/HECTARE

YEAR= 69-70   COST=184.43 $/HA   TILLAGE TRACTOR=                 56.67 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                 56.67 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     4.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                 8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              32.58 LITERS/HECTARE

YEAR= 70-71   COST=248.15 $/HA   TILLAGE TRACTOR=                201.34 KW                 81.  81.   0.  81.  81.   0.   0.   0.
                                 UTILITY TRACTOR=                104.40 KW                  0.   0.   0.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                     8.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              13.71 LITERS/HECTARE

YEAR= 71-72   COST=1[illegible]2.38 $/HA   TILLAGE TRACTOR=                 64.13 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                 64.13 KW                 81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                     4.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                 8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              32.70 LITERS/HECTARE

YEAR= 72-73   COST=2[illegible]5.[illegible]2 $/HA   TILLAGE TRACTOR=                201.34 KW                 81.  81.  81.  81.  81.  66.  66.  66.
                                 UTILITY TRACTOR=                104.40 KW                 81.   0.   0.   0.   0.   0.   0.   0.
                                 COMBINE SIZE=                     8.00 ROWS
                                 BEET HARVEST CAPACITY=            0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=       0.00 DRIVERS
                                 DIESEL FUEL USEAGE=              23.79 LITERS/HECTARE
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YEAR= 73-74   COST=214.54 $/HA   TILLAGE TRACTOR=                  70.10 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                  70.10 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                      4.00 ROWS
                                 BEET HARVEST CAPACITY=             0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                 12.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               32.83 LITERS/HECTARE

YEAR= 74-75   COST=164.06 $/HA   TILLAGE TRACTOR=                  54.44 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                  54.44 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                      2.00 ROWS
                                 BEET HARVEST CAPACITY=             0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                  8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               32.56 LITERS/HECTARE

YEAR= 75-76   COST=164.35 $/HA   TILLAGE TRACTOR=                  55.18 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                  55.18 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                      2.00 ROWS
                                 BEET HARVEST CAPACITY=             0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                  8.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               32.56 LITERS/HECTARE

YEAR= 76-77   COST=150.32 $/HA   TILLAGE TRACTOR=                  49.22 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 UTILITY TRACTOR=                  49.22 KW                81.  81.  81.  81.  81.  81.  81.  81.
                                 COMBINE SIZE=                      2.00 ROWS
                                 BEET HARVEST CAPACITY=             0.00 HECTARE/HR
                                 ROW PLANTER SIZE=                  6.00 ROWS
                                 EXTRA ALFALFA MEN REQUIRED=        0.00 DRIVERS
                                 DIESEL FUEL USEAGE=               32.65 LITERS/HECTARE
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RANKED MACHINERY SETS FOR A 1.0 OPERATOR 161.9 HECTARE C-NB FARM

RANK	YEAR	COST $/HA	LARGE TRACTOR	SMALL TRACTOR	COMBINE (ROWS)	PLANTER (ROWS)	BEET CAPACITY (HA/HR)	ALFALFA MEN (EXTRA)	FUEL USE (LITER/HA)
28	67-68		DATE CONSTRAINT VIOLATED FOR DISKING OF NAVY BNS 1						
27	70-71		DATE CONSTRAINT VIOLATED FOR DISKING OF NAVY BNS 1						
26	72-73		DATE CONSTRAINT VIOLATED FOR FLD CULT 1 OF CORN ONE						
25	62-63	246.24	69.	69.	6.	12.	0.00	0.	32.81
24	68-69	241.33	123.	104.	2.	12.	0.00	0.	33.53
23	57-58	219.40	78.	78.	4.	12.	0.00	0.	32.96
22	60-61	215.97	99.	99.	2.	12.	0.00	0.	33.38
21	73-74	214.54	70.	70.	4.	12.	0.00	0.	32.53
20	65-66	213.95	69.	69.	4.	12.	0.00	0.	32.81
19	55-56	204.92	87.	87.	2.	12.	0.00	0.	33.11
18	71-72	192.38	64.	64.	4.	8.	0.00	0.	32.70
17	59-60	186.67	62.	62.	4.	8.	0.00	0.	32.66
16	69-70	184.43	57.	57.	4.	8.	0.00	0.	32.58
15	51-52	183.55	66.	66.	2.	8.	0.00	0.	32.75
14	61-62	169.80	49.	49.	4.	6.	0.00	0.	32.65
13	52-53	165.65	59.	59.	2.	8.	0.00	0.	32.61
12	53-54	164.35	55.	55.	2.	8.	0.00	0.	32.56
11	75-76	164.35	55.	55.	2.	8.	0.00	0.	32.56
10	50-51	164.06	54.	54.	2.	8.	0.00	0.	32.56
9	74-75	164.06	54.	54.	2.	8.	0.00	0.	32.56
8	66-67	163.78	54.	54.	2.	8.	0.00	0.	32.55
7	64-65	161.95	51.	51.	2.	8.	0.00	0.	32.55
6	49-50	150.32	49.	49.	2.	6.	0.00	0.	32.65
5	54-55	150.32	49.	49.	2.	6.	0.00	0.	32.65
4	56-57	150.32	49.	49.	2.	6.	0.00	0.	32.65
3	58-59	150.32	49.	49.	2.	6.	0.00	0.	32.65
2	63-64	150.32	49.	49.	2.	6.	0.00	0.	32.65
1	76-77	150.32	49.	49.	2.	6.	0.00	0.	32.65

APPENDIX E

MODEL OUTPUT FOR A C-NB FARM; USING THE NINTH YEAR OF AVAILABLE WORKDAY DATA, COMPLETE SET OF STATISTICS

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C-NB
1  161.87
 1  0.50
 7  0.50
15  0.50
18  0.50
00
 1 7  0.50
 4 1  0.50
0000
  0.0
  828  1002  28  18
 1009  1113  25  15
 1009  1127   4   7
  828  1127  20   1
  828   515   1   1  1127
  424   515   6   1
  424   515  16   1
  424   515  22   1
 1009   619   1   7  1127
  410   619   3   7
  515   619   6   7
  522   619   7   7
  522   619  16   7
  529   619  13   1
  529   619  11   1
  619   710  13   7

  4   1   9   9
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APPENDIX E

MODEL OUTPUT FOR A C-NB FARM; USING THE NINTH YEAR OF AVAILABLE WORKDAY DATA, COMPLETE SET OF STATISTICS

ROTATION=C-NB

OPERATION NUMBER	OPERATION	CROP	STARTING DATE	FINISHING DATE	FIELD WORK HOURS/DAY	DISCONTINUE FOR THE PERIOD OF
1	HRVST NAVY	NAVY BEANS	828	1001	6.0	
2	HRVST CORN	CORN	1009	1112	10.0	
3	DISKING	NAVY BNS 1	1009	1126	12.0	
4	FERT SPRD	CORN ONE	828	1126	12.0	
5	MB PLOWING	CORN ONE	828	514	12.0	1127TO-409
6	FLD CULT 1	CORN ONE	424	514	12.0	
7	ROW PLANT	CORN ONE	424	514	12.0	
8	SPRAY	CORN ONE	424	514	12.0	
9	MB PLOWING	NAVY BNS 1	1009	618	12.0	1127TO-409
10	DISK HAROW	NAVY BNS 1	410	618	12.0	
11	FLD CULT 1	NAVY BNS 1	515	618	12.0	
12	FLD CULT 2	NAVY BNS 1	522	618	12.0	
13	ROW PLANT	NAVY BNS 1	522	618	12.0	
14	ROW CULT	CORN ONE	529	618	12.0	
15	NH3 APPLIC	CORN ONE	529	618	12.0	
16	ROW CULT	NAVY BNS 1	619	709	12.0	

PERCENTAGE OF EXTRA LABOR AVAILABLE PER WEEK 0.00 TOTAL CROP HECTARES= 161.9

HOURS AVAILABLE FOR ALL OPERATIONS

	410	417	424	501	508	515	522	529	605	612	619	626	703	710	717	724	731	807	814	821	828	904	911	918	925	1002	1009	1016	1023	1030	1106	1113	1120
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	10.	31.	15.	21.	36.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	34.	17.	26.	43.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	72.	0.	0.	0.	10.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	62.	62.	31.	41.	72.	72.	72.	41.	21.	31.	51.	21.	51.
5	31.	31.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	62.	62.	0.	10.	62.	72.	72.	0.	0.	0.	10.	0.	0.
6	0.	0.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	46.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	31.	31.	31.	72.	62.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	72.	0.	0.	0.	10.	0.	0.
10	31.	31.	31.	72.	62.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	41.	51.	31.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

SELECTION OF COMBINE CAPACITY

2. ROW COMBINE

SELECTION OF TRACTOR SIZE

```
           TILLAGE TRACTOR KILOWATT=   59.7              SECOND TRACTOR KILOWATT=   59.7
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  41.03

           TILLAGE TRACTOR KILOWATT=   89.5              SECOND TRACTOR KILOWATT=   89.5
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  37.57

           TILLAGE TRACTOR KILOWATT=  119.3              SECOND TRACTOR KILOWATT=  104.4
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  34.27

           TILLAGE TRACTOR KILOWATT=  149.1              SECOND TRACTOR KILOWATT=  104.4
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  30.97

           TILLAGE TRACTOR KILOWATT=  179.0              SECOND TRACTOR KILOWATT=  104.4
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  27.67

           TILLAGE TRACTOR KILOWATT=  201.3              SECOND TRACTOR KILOWATT=  104.4
NOT ABLE TO FINISH OPERATION = DISK          FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  27.61
```

HOURS AVAILABLE FOR ALL OPERATIONS

	410	417	424	501	508	515	522	529	605	612	619	626	703	710	717	724	731	807	814	821	828	904	911	918	925	1002	1009	1016	1023	1030	1106	1113	1120
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	10.	31.	15.	21.	36.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	34.	17.	25.	43.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	72.	0.	0.	0.	10.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	62.	62.	31.	41.	72.	72.	72.	41.	21.	31.	51.	21.	51.
5	31.	31.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	62.	62.	0.	10.	52.	72.	72.	0.	0.	0.	10.	0.	0.
6	0.	0.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	31.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	46.	72.	62.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	31.	31.	31.	72.	62.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	72.	0.	0.	0.	10.	0.	0.
10	31.	31.	31.	72.	62.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	62.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	72.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	41.	72.	72.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	41.	51.	31.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

SELECTION OF COMBINE CAPACITY

4. ROW COMBINE

SELECTION OF TRACTOR SIZE

TILLAGE TRACTOR KILOWATT= 59.7 SECOND TRACTOR KILOWATT= 59.7
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 19.17

TILLAGE TRACTOR KILOWATT= 89.5 SECOND TRACTOR KILOWATT= 89.5

TILLAGE TRACTOR KILOWATT= 67.1 SECOND TRACTOR KILOWATT= 67.1
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 11.45

TILLAGE TRACTOR KILOWATT= 74.6 SECOND TRACTOR KILOWATT= 74.6
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 3.73

TILLAGE TRACTOR KILOWATT= 82.0 SECOND TRACTOR KILOWATT= 82.0

TILLAGE TRACTOR KILOWATT= 75.3 SECOND TRACTOR KILOWATT= 75.3
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 2.96

TILLAGE TRACTOR KILOWATT= 76.1 SECOND TRACTOR KILOWATT= 76.1
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 2.19

TILLAGE TRACTOR KILOWATT= 76.8 SECOND TRACTOR KILOWATT= 76.8
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = 1.41

TILLAGE TRACTOR KILOWATT= 77.6 SECOND TRACTOR KILOWATT= 77.6
NOT ABLE TO FINISH OPERATION = DISK FOR CROP = NAVY BNS 1 BY 1120 HECTARES LEFT = .64

TILLAGE TRACTOR KILOWATT= 78.3 SECOND TRACTOR KILOWATT= 78.3

WORK SCHEDULE

TILLAGE TRACTOR KILOWATT= 78.3 SECOND TRACTOR KILOWATT= 78.3

WEEK OF 828 COMBINE= 10.3 TILLAGE TRACTOR= 25.7 UTILITY TRACTOR= 2.1

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BEANS	PCKUP HEAD	21.9	21.9	10.29	2.12	10.29
CORN ONE	FERT SPRDR	21.9	21.9	2.12	10.30	61.71
CORN ONE	MB PLOW	21.9	21.9	25.66	.85	61.71

WEEK OF 904 COMBINE= 27.8 TILLAGE TRACTOR= 28.2 UTILITY TRACTOR= 5.7

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BEANS	PCKUP HEAD	59.1	80.9	27.81	2.12	27.81
CORN ONE	FERT SPRDR	59.1	80.9	5.74	10.30	61.71
CORN ONE	MB PLOW	24.0	45.8	28.17	.85	61.71

WEEK OF 911 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 918 COMBINE= 0.0 TILLAGE TRACTOR= 10.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	MB PLOW	8.8	54.6	10.29	.85	10.29

WEEK OF 925 COMBINE= 0.0 TILLAGE TRACTOR= 30.9 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	MB PLOW	26.3	80.9	30.94	.85	61.71

WEEK OF 1002 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1009 COMBINE= 60.0 TILLAGE TRACTOR= 12.0 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN	CORN HEAD	57.4	57.4	60.00	.96	60.00
NAVY BNS 1	DISK	43.6	43.6	12.00	3.64	72.00

WEEK OF 1016 COMBINE= 24.6 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN	CORN HEAD	23.5	80.9	24.61	.96	24.61

WEEK OF 1023 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1030 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1106 COMBINE= 0.0 TILLAGE TRACTOR= 10.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	DISK	37.3	80.9	10.25	3.64	10.29
NAVY BNS 1	MB PLOW	.0	.0	.04	.85	10.29

WEEK OF 1113 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1120 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 410 COMBINE= 0.0 TILLAGE TRACTOR= 30.9 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	MB PLOW	19.8	19.8	23.28	.85	30.86
NAVY BNS 1	DISK HRRW	19.8	19.8	7.56	2.62	30.86

WEEK OF 417 COMBINE= 0.0 TILLAGE TRACTOR= 30.9 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS

NAVY BNS 1	MB PLOW	19.8	39.7	23.29	.85	30.86
NAVY BNS 1	DISK HRRW	19.8	39.7	7.57	2.62	30.86

WEEK OF 424 COMBINE= 0.0 TILLAGE TRACTOR= 15.8 UTILITY TRACTOR= 27.1

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	FLD CULT 1	57.5	57.5	15.80	3.64	30.86
CORN ONE	PLANTER	57.5	57.5	15.06	3.81	30.86
CORN ONE	SPRAYER	57.5	57.5	12.01	4.78	46.29

WEEK OF 501 COMBINE= 0.0 TILLAGE TRACTOR= 60.9 UTILITY TRACTOR= 11.1

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	FLD CULT 1	23.5	80.9	6.46	3.64	72.00
CORN ONE	PLANTER	23.5	80.9	6.16	3.81	72.00
CORN ONE	SPRAYER	23.5	80.9	4.91	4.78	72.00
NAVY BNS 1	MB PLOW	35.0	74.7	41.11	.85	72.00
NAVY BNS 1	DISK HRRW	35.0	74.7	13.37	2.62	72.00

WEEK OF 508 COMBINE= 0.0 TILLAGE TRACTOR= 9.7 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	MB PLOW	6.3	80.9	7.35	.85	61.71
NAVY BNS 1	DISK HRRW	6.3	80.9	2.39	2.62	61.71

WEEK OF 515 COMBINE= 0.0 TILLAGE TRACTOR= 22.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	FLD CULT 1	80.9	80.9	22.25	3.64	61.71

WEEK OF 522 COMBINE= 0.0 TILLAGE TRACTOR= 22.3 UTILITY TRACTOR= 21.2

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	FLD CULT 2	80.9	80.9	22.25	3.64	72.00
NAVY BNS 1	PLANTER	80.9	80.9	21.22	3.81	72.00

WEEK OF 529 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 32.9

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	ROW CULT	80.9	80.9	14.21	5.70	41.14
CORN ONE	NH3 APPLIC	80.9	80.9	18.65	4.34	41.14

WEEK OF 605 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 612 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 619 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 14.2

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	ROW CULT	80.9	80.9	14.21	5.70	41.14

WEEK OF 626 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 703 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

MACHINERY SET

TILLAGE TRACTOR KILOWATT= 78.3 SECOND TRACTOR KILOWATT= 78.3 COMBINE SIZE= 4.

OPERATION	SIZE	DRAFT	FLD EFF	TR EFF	SPEED (KM/HR)	FLD CAP (HA/HR)	FUEL CSPN (L/HA)
PCKUP HEAD	6.00 ROWS	0.00	.67	-I	6.94	2.12	5.49
BEAN PULLR	6.00 ROWS	2112.91 N/ROW	.80	.80	8.05	2.94	2.58
CORN HEAD	4.00 ROWS	0.00	-I	-I	4.83	.96	6.06
DISK	6.50 METER	3794.42 N/M	.85	.75	6.58	3.64	2.78
FERT SPRDR	18.29 METER	875.63 N/M	.70	.80	8.05	10.30	.81
MB PLOW	4.00 BOTM	16272.20 N/M	.80	.80	6.55	.85	11.87
FLD CULT 1	4.72 METER	3794.42 N/M	.85	.75	9.06	3.64	2.78
PLANTER	12.00 ROWS	1712.57 N/ROW	.55	.72	7.58	3.81	2.65
SPRAYER	9.14 METER	583.76 N/M	.65	.72	8.05	4.78	1.11
MB PLOW	4.00 BOTM	16272.20 N/M	.80	.80	6.55	.85	11.87
DISK HRRW	4.34 METER	4961.93 N/M	.80	.75	7.53	2.62	3.86
FLD CULT 1	4.72 METER	3794.42 N/M	.85	.75	9.06	3.64	2.78
FLD CULT 2	4.72 METER	3035.53 N/M	.85	.60	9.06	3.64	2.78
PLANTER	12.00 ROWS	1712.57 N/ROW	.55	.72	7.58	3.61	2.65
ROW CULT	12.00 ROWS	1668.08 N/ROW	.80	.72	7.79	5.70	1.77
NH3 APPLIC	12.00 ROWS	1779.29 N/ROW	.65	.72	7.30	4.34	2.33
ROW CULT	12.00 ROWS	1668.08 N/ROW	.80	.72	7.79	5.70	1.77

MACHINERY COST ANALYSIS

INTEREST RATE= .13 FUEL COST .20 $/LITER 8 YEAR DEPRECIATION SCHEDULE

IMPLEMENT	QUANTITY	USE HRS	PRICE	DEPRCTN	INTEREST	INS&HOUS	REPAIRS	FUEL	TOTAL
MB PLOW	1	190.11	7425.00	835.31	530.89	74.25	564.64	940.48	2945.58
DISK	1	53.17	9511.00	1069.99	680.04	95.11	164.36	263.03	2272.52
FLD CULT 2	1	66.76	2690.00	302.63	192.34	26.90	58.36	330.25	910.47
NH3 APPLIC	1	18.65	3200.00	360.00	228.80	32.00	22.38	92.28	735.46
ROW CULT	1	28.42	4717.00	530.66	337.27	47.17	43.57	140.58	1099.24
PLANTER	1	42.44	22438.00	2524.28	1604.32	224.38	714.15	209.93	5277.06
FERT SPRDR	1	7.86	2500.00	281.25	178.75	25.00	12.28	32.23	529.50
SPRAYER	1	16.92	2640.00	297.00	188.76	26.40	27.92	43.96	584.04
BEAN PULLR	1	27.50	7996.00	899.55	571.71	79.96	82.46	102.07	1735.75
CORN HEAD	1	84.61	9037.00	1016.66	646.15	90.37	126.17	239.99	2119.34
PCKUP HEAD	1	38.09	7855.00	883.69	561.63	78.55	49.37	217.49	1790.74
COMBINE	1	122.71	36179.00	4070.14	2586.80	361.79	732.51	0.00	7751.23
TILL TRCTR	1	310.04	23685.38	2664.60	1693.50	236.85	660.92	0.00	5255.88
UTIL TRCTR	1	141.79	11368.98	1279.01	812.88	113.69	302.25	0.00	2507.83
			---------	---------	---------	---------	---------	---------	---------
			151242.36	17014.76	10813.83	1512.42	3561.33	2512.31	35514.65

SELECTION OF COMBINE CAPACITY

6. ROW COMBINE

SELECTION OF TRACTOR SIZE

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        TILLAGE TRACTOR KILOWATT=   59.7           SECOND TRACTOR KILOWATT=   59.7
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  19.17

        TILLAGE TRACTOR KILOWATT=   89.5           SECOND TRACTOR KILOWATT=   89.5

        TILLAGE TRACTOR KILOWATT=   67.1           SECOND TRACTOR KILOWATT=   67.1
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =  11.45

        TILLAGE TRACTOR KILOWATT=   74.6           SECOND TRACTOR KILOWATT=   74.6
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =   3.73

        TILLAGE TRACTOR KILOWATT=   82.0           SECOND TRACTOR KILOWATT=   82.0

        TILLAGE TRACTOR KILOWATT=   75.3           SECOND TRACTOR KILOWATT=   75.3
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =   2.96

        TILLAGE TRACTOR KILOWATT=   76.1           SECOND TRACTOR KILOWATT=   76.1
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =   2.19

        TILLAGE TRACTOR KILOWATT=   76.8           SECOND TRACTOR KILOWATT=   76.8
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =   1.41

        TILLAGE TRACTOR KILOWATT=   77.6           SECOND TRACTOR KILOWATT=   77.6
NOT ABLE TO FINISH OPERATION = DISK        FOR CROP = NAVY BNS 1 BY  1120 HECTARES LEFT =    .64

        TILLAGE TRACTOR KILOWATT=   78.3           SECOND TRACTOR KILOWATT=   78.3
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WORK SCHEDULE

TILLAGE TRACTOR KILOWATT= 78.3 SECOND TRACTOR KILOWATT= 78.3

WEEK OF 828 COMBINE= 10.3 TILLAGE TRACTOR= 30.8 UTILITY TRACTOR= 2.5

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BEANS	PCKUP HEAD	26.2	26.2	10.29	2.55	10.29
CORN ONE	FERT SPRDR	26.2	26.2	2.55	10.30	61.71
CORN ONE	MB PLOW	26.2	26.2	30.80	.85	61.71

WEEK OF 904 COMBINE= 21.5 TILLAGE TRACTOR= 34.9 UTILITY TRACTOR= 5.3

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BEANS	PCKUP HEAD	54.7	80.9	21.46	2.55	21.46
CORN ONE	FERT SPRDR	54.7	80.9	5.31	10.30	61.71
CORN ONE	MB PLOW	29.7	56.0	34.94	.85	61.71

WEEK OF 911 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 918 COMBINE= 0.0 TILLAGE TRACTOR= 10.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	MB PLOW	8.8	64.7	10.29	.85	10.29

WEEK OF 925 COMBINE= 0.0 TILLAGE TRACTOR= 19.0 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	MB PLOW	16.2	80.9	19.03	.85	61.71

WEEK OF 1002 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1009 COMBINE= 60.0 TILLAGE TRACTOR= 12.0 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN	CORN HEAD	76.5	76.5	60.00	1.27	60.00
NAVY BNS 1	DISK	43.6	43.6	12.00	3.64	72.00

WEEK OF 1016 COMBINE= 3.5 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN	CORN HEAD	4.4	80.9	3.49	1.27	3.49

WEEK OF 1023 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1030 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1106 COMBINE= 0.0 TILLAGE TRACTOR= 10.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	DISK	37.3	80.9	10.25	3.64	10.29
NAVY BNS 1	MB PLOW	.0	.0	.04	.85	10.29

WEEK OF 1113 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 1120 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 410 COMBINE= 0.0 TILLAGE TRACTOR= 30.9 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	MB PLOW	19.8	19.8	23.28	.85	30.86
NAVY BNS 1	DISK HRRW	19.8	19.8	7.58	2.62	30.86

WEEK OF 417 COMBINE= 0.0 TILLAGE TRACTOR= 30.9 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	MB PLOW	19.8	39.7	23.29	.85	30.86
NAVY BNS 1	DISK HRRW	19.8	39.7	7.57	2.62	30.85

WEEK OF 424 COMBINE= 0.0 TILLAGE TRACTOR= 15.8 UTILITY TRACTOR= 27.1

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	FLD CULT 1	57.5	57.5	15.80	3.64	30.86
CORN ONE	PLANTER	57.5	57.5	15.06	3.81	30.86
CORN ONE	SPRAYER	57.5	57.5	12.01	4.78	46.29

WEEK OF 501 COMBINE= 0.0 TILLAGE TRACTOR= 60.9 UTILITY TRACTOR= 11.1

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	FLD CULT 1	23.5	80.9	6.46	3.64	72.00
CORN ONE	PLANTER	23.5	80.9	6.16	3.81	72.00
CORN ONE	SPRAYER	23.5	80.9	4.91	4.78	72.00
NAVY BNS 1	MB PLOW	35.0	74.7	41.11	.85	72.00
NAVY BNS 1	DISK HRRW	35.0	74.7	13.37	2.62	72.00

WEEK OF 508 COMBINE= 0.0 TILLAGE TRACTOR= 9.7 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	MB PLOW	6.3	80.9	7.35	.85	61.71
NAVY BNS 1	DISK HRRW	6.3	80.9	2.39	2.62	61.71

WEEK OF 515 COMBINE= 0.0 TILLAGE TRACTOR= 22.3 UTILITY TRACTOR= 0.0

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	FLD CULT 1	80.9	80.9	22.25	3.64	61.71

WEEK OF 522 COMBINE= 0.0 TILLAGE TRACTOR= 22.3 UTILITY TRACTOR= 21.2

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	FLD CULT 2	80.9	80.9	22.25	3.64	72.00
NAVY BNS 1	PLANTER	80.9	80.9	21.22	3.81	72.00

WEEK OF 529 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 32.9

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
CORN ONE	ROW CULT	80.9	80.9	14.21	5.70	41.14
CORN ONE	NH3 APPLIC	80.9	80.9	18.65	4.34	41.14

WEEK OF 605 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 612 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 619 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 14.2

CROP	OPERATION	HECTAREWK	HECTARETOT	TIME	HECTARES/HR	MAXIMUM HOURS
NAVY BNS 1	ROW CULT	80.9	80.9	14.21	5.70	41.14

WEEK OF 626 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

WEEK OF 703 COMBINE= 0.0 TILLAGE TRACTOR= 0.0 UTILITY TRACTOR= 0.0

MACHINERY SET

TILLAGE TRACTOR KILOWATT= 78.3 SECOND TRACTOR KILOWATT= 78.3 COMBINE SIZE= 6.

OPERATION	SIZE	DRAFT	FLD EFF	TR EFF	SPEED (KM/HR)	FLD CAP (HA/HR)	FUEL CSPN (L/HA)
PCKUP HEAD	12.00 ROWS	0.00	.65	-1	4.29	2.55	5.49
BEAN PULLR	6.00 ROWS	2112.91 N/ROW	.80	.80	8.05	2.94	2.39
CORN HEAD	6.00 ROWS	0.00	-1	-1	4.43	1.27	6.06
DISK	6.50 METER	3794.42 N/M	.85	.75	6.58	3.64	2.78
FERT SPRDR	18.29 METER	875.63 N/M	.70	.80	8.05	10.30	.81
MB PLOW	4.00 BOTM	16272.20 N/M	.80	.80	6.55	.85	11.97
FLD CULT 1	4.72 METER	3794.42 N/M	.85	.75	9.06	3.64	2.78
PLANTER	12.00 ROWS	1712.57 N/ROW	.55	.72	7.58	3.81	2.65
SPRAYER	9.14 METER	583.76 N/M	.65	.72	8.05	4.78	1.11
MB PLOW	4.00 BOTM	16272.20 N/M	.80	.80	6.55	.85	11.87
DISK HRRW	4.34 METER	4961.93 N/M	.80	.75	7.53	2.62	3.96
FLD CULT 1	4.72 METER	3794.42 N/M	.85	.75	9.06	3.64	2.78
FLD CULT 2	4.72 METER	3035.53 N/M	.85	.60	9.06	3.64	2.78
PLANTER	12.00 ROWS	1712.57 N/ROW	.55	.72	7.58	3.81	2.65
ROW CULT	12.00 ROWS	1668.08 N/ROW	.80	.72	7.79	5.70	1.77
NH3 APPLIC	12.00 ROWS	1779.29 N/ROW	.65	.72	7.30	4.34	2.33
ROW CULT	12.00 ROWS	1668.08 N/ROW	.80	.72	7.79	5.70	1.77

MACHINERY COST ANALYSIS

INTEREST RATE= .13 FUEL COST .20 $/LITER 8 YEAR DEPRECIATION SCHEDULE

IMPLEMENT	QUANTITY	USE HRS	PRICE	DEPRCTN	INTEREST	INS&HOUS	REPAIRS	FUEL	TOTAL
MB PLOW	1	190.11	7425.00	835.31	530.89	74.25	564.64	940.48	2945.58
DISK	1	53.17	9511.00	1069.99	690.04	95.11	164.36	263.03	2272.52
FLD CULT 2	1	66.76	2690.00	302.63	192.34	26.90	58.36	330.25	910.47
NH3 APPLIC	1	18.65	3200.00	360.00	228.80	32.00	22.39	92.29	735.46
ROW CULT	1	28.42	4717.00	530.66	337.27	47.17	43.57	140.58	1099.24
PLANTER	1	42.44	22438.00	2524.28	1604.32	224.38	714.15	209.93	5277.06
FERT SPRDR	1	7.86	2500.00	281.25	178.75	25.00	12.29	32.23	529.50
SPRAYER	1	16.92	2640.00	297.00	188.76	26.40	27.92	43.96	584.04
BEAN PULLR	1	27.50	7996.00	899.55	571.71	79.96	82.46	102.07	1735.75
CORN HEAD	1	63.49	12740.00	1433.25	910.91	127.40	133.45	239.99	2845.02
PCKUP HEAD	1	31.75	7855.00	883.69	561.63	78.55	41.14	217.49	1782.51
COMBINE	1	95.24	45641.00	5134.61	3263.33	456.41	717.20	0.00	9571.55
TILL TRCTR	1	310.04	23685.38	2664.60	1693.50	236.85	660.92	0.00	5255.88
UTIL TRCTR	1	141.79	11368.98	1279.01	812.89	113.69	302.25	0.00	2507.83
			---------	---------	---------	---------	---------	---------	---------
			164407.36	18495.83	11755.13	1644.07	3545.09	2612.31	38052.42

YEAR= 57-58 COST=219.40 $/HA

TILLAGE TRACTOR=	78.30 KW	81.	81.	81.	81.	81.	81.	81.	81.
UTILITY TRACTOR=	78.30 KW	81.	81.	81.	81.	81.	81.	81.	81.
COMBINE SIZE=	4.00 ROWS								
BEET HARVEST CAPACITY=	0.00 HECTARE/HR								
ROW PLANTER SIZE=	12.00 ROWS								
EXTRA ALFALFA MEN REQUIRED=	0.00 DRIVERS								
DIESEL FUEL USEAGE=	32.96 LITERS/HECTARE								

RANKED MACHINERY SETS FOR A 1.0 OPERATOR 161.9 HECTARE C-NB FARM

RANK	YEAR	COST $/HA	LARGE TRACTOR	SMALL TRACTOR	COMBINE (ROWS)	PLANTER (ROWS)	BEET CAPACITY (HA/HR)	ALFALFA MEN (EXTRA)	FUEL USE (LITER/HA)
20	57-58	219.40	78.	78.	4.	12.	0.00	0.	32.96

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