EXPANSION OF AN OPTIMAL MACHINERY COMPLEMENT SELECTION SYSTEM

By

SCOTT MORRIS HININGER

Bachelor of Science in Agriculture

Oklahoma State University

Stillwater, Oklahoma

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EXPANSION OF AN OPTIMAL MACHINERY

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SYSTEM

Thesis Approved:

Daniel D. Kletke
Thesis Adviser

Paul D. Hummer

Alan E. Baquet

Norman N. Durham
Dean of Graduate College

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CHAPTER I

INTRODUCTION

Farmers are continually called upon to make capital investment decisions. Next to land, machinery purchases require the greatest amount of capital. In addition to financial considerations, farm managers selecting machinery must consider the number of acres farmed, the crops grown, the amount of labor available, and the time available to complete the field work. The farmer must balance his selection of machinery between the risk of loss from not completing field work in the optimum time period and the cost of having excess machinery capacity be idle a great deal of the time.

Many farmers have difficulty finding the "right" machinery combination that will provide the necessary level of machinery services. Agricultural financiers credit mismanagement in farm machinery acquisition and use as a major culprit in farm business failures (3). Machinery-related expenses, such as fuel, hired labor, and repairs, may also constitute as much as 35% to 50% of an individual farm's operating expenses (16). Therefore, it would seem that a substantial savings and increased productivity could be obtained with better selection and allocation of complements by farmers.

The farm manager must make decisions in regard to machinery requirements today but must also be looking into the future. Between the years 1960 and 1980, total farm numbers declined 41.7% (25). During the same period the number of farms having cash receipts of more than $40,000 increased 264%. These larger "commercial" farms in 1978 represented 33.7% of the total number of farms and marketed 78.1% of total farm output, compared to only 8.6% of the farms and 32.8% of production in 1960.

At the other end of the economic spectrum, farms with less than $5,000 in sales, represented 62.2% of all farms in 1960 and declined to 44.7% of all farms in 1980 (25). This change represents an exit from the farming industry (or, for a few, an expansion in size) of 1.3 million farms in only 17 years. Thus 97% of the decline in farm numbers between 1960 and 1980 can be attributed to the demise of these "small" farms. The average farm size in the United States has increased from 297 acres in 1960 to 453 acres in 1980 (26). Oklahoma's average farm size was 252 acres per farm in 1950, and has expanded to 486 acres per farm in 1980 (25).

Machinery has been used extensively by farmers to replace labor in the input mix, allowing farmers to stretch their own labor over more acres and activities. In 1940 farmer's owned $1.8 billion worth of tractors. By 1977 the tractor investment had increased to $9.4 billion. Farm labor decreased from 20.5 billion in 1940 to 4.3 billion in 1979 (nominal dollars) (24). The capital required for machinery investment continues to be the largest non-real estate use of capital found on the balance sheet of the farming sector (25).

Machinery alternatives, available for addition to or deletion from a farmer's machinery complement, may vary in age by as much as 10 to 15 years. In addition, machines serving in the machinery "pool" may have been purchased for an entirely different function or crop tillage system. These considerations result in two important dimensions of the farmer's decision space which are:

1. What are the machinery alternatives available for purchasing (both new and used)?
2. What machines in the current complement can be kept and incorporated into the new "optimum" complement?

Optimum farm machinery management occurs when the economic performance of the total machine system has been maximized. Optimal farm machinery management, then, requires that the individual operations in a machine system must be adjusted and combined in such a manner that their over-all performance returns the greatest profit to the farm business. It should be emphasized that it is the cost of doing the required work with a machinery system that is to be minimized and not the cost of use of individual implements. Cost minimization must occur while still obtaining a satisfactory level of machinery service. The selection decision for even a single addition or replacement inevitably determines, at least in part, the feasibility and economic flexibility of a much wider investment plan involving the entire farm machinery system.

The tractor is the most important item in a farm machinery complement, both in terms of the dollar investment it represents and by the key role it plays in determining the size and composition of the complement. In general, a shift to larger farm equipment generally must be preceded, if not accompanied, by an increase in tractor power. Since most agricultural production requiring field machinery is seasonal, equipment will necessarily have high and low periods of usage and quite probably stand idle much of the time.

The trade-off between labor-intensive operations and machinery intensive operations is also difficult for the farmer to analyze, yet it plays a very important role in a farmer's choice of machinery. Availability of labor is undeniably a problem in agriculture. Traditional wage rates are low relative to other segments of the economy. In addition, most farmers need only seasonal help while most laborers prefer year-round employment. The effective wage rate for a farm laborer, for example, earning $10,000 per year (2,400 hours maximum) can vary between $4.00 (fully employed) and $12.50 (assuming 800 hours of productive labor per year). The optimal machinery complements in the above range would be substantially different from the one using the more typical farm wage rate. A relevent question is: should farm machinery valued at between $50,000.00 and $100,000.00 be entrusted to workers receiving minimum wage?

Increasing the machinery capacity presents a form of insurance, enabling adequate performance over a wider span of weather conditions. But the problem facing many farm operators is two-fold. First, what is the optimum, or least-cost, set of farm machinery for a particular farm operation? Second, what is the cost of having some excess capacity in machinery so that the operator can be assured of getting his crop planting and or harvesting completed in a year when the normal planting and/or harvesting period is shortened by adverse weather conditions.

Any machine combination, other than the least-cost combination under optimum conditions, must be justified by the value placed on the timeliness of performing the operations within the given time period and/or personal preferences. If a farmer buys a tractor larger than needed, fixed costs will rise considerably. Although the added fixed costs from owning a larger tractor is usually about the same as the savings in labor, the timeliness benefits may be very real.

Oklahoma farmers do not have readily available to them either directly or indirectly through management services, a practical, understandable, and economically sound machinery selection model to update, advise and guide them in their machinery management decisions. A computerized decision aid capable of identifying optimum machinery complements within the decision space faced by farmers, could be of real economic assistance to the farmers of Oklahoma.

Information on the effect of wage rates on machinery selection will be a valuable aid to the farmer in planning his machinery purchase. This information may also be useful to policy makers in evaluating the effects of a higher wage rate on agricultural employment.

Purpose of the Study

The primary purpose of this study is to provide information on the effect alternative timeliness requirements and wage rates on least-cost farm machinery complements. This information will be available for use by farmers to help determine the optimal combination of machinery and labor for their particular farming organization and risk aversion level. The areas of Oklahoma to be considered are Texas county, Canadian county and Muskogee county. The machinery complements for the three different areas of the state will be compared to each other, so that Oklahoma's different farm sizes, cropping patterns, weather conditions and farming practices, can be compared. These comparisons should lead to some general conclusions that will be of economic value to farmers throughout the state.

Objectives

1. Update the weather data required for determining time available information for each area of the state. This will be used for specifying time available in each time period for performing field operations a chosen percentage of the time in each of the resource situations for which machines will be selected.
2. Identify optimum machinery complements for three areas of Oklahoma (Texas county, Canadian county, and Muskogee county) with different farm resource situations.
3. Summarize the results in such a way that farm managers can use the information as a guide for making machinery complement decisions.

Data Requirements and Procedures

The data necessary to select the least-cost machinery complements are:

1. The days available for completing field work in each critical time period throughout the year.
2. The acres to be covered by each field operation

in each time period.

3. The costs and capacities of the machines from which the least-cost complements will be chosen.

The above data is used to determine optimal machinery complements. The first step in determining the days available is the collection of rainfall data. Sixty years of daily rainfall data are collected for weather stations in Texas county, Canadian county and Muskogee county. This data is used as input into a model developed by Reinschmiedt (22) to develop a days available frequency distribution. The resulting frequency distribution provides the days available to perform field work for each time period and for different timeliness levels. Each year is broken into 24 one-half month time periods. The concept of timeliness as used in this study relates to the ability of the machinery complement to perform the specified tasks a given percentage of the time. A 70% timeliness level requires the specificaton of the number of days during which field work could successfully be completed 7 years out of 10. The timeliness constraint will be discussed in more detail in the next chapter.

Information on average farm size and crops grown is utilized from Oklahoma Agriculture Statistics (18), on average farm size, crops grown. This information is used to determine crop mixes and farm sizes to be considered in this study.

Once the crop mix is determined for each study county of the state, the implements needed for performing each field operation in each time period are specified. The Oklahoma State Crop Budgets (18) are the principal source of field operation requirements.

The prices for all different implement size are compiled from dealer's prices of the machinery used. Matching of tractors and implements is accomplished using fact sheets (2), and the Agricultural Engineers Year Book (1). All of the collected information is incorporated into a model developed by Griffin (6). This model is discused in Chapter II. Finally, a report writer prints the solution in tabular form.

Optimal machinery solutions are then found for a number of situations. Each situation involves change in one or more of the following; farm size, crop mix, soil type, timeliness level, wage rate, and location.

Literature Review

Substantial research has been completed in the area of farm machinery costs and performance. A multitude of studies have analyzed machinery cost and cost coefficients and parameters. Hunt (11), Bowers (2), Grevis-James (5), and others have isolated these cost components and have estimated the appropriate procedures for finding them. Many universities, state experimental stations, and state extension services (Arizona, Iowa, North Dakota, Oklahoma

State University and others) report current machinery costs for three states. Since these figures are widely available, a detailed analysis will not be given here. The reader is directed to the bibiliography and particularly to the Agricultural Engineer's Yearbook (1) for these facts.

McIsaac and Lovering (17) in Canada developed a computer program in 1977 for calculating least-cost implement sizes for tillage and seeding of cereals. The data needed for input into the program included machinery prices, equipment use and hours of life estimates, implement draft requirements, repair rates, and operating efficiencies. Also needed were acres to be covered and which field operations will be performed. The program included a penalty cost for the value of crop losses due to late seeding. The program calculated the set of machinery which would perform the given field work for the lowest total cost. Total cost was the sum of tractor, implement, labor, and penalty costs. The program did not take into account the suitability of the tractors selected for other farm needs during the year. The program also did not consider scheduling of operations between two tractors.

Osborn and Barrick (19) developed a model for selection of equipment for farms on the Texas high Plains. They determined least-cost equipment combinations for three typical farm sizes and evaluated the effects of alternative wage rates on the least-cost systems. Required input data included equipment prices, tractor and implement operating characteristics, and the field operations to be performed. Their model selected equipment combinations on the basis of technical feasibility, time requirements, and annual costs, both fixed and variable. Osborn and Barrick found that size of equipment had little effect on annual cost. That is, it was difficult to reduce annual costs by moving toward a more capital intensive operation. Osborn and Barrick also concluded that the relative availability of short-term versus long-term capital was important in the selection of a machinery system. If use of short-term capital is restricted relative to long-term capital, long-term capital should be invested in larger equipment. Conversely, if long-term capital is more limiting, smaller equipment should be purchased and more labor hired.

Hunt (9), (10) added a more precise and dynamic mathematical model for tractor performance, thereby providing an "optimal" travel speed for each operation, as well as the "correct" machine sizes. Unfortunately, as Hunt notes, the tractor and implement sizes selected by the program did not conform to typical equipment found on surveyed farms. The Hunt program did, however, serve as the stepping stone for future machinery selection models.

Griffin (7) programed a one-tractor optimum machinery complement selection model allowing for tillage requirements for a particular farm enterprise mix to be divided or combined into as many as 24 mutually exclusive time periods (each representing a two week interval), each with its own timeliness constraint. Operational requirements of each particular implement type can appear in any number of these time slots, possibly competing in each time slot with one or more other required functions for the particular tractor or tractors used.

Farmers were surveyed to obtain their estimates of field work time loss caused by various rainfall amounts (22). This information was then used along with a rainfall simulation model to develop distributions of numbers of field work days. Alternative timeliness levels were calculated from the frequency distributions. These field time values were then used as time constraints in the mixed integer programming model.

The algorithm utilizes the least-cost comparision and partial budgeting techniques generally followed by other combinatorial programs. The advantage of one size or model of a particular implement type over another, when no tractor change is needed, depends on the economic trade-off between initially higher investment, but greater capacity machinery, and generally lower investments, and smaller capacity implements.

A study by Kletke and Griffin (15) at Oklahoma State University looked at the effect of alternative wage rates on optimal machinery complements. A mixed integer, linear programming model was developed to determine optimum machinery complements for Northcentral Oklahoma wheat farms. The types of data required for the model were the hours available for field work in each critical time period, the acres to be covered by each field operation in each time period, the cost and computational parameters for all machines from which the optimal machinery complements were chosen.

The farm situations analyzed were relatively simple ones. Only 5 of 24 possible time periods were used. No more than one field operation took place in any given two week time period and the least-cost machinery complement was chosen from a set of 27 machines. Kletke and Griffin found that as labor costs increased relative to machinery cost, farmers should substitute larger implements and tractors for hired labor. As farm size increased, the impact of higher wage rates on the optimal complement was substantial. Higher wage rates may also be interpreted to mean a scarcity of available labor.

Review of Subseqent Chapters

The first part of Chapter II contains some of the theoretical concepts upon which this study is based. In addition, the technical and economic relationships required for data preparation are presented. Finally, a brief discusion of the solution procedure is discused. Chapter II gives some economic insight into what happens in the different situations, and indicates how the different situations are put together in the model. Chapter III presents the results. Each situation analyzed is described and the resulting optimal machinery complement is presented. An attempt is also made to draw implications from the various results. Chapter IV summarizes the results and implications. Chapter IV also outlines expected weaknesses in the model and suggests future topics for additional research.

CHAPTER II

THE COMPUTER MODEL

Economic Theory And Evaluation

Some machinery costs occur primarily as a result of ownership, while other costs occur according to the degree which the machine is used. Ownership costs include the annual cost of the original investment (depreciation and interest), insurance, property taxes and machinery housing. Operating or variable cost include fuel, oil, lubricants, repairs, maintenance and labor.

Labor and capital are generally thought of as substitutes for for each other in agricultural production. A farm operation may be very capital intensive, or very labor intensive, or may use any combination of capital and labor to accomplish the necessary field work. The substitution of capital for labor comes about by using large, high capacity machinery capable of completing field work in fewer hours per day rather than using small, low capacity machinery using more hours to complete the field work. As long as field work operations are completed in the same time period output will remain the same irrespective of the size of machinery or amount of labor it takes to accomplish the operations.

The farmer may reduce crop losses by purchasing machinery with excess capacity to complete the field operations in years when the days available for field work are severely limited by the weather. The higher capacity machinery requires less hours of labor to complete the field work but is available only at a higher fixed cost.

Cost minimization problems involving machinery selection contain both fixed and variable costs which can be easily solved by the use of mixed integer programming. Each production process may be divided into two activities, one for fixed cost and one for variable cost. The fixed cost activities enter the solution at integer values. If a machine is owned, the fixed costs are incurred whether the machine is used or not. The variable cost activities enter the solution as continuous variables, depending on the amount the implements are used. The amount of implement usage depends upon the requirements of the field operations considered. The least-cost solution will contain the machinery complement with the lowest total cost which will satisfy the production requirements without exceeding the resource limitations (4).

Three basic types of data are needed for the model; machinery cost and capacity data, probabilities on the number of available field work days, and the identification of field work operations to be performed. For the purposes of this study, it is assumed that there is no existing set of machinery and the crop production plan is assumed to be repeated year after year. Therefore the technical coefficients and prices will remain the same. Table I lists the technical coefficients used in this model. The technical coeficients are based on current Oklahoma State Crop Budgets (18). The formulas for the technical coefficients can be found in the operations procedure manual for the Enterprise Budget Generator (20).

The Model

The over all flow of the model first requires inserting the constraints of the farming situaiton. Next the desired constraints are analyzed and processed by the model. This is accomplished by the use of a matrix generator program. Then the MPSX program uses this matrix data for finding a continuous optimal solution for the specified situation. After a continuous solution is found the MPSX program searches for a mixed integer solution. A continuous solution is defined as allowing fractions of implements into the solution, and a integer solution is defined as allowing only discrete unit of implements into the solution. After the first integer solution is found the program continues to search for a better integer solution (lower cost). Eventually the program will find an optimal integer

TABLE I

TECHNICAL COEFFICIENTS USED IN THE OPTIMUM MACHINERY COMPLEMENT SELECTION MODEL

PARAMETER DESCRIPTION	VALUE
Price per gallon of gasoline	$1.23
Price per gallon of L.P. gas	0.60
Price per gallon of diesel	1.02
Interest rate per dollar	0.14
Machinery insurance rate (price/dollar of average investment insured)	0.02
Machinery tax rate (price/dollar of purchase value)	0.00
Price of machinery labor/hr.	3.90
Maximum number of tractors allowed in complement	10.00
Maximum number of tractor-operators allowed in complement	10.00
Factor by which machine hours are multiplied to obtain tractor hours	1.10
Factor by which tractor hours are multiplied to obtain machinery labor requirements	1.10
Factor by which the time available is inflated for tractors	1.10

machinery complement solution (least-cost solution). This solution is printed in tabular form by a report writer. The report writer details the implements used, the amount of hours in each time period each implement is used, the tractors to be used and the amount of hours in each time period the tractors are used. Finally, the total amount of implement and tractor hours used in each time period are tallied along with the costs associated with the optimal machinery complement.

Characteristics

The machinery selection model plans for one year and for each additional year the same requirements and resources are used. The model is capable of using custom work charged on a per acre basis. The implements and tractors are purchased in discrete units.

The model allows transfering part of the field work to the following or preceding time period at a specified cost per acre. The transfer cost is set at 30% of the prevailing custom rate. Also, the number of acres which could be transfered to a different time period is set at 30% of the total acreage covered by the particular implement in that time period. This procedure is used, on occasion, to prevent the machinery selection program from buying a machine and using it only a few hours per year. If a certain amount of free labor is available for use in a time period this can be incorporated into the model. Allowing only a certain amount of operators and/or tractors to enter a solution can be handled. For a full explanation of the objective function equation the reader is directed to work done by Griffin (6).

The farm sizes and crop mixes considered for each of the three areas of Oklahoma are based on Oklahoma Agricultural Statistics (18) and a working knowledge, of actual conditions in each area. The wage rate is used as a proxy for labor availability. A low wage rate indicates an abundant supply of labor while a high wage rate may be interpreted as a scarcity of labor. Scarcity of available hired labor may induce farmers to substitute capital for labor by purchasing large, high capacity machinery which will complete field operations faster, thus requiring fewer hours of labor.

In 1970, International Business Machines Incorporated (IBM) (12) introduced a program product known as MPSX (Mathematical Programming Systems Extended), providing expanded capabilities over its predecessor, IBM's MPS/360 (13). One extension of the new IBM system was the availability of a mixed integer linear programming algorithm with computational efficiency and solution speed previously unavailable. Far superior to previous MIP computer programming packages, the MPSX-MIP system, when properly harnessed, makes an MIP formulation of the machinery selection problem a viable alternative. The MPSX and its supporting programs provide a mathematical programming system that includes a control program and control program compiler, a set of procedures for linear, separable, and mixed integer programming, and various matrix generation and report writing aids (14). The algorithm is capable of solving continuous linear programming problems with up to 16,383 constraints. The MIP program logic is limited to a maximum of 4095 integer variables, but the realistic limit is much smaller dependending on the specific problem type and structure used (13). MPSX-MIP is the solving algorithm used in this study.

The output generated by the OMCSS program is used as input to the MPSX program for finding the optimal machinery complement. The information provided MPSX is organized so that each implement selected must come into the solution as an integer, thus eliminating a major criticism of standard linear programming for machinery selection. The MPSX mixed integer program systematically searches through the possible solutions to find the optimum set of machinery. The solutions found using MPSX-MIP will be discused in the following chapter.

Limitations

Weather conditions vary from year to year, and the model does not take this into consideration. For example, the given percentage of the time chosen for performing field operations is not changed from year to year. Therefore the machinery capable of performing the field operations say seven out of ten years will not be able to perform the given field operatins in the specified time period three years due to adverse weather conditions. And there will be some years out of those seven years when the weather conditions will allow some excess capacity in the same set of machinery. This model considers not being able to perform field work because of wet weather conditions but does not consider weather conditions that are too dry to perform the necessary field operations.

Another problem occurs when there are several optimal machinery complements with the same cost. The model picks the first complement it comes to as the optimal machinery complement. Since each optimal complement would have a different machinery complement, the one chosen would depend on a given farmers preference or needs.

Changes over time such as input prices, technology, crop mixes, cultivation methods and tractor implement combinations are not considered in this model. Other changes not considered include, income tax considerations dealing with tax incentives and disincentives involved with investment tax credits, depreciation schedules and capital gains. Capital investment decisions, cash flow analysis and other financial aspects of owning machinery are also not included in this model.

The simultaneous selection of an optimal crop mix and an optimal machinery complement is not possible with this model. The model also does not take into consideration the replacing over time of an existing machinery complement with the optimal machinery complement.

Data Requirements

In the selection of an optimal machinery complement decision making must take place in an environment of uncertainty. There is a tradeoff between the number of days available during a time period and the percentage of time the field operations can be performed (timeliness). The cost associated with timeliness is the cost of not being able to complete or perform a job or task at or during the "optimum" time period. Examples are, late planting, late harvesting, or late seedbed preparation. Each will cause possible reductions in production and/or additional expenses in performing machinery operations. The inability of an implement to complete a job within the optimum time period, can be considered an expense. Therefore the optimum machine size balances the low ownership cost advantage of small capacity machines with the timely-operation advantages of large machines.

Table II shows the days available for each time period (24 total), and for three timeliness levels (95%, 85% and 70%).

TABLE II

THE DAYS AVAILABLE FOR FIELD WORK IN EACH TIME PERIOD FOR CANADIAN, TEXAS, AND MUSKOGEE COUNTIES

COUNTY	CANADIAN			CANADIAN			TEXAS			MUSKOGEE		
SOIL TYPE	CLAY LOAM			SANDY LOAM			SANDY LOAM			SANDY LOAM		
TIMELINESS LEVEL	95%	85%	70%	95%	85%	70%	95%	85%	70%	95%	85%	70%
Period*												
Jan 1	8.75	11.00	13.50	9.75	12.00	14.00	14.50	15.25	0.0	9.00	11.00	12.50
Jan 2	9.00	10.75	12.25	10.25	11.75	13.50	13.75	14.25	15.00	7.75	10.25	11.75
Feb 1	9.00	11.25	12.25	10.00	11.75	12.75	12.00	13.25	13.25	6.75	9.50	11.50
Feb 2	8.75	10.75	12.25	9.75	11.25	12.75	12.50	13.25	13.75	6.25	8.50	10.50
Mar 1	9.00	11.25	13.50	10.50	12.00	14.00	13.50	14.50	15.00	7.50	9.75	12.00
Mar 2	8.75	10.75	12.75	9.75	12.00	13.00	12.00	13.00	14.00	8.00	9.50	11.50
Apr 1	6.00	8.50	11.50	7.50	9.75	12.25	11.00	12.75	14.00	6.25	7.50	9.75
Apr 2	5.75	8.00	10.50	7.25	9.50	11.50	10.50	12.50	14.00	4.75	7.00	9.50
May 1	4.50	7.50	10.00	6.50	9.50	11.00	10.00	11.75	13.50	5.00	7.75	9.75
May 2	2.75	6.50	8.75	4.75	8.00	10.00	8.00	10.25	12.00	5.25	7.75	10.00
Jun 1	5.25	8.50	11.25	7.25	10.00	12.00	8.00	11.25	12.50	5.75	7.75	10.00
Jun 2	5.75	9.50	11.75	6.75	10.25	12.00	9.50	11.00	12.50	5.50	8.50	11.00
Jul 1	7.25	11.00	13.00	8.50	11.50	13.25	9.50	11.75	13.50	9.25	11.50	13.50
Jul 2	7.75	11.00	12.50	8.50	11.75	12.50	9.00	11.00	12.50	9.50	11.75	12.50
Aug 1	9.00	11.75	12.50	10.25	12.25	13.50	9.50	11.75	13.25	9.50	11.00	12.75
Aug 2	9.00	11.00	12.50	10.25	11.50	12.50	9.00	11.75	12.75	8.50	10.50	12.25
Sep 1	7.50	9.75	11.25	8.00	10.50	12.00	9.25	11.50	13.50	6.50	8.50	11.25
Sep 2	7.50	9.50	11.25	8.75	10.50	12.00	9.75	12.00	13.75	6.25	9.00	11.25
Oct 1	7.50	10.00	12.25	8.50	10.50	12.50	11.50	13.00	15.00	7.50	9.50	12.00
Oct 2	7.00	9.50	12.00	8.50	10.25	12.50	11.25	12.75	14.00	7.00	10.50	12.00
Nov 1	8.25	10.25	12.75	9.00	11.00	13.00	12.00	14.00	14.50	7.25	10.50	12.00
Nov 2	8.75	11.00	13.00	9.75	11.50	13.25	12.00	14.00	14.50	7.75	10.50	12.00
Dec 1	9.50	11.50	13.50	10.00	12.40	14.00	14.00	14.75	15.25	7.75	10.00	12.00
Dec 2	8.50	10.25	12.50	9.50	11.25	13.00	12.50	13.50	14.25	6.50	8.75	11.00

* 1 is equal to the first half of month and 2 is equal to the second half of month.

The numbers in the table are multiplied by the hours to be worked each day in a given time period in order to obtain the total hours of work available per time period. Reinschmidt developed a methodology for working with rainfall uncertainty (22). His procedure utilizes historical rainfall data for a particular area to prepare distributions of work days available in each time period during the year. The user picks a timeliness level for each period consistant with his preferences concerning the percent of time he wants field work done in the specific time period.

The program Reinschmidt developed is used in this study. The computer program used to prepare the distributions of days available is a rainfall simulator model. For this study, 60 years of daily rainfall was collected for one weather station in each of the three counties studied (Texas, Canadian, Muskogee). The days available are entered into the machinery selection model as presented in Table II The model also takes into account differences in soil types (sandy loam and clay loam).

Machinery

A representative set of tractors and implements comprising the machinery complement is selected considering all possible field operations needed for the three study areas in Oklahoma. The total machinery required for a given size of farm is calculated by multiplying the number of acres each crop is used by the crop's required field operations and for each time period and then summed for all crops and field operations.

Table III lists for each machine the component costs both fixed and variable. The prices for these machines are tallied out of dealers price books.

The total operating cost per acre is computed from machinery cost per hour and field efficiencey, field speed, and machine width. Machinery usage per acre covered is equal to: 8.25 / (SPEED X WIDTH X EFF), where, the SPEED is the effective speed (miles per hour) of the machine as it travels over the acre. The WIDTH is the number of feet covered by the implement in one pass, and EFF is the field efficiency of the machine or ratio of the actual capacity of the machine to its theoretical capacity.

Farm Organization and Field Operations

Tables IV, V and VI list the different implements, the implement sizes and the implement "ranks" for each of the three counties (Texas, Canadian, and Muskogee). Where "rank" is the size of implements that can be pulled by a given size tractor. For example a tractor of rank 4 can pull all implements less than or equal to rank 4. Table IV lists the different implements, machinery codes and machinery sizes for Canadian county. The offset disk has

TABLE III

DESCRIPTIONS, CAPABILITIES, AND COSTS OF MACHINERY USED BY THE OPTIMUM MACHINERY COMPLEMENT SELECTION PROGRAM IN CANADIAN COUNTY

MACHINE NAME	SIZE (ft)	FIELD CAPACITY	CURRENT MACHINE VALUE	MACHINE LIST PRICE	FUEL COST /HR.	LUBRICATION OIL/HR.	REPAIR COST/ HOUR	TOTAL VARIABLE COST/HR.	OTHER OWNER SHIP	DEPRECIATION (1)	TOTAL FIXED COST
Offset Disk	7.8	3.767	$6220.00	$6911.00	$ 0.0	$ 0.0	$1.5926	$1.70407	$ 74.421	$1129.26	$1203.68
Offset Disk	11.6	5.602	8377.00	9215.00	0.0	0.0	2.1235	2.27217	100.066	1521.72	1621.78
Offset Disk	15.2	7.340	9770.00	10747.00	0.0	0.0	2.4766	2.65992	116.705	1774.76	1891.47
Offset Disk	27.0	11.137	17704.00	19671.00	0.0	0.0	4.5330	4.85034	211.826	3217.21	3426.04
M.B. Plow 3-16"	4.0	1.358	2035.00	2261.00	0.0	0.0	0.5210	0.55750	24.348	369.46	393.81
M.B. Plow 4-18"	6.0	2.535	6134.00	6747.00	0.0	0.0	2.2992	2.46010	73.271	1114.27	1187.54
M.B. Plow 5-18"	7.5	3.477	7134.00	7847.00	0.0	0.0	2.6740	2.86119	85.217	1295.93	1381.14
M.B. Plow 6-18"	9.0	4.173	8709.00	9579.00	0.0	0.0	3.2642	3.49271	104.030	1582.04	1686.07
M.B. Plow 8-18"	12.0	5.564	9425.00	10368.00	0.0	0.0	3.5331	3.78040	112.585	1712.09	1824.67
Drill	10.0	3.927	2971.00	3301.00	0.0	0.0	1.3645	1.46000	35.548	539.39	574.94
Drill	30.0	11.782	5179.00	5754.00	0.0	0.0	2.3784	2.54493	61.965	940.27	1002.23
Drill	40.0	13.964	6389.00	7099.00	0.0	0.0	5.1091	5.46674	76.444	1159.94	1236.38
Drill	60.0	20.945	7386.00	8207.00	0.0	0.0	5.9065	6.31998	88.373	1340.95	1429.32
Spring Har	12.5	5.621	564.00	627.00	0.0	0.0	0.1445	0.15460	6.749	102.39	109.14
Spring Har	22.5	10.118	1001.00	1112.00	0.0	0.0	0.2563	0.27419	11.975	181.74	193.71
Spring Har	34.5	15.515	1580.00	1755.00	0.0	0.0	0.4044	0.43274	18.904	286.86	305.76
Spring Har	48.5	21.810	2052.00	2280.00	0.0	0.0	0.5254	0.56219	24.552	372.55	397.10
Spring Har	60.5	27.207	2696.00	2995.00	0.0	0.0	0.6902	0.73849	32.256	489.47	521.73
Chisel Plow	8.0	3.103	1899.00	2110.00	0.0	0.0	0.5813	0.62195	22.721	344.77	367.49
Chisel Plow	12.0	4.655	2221.00	2468.00	0.0	0.0	0.6799	0.72748	26.574	403.23	429.80
Chisel Plow	16.0	6.206	2749.00	3054.00	0.0	0.0	0.8413	0.90021	32.891	499.09	531.98
Chisel Plow	23.0	8.921	7070.00	7856.00	0.0	0.0	2.1642	2.31566	84.593	1283.57	1368.17
Chisel Plow	37.0	14.352	11128.00	12364.00	0.0	0.0	4.9607	5.30798	133.145	2020.32	2153.47
Planter 8-Row	20.0	8.121	15002.00	16669.00	0.0	0.0	9.1651	9.80671	179.498	2723.66	2903.15
Planter 16-Row	40.0	16.242	28713.00	43014.00	0.0	0.0	23.6505	25.30598	463.197	7028.46	7491.66
Cultivator 4-Row	12.2	4.656	1975.00	2173.00	0.0	0.0	0.5008	0.53580	23.593	358.76	382.36
Cultivator 6-Row	20.0	7.001	2848.00	3133.00	0.0	0.0	0.7220	0.77251	34.020	517.35	551.37
Cultivator 8-Row	26.7	9.347	3661.00	4027.00	0.0	0.0	0.9280	0.99295	43.731	665.04	708.77
Cultivator 12-Row	40.0	14.003	5479.00	6027.00	0.0	0.0	1.3889	1.48610	65.448	995.28	1060.73
Tractor 61 hp	61.0	0.0	12636.00	14040.00	2.738	0.411	0.9264	4.35991	167.832	2208.03	2375.86
Tractor 80 hp	80.0	0.0	16321.50	18135.00	3.590	0.539	1.1965	5.69828	216.783	2852.04	3068.83
Tractor 111 hp	111.0	0.0	25699.90	28555.00	4.092	0.747	1.8841	8.14589	341.346	4490.84	4832.18
Tractor 156 hp	156.0	0.0	36000.00	40000.00	7.001	1.050	2.6392	11.439.00	478.154	6290.69	6768.84
Tractor 225 hp	225.0	0.0	65403.50	72671.00	10.098	1.515	4.7948	17.55602	868.693	11428.69	12297.38

TABLE IV

IMPLEMENT SIZES AND "RANKING" FOR CANADIAN COUNTY

	SIZE	RANK[1] DIV. DRY SANDY LOAM	RANK DIV. DRY CLAY LOAM	RANK[2] DIV. IRR. SANDY LOAM	RANK[3] SPEC. DRY SANDY LOAM
MACHINE CODE 201					
OFFSET DISK	7.8'	3	4	3	3
	11.0'	4	5	4	4
	13.0'	5	6	5	5
	15.0'		7		
	27.0'	7		7	7
MOLDBOARD PLOW[9]	2-B		3		
	3-B	3	4	3	
	4-B	4	6	4	
	5-B	5	7	5	
	6-B	6	8	6	
	8-B	7		7	
CHISEL PLOW	8.0'	3	5	3	3
	12.0'	4	6	4	4
	16.0'	5	7	5	5
	20.0'		8		
	23.0'	6		6	6
	37.0'	7		7	7
CULTIVATOR	4-ROW	3	5	3	
	6-ROW	4	7	4	
	8-ROW	5	8	5	
	12-ROW	6		6	
LISTER	8' 3"			2	
	15' 6"			4	
	18' 7"			5	
	26'10"			6	
TRACTOR	61 HP	3	3	3	3
	80 HP	4	4	4	4
	111 HP	5	5	5	5
	156 HP	6	6	6	6
	175 HP		7		
	225 HP	7	8	7	7
MACHINE CODE 202					
DRILL	10'	1		1	1
	20'		2		
	30'	2	3	2	2
	40'	3	4	3	3
	60'	4	5	4	4
SPRINGTOOTH HARROW	12'6"	2		2	2
	18'6"		3		
	22'6"	4	4	4	4
	34'6"	5	5	5	5
	40'6"		6		
	48'6"	6	7	6	6
	60'6"	7	8	7	7
PLANTER	6-ROW		1		
	8-ROW	1		1	
	12-ROW		2		
	16-ROW	2	3	2	

1. Diversified Dryland Farming consisting of: 50% wheat, 30% cotton, 10% Grain Sorghum, 10%peanuts.

2. Diversified Irrigated Farming consisting of: 50% Dryland wheat, 10% Dryland cotton, 20% Irrigated cotton, 10% Irrigated peanuts, 10% Irrigated Sorghum.

3. Specialized Dryland Farming consisting of: 100% wheat.

TABLE V

IMPLEMENT SIZES AND "RANKING" FOR MUSKOGEE COUNTY

	SIZE	RANK[4] DIV. DRY SANDY LOAM	RANK[5] SPEC. DRY SANDY LOAM
MACHINE CODE 201			
MOLDBOARD MOW	3-B	3	3
	4-B	4	4
	5-B	5	5
	6-B	6	6
	8-B	7	7
CULTIVATOR	4-ROW	3	3
	6-ROW	4	4
	8-ROW	5	5
	12-ROW	6	6
TRACTOR	61 HP	3	3
	80 HP	4	4
	111 HP	5	5
	156 HP	6	6
	225 HP	7	7
MACHINE CODE 202			
TANDEM DISK	7'8"	2	2
	15'8"	3	3
	21'4"	4	4
	30'0"	5	5
	40'4"	6	6
DRILL	10'	1	1
	30'	2	2
	40'	3	3
	60'	4	4
SPRINGTOOTH HARROW	12'6"	2	2
	22'6"	4	4
	34'6"	5	5
	48'6"	6	6
	60'6"	7	7
PLANTER	8-ROW	1	1
	16-ROW	2	2
SPIKETOOTH HARROW	6'	1	1
	12'	2	2
	18'	3	3
	24'	4	4

4. Diversified Dryland farming consisting of: 35% wheat, 30% Soybeans, 20% grain sorghum, 15% peanuts.

5. Specialized Dryland farming consisting of: 50% soybeans, 50% wheat.

TABLE VI

IMPLEMENT SIZES AND "RANKING" FOR TEXAS COUNTY

	SIZE	RANK[6] DIV. DRY SANDY LOAM	RANK[7] DIV. IRR. SANDY LOAM	RANK[8] SPEC. DRY SANDY LOAM
MACHINE CODE 201				
OFFSET DISK	7'8"	3	3	
	11'0"	4	4	
	13'0"	5	5	
	27'0"	7	7	
CHISEL PLOW	8'	3	3	3
	12'	4	4	4
	16'	5	5	5
	23'	6	6	6
	37'	7	7	7
RODWEEDER	23'	2		2
	29'	3		3
	37'	4		4
	47'	5		5
SHREDDER FLAIR	14'		2	
TRACTOR	61 HP	3	3	3
	80 HP	4	4	4
	111 HP	5	5	5
	156 HP	6	6	6
	225 HP	7	7	7
MACHINE CODE 202				
DRILL	10'	1	1	1
	30'	2	2	2
	40'	3	3	3
	60'	4	4	4
PLANTER	8-ROW	1	1	
	16-ROW	2	2	
FIELD CULTIVATOR	12'6"	3	3	3
	18'6"	4	4	4
	28'6"	5	5	5
	34'6"	6	6	6
	48'6"	7	7	7
MACHINE CODE 203				
SPRAYER	100 GAL	1	1	1
	350 GAL	2	2	2
	500 GAL	3	3	3
ROTARY HOE	15'		1	
	28'		2	
	30'		3	
	41'		4	
BALER	7'6"		3	

6. Diversified Dryland farming consisting of: 70% wheat, 30% Grain Sorghum.

7. Diversified irrigated farming consisting of: 24% Dryland Wheat, 9% Dryland Grain Sroghum, 33% Irr. Grain Sorghum, 17% Irr. Corn, 17% Irr. Alfalfa.

8. Specialized Dryland farming consisting of: 100% Wheat.

9. Measured in bottoms per plow.

a machinery code of 201 and has five different sizes. On a diversified dryland sandy loam soil the 7.8' offset disk is ranked a 3. Where the 7.8' offset disk on a diversified dryland clay loam soil is ranked a 4. This results because implements pull harder on clay loam soils and therefore require larger tractors.

Tables VII and VIII outline for each crop grown, the machinery used and the time period in which the operations will be performed. Table VII presents information on the crops grown in Canadian county. The first crop listed is dryland wheat. For example the offset disk is used in the second half of June. The chisel is used in the second half of June, the second half of July and the second half of August. Table VIII provides the same information for Muskogee and Texas counties.

Input Data

Table IX lists the input requirements for the OMCSS model (8). The first line provides the problem a name. "NONRNP 080715", indicates to the program that there are eight different kinds of machinery including a tractor, and there are seven ranks (machine sizes) and fifteen different time periods for this particular farm. The next card $ENDSEC$, is used to terminate sections of input and insert comments about the data.

TABLE VII

THE MACHINERY USED AND THE TIME PERIOD THE OPERATIONS ARE PERFORMED FOR EACH CROP GROWN IN CANADIAN COUNTY

CANADIAN COUNTY

IMPLEMENT	TIME PERIOD USED	IMPLEMENT	TIME PERIOD USED
DRYLAND WHEAT		IRRIGATED GRAIN SORGHUM	
OFFSET DISK	June - 2	MOLDBOARD PLOW	February - 2
CHISEL	June - 2	OFFSET DISK	March - 1
CHISEL	July - 2	OFFSET DISK	March - 2
CHISEL	August - 2	LISTER	April - 2
DRILL	October - 1	PLANTER	April - 2
SPRINGTOOTH HARROW	October - 1	CULTIVATOR	May - 2
IRRIGATED COTTON		CULTIVATOR	June - 2
MOLDBOARD PLOW	February - 1	CULTIVATOR	July - 1
OFFSET DISK	March - 1	CHISEL	February - 2
OFFSET DISK	March - 2	CHISEL	March - 2
LISTER	April - 2	SPRINGTOOTH HARROW	April - 2
PLANTER	April - 2	DRYLAND PEANUTS	
PLANTER	May - 2	MOLDBOARD PLOW	April - 1
CULTIVATOR	May - 2	OFFSET DISK	April - 2
CULTIVATOR	June - 2	OFFSET DISK	May - 1
CULTIVATOR	July - 1	OFFSET DISK	May - 2
CULTIVATOR	July - 2	PLANTER	May - 2
CULTIVATOR	August - 2	CULTIVATOR	June - 2
IRRIGATED PEANUTS		CULTIVATOR	July - 1
MOLDBOARD PLOW	April - 1	CULTIVATOR	July - 2
OFFSET DISK	April - 1	DRYLAND COTTON	
OFFSET DISK	May - 2	MOLDBOARD PLOW DECEMBER	December - 1
PLANTER	May - 2	OFFSET DISK	January - 2
CULTIVATOR	June - 2	OFFSET DISK	May - 1
CULTIVATOR	July - 1	OFFSET DISK	May - 2
CULTIVATOR	July - 2	SPRINGTOOTH HARROW	May - 2
DRYLAND GRAIN SORGHUM		PLANTER	May - 2
OFFSET DISK	January - 2	CULTIVATOR	June - 2
OFFSET DISK	May - 1	CULTIVATOR	July - 1
CHISEL	Febuary - 2	CULTIVATOR	July - 2
CHISEL	April - 2		
PLANTER	May - 2		
CULTIVATOR	June - 2		
	July - 1		

TABLE VIII

THE MACHINERY USED AND THE TIME PERIOD THE OPERATIONS ARE PERFORMED FOR EACH CROP GROWN IN MUSKOGEE AND TEXAS COUNTY

MUSKOGEE COUNTY

IMPLEMENTS	TIME PERIOD USED
DRYLAND GRAIN SORGHUM	
MOLDBOARD PLOW	March - 2
TANDEM DISK	April - 1
SPRINGTOOTH HARROW	April - 1
PLANTER	May - 2
CULTIVATOR	June - 2
CULTIVATOR	July - 2
DRYLAND WHEAT	
MOLDBOARD PLOW	July - 2
TANDEM DISK	August - 2
TANDEM DISK	September - 2
SPIKETOOTH HARROW	August - 2
DRILL	September - 2
DRYLAND PEANUTS	
MOLDBOARD PLOW	January - 2
TANDEM DISK	April - 1
TANDEM DISK	May - 1
SPRINGTOOTH HARROW	May - 1
PLANTER	May - 2
CULTIVATOR	June - 2
CULTIVATOR	July - 2
DRYLAND SOYBEANS	
MOLDBOARD PLOW	February - 2
TANDEM DISK	April - 1
TANDEM DISK	May - 1
SPRINGTOOTH HARROW	May - 1
PLANTER	May - 2
CULTIVATOR	June - 2
CULTIVATOR	July - 2

TEXAS COUNTY

IMPLEMENTS	TIME PERIOD USED
IRRIGATED CORN	
STALK SHREDER	February - 2
OFFSET DISK	February - 2
OFFSET DISK	May - 2
CHISEL	February - 2
PLANTER	April - 2
ROTARY HOE	June - 1
IRRIGATED GRAIN SORGHUM	
STALK SHREDER	February - 1
OFFSET DISK	March - 2
OFFSET DISK	May - 1
CHISEL	March - 2
CULTIVATOR	May - 1
PLANTER	June - 1
ROTARY HOE	July - 1
DRYLAND GRAIN SORGHUM	
OFFSET DISK	March -2
PLANTER	June - 1
CULTIVATOR	June - 1
CULTIVATOR	June - 2
DRYLAND WHEAT	
CHISEL	June - 1
CULTIVATOR	August - 2
CULTIVATOR	September - 2
DRILL	September - 2
SPRAYER	January - 2
SPRAYER	February - 1
SPRAYER	August - 2
IRRIGATED ALFALFA	
BALER	June - 1
BALER	July - 1
BALER	August - 2
BALER	September - 2

TABLE IX

A SAMPLE INPUT DATA SET FOR THE OKLAHOMA MACHINERY COMPLEMENT SELECTION SYSTEM

```
PROBLEM     CANADIAN
NONSUP     080715
$ENDSEC$SOUTHWEST, CANADIAN COUNTY, MACHINERY COMPLEMENT SELECTION OCT 12
PARMCHNG03 1.02
PARMCHNG06  .14
PARMCHNG10 3.90
$ENDSEC$    100% DRY LAND FARMING WITH 50% WHEAT, 30% COTTON, 10% GRAIN
$ENDSEC$ SORGHUM, 10% PEANUTS, WITH 8 HOURS PER DAY AVAILABLE DURING
$ENDSEC$ JANUARY, FEBRUARY, DECEMBER, AND 10 HOURS AVAILABLE DURING THE
$ENDSEC$ REST OF THE YEAR, ON SANDY LOAM SOIL.
PERIOD.
40.    0.0    0.0    10.    50.    40.    50.    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0
0.0    0.0    10.    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    30.
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.    0.0
0.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    30.    0.0    0.0    0.0    0.0    50.    0.0
0.0    0.0    0.0
0.0    10.    0.0    10.    0.0    0.0    50.    0.0    50.    50.    0.0    0.0
0.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    56.    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    0.0    50.    50.    40.    0.0    0.0    0.0
0.0    0.0    0.0
82.    78.    75.    72.5   65.    47.5   67.5   85.    85.    102.5  90.    76.
72.5   102.5  76.
$ENDSEC$ PERIODS USED: JAN2 FEB2 APRIL1 APRIL2  MAY1 MAY2 JUNE2 JULY1
$ENDSEC$ JULY2 AUG2 OCT1 DEC1 JUNE1 AUG1 DEC2
TIMLINSS
        1  5  4 1.48   144.
        6  6 13 1.48   144.
        5  7 13 1.00   220.
        1  7 13 1.48   144.
        1  7  8 1.48   144.
        5  7  8 2.00   144.
        7  7 13 1.35   144.
        1  6 13 1.48   144.
        5  9 14 2.00   144.
        5 10 14 2.00   144.
        2 12 15 2.57    86.4
$ENDSEC$
$ENDSEC$ 30% OF CUST. HIRE RATE/COST  30% OF ACRES TRANSFERRED
FARMSIZE 9.6
RANK
OFFSET DISK                          201070 201071 201073        201074
M. B. PLOW                           201032 201033 201034 201035 201037
DRILL                  201051 202053 202054 202055
SPRINGTOOTH                   202061        202063 202065 202067 202069
CHISEL                               201091 201092 201093 201095 201097
PLANTER                202033 202035
ROW CULTIVATOR                       201061 201062 201063 201064
TRACTOR                              201002 201003 201004 201006 201008
```

The following three cards set the price of diesel at \$1.02 per gallon, the interest rate at 14%, and the wage rate to \$3.90 per hour.

The next block of data beginning with PERIOD and ending with \$ENDSEC\$ defines the field operations to be performed by each machine in each time period. There are two lines of data near the bottom of Table IX for each machine and the machine must be in the same order as found in the RANK data. The first two lines in the PERIOD block of data are for the offset disk and the fifteen numbers to the right are the percent of total farm acres to be covered by the offset disk in each of the fifteen time periods. The user specifies the time interval included in each time period. In this example the offset disk will cover 10% of the farm in the 4th period, 50% in the 5th, 40% in the 6th and 50% in the 7th time period. The succeeding lines are for the remaining field operations except for the last line which is for tractors. Each number in the tractor row is the number of field hours available in that time period. These numbers are chosen to insure the proper timeliness level and number of hours worked per day. The next two cards are \$ENDSEC\$ and are comment cards indicating the order and which time periods are considered in this situation. The next set of cards begin with TIMELINSS and ends with \$ENDSEC\$. These cards allow the transfer of machinery operations from one time period to another at a cost. For example the first card after TIMELINSS begins with a 1 which indicates implement 1 (offset disk) can transfer its field operations in time period 5 (May 1) to time period 4 (April 2) at a cost of $1.48 per acre and can transfer up to 144 acres of field operations. The first number indicates which implement (from the RANK section) is able to transfer its field operations; the second two numbers indicate which time period the transfer is taken from; the next two numbers indicate the time period where the transfer terminates; the next set of numbers is the cost per acre associated with the transfer; and the last set of numbers is the total amount of acres that can be transfered.

The next card is FARMSIZE and indicates how many acres are considered in the situation. The next set of cards begin with RANK and end with TRACTOR. This block shows the "ranking" of tractors and implements. A tractor of a given rank has sufficient power to "pull" an implement of the same or lesser rank. As an examle, for tractor 201002, the first three numbers indicate the machinery code and the last three indicates the size, (61 horsepower), in this case. The 61 horsepower tractor can pull the 4-row cultivator, number 201061), or any implement above it or to the left. Therefore tractor number 201008 (225 horsepower) can pull any implement available in this complement. Tractor number 201006 (156 horsepower) cannot pull the 37' chisel plow (201097).

Summary

The OMCSS operation follows several steps. First the complement is constructed from an assortment of implements and tractors. Secondly the ranking of the machines is specified to provide the correct tractor-implement matching (2). Thirdly, the tillage requirements for a particular farm enterprise mix are divided into time periods, with each time period having an hours available constraint.

A mixed integer programming model (6) is used to determine least-cost farm machinery complements. Mixed integer programming is well suited to finding solutions for problems involving both fixed and variable costs, found in farm machinery selection models. The model identifies the least-cost combinations of machinery which would complete the field work operations in the appropriate time periods. The model calculates the hours of implement and tractor use by time period and the hours of labor which must be hired in each time period.

The relevant cost components of machinery management are described and a selection model for determining optimal farm machinery complements and scheduling is presented and relevant variables defined. Some of the limitations and shortcomings of the model are also discussed.

CHAPTER III

Results

Machinery selection is based on a number of factors including; the number of acres farmed, the crops grown, the amount of labor available, and the time available to complete the field work. Oklahoma has a wide variation in climatic conditions, soil types, and cropping systems, indicating a wide range of optimal machinery complements.

Ten different situations or cases are analyzed in this chapter. Each case is a farm situation in one of three counties of Oklahoma (Texas, Canadian, or Muskogee). Each county contains different soil types, (sandy loam or clay loam), farming operations (dryland farming or a combination of dryland and irrigated farming), crop mixes, and two different assumptions on hours available for field work per day (eight hours during winter 9 time periods and 10 hours during summer time periods, or 10 hours during winter periods and 12 hours during summer periods). Optimal complements are determined for each situation defined above using various assumptions on timeliness (95%, 85%, 70%) and wage rates ($3.90, $8.00, $16.00).

Tables XI to XIV show a complete set of timeliness and wage rate combinations. Tables XV to XIX show only a selected few of the combinations mentioned above due to the extra expense and time involved for completing all possible runs that would be required. Also relatively little additional information would be obtained.

A Diversified 960 Acre Sandy Loam Soil Farm in Canadian County

Table X presents the results for Case A. Case A is a Canadian County dryland farm with 960 acres on sandy loam soil. Eight work hours are available per day during the winter time periods and 10 work hours are available during the summer time periods. The crop mix consists of 50% wheat, 30% cotton, 10% grain sorghum, and 10% peanuts. The first three columns, A-1, A-2, A-3, present the optimum machinery complements as the wage rate is changed with all else held constant. The timeliness level is held constant at 95%.

Analysis of Wage Rate Changes at 95% Timeliness Level

Situation A-1 in Table X contains one of each of the following machines: 11' offset disk, 3 bottom moldboard plow, 4 bottom moldboard plow, 30' drill, 22' 6" springtooth harrow. 8' chisel, 12' chisel, 8-row planter, 6-row

TABLE X

CASE A: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 960 ACRES, DIVERSIFIED[1] DRY LAND FARMING, SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORK HOURS AVAILABLE DURING THE WINTER MONTHS

MACHINERY	SIZE	RANK	Situation (Number of machines used per situation) A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
Offset Disk	11'	4	1			1			1		
Offset Disk	15'	5		1	1		1	1		1	1
M. B. Plow	3-16"	3	1								
M. B. Plow	4-18"	4	1			1					
M. B. Plow	5-18"	5		1			1	1	1	1	1
M. B. Plow	6-18"	6			1						
Drill	30'	2	1	1		1	1		1	1	1
Drill	60'	4			1			1			
Springtooth	22'6"	4	1			1					
Springtooth	34'6"	5		1			1	1	1	1	1
Springtooth	48'6"	6			1						
Chisel	8'	3	1								
Chisel	12'	4	1			1					
Chisel	16'	5		1			1	1	1	1	1
Chisel	23'	6			1						
Planter	8-Row	1	1	1	1	1	1	1	1	1	1
Row Cultivator	6-Row	4	1			1			1		
Row Cultivator	8-Row	5		1			1	1		1	1
Row Cultivator	12-Row	6			1						
Tractor	61 HP	3	1							1	1
Tractor	80 HP	4	2			2			1		
Tractor	111 HP	5		2	1		2	2	1	1	1
Tractor	156 HP	6			1						
Machine Cost			$34169.	$38936.	$48145.	$30106.	$37706.	$46595.	$31246.	$35663.	$44589.
Fixed Cost			17164.	18389.	22337.	14027.	18388.	18815.	16198.	15932.	15932.
Variable Cost			15769.	19317.	25019.	15502.	19317.	27779.	15047.	18871.	27789.
Transfer Cost[3]			1235.73	1230.02	788.97	577.					859.
Total Labor Hours			1533.13	1115.78	899.96	1455.00	1115.78	1094.21	1267.38	1115.78	1115.78
Wage Rate			$3.90	$8.00	$16.00	$3.90	$8.00	$16.00	$3.90	$8.00	$16.00
Timeliness Level			95%	95%	95%	85%	85%	85%	70%	70%	70%

1 Crop Mix: 50% Wheat, 30% Cotton, 10% Grain Sorghum, 10% Peanuts.

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

cultivator, 61 horsepower tractor and two 80 horsepower tractors. The cost components (Figure 1) are as follows, average annual machine cost is $35.59 per acre. Average annual fixed cost of $17.88 per acre. Average annual variable cost of $16.43 per acre, transfer cost of $1.30 per acre, and labor requirements of 1.60 hours per acre.

In the A-2 situation, the wage rate changes from $3.90 to $8.00. The optimal solution indicates the following changes should be made in the machinery complement. At a wage rate of $3.90, one 61 horsepower tractor and two 80 horsepower tractors are required while at a wage rate of $8.00 the solution contained two 111 horsepower tractors. The offset disk increases in size from 11' to 15', the 4 bottom moldboard plow is replaced by a 5 bottom moldboard plow. The springtooth increases in size from 22'6" to 34'6". The chisel increases in size from 12' to 16'. The cultivator increases in size from a 6-row to an 8-row. Average annual machine cost increases from $35.59 to $40.59 per acre, annual fixed cost increases from $17.88 to $19.15 per acre, annual variable cost increases from 16.43 to $20.12, transfer cost increases from $1.28 from $1.32 per acre, and labor hours decrease to 1.6 to 1.16 hour s per acre.

In the A-3 situation, the wage rate changes from $8.00 to $16.00. The optimal solution indicates the following changes should be made in the machinery complement. At a

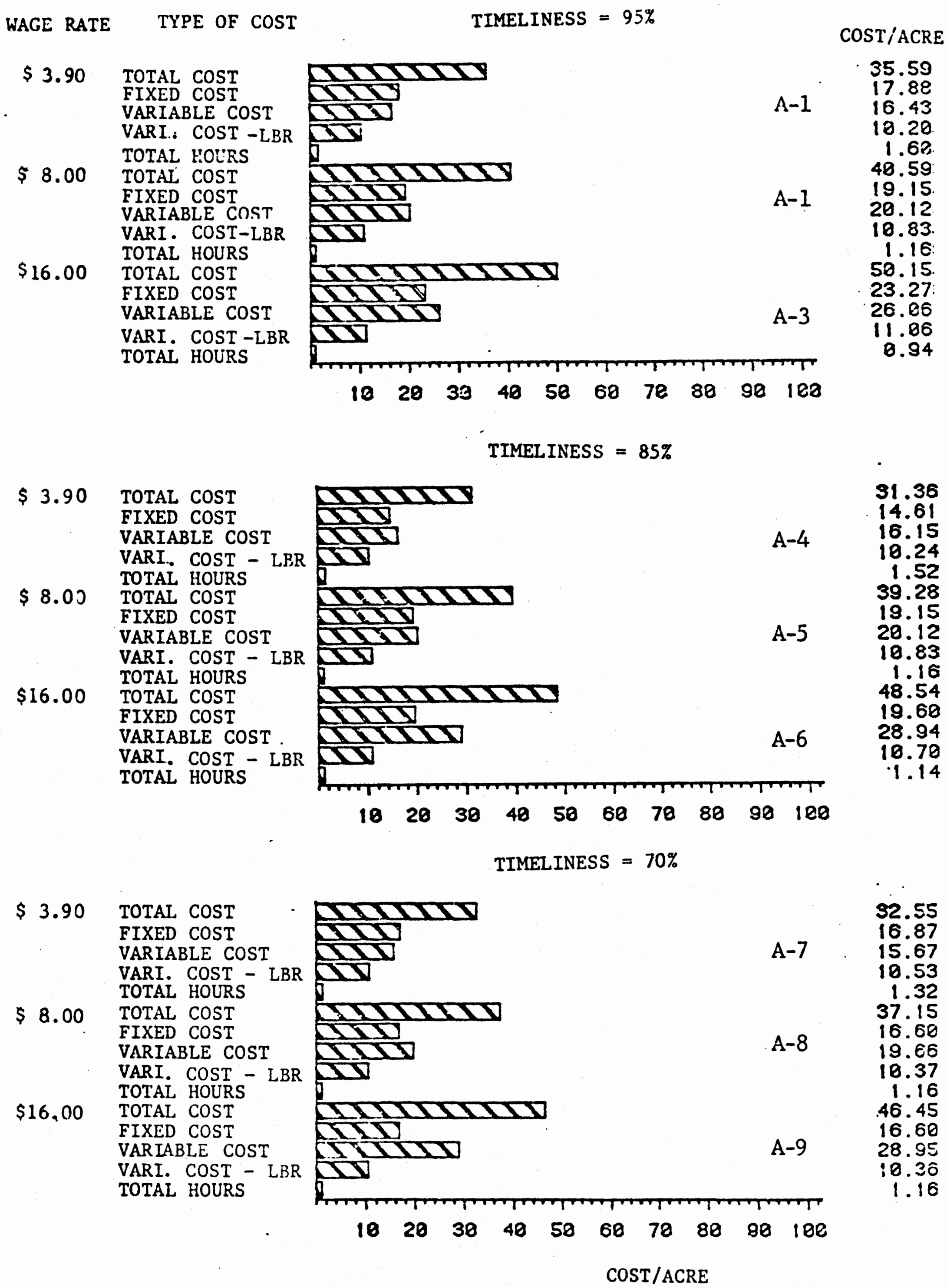


Figure 1. Case A: Optimal Farm Machinery Complements for Canadian County, 960 Acres, Diversified Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During Winter Months

wage rate of $8.00, two 111 horsepower tractors are required. While at a wage rate of $16.00 the solution contains an 111 horsepower tractor and an 156 horsepower tractor. The five bottom moldboard plow is replaced by a six bottom moldboard plow. The drill increases in size from 30' to 60'. The springtooth increases in size from 34'6" to 48'6". The cultivator increases in size from 8 rows to 12 rows. The average annual machinery cost increases from $40.59 to $50.15 per acre and the annual fixed cost increases from $19.15 to $23.27 per acre. The annual variable cost increases from $20.12 to $26.06 per acre while the transfer cost declines from $1.32 to $.82 per acre. Labor hours decline from 1.16 to .94 hours available per acre.

Wage Rate Changes at the 85% Timeliness Level

At the 85% timeliness level (A-4, A-5, and A-6; Table X) the size of implements increases as the wage rate increases from $3.90 to $8.00 to $16.00. The change between A-4 ($3.90 wage rate), and A-5 ($8.00 wage rate), is an increase in offset disk size from 11' to 15', the moldboard plow size increases from 4 bottoms to 6 bottoms, the springtooth harrow size increases from 22' 6" to 34' 6". The chisel size increases from 12' to 16', the cultivator size increases from 6 rows to 8 rows and the tractors change from two 80 horsepower tractors to one 111 horsepower tractor. The only change in implement size as the wage rate increases from $8.00 (A-5) to $16.00 (A-6), is the drill size which increases from 30' to 60'.

Wage Rate Changes at the 70% Timeliness Level

At the 70% timeliness level (A-7, A-8, A-9), the size of the implements used increases as the wage rate increases from $3.90 to $8.00 to $16.00. The increase from a $3.90 wage rate (A-7) to a $8.00 wage rate (A-8), results in the offset disk increasing in size from 11' to 15' and the increasing in size from 6 rows to 8 rows. The tractor combination decreases in power from two tractors of 80 and 111 horsepower to two tractors of 61 and 111 horsepower. The optimal machinery solutions indicate that as the wage rate increases from $3.90 to $8.00 the 111 horsepower tractor is used more hours at the $8.00 wage rate than at the $3.90 wage rate. The 61 horsepower tractor is used fewer annual hours at the $8.00 wage rate than the 80 horsepower tractor at the $3.90 wage rate. Therefore, the solution at an $8.00 wage rate uses the large tractor more hours and the small tractor less hours relative to the tractor use at the $3.90 wage rate. There is no difference between the machinery complements at the $8.00 wage rate (A-8) and the $16.00 wage rate (A-9).

The size of machinery utilized increases as the wage rate increases. As a result all costs associated with a machinery complement increases as the wage rates increase. Also as the wage rates increase the total labor hours decreases but the total labor expense increases.

Impact of Varying the Timeliness Level and Wage Rate

The average annual machinery cost increases as the wage rate increases at each separate timeliness level. The annual fixed cost for the 95% and 85% timeliness levels increases as the wage rate increases. But the fixed cost at the 70% timeliness level decreases as the wage rate increases from $3.90 to $8.00 and stays the same as the wage rate increases from $8.00 to $16.00. Due to a trade off between fixed cost and variable cost, the annual variable cost for each timeliness level increases as the wage rate increases.

Average annual machinery cost and annual fixed cost at each wage rate tends to decrease as the timeliness level decreases. The annual variable cost at the $3.90 and $8.00 wage rates, decrease as the timeliness level declines. The annual variable cost given a $16.00 wage rate tends to increase as the timelness level decreases.

Implications

Holding the wage rate constant at $3.90 and decreasing the timeliness level requirements (95% to 85% to 70%) causes a decrease in the number of implements in each complement but increases the size of these implements. For high timeliness requirements (95%) there are situations where two tractors are required to get the work done because of relatively little time being available in the time periods. However, at a low timeliness level (70%) one slightly larger machine can handle the task. Thus, in certain situations decreasing timeliness requirements may cause the purchase of larger machines.

A Diversified 480 Acre Sandy Loam Soil
Farm in Canadian County

Case B is a 480 acre farm in Canadian County (Table XI). The crop mix consists of 50% wheat, 30% cotton, 10% grain sorghum, and 10% peanuts. All the crops are grown using dryland farming on sandy loam soil. Ten hours are available per day during the spring, summer, and fall time periods, and eight hours are available per day during the winter time periods. The wage rate and timeliness levels are varied giving nine different combinations.

TABLE XI

CASE B: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 480 ACRES, DIVERSIFIED[1] DRY LAND FARMING, SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORK HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	Situation (Number of machines used per situation)								
			B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
Offset Disk	11'	4	1	1	1				1		
Offset Disk	15'	5				1	1	1		1	1
M. B. Plow	3-16"	3							1		
M. B. Plow	4-18"	4	1	1	1						
M. B. Plow	5-18"	5				1	1	1		1	1
Drill	30'	2	1	1	1	1	1	1	1	1	1
Springtooth	22'6"	4	1	1	1				1		
Springtooth	34'6"	5				1	1	1		1	1
Chisel	12'	4	1	1	1				1		
Chisel	16'	5				1	1	1		1	1
Planter	6-Row	1	1	1	1	1	1	1	1	1	1
Row Cultivator	6-Row	4	1	1	1				1		
Row Cultivator	8-Row	5				1	1	1		1	1
Tractor	80 HP	4	2	2	2				1		
Tractor	111 HP	5				1	1	1		1	1
Total Cost			$21778.	$24761.	$30581.	$20927.	$23215.	$27678.	$18601.	$23215.	$27678.
Fixed Cost			14027.	14027.	14027.	13556.	13556.	13556.	10164.	13556.	13556.
Variable Cost			7751.	10734.	16554.	7371.	9658.	14121.	8365.	9658.	14121.
Transfer Cost[3]									$72.		
Total Labor Hours			727.55	727.55	727.55	557.89	557.89	557.89	807.01	557.89	557.89
Wage Rates			$3.90	$8.00	$16.00	$3.90	$8.00	$16.00	$3.90	$8.00	$16.00
Timeliness			95%	95%	95%	85%	85%	85%	70%	70%	70%

1 Crop Mix: 50% Wheat, 30% Cotton, 10% Grain Sorghum, 10% Peanuts

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

Changes in the Machinery Complements

As the wage rate changes from $3.90 to $8.00 to $16.00 (Cases B-1, B-2, B-3), with the timeliness level set at 95% there are no changes made in the machinery complement. The complement is based on two 80 horsepower tractors. The only change in costs are those resulting from higher wage rates.

When the timeliness level is changed to 85% (Cases B-4, B-5, B-6), again wage rate has no effect on the complement chosen. However, decreasing the timeliness requirement (95% to 85%) changes the complement based on two 80 horsepower tractors to a complement based on one 111 horsepower tractor. All the implements are the maximum size the tractor can pull except for the planter and the drill which are smaller than maximum.

At the 70% timeliness level (B-7, B-8, B-9), the complement changes from B-7 ($3.90 wage rate) to B-8 ($8.00 wage rate) but complements B-8 ($8.00 wage rates) and B-9 ($16.00 wage rate) are the same. At a $3.90 wage rate the complement is based on one 80 horsepower tractor while for higher wage rates the complement is based on a 111 horsepower tractor.

Changes in Cost of the Machinery Complements

As seen in Figure 2 at each of the wage rates, $3.90, (B-1, B-4, B-7), $8.00, (B-2, B-5, B-8), and $16.00, (B-3, B-6, B-9), average annual machinery costs decreases as the timeliness level decreases from 85% to 70%

In general machinery complements include larger implements as the timeliness level decreases from 95% to 85%. This is because the number of tractors change from two to one and larger implements are correspondingly used. It is interesting to note that at the, 95% timeliness level and $3.90 wage rate, the complements are nearly the same as the 70% timeliness level and $3.90 wage rate. With the main difference being that the 95% timeliness level complement requires two tractors while the 70% timeliness level complement requires only one tractor.

Implications of Changing Farm Size on Sandy Loam Soils

For a 480 acre farm (Case B), not many changes occur in the optimal machinery complements as the wage rate changes. This implies that relatively small farms will not readily adjust their complements because of wage rate changes. As the timeliness requirements decline there are relatively minor changes in the machinery used, mainly being a shift from two tractors to one tractor.

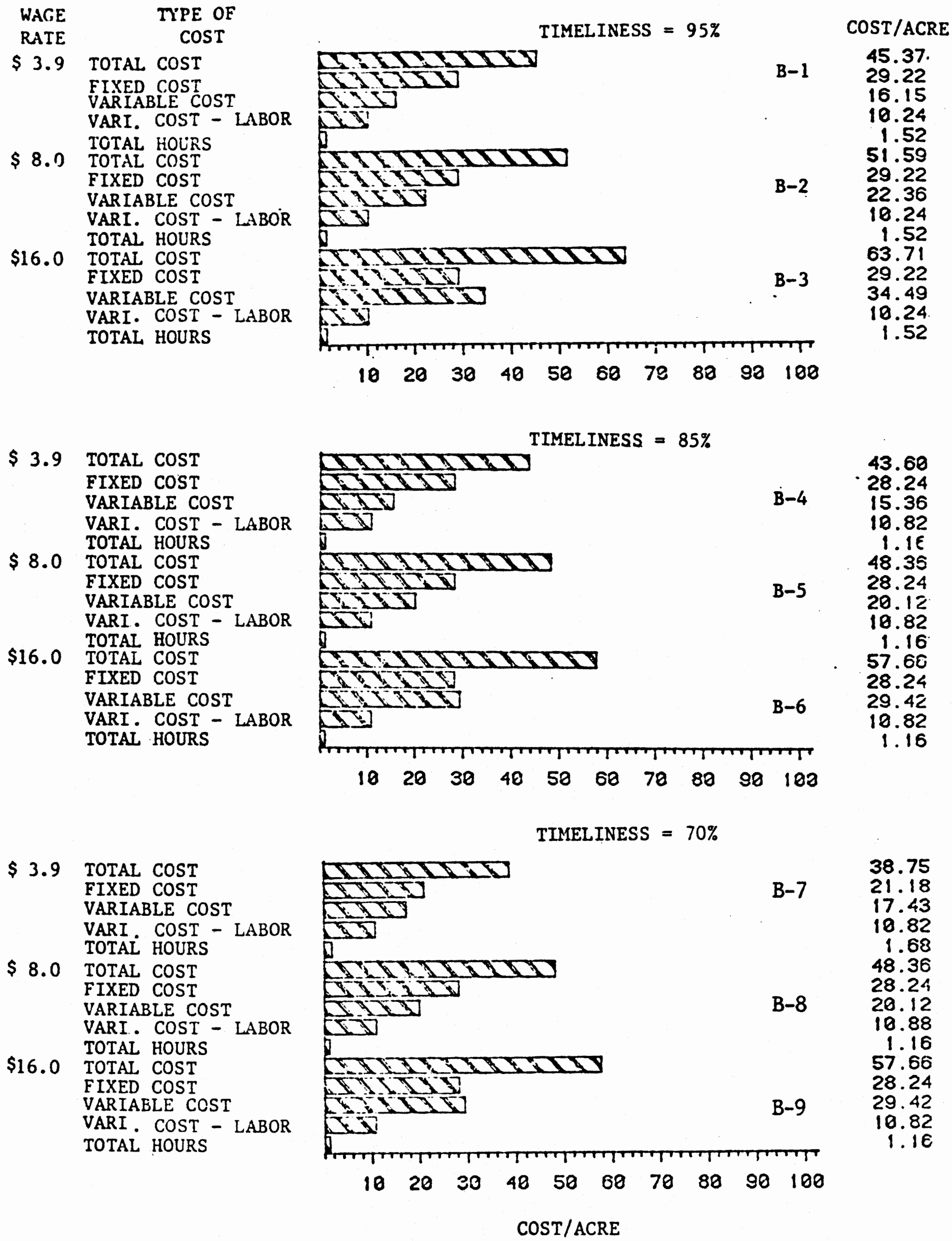


Figure 2. Case B: Optimal Farm Machinery Complements for Canadian County, 480 Acres, Diversified Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

The changes in the optimal machinery complement when moving from a 960 acre farm (Case A) to a 480 acre farm (Case B) are significant. The average annual machinery cost per acre is from 16% to 28% higher on the 480 acre farm than on the 960 acre farm. There are more tractors and implements used to perform the field operations on the large farm than on the small farm. Generally both farms use the same size of tractor to base the machinery complement on. But the 960 acre farm has in addition either a comparable size tractor or a smaller size tractor to help perform the needed field operations on the additional acres. Even though the 960 acre farm is twice as large as the 480 acre farm the machinery used on the 960 acre farm is not twice as large. This is due to economies of size being reached on the 960 acre farm and the 480 acre farm having excess machinery capacity.

Large farms are apparently much more responsive to changes in wage rates than are small farms. Both farms have about the same response to changes in timeliness level. When timeliness is not a factor the total hours per acre are about the same for the large farm and the small farm. When the timeliness is a factor the small farm uses more total hours per acre than the large farm. The reason for this is the large farm uses either a larger set of tractors or uses an additional tractor. The cost savings associated with low timeliness requirements outweigh the benefits of reduced labor usage.

Effects of Changing Soil Type

This section discusses the changing of soil type from sandy loam soil (Cases A and B) to clay loam soil (Cases C and D). Case C is a 480 acre farm and Case D is a 960 acre farm in Canadian county. Both Cases C and D are on a dryland farm with the crop mix consisting of 50% wheat, 30% cotton, 10% grain sorghum, and 10% peanuts. Both farms have ten hours available per day for working in the spring, summer, and fall time periods, and eight hours available per day for work during the winter time periods. The machinery complement for Case C is in Table XII, and the costs per acre in Figure 3 are for Case C. The machinery complement for Case D is Table XIII, and the costs per acre in Figure 4 are for Case D. The shift to a tighter soil alters the results in two ways. First, the work time available is less for clay loam soils in each time period because the clay loam soils dry more slowly. Secondly, implements pull harder on clay loam soils. This decreases the maximum size of implements that tractors can pull.

Changes in Machinery Complements

Clay loam soils (Case C) require more and larger equipment than do sandy loam soils (Case B). This indicates that machinery complements selected for clay loam soils are

TABLE XII

CASE C: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 480 ACRES, DIVERSIFIED[1] DRY LAND FARMING, CLAY LOAM SOIL, 10 WORK HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORK HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9
			(Number of machines used per situation)								
Offset Disk	7.8'	4							1		
Offset Disk	11'	5	1	1		1					
Offset Disk	13'	6			1		1	1			
Offset Disk	15'	7								1	1
M. B. Plow	2-16"	3				1					
M. B. Plow	3-16"	4	1	1		1			1		
M. B. Plow	4-18"	6			1		1	1			
M. B. Plow	5-18"	7								1	1
Drill	30'	3	1	1	1	1	1	1	1	1	1
Springtooth	34'6"	5	1	1	1	1	1				
Springtooth	40'6"	6						1	1		
Springtooth	48'6"	7								1	1
Chisel	8'	5	1	1		1					
Chisel	12'	6			1		1	1	1		
Chisel	16'	7								1	1
Planter	6-Row	1		2		1	1	1	1	1	1
Planter	12-Row	2	1		1						
Row Cultivator	4-Row	5	1	1	1	1	1	1	1		
Row Cultivator	6-Row	7								1	1
Tractor	80 HP	4							1		
Tractor	111 HP	5	2	2	1	2		1			
Tractor	156 HP	6			1		1	1	1		
Tractor	175 HP	7								1	1
Machine Cost			$32726.	$35471.	$43321.	$28609.	$29945.	$39367.	$28013.	$31901.	$36635.
Fixed Cost			20275.	18569.	23198.	16488.	14244.	19099.	15994.	18511.	18511.
Variable Cost			11892.	16074.	19777.	12120.	15096.	20267.	12019.	13389.	18123.
Transfer Cost[3]			108.	828.			605.				
Total Labor Hours			942.26	968.96	729.00	970.40	755.70	751.27	954.43	591.74	591.74
Wage Rate			$3.90	$8.00	$16.00	$3.90	$8.00	$16.00	$3.90	$8.00	$16.00
Timeliness Level			95%	95%	95%	85%	85%	85%	70%	70%	70%

1 Crop Mix: 50% Wheat, 30% Cotton, 10% Grain Sorghum, 10% Peanuts
2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.
3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

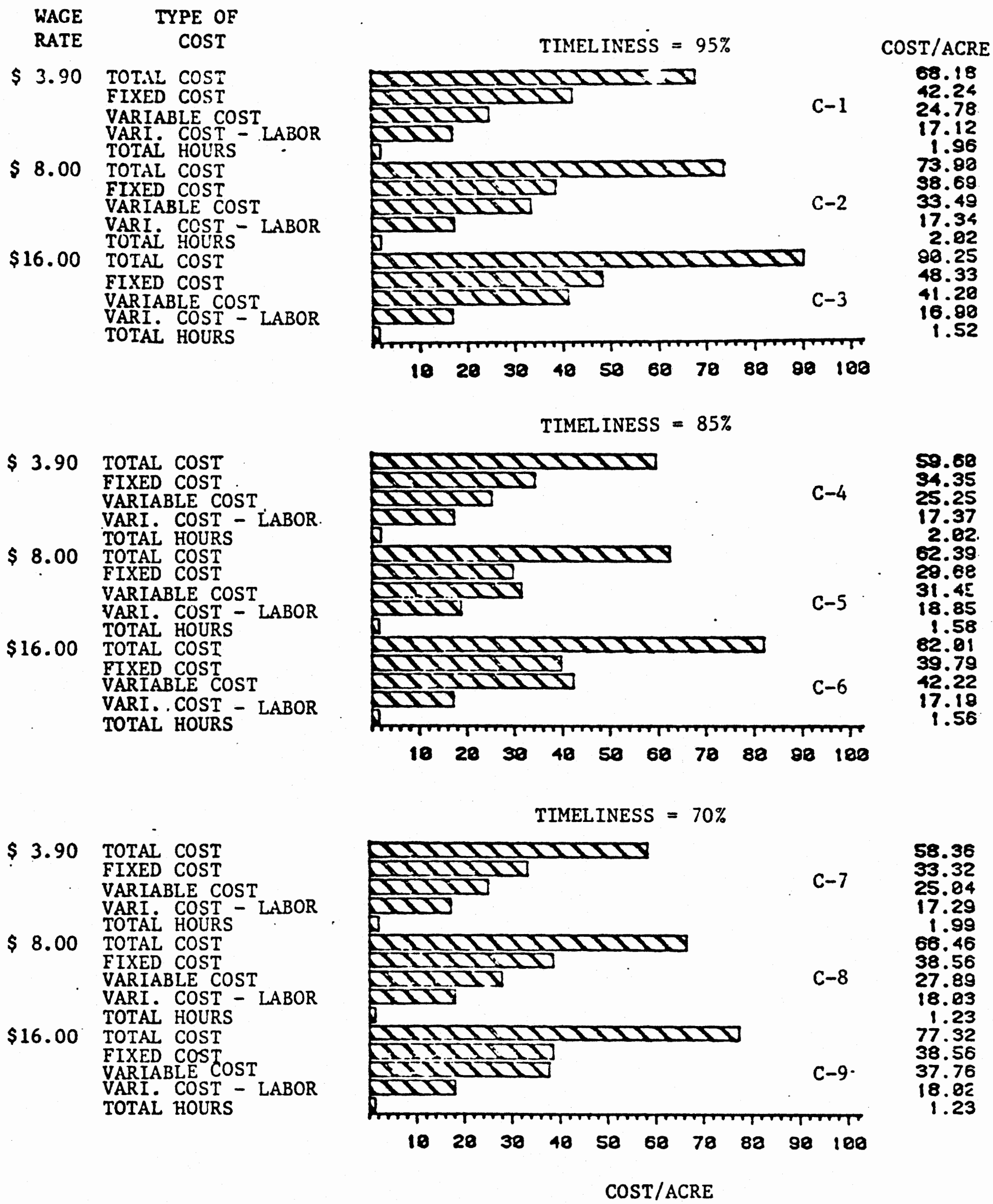


Figure 3. Case C: Optimal Farm Machinery Complements for Canadian County, 480 Acres, Diversified Dry Land Farming, Clay Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

TABLE XIII

CASE D: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY WITH, 960 ACRES OF DRY LAND FARMING ON CLAY LOAM SOIL, WITH 8 HOURS AVAILABLE DURING WINTER AND 10 HOURS AVAILABLE DURING SUMMER PER DAY [1]

MACHINERY	SIZE	RANK[2]	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9
			Situation (Number of Machines used per situation)								
Offset Disk	7.8'	4		1							
Offset Disk	11'	5	2	1	1	1			1		
Offset Disk	13'	6					1				
Offset Disk	15'	7			1			1		1	1
M. B. Plow	2-18"	4	2								
M. B. Plow	4-18"	6				1	1		1		
M. B. Plow	5-18"	7		1						1	1
M. B. Plow	6-18"	8			1			1			
Drill	30'	3	1	1	1	1	1		1	1	1
Drill	60'	5						1			
Springtooth	34'6"	5	1						1		
Springtooth	40'6"	6				1	1				
Springtooth	48'6"	7		1						1	1
Springtooth	60'6"	8			1			1			
Chisel	8'	5	2								
Chisel	12'	6				1	1		1		
Chisel	16'	7		1						1	1
Chisel	20'	8			1			1			
Planter	6 Row	1				2	1		1	1	1
Planter	16 Row	3	1	1	1			1			
Row Cultivator	4 Row	5	2	1	1	2	1		1		
Row Cultivator	6 Row	7		1						1	1
Row Cultivator	8 Row				1			1			
Tractor	61 HP	3			1					1	1
Tractor	80 HP	4		1							
Tractor	111 HP	5	3	1	1	1	1		1		
Tractor	156 HP	6				1	1		1		
Tractor	175 HP	7		1						1	1
Tractor	225 HP	8			1			1			
Machine Cost			$54287.	$60001.	$69247.	$45645.	$51811.	$60651.	$41801.	$47558.	$57026.
Fixed Cost			28827.	32804.	35420.	21768.	21898.	26635.	18946.	20837.	20887.
Variable Cost			23496.	25439.	31935.	22378.	28543.	32465.	22337.	25415.	34882.
Transfer Cost[3]			1964.	1758.	1892.	1499.	1370.	1551.	518.	1256.	1257.
Total Labor Hours			1871.	1315.	1047.	1558.	1502.	943.	1567.	1183.	1183.
Wage Rate			$3.90	$8.00	$16.00	$3.90	$8.00	$16.00	$3.90	$8.00	$16.00
Timeliness Level			95%	95%	95%	85%	85%	85%	70%	70%	70%

1 Crop Mix: 50% Wheat, 30% Cotton, 10% Grain Sorghum, 10% Peanuts.

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

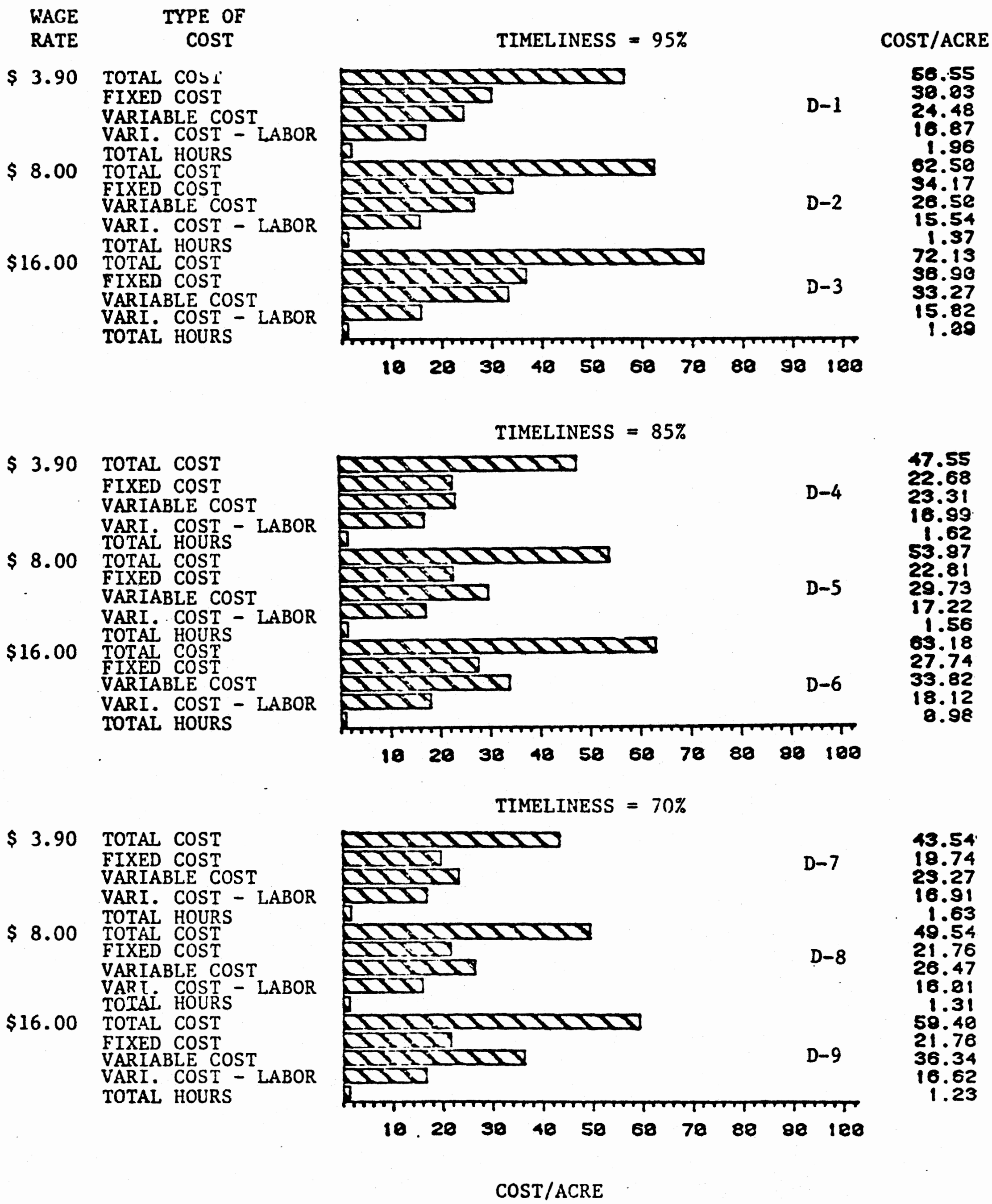


Figure 4. Case D: Optimal Farm Machinery Cost Per Acre for Canadian County, 960 Acres, Diversified[1] Dry Land Farming, Clay Loam Soil, 10 Work Hours available During the Summer Months and 8 Work Hours Available During the Winter Months

more sensitive to changes and therefore change machinery sizes and combinations more often than machinery complements on sandy loam soils. The size of tractors and implements required for clay loam soils are considerably larger in size than those required for sandy loam soils. At a $3.90 wage rate and 95% timeliness level the optimal machinery complement on sandy loam soil includes two 80 horsepower tractors while on clay loam soils two 111 horsepower tractors are required. At a $16.00 wage rate and 70% timeliness level the sandy loam soil complement requires one 111 horsepower tractor while the clay loam soil complement requires one 175 horsepower tractor. At a $3.90 wage rate and 95% timeliness level the clay loam soils (C-1), have 1.96 total labor hours required per acre while the sandy loam soils (B-1), have 1.52 total labor hours required per acre. At a $16.00 wage rate and 70% timeliness level the clay loam soils (C-9) have 1.23 total labor hours required per acre while the sandy loam soils (B-9), have 1.16 total labor hours required per acre. The general implication is that adjustments in machinery complements will be more pronounced on clay loam soils than on sandy loam soils.

When the soil type changes on the 960 acre farm there is a big difference in the machinery complements. At the 95% timeliness level the clay loam soil farm uses three tractors compared to the sandy loam soil farm which uses two smaller sized tractors. When the timeliness level is relaxed to 70% the machinery, complements require fewer tractors. However the tractors on the clay loam soil farm were larger than the tractors on the sandy loam soil farms.

Differences in the Costs Between Sandy Loam Soils and Clay Loam Soils

There is quite a difference between the costs associated with sandy loam soils and clay loam soils. The average annual machinery cost on the 480 acre size farm is generally $20.00 per acre higher on the clay loam soil farm than the sandy loam soil farm, at any wage rate or timeliness level. This is due to the increase in the number of machines and sizes of machinery used. As timeliness becomes more of a constraint it is noted that there is a bigger increase in average annual machinery cost on the clay loam soil farm than on the sandy loam soil farm, for each wage rate. At the 85% timeliness level as the wage rates increase the clay loam soil farm has higher variable costs per acre than fixed costs per acre. While the sandy loam soil farm doesn't start showing this relationship wage rates are higher. The same machinery complement is used for each wage rate at the 85% timeliness level and the hours of usage don't vary. As a result, when the wage rate increases the variable cost will increase by the amount of the increased labor cost and fixed cost will remain the same.

There is less variation in the annual average machinery cost per acre on the 960 acre farm as the timeliness level increases for both the sandy loam soil and the clay loam soil. The average annual machinery cost per acre is generally only $10.00 per acre higher on the clay loam soil than the sandy loam soil. At both farm sizes the machinery complements for the clay loam soils contain a wider range of implement sizes indicating farmers with clay loam soils are more responsive, by varying the implement size, to changes in wage rates and timeliness levels.

Implications

On the 480 acre clay loam soil farm for each timeliness level wage rate increases tend to increase implement size and total labor hours used per year tend to decrease. At each wage rate the implement sizes increase as the timeliness level decreases. Also, total labor hours increase as the timeliness level changes from 95% to 85% and then decreases as the timeliness level changes from 85% to 70%. This apparent inconsistency is due to the discretness in machinery complement capabilities.

For each farm situation on the 480 acre clay loam soil farm, machines are selected based on the size of tractor or tractors used. For most situations the complement is filled out with the largest machinery each tractor can pull. At the 70% timeliness level, machinery complements are based on a 175 horsepower tractor (Rank 7) and all major implements are of rank 7 which is the largest implement size available to do the field work. This is true at both the $8.00 and $16.00 wage rates. In general, at each wage rate, as the timeliness level decreases, tractor sizes will increase and tractor numbers will decrease. As the wage rate changes there is less variation in average annual machinery cost on the 960 acre farm, than on smaller farms.

Effects of Farm Size, on a Specilized Canadian County Farm

The machinery and costs associated with this section are Cases E, F, G, (Tables XIV, XV and XVI, Figures 5, 6 and 7) and include three sizes of sandy loam farms (480, 960 and 1440 acres) in Canadian County. The crop mix on all three farms consists of 100% dryland wheat. Ten hours of work time are available per day. These situations were included to determine the effect of farm size on machinery complements and their costs.

Changes in the Machinery Complements

This section deals with a wage rate of $8.00 and a timeliness level of 85% (E-3, F-3, G-3) and the implications drawn will apply to the other wage rates and timeliness levels. As the farm size increases from 480 acres to 960

TABLE XIV

CASE E: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 480 ACRES, SPECIALIZED[1] DRY LAND FARMING, SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE PER DAY

Machinery	Size	Rank[2]	Situation E-1	E-2	E-3	E-4	E-5
			(Number of machines used per situation)				
Offset Disk	7.8'	3	1				
Offset Disk	11'	4		1	1	1	1
Offset Disk	15'	5					
Drill	30'	2	1	1	1	1	1
Drill	60'	4					
Springtooth	22'6"	4	1	1	1	1	1
Springtooth	34'6"	5					
Springtooth	48'6"	6					
Chisel	8'	3					
Chisel	12'	4	1	1	1	1	1
Chisel	16'	5					
Chisel	23'	6					
Tractor	61 HP	3	1				
Tractor	80 HP	4	1	1	1	1	1
Tractor	111 HP	5					
Tractor	156 HP	6					
Machine Cost			$17132.	$12162.	$14559.	$19237.	$12162.
Fixed Cost			8274.	6316.	6316.	6316.	6316.
Variable Cost			8683.	5845.	8243.	12921.	5845.
Transfer Cost[3]			175.				
Total Labor Hours			635.24	584.73	584.73	584.73	584.73
Wage Rate			$8.00	$3.90	$8.00	$16.00	$3.90
Timeliness Level			95%	85%	85%	85%	70%

[1] Crop Mix: 100% Wheat

[2] Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

[3] Transfer Cost: The added cost of moving the operation of an implement to another time period.

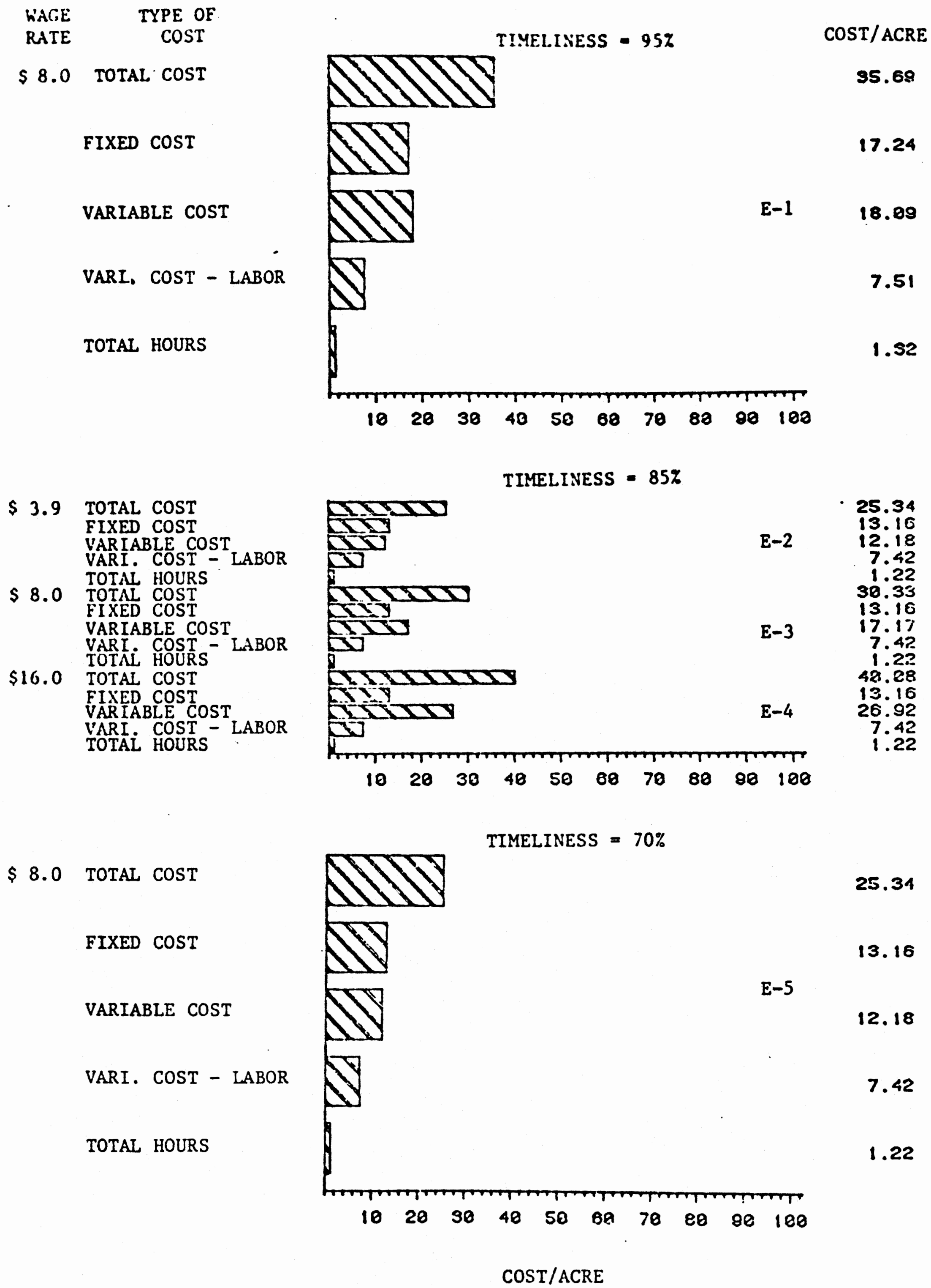


Figure 5. Case E: Optimal Farm Machinery Complements for Canadian County, 480 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available Per Day

TABLE XV

CASE F: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 960, ACRES, SPECIALIZED[1] DRY LAND FARMING, SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE PER DAY

Machinery	Size	Rank[2]	Situation F-1	F-2	F-3	F-4	F-5
			(Number of machines used per situation)				
Offset Disk	11'	4		1	1	1	
Offset Disk	15'	5	1				1
Drill	30'	2		1			
Drill	60'	4	1		1	1	1
Springtooth	22'6"	4		1	1		
Springtooth	34'6"						
Springtooth	48'6"	6	1			1	1
Chisel	8'	3					
Chisel	12'	4		2	2		
Chisel	16'	5	1				
Chisel	23'	6	1			1	1
Tractor	61 HP	3					
Tractor	80 HP	4		2	2	1	
Tractor	111 HP	5	1				
Tractor	156 HP	6	1			1	1
Machine Cost			$30184.	$21506.	$26242.	$33390.	$25362.
Fixed Cost			17219.	9814.	10242.	14654.	11854.
Variable Cost			12965.	11691.	16000.	18736.	13507.
Transfer Cost[3]							
Total Labor Hours			672.26	1169.45	1126.32	706.70	657.59
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%

1 Crop Mix: 100% Wheat
2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.
3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

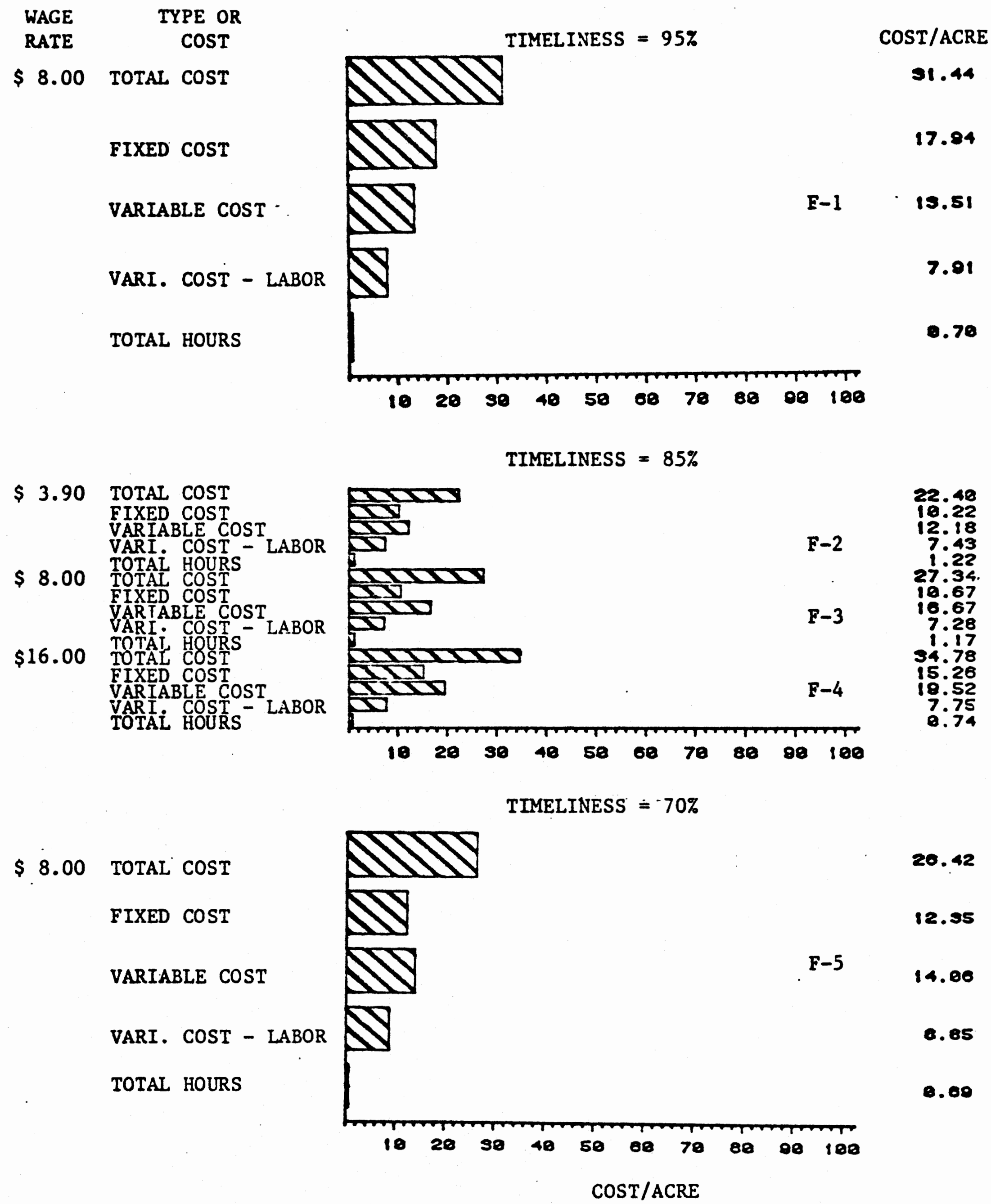


Figure 6. Case F: Optimal Farm Machinery Complements for Canadian County, 960 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available Per Day

TABLE XVI

CASE G: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 1440 ACRES, SPECIALIZED[1] DRY LAND FARMING, SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE PER DAY

Machinery	Size	Rank[2]	Situation G-1	G-2	G-3	G-4	G-5
			(Number of machines used per situation)				
Offset Disk	11'	4	1				
Offset Disk	15'	5	1	1	1	1	1
Drill	30'	2					
Drill	60'	4	1	1	1	1	1
Springtooth	22'6"	4					
Springtooth	34'6"	5		1			1
Springtooth	48'6"	6	1		1	1	
Chisel	8'	3		1			
Chisel	12'	4		1			
Chisel	16'	5	1	1	1	1	2
Chisel	23'	6	1		1	1	
Tractor	61 HP	3		1			
Tractor	80 HP	4	1	1			
Tractor	111 HP	5	1	1	1	1	2
Tractor	156 HP	6	1		1	1	
Machine Cost			$42049.	$32124.	$36820.	$45072.	$35620.
Fixed Cost			21909.	16891.	17219.	17219.	14354.
Variable Cost			19830.	15232.	19601.	27853.	21265.
Transfer Cost[3]			310.				
Total Labor Hours			1092.86	1556.00	1031.55	1031.55	1275.15
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%

1 Crop Mix: 100% Wheat

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

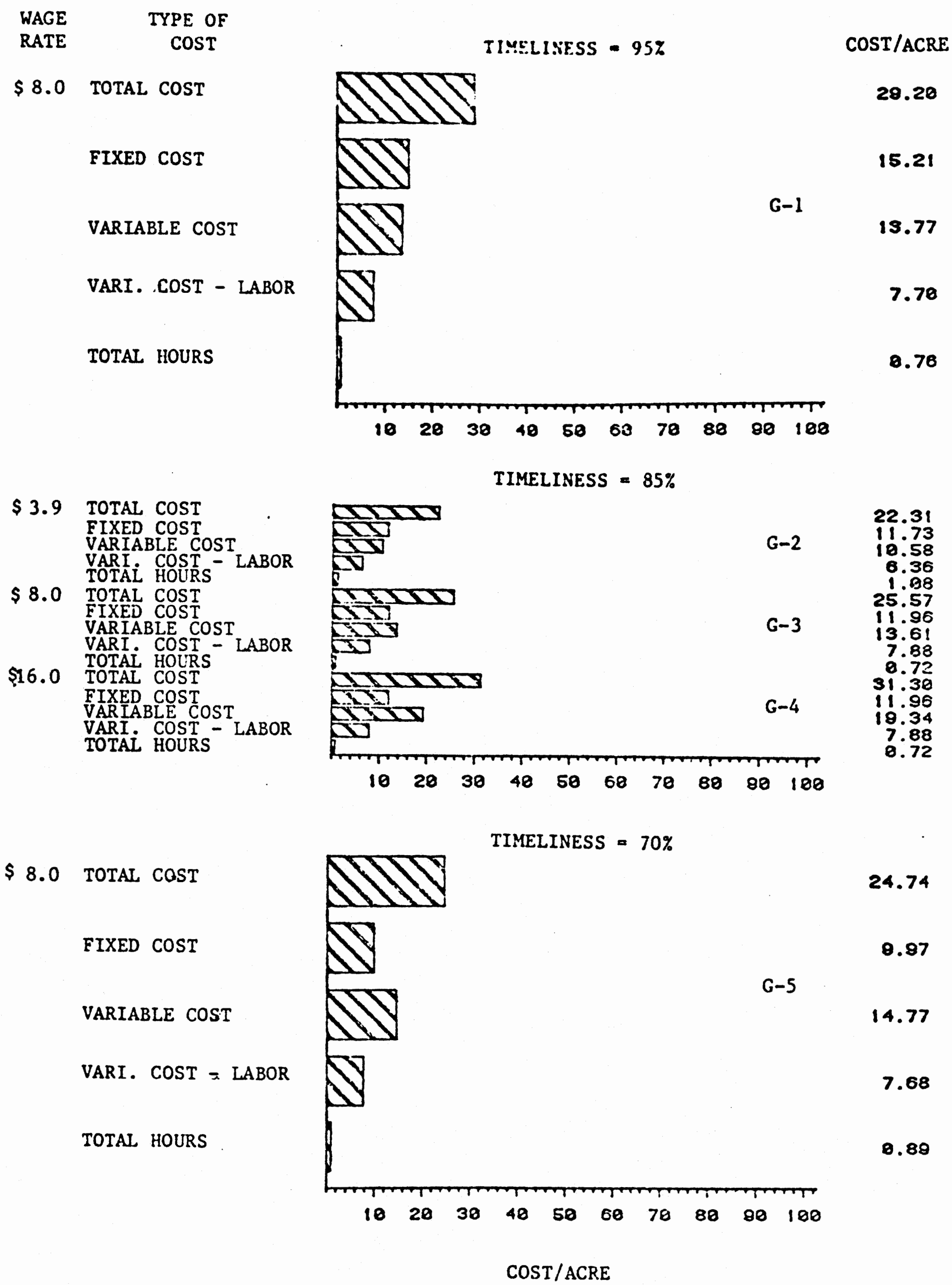


Figure 7. Case G: Optimal Farm Machinery Complements for Canadian County, 1440 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available Per Day

acres the machinery complement changes from using one 80 horsepower tractor to using two 80 horsepower tractors, so as the farm size doubles the tractor horsepower doubles. As the farm size increase from 960 acres to 1440 acres the machinery complement changes from two 80 horsepower tractors to one 111 horsepower tractor and one 156 horsepower tractor. The size of the associated implements on the 1440 acre farm are equally bigger than the implements on the 960 acre farm.

Changes in Machinery Costs

This section looks at the changes in machinery costs with an $8.00 wage rate and 85% timeliness level. The other situations will have the same general implications. As the farm size increases from 480 acres to 960 acres the average annual machinery cost per acre decreases from $30.33 per acre to $27.34 per acre. The change in the machinery complement is not proportional to the increase in the farm size thus giving the lower cost per acre. The annual fixed cost per acre decreases from $13.16 to $10.67 per acre. The lower annual fixed cost per acre indicates the cost is spread over more acres, since the machinery complement can complete the field operation needs on the additional acres without increasing proportionally in size. The annual variable cost per acre decreases from $17.17 per acre to $16.67 per acre. The total hours labor required per acre decreases from 1.22 to 1.17.

As the farm size increases from 960 acres to 1440 acres the average annual machinery cost per acre decreases from $27.43 to $25.57. The annual fixed cost per acre increases from $10.67 per acre to $11.96 per acre. The annual variable cost per acre decreases from $16.67 per acre to $13.61 per acre. The total labor hours available per acre decreases from 1.17 to .72. This indicates that as farm size is increased to 1440 acres there is a substantial increase in the size of implements and tractors used. This would also indicate there is more variable cost per acre used for lubrication and fuel. However, this machinery has a greater capacity to perform the field work in a shorter period of time, so less hours per acre are needed. The total effect of increasing farm size is a lower average annual machinery cost per acre.

Implicatons of Changing Farm Organization

Generally at the 480 acre farm size the diversified dryland farm has larger sized tractors than the specialized dryland farm. This is due mainly to having more field operations to perform in a given time period for the diversified dryland farm. The cost per acre is considerably more per acre on the diversified and dryland farm because of the need for more types of implements for performing the necessary field operations. The total labor hours available per acre are higher on the specialized dryland farm. The main indication is that the diversified dryland farm requires larger tractors and more implements to perform the necessary field operations which results in greater costs per acre but requires less labor hours per acre.

Effects of Longer Work Days

This section discusses the effects of longer work days on the optimal machinery complement. If the constraint on the amount of hours can be worked per day is relaxed allowing more time to perform the necessary field operations, the effects of timeliness on the machinery complements should be eased. Table XVII shows a partial listing of the possible situations available for the longer work days. Figure 8 lists the costs associated with longer work days. This situation (Case H) is located in Canadian county on a specialized dryland farm. There are three farm sizes considered, 480 acres, 960 acres, and 1440 acres. The crop mix on each farm consists of 100% wheat. However, there are 12 hours available per day for work instead of 10 hours available per day as used in the previous section.

TABLE XVII

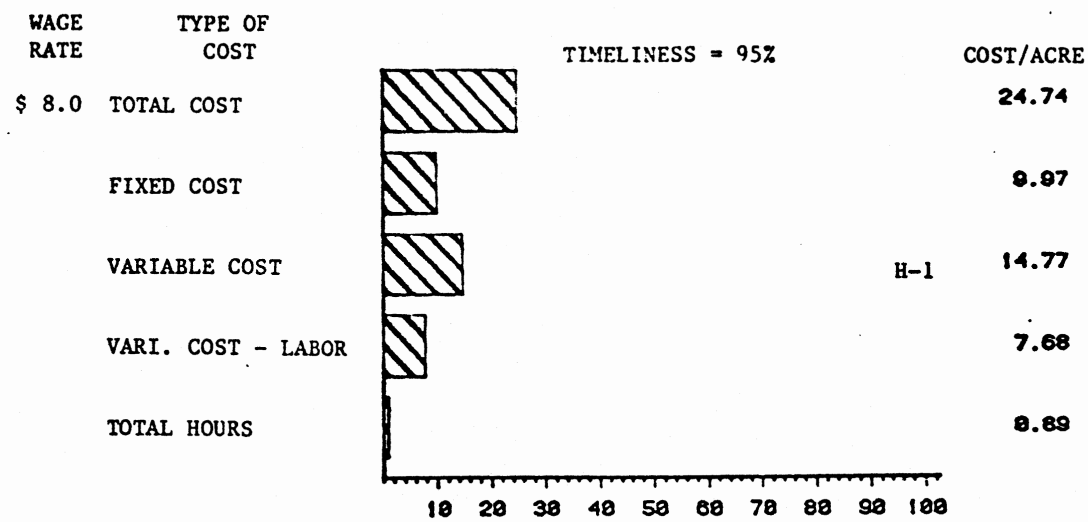
CASE H: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY, 1440 ACRES, 960 ACRES, 480 ACRES, SPECIALIZED[1] DRY LAND FARMING, SANDY LOAM SOIL, 12 HOURS AVAILABLE PER DAY

Machinery	Size	Rank[2]	H-1	H-2	H-3	H-4	H-5	H-6	H-7
			(Number of machines used per situation)						
Offset Disk	11'	4			1				1
Offset Disk	15'	5	1	1		1	1	1	
Drill	30'	2			1				1
Drill	60'	4	1	1		1	1	1	
Springtooth	22'6"	4			1				1
Springtooth	34'6"	5	1	1				1	
Springtooth	48'6"	6				1	1		
Chisel	12'	4			2				1
Chisel	16'	5	2	2				1	
Chisel	23'	6				1	1		
Tractor	80 HP	4			2				1
Tractor	111 HP	5	2	2				1	
Tractor	156 HP	6				1	1		
Machine Cost			$35620.	$28531.	$21506.	$25362.	$30623.	$23167.	$14559.
Fixed Cost			14354.	14354.	9814.	11854.	11854.	8990.	6316.
Variable Cost			21265.	14176.	11691.	13507.	18768.	14176.	8243.
Transfer Cost[3]									
Total Labor Hours			1275.15	850.10	1169.45	657.59	657.59	850.	584.73
Acres			1440.	960.	960.	960.	960.	960.	480.
Wage Rate			$8.00	$8.00	$3.90	$8.00	$16.00	$8.00	$8.00
Timeliness Level			85%	95%	85%	85%	85%	70%	85%

[1] Crop Mix: 100% Wheat

[2] Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

[3] Transfer Cost: The added cost of moving the operation of an implement to another time period.



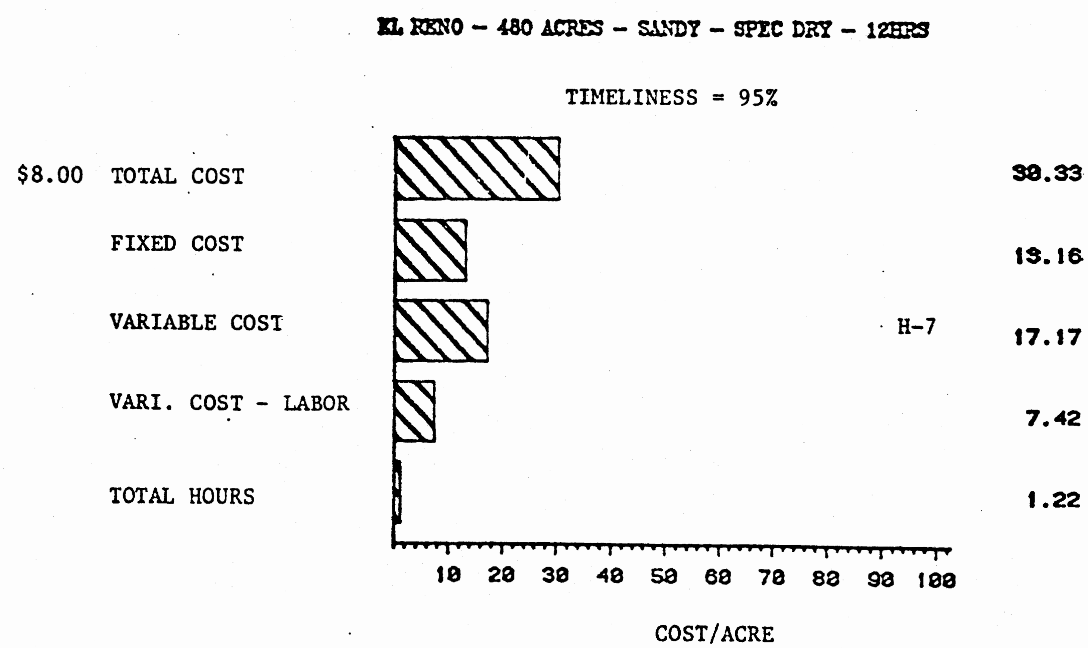


Figure 8. Case H: Optimal Farm Machinery Complements for Canadian County, 1440 Acres, 480 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 12 Hours Available Per Day

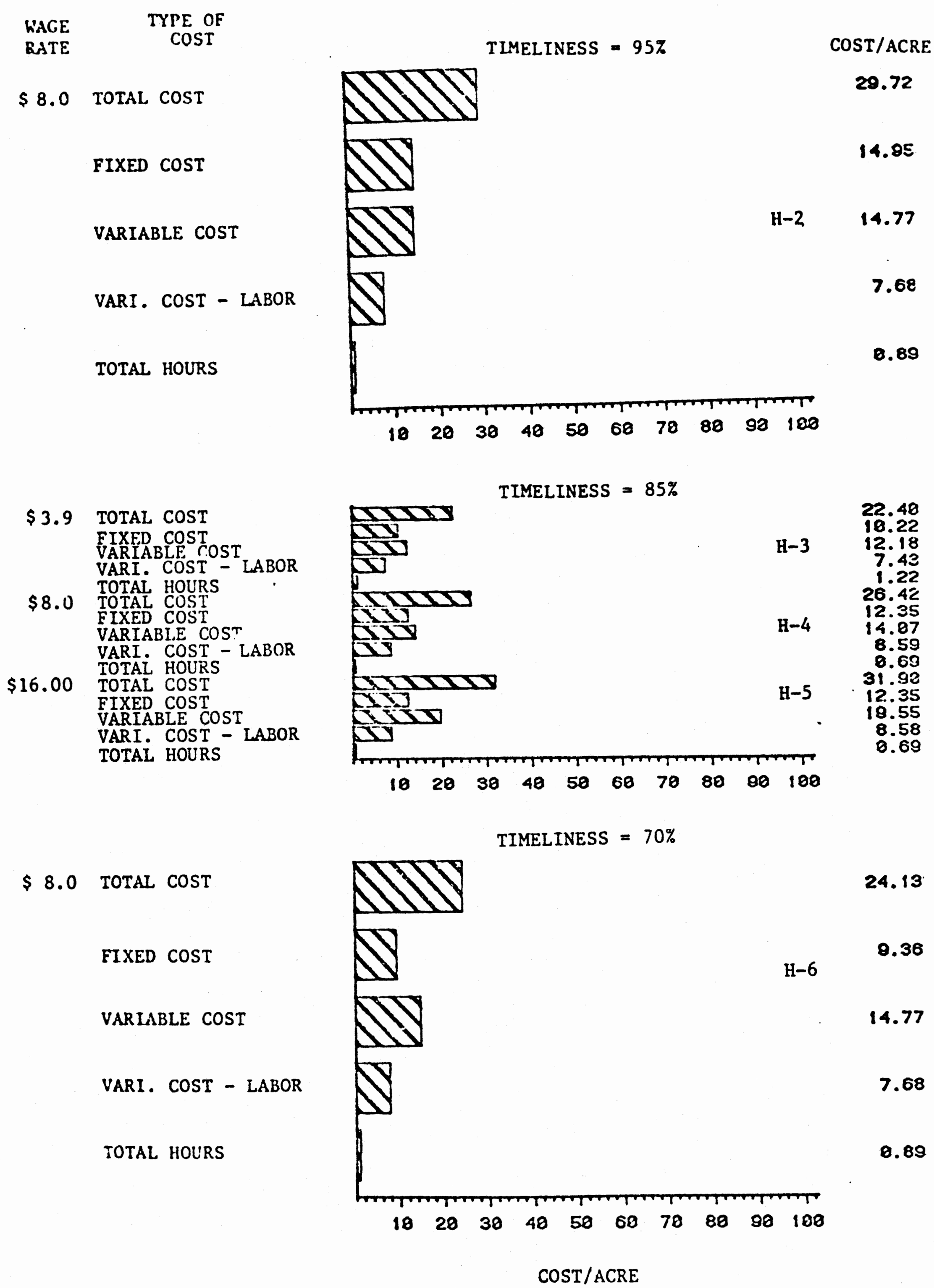


Figure 9. Case H: Optimal Farm Machinery Complements for Canadian County, 960 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 12 Hours Available Per Day

Changes in Machinery Complements

The 1440 acre farm ($8.00 wage rate and 85% timeliness level) with 10 hours available per day (F-3), has a machinery complement based on one 111 horsepower tractor and one 156 horsepower tractor. When the work hours available per day increase to 12 (H-1), the machinery complement changes to two 111 horsepower tractors.

The 960 acre farm ($8.00 wage rate and 85% timeliness level) with 10 hours available per day (E-3), has a machinery complement based on two 80 horsepower tractors. When the hours available per day increase to 12 (H-4) the machinery complement is based on one 156 horsepower tractor.

The 480 acre farm ($8.00 wage rate and 85% timeliness level) with 10 hours available per day and the farm with 12 hours available per day each have the same machinery complements. This indicates there is excess machinery capacity and the increase in work hours has no effect.

These results indicate that when there are more hours available to perform th necessary field operations the size and number of tractors and implements used decrease. Therefore allowing more time to perform the field operations has the same effect as relaxing the timeliness level.

Changes in the Cost of the Complements

This section deals with the changing machinery costs due to increased hours worked per day at the 85% timeliness level and $8.00 wage rate, with the other timeliness levels and wage rates having the same implications. On the 480 acre farm all the costs are the same, because both farms have the same machinery complements.

On the 960 acre farm size the average annual machinery cost decreases from $27.34 per acre with 10 hours available per day to $26.42 per acre with 12 hours available per day. With more hours available per day the fixed cost increases from $10.67 per acre to $12.35 per acre. The variable cost per acre decreases from $16.67 per acre to $14.07 per acre. The hours labor decreases from 1.17 hours per acre to .69 hours per acre when the total hours available per day increases. This big shift results because one tractor replaces two.

On the 1440 acre farm size when the days available for field work increase, the average annual machinery cost per acre decreases from $25.57 to $24.75 per acre. The annual fixed cost per acre decreases from $11.96 to $9.97 per acre. The annual variable cost per acre increases from $13.61 to $14.77 per acre. The total labor hours required per acre increases from .72 to .89.

The results indicate that as the hours available for work per day are increased there is a decrease in the average annual machinery cost per acre. Cost savings can result from requiring less labor, buying one tractor instead of two, variable costs changing because of changes in labor required. Fixed costs can change substantially if one tractor can replace two tractors. The combination of fixed and variable costs will always be less for longer work days. However it is difficult to anticipate exactly how the costs are going to change for a particular situation.

Impact of Hours Worked Per Day

Increasing the available work hours per day has the same effect as relaxing the timeliness constraint. In either case the size and number of tractors and implements decrease when the available hours per day are increased to perform the necessary field operations, resulting in a savings in total cost per acre.

A Canadian County Irrigated Farm

This section analyzes the impact of adding irrigation to the farm organization and the effects this has on the optimal machinery complements and their associated costs. The farm is located in Canadian county with farm sizes of 480 acres and 960 acres. The crop mix for both farms consists of 60% dryland farming (50% wheat and 10% cotton) and 40% being irrigated (20% cotton, 10% grain sorghum and 10% peanuts). All the land is sandy loam soil. Eight work hours are available per day in the winter time periods and ten hours are available per day the remaining time periods. The optimal machinery complements and associated cost are listed in Table XVIII and Figure 10 which is labled as Case I.

This situation is very similar to the first situation of a Canadian county farm on sandy loam soil. Both situations have the same crops grown except this situation incorporates some irrigation into the farm organization. The hours available for work each day are the same for both situations. However since this situation uses irrigation on part of the crops there is a need to use implements especially designed for irrigation.

Changes in the Machinery Complement due to Irrigation

When irrigation is added to the farm organization, at an $8.00 wage rate and 85% timeliness level for both 480 acre farms, the machinery complement changes are based on one 111 horsepower tractor. However the irrigated farm has

TABLE XVIII

CASE I: OPTIMAL FARM MACHINERY COMPLEMENTS FOR CANADIAN COUNTY WITH, 960 ACRES AND 480 ACRES OF DIVERSIFIED IRRIGATED LAND FARMING, ON SANDY LOAM SOIL WITH 8 TO 10 HOURS PER DAY AVAILABLE FOR WORKING[1]

Machinery	Size	Rank[2]	Situation I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10
			(Number of Machines used per Situation)									
Offset Disk	11'	4	1	1	1	1		1	1			
Offset Disk	15'	5					1			1	1	1
M. B. Plow	3-16"	3						1	1			
M. B. Plow	4-18"	4	1	1	1							
M. B. Plow	5-18"	5					1			1	1	1
M. B. Plow	6-18"	6				1						
Drill	30'	2	1	1	1	1	1	1	1	1	1	1
Springtooth	22'6"	4		1				1	1			
Springtooth	34'6"	5					1			1	1	1
Springtooth	48'6"	6	1		1	1						
Chisel	12'	4		1				1	1			
Chisel	16'	5					1			1	1	1
Chisel	23'	6	1		1	1						
Planter	8 Row	1	1	1	1	1	1	1	1	1	1	1
Planter	6 Row	4		1			1	1	1			
Row Cultivator	8 Row	5								1	1	1
Row Cultivator	12 Row	6	1		1	1						
Lister	15'6"	4		1				1	1			
Lister	18'7"	5					1			1	1	1
Lister	26'10"	6	1		1	1						
Tractor	80 HP	4	1	2	1	1	1	2	1			
Tractor	111 HP	5					1			1	1	1
Tractor	156 HP	6	1		1	1						
Machine Cost			$39496.	$30943.	$38897.	$47309.	$37540.	$25505.	$19280.	$24064.	$28765.	$24064.
Fixed Cost			19858.	17751.	19858.	20357.	16912.	13657.	10589.	14000.	14000.	14000.
Variable Cost			19119.	16030,	19038.	26952.	20376.	11847.	8474.	10063.	14764.	10063.
Transfer Cost[3]			519.	461.			252.					
Total Labor Hours			1082.12	1526.74	1082.12	1028.32	1254.37	822.77	822.77	587.63	587.63	587.63
Acres			960.	960.	960.	960.	960.	480.	480.	480.	480.	480.
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00	$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%	95%	85%	85%	85%	70%

1 Crop Mix: 50% Dryland Wheat, 10% Dryland Cotton, 20% Irrigated Cotton, 10% Irrigated Peanuts, 10% Irrigated Grain Sorghum.
2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.
3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

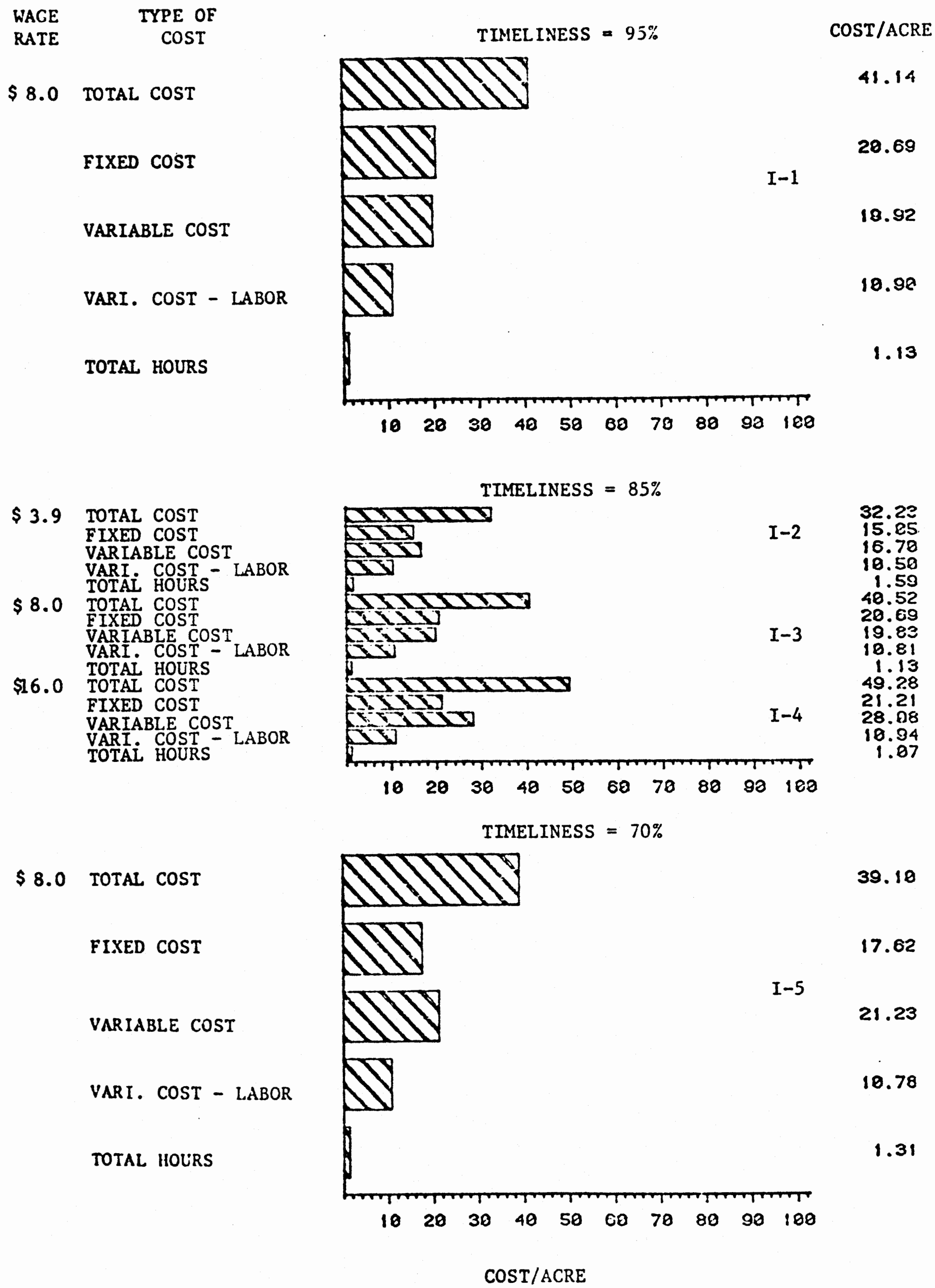


Figure 10. Case I: Optimal Farm Machinery Complements for Canadian County, 480 Acres, Diversified Irrigated Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

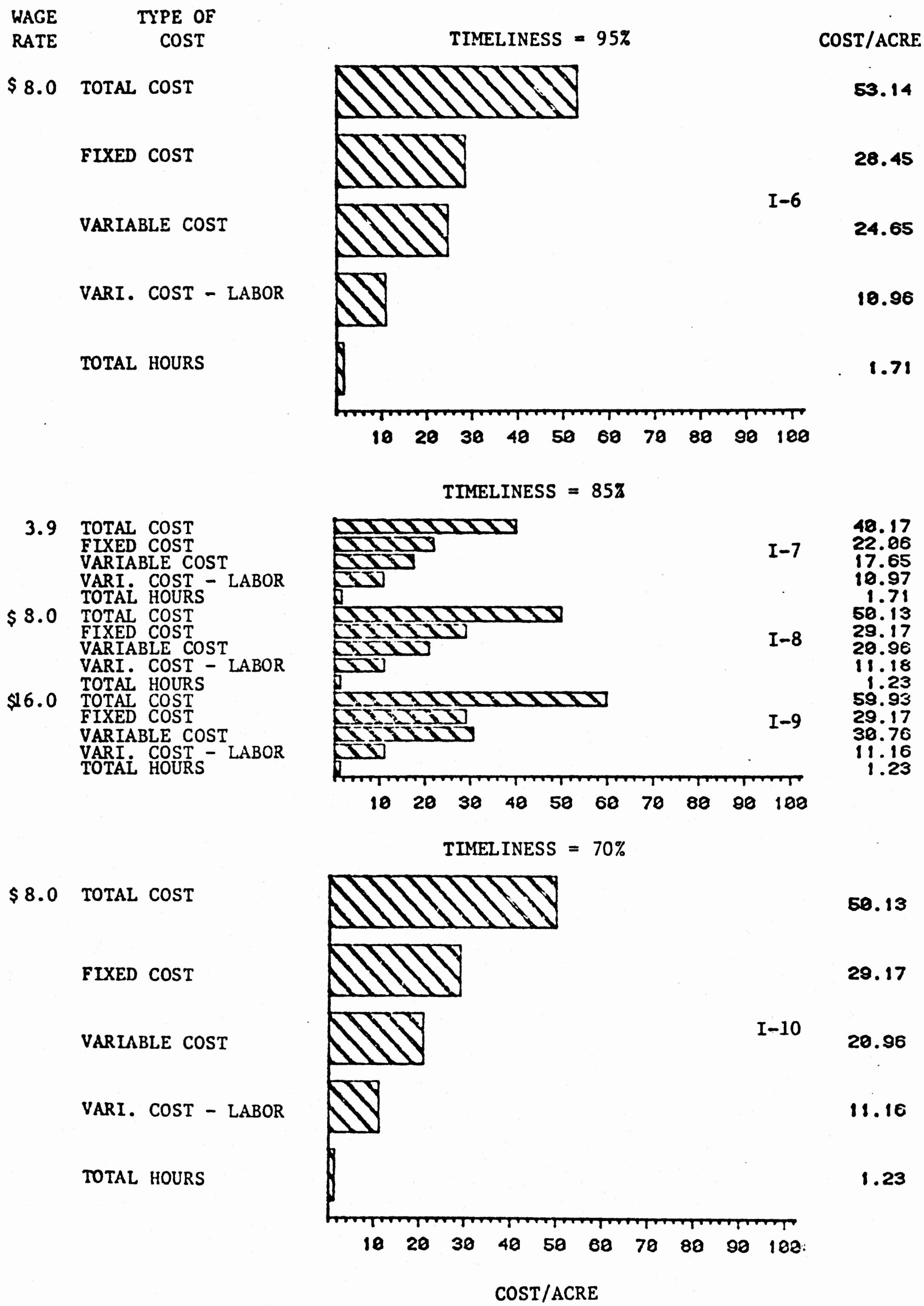


Figure 11. Case I: Optimal Farm Machinery Complements for Canadian County, 960 Acres, Diversified Irrigated Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

a row cultivator and a lister where the dryland farm only uses a field cultivator. The 960 acre farm the machinery complement changes from using two 111 horsepower tractors to one 80 horsepower tractor and one 156 horsepower tractor.

Changes in Machinery Costs Due to Irrigation

When irrigation is added to the 480 acre farm organization with an $8.00 wage rate and 85% timeliness level, the average annual machinery cost per acre increases from $48.36 per acre to $50.13 per acre. The annual fixed cost increases from $28.24 to $29.17 per acre. The annual variable cost increases from $20.12 to $20.96 per acre. The total hours worked increases from 1.16 per acre to 1.23 per acre. The increases in cost are mainly due to the addition of a lister and the performing of some field operations using implements designed for irrigation instead of dryland farming.

When irrigation is added to the 960 acre farm organization with an $8.00 wage rate and 85% timeliness level, the average annual machinery cost increases from $39.28 per acre to $40.52 per acre. The annual fixed cost increases from $19.16 to $20.69 per acre. The annual variable cost decreases from $20.12 to $19.83 per acre. The total hours worked decreases from 1.16 per acre to 1.13 per acre. The increases in costs are due to the additional implements used and changes in tillage operations.

Implications of Irrigation on Machinery Complements

The results indicate very little change in the machinery complements and costs associated with adding irrigation to the farm organization. This would indicate that changing from a dryland cropping organization to one with some irrigated crops could be accomplished with very little change in additional machinery cost. The fixed cost associated with adding irrigation and the increase in production due to irrigation would be the two main considerations in deciding whether or not to use some irrigation.

A Diversified Muskogee County Farm

This situation looks at a diversified 450 acre Muskogee County farm. The crop mix consists of 35% wheat, 30% soybeans, 20% grain sorghum and 15% peanuts. All the crops are grown using dryland farming on sandy loam soil. Eight hours are available per day during the winter time periods and 10 hours are available per day for the remaining time periods. The machinery complements are listed in Table XIX, Case J, and the per acre costs listed in Figure 12 are associated with the machinery complements.

TABLE XIX

CASE J: OPTIMAL FARM MACHINERY COMPLEMENTS FOR MUSKOGEE COUNTY, 450 ACRES, DIVERSIFIED DRY LAND FARMING SANDY LOAM SOIL, 10 WORK HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORK HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	Situation J-1	J-2	J-3	J-4	J-5
			(Number of Machines used per Situation)				
Tandem Disk	15'8"	3	1	1	1	1	1
M. B. Plow	4-18"	4		1	1	1	1
M. B. Plow	5-18"	5	1				
Drill	10'	1		1			
Drill	30'	2	1		1	1	1
Springtooth	22'6"	4		1	1	1	1
Springtooth	34'6"	5	1				
Planter	6 Row	1	1	1	1	1	1
Row Cultivator	6 Row	4		1	1	1	1
Row Cultivator	8 Row	5	1				
Spike Harrow	24'	4	1	1	1	1	1
Tractor	80 HP	4		1			1
Tractor	111 HP	5	1		1	1	
Machine Cost			$20552.	$16170.	$18606.	$23148.	$18606.
Fixed Cost			12286.	9632.	10059.	10059.	10059.
Variable Cost			8265.	6537.	8546.	13088.	8546.
Transfer Cost							
Total Labor Hours			471.91	600.04	567.69	567.69	567.69
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%

1 Crop Mix: 35% Wheat, 30% Soybeans, 20% Grain Sorghum, 15% Peanuts.
2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.
3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

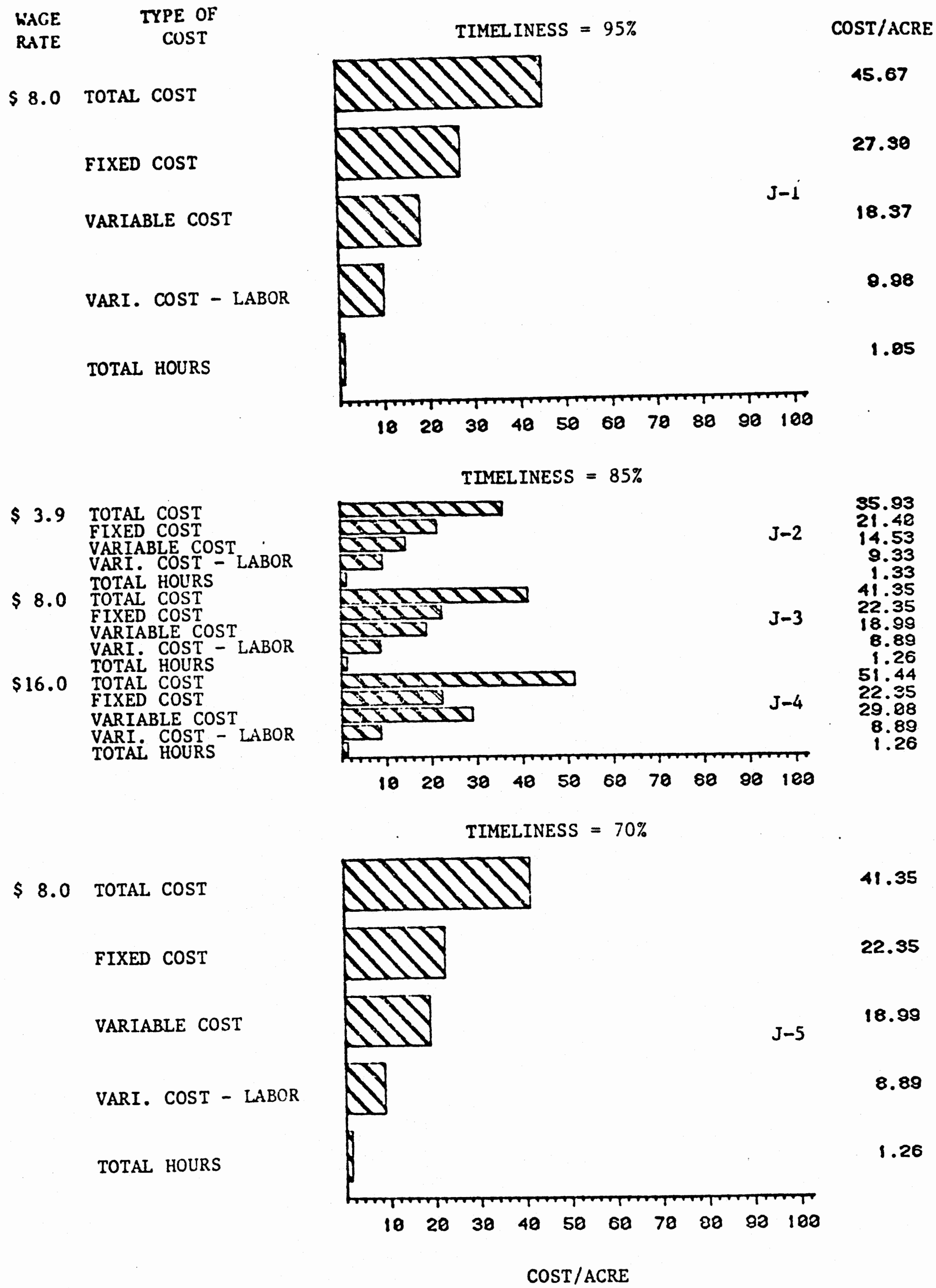


Figure 12. Case J: Optimal Farm Machinery Complements for Muskogee County, 450 Acres, Diversified Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

Changes in Machinery Complements on a Diversified Farm

The machinery complements in Muskogee county change very little when there is a change in the wage rate and timeliness level, mainly due to the relatively small farm size used. The machinery complements are generally based on a 111 horsepower tractor. The basic machinery complement is such that in order to perform the necessary field operations the machinery complement has some excess capacity and therefore very few changes are required due to wage rate and/or timeliness level changes.

Changes in Costs of Machinery Complements

At an $8.00 wage rate the costs are the same for 70% and 85% timeliness levels. When the timeliness level increases from 85% to 95% the average annual machinery cost increases from $41.35 to $45.67 per acre. The annual fixed cost increases from $22.35 to $27.30 per acre. The annual variable cost decreases from $18.99 to $18.37 per acre. The total hours labor required decreases from 1.26 to 1.05 per acre.

At the 85% timeliness level all costs per acre increase as the wage rate increases and the total hours labor required per acre decreases.

Implications

The machinery complements in this section are such that a farmer would almost be indifferent to wage rate changes and timeliness level constraints. The optimal farm machinery complements for Muskogee county change very little under the various timeliness and wage rate assumptions.

A Specialized Muskogee County Farm

This situation discusses the changes in machinery complements and machinery costs on a 450 acre specialized dryland farm in Muskogee county. The crop mix consists of 50% wheat and 50% soybeans, on a sandy loam soil. The optimal machinery complements are listed in Table XX and Figure 13 lists the per acre machinery costs. The situation is refered to as Case K.

Changes in Machinery Complements

The machinery complements are based on a 80 horsepower tractor. The complements vary little as the wage rate and timeliness level changes. This is due to the relatively small farm size.

TABLE XX

CASE K: OPTIMAL FARM MACHINERY COMPLEMENTS FOR MUSKOGEE COUNTY, 450 ACRES, SPECIALIZED DRY LAND FARMING, SANDY LOAM SOIL 8 HOURS PER WORK DAY AVAILABLE IN WINTER AND 10 HOURS PER DAY AVAILABLE IN SUMMER[1]

Machinery	Size	Rank[2]	K-1	K-2	K-3	K-4	K-5
			(Situation) (Number of Machines used per Situation)				
Tandem Disk	15'8"	3	1	1	1	1	1
M. B. Plow	4-18"	4	1				1
M. B. Plow	5-18"	5		1	1	1	
Drill	10'	1					
Drill	30'	2	1	1	1	1	1
Springtooth	22'6"	4	1	1			1
Springtooth	34'6"	5			1	1	
Planter	6 Row	1	1	1	1	1	1
Row Cultivator	6 Row	4	1				1
Row Cultivator	8 Row	5		1	1	1	
Spike Harrow	24'	4	1	1	1	1	1
Tractor	80 HP	4	1				1
Tractor	111 HP	5		1	1	1	
Machine Cost			$18444.	$18387.	$20271.	$23934.	$18267.
Fixed Cost			10059.	12174.	12286.	12286.	10059.
Variable Cost			8182.	6213.	7984.	11648.	8182.
Transfer Cost			203.				26.
Total Labor Hours			495.44	467.24	457.89	457.89	545.00
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%

1 Crop Mix: 50% Soybeans, 50% Wheat

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

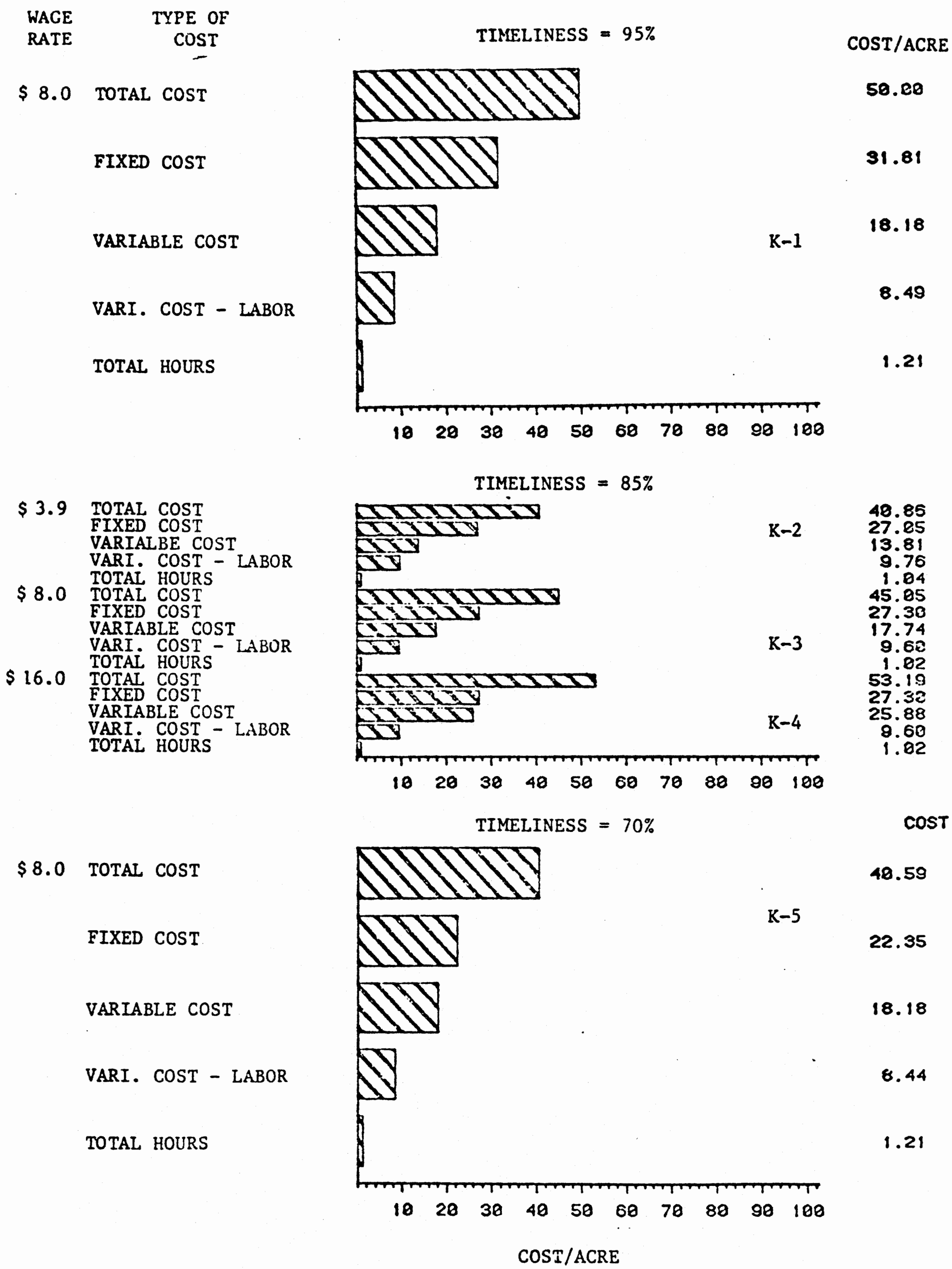


Figure 13. Case K: Optimal Farm Machinery Complements for Muskogee County, 450 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 10 Work Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

Changes in the Costs of the Machinery Complements

At an $8.00 wage rate varying the timeliness level from 70% to 85%, the average annual machinery cost increases from $40.59 per acre to $45.05 per acre. The annual fixed cost increases from $22.35 per acre to $27.30 per acre. The variable cost decreases from $18.18 per acre to $17.74 per acre. The total labor hours decrease from 1.21 per acre to 1.02 per acre. As the timeliness level increases from 85% to 95% at the same wage rate similar results occur.

Implications of Diversification and Specialization

This section discusses the differences between a diversified and a specialized dryland farm in Muskogee county. There are no additional implements needed for either farm. The specialized farm is based on an 111 horsepower tractor and the diversified farm is based on an 80 horsepower tractor. This indicates the farm organization has an effect on the machinery complement. Diversified farms can often use machinery in more different time periods than can specialized farms. The average annual machinery cost is generally higher for specialized farms. But the cost is usually less than $5.00 per acre different between he two farm organizations. The reason for the cost decrease is a decrease in the size of tractors and implements used. In general, specialized farms will require larger equipment at a slightly higher cost per acre.

Texas County Farm Organizations

The specilized farm (N-5) is based on two 80 horsepower tractors. The machinery complement on the diversified dryland farm has larger implements and tractors than the other two farms.

Three different farms are examined in Texas county. The first farm has 1280 acres of diversified dryland farming on sandy loam soil. The crop mix consists of 70% wheat and 30% sorghum (Case L, Table XXI, and Figure 14). The second farm has 1280 acres of sandy loam soil on a diversified irrigated farm with the crop mix consisting of 33% dryland (24% wheat and 9% grain sorghum) and 67% irrigated (33% grain sorghum, 17% corn, and 17% alfalfa),(Case M, Table XXII, and Figure 15). The last farm has 1280 acres of sandy loam soil on a 100% dryland wheat farm, (Case N, Table XXIII, and Figure 16). All three farm organizations have eight hours available for work per day during the winter time periods and ten hours available for work per day during the spring, summer and fall time periods.

TABLE XXI

CASE L: OPTIMAL FARM MACHINERY COMPLEMENTS IN TEXAS COUNTY, 1280 ACRES, DIVERSIFIED DRY LAND FARMING, SANDY LOAM SOIL, 10 WORKING HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORKING HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	(Situation) L-1	L-2	L-3	L-4	L-5
			(Number of Machines used per Situation)				
Offset Disk	7.8'	3	1	1	1		1
Offset Disk	15'	5				1	
Drill	30'	2	1	1	1		1
Drill	60'	4				1	
Planter	8 Row	1	1	1	1	1	1
Field Cultivator	18'6"	4		1			1
Field Cultivator	28'6"	5			1	1	
Field Cultivator	34'6"	6	1				
Chisel	8'	3		1	1		1
Chisel	12'	4		1			1
Chisel	16'	5			1	1	
Rodweeder	23'	6	1				
Rodweeder	29'	3		1			1
Rodweeder	47'	5	1		1	1	
Sprayer	350 G	2	1	1	1	1	1
Tractor	61 HP	3	1	1	1	1	1
Tractor	80 HP	4		1			1
Tractor	111 HP	5			1	1	
Tractor	156 HP	6	1				
Machine Cost			$31445.	$24469.	$29312.	$35186.	$28471.
Fixed Cost			18197.	12893.	15558.	16305.	12393.
Variable Cost			12760.	10505.	13239.	18055.	14812.
Transfer Cost			488.	1071.	515.	826.	766.
Total Labor Hours			735.39	1042.11	847.30	723.35	1048.16
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness			95%	85%	85%	85%	70%

[1] Crop Mix: 70% Dry Land Wheat, 30% Dry Land Grain Sorghum.

[2] Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

[3] Transfer Cost: The added cost of moving the operation of an implement to another time period.

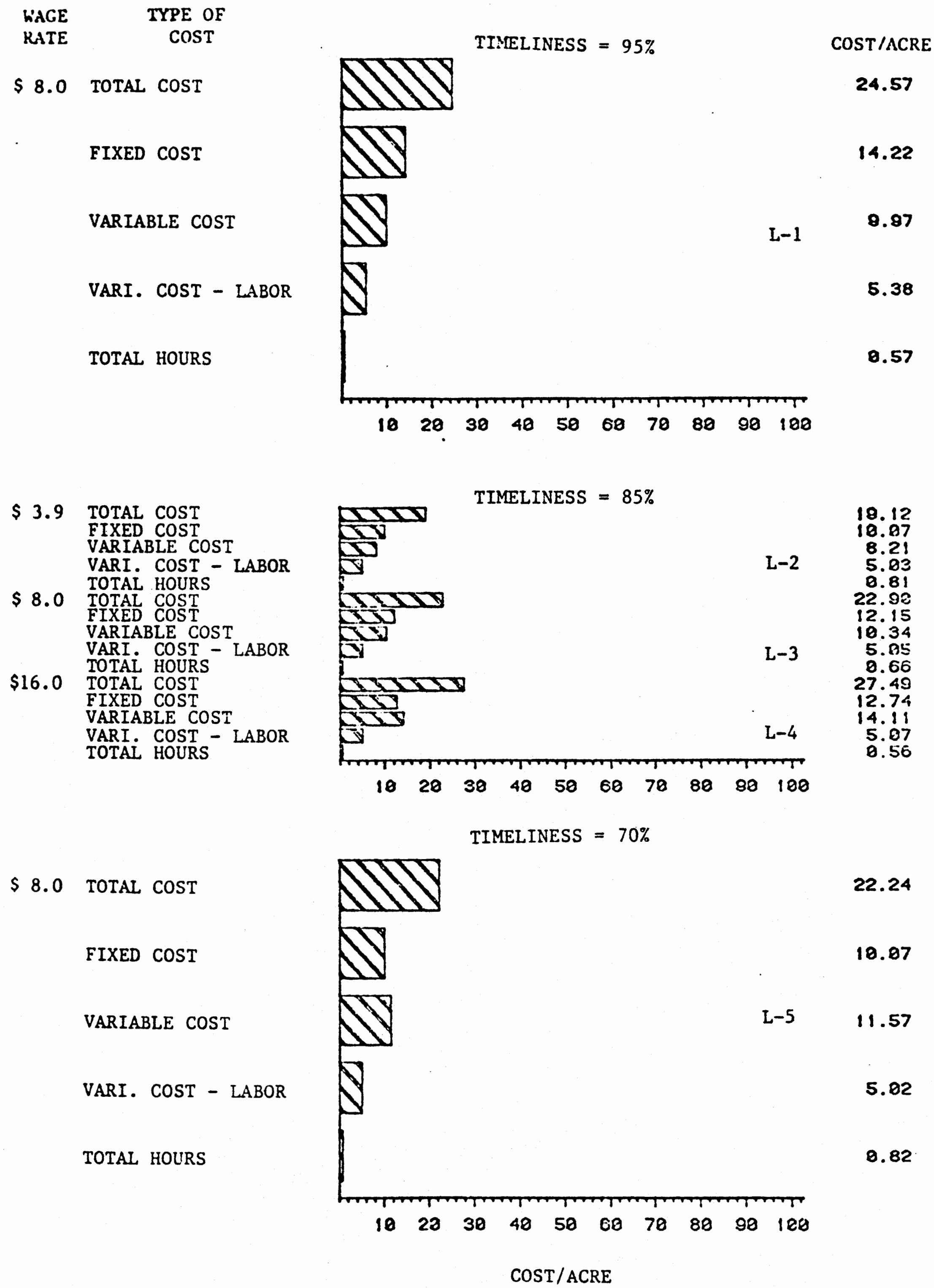


Figure 14. Case L: Optimal Farm Machinery Complements for Texas County, 1280 Acres, Diversified Dry Land Farming Sandy Loam Soil, 10 Working Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

TABLE XXII

CASE M: OPTIMAL FARM MACHINERY COMPLEMENTS FOR TEXAS COUNTY, 1280 ACRES, DIVERSIFIED IRRIGATED FARMING, SANDY LOAM SOIL, 10 WORKING HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORKING HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	Situation M-1	M-2	M-3 (Number of Machines used per Situation)	M-4	M-5
Offset Disk	11'	4		1	1		1
Offset Disk	15'	5	1			1	
Drill	30'	2	1	1	1	1	
Drill	60'	4					1
Chisel	8 Row	3		1			
Chisel	12 Row	4		1	1		1
Chisel	16 Row	5	1			1	
Planter	6 Row	1	1	1	1	1	1
Field Cultivator	12'6"	3		1			
Field Cultivator	18'6"	4			1		1
Field Cultivator	28'6"	5	1			1	
Shredder	14'	2	1	1	1	1	1
Rotary Hoe	28'	2		1	1		
Rotary Hoe	30'	3	1			1	1
Baler	23	3	1	1	1	1	1
Sprayer	36'	2	1	1	1	1	1
Tractor	61 HP	3	1	1		1	
Tractor	80 HP	4		1	2		2
Tractor	111 HP	5	1			1	
Machine Cost			$40127.	$33340.	$39411.	$49144.	$39654.
Fixed Cost			19402.	16622.	17236.	19402.	17725.
Variable Cost			19871.	16646.	22138.	29344.	21929.
Transfer Cost			854.	72.	37.	435.	
Total Labor Hours			1198.02	1606.41	1429.17	1198.02	1411.37
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness			95%	85%	85%	85%	70%

[1] Crop Mix: 24% Dryland Wheat, 9% Dryland Grain Sorghum, 33% Irrigated Grain Sorghum, 17% Irrigated Corn, 17% Irrigated Alfalfa.

[2] Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

[3] Transfer Cost: The added cost of moving the operation of an implement to another time period.

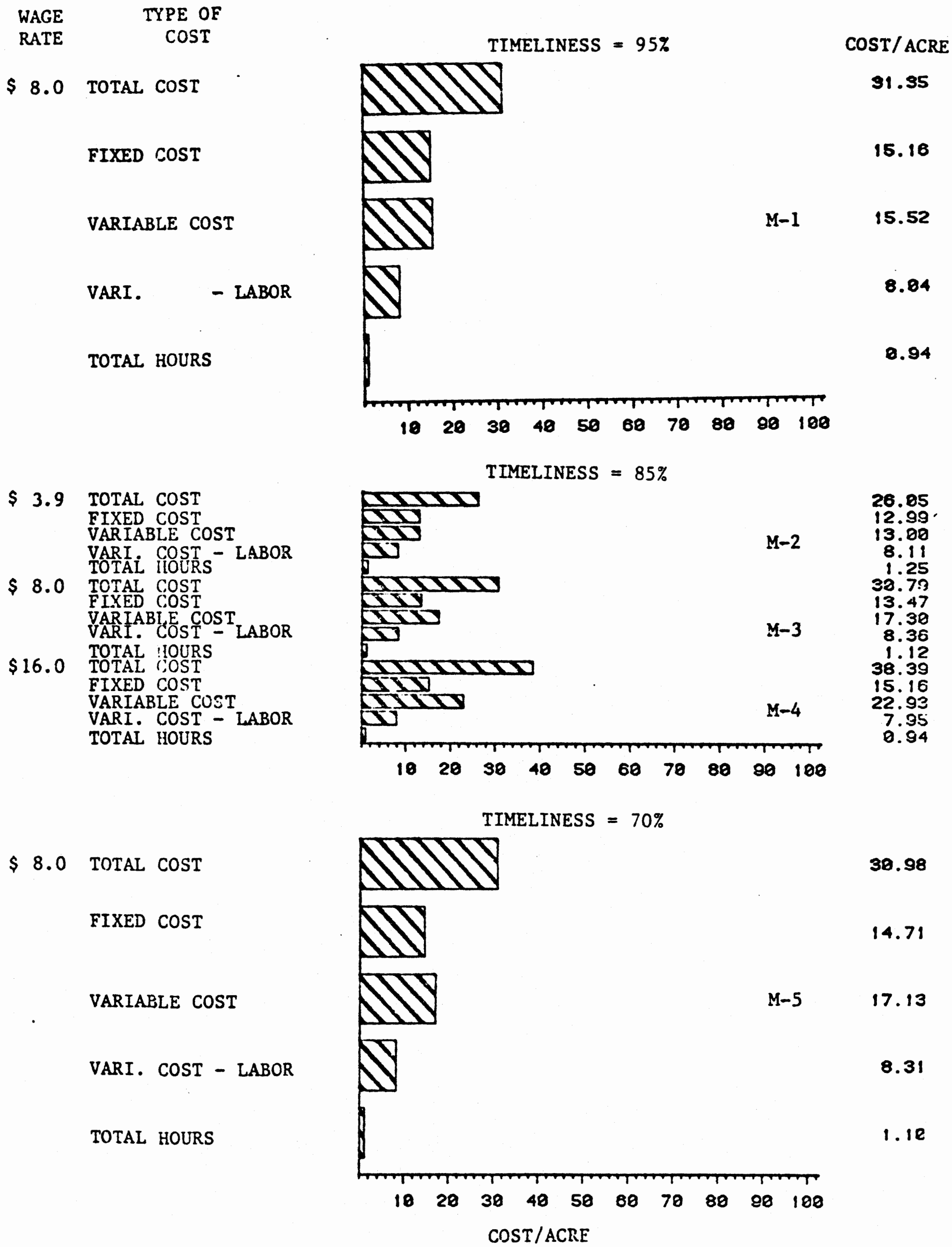


Figure 15. Case M: Optimal Farm Machinery Complements for Texas County, 1280 Acres, Diversified Irrigated Dry Land Farming, Sandy Loam Soil, 10 Working Hours Available During the Winter Months

TABLE XXIII

CASE N: OPTIMAL FARM MACHINERY COMPLEMENTS FOR TEXAS COUNTY, 1280 ACRES, SPECIALIZED DRY LAND FARMING, SANDY LOAM SOIL, 10 WORKING HOURS AVAILABLE DURING THE SUMMER MONTHS AND 8 WORKING HOURS AVAILABLE DURING THE WINTER MONTHS

Machinery	Size	Rank[2]	Situation N-1	N-2	N-3	N-4	N-5
			(Number of Machines used per Situation)				
Drill	30'	2		1			
Drill	60'	4	1		1	1	1
Chisel	12'	4	1	2	2	2	2
Chisel	16'	5	1				
Chisel	23'	6				1	
Field Cultivator	18'6"	4		2	2		2
Field Cultivator	28'6"	5	1				
Field Cultivator	34'6"	6				1	
Rod Weeder	37'	4		1	1		1
Rod Weeder	47'	5	1			1	
Sprayer	350 G	2	1	1	1	1	1
Tractor	80 HP	4	1	2	2	1	2
Tractor	111 HP	5	1				
Tractor	156 HP	6				1	
Machine Cost			$24101.	$19845.	$23227.	$27897.	$23009.
Fixed Cost			12633.	10509.	10936.	12141.	10936.
Variable Cost			10717.	8937.	11891.	15289.	11891.
Transfer Cost			751.	399.	400.	468.	182.
Total Labor Hours			664.46	878.78	821.27	532.77	821.27
Wage Rate			$8.00	$3.90	$8.00	$16.00	$8.00
Timeliness Level			95%	85%	85%	85%	70%

1 Crop Mix: 100% Dryland Wheat.

2 Rank: The ordering of machine sizes so a tractor of given rank can pull the same Rank implement or smaller.

3 Transfer Cost: The added cost of moving the operation of an implement to another time period.

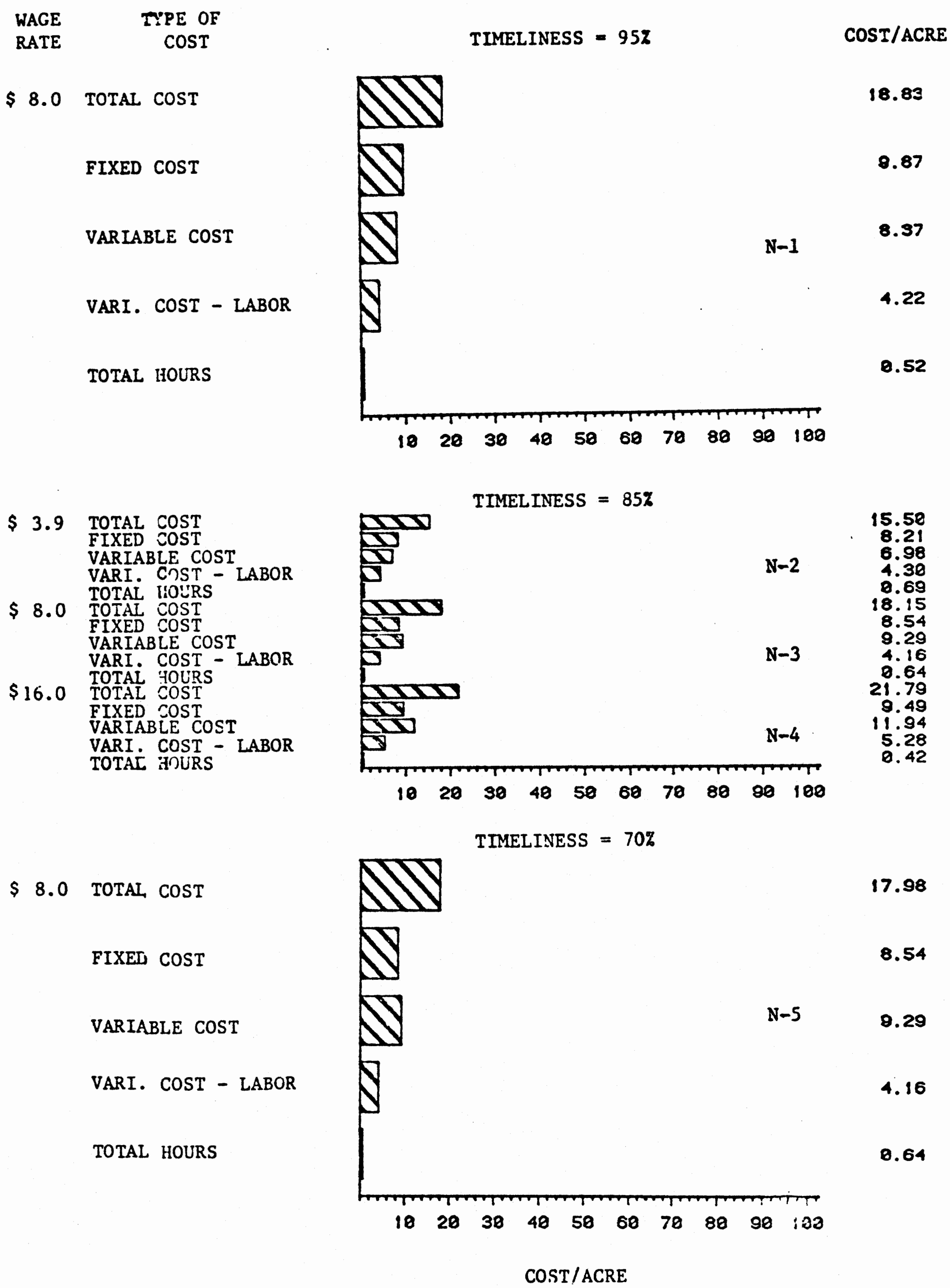


Figure 16. Case N: Optimal Farm Machinery Complements for Texas County, 1280 Acres, Specialized Dry Land Farming, Sandy Loam Soil, 10 Working Hours Available During the Summer Months and 8 Work Hours Available During the Winter Months

Changes in the Machinery Complements

The machinery complement at the $8.00 wage rate and 85% timeliness level for the diversified farm (L-3) is based on one 61 horsepower tractor and one 111 horsepower tractor. The irrigated farm (M-3) is based on two 80 horsepower tractors, and the specialized farm (N-3) is also based on two 80 horsepower tractors.

At the $8.00 wage rate and 95% timeliness level the machinery complement for the diversified farm (L-1) is based on the one 61 horsepower tractor and one 156 horsepower tractor. The irrigated farm is based (M-1) on one 61 horsepower tractor and one 111 horsepower tractor. The specialized farm (N-1) is based on one 80 horsepower tractor and one 111 horsepower tractor.

At the $8.00 wage rate and 70% timeliness level, all three farms could be operated with complements based on two 80 horsepower tractors. has larger implements and tractors than the other two farms. The irrigated farm and the specialized farm generally have the same size tractors. But there are more implements needed to perform the field operations on the irrigated farm. The most amount of equipment used is on the irrigated farm and the least amount of equipment used is on the specialized farm.

Changes in Costs of the Machinery Complements

As the timeliness level increases, all three farms show an increase in the average annual machinery cost per acre given an $8.00 wage rate (Figure 14, L-5, L-3, L-1), (Figure 15, M-5, M-3, M-1), (Figure 16, N-5, N-3, N-1). The irrigated farm requires about 70% more labor per acre than the dryland farms. This coupled with the additional machinery required causes the cost per acre for the irrigated farm to be much greater than the dryland farms.

The diversified dryland farm has higher costs and labor requirements than the specialized dryland farm. It is hypothesized that on diversified farms smaller machinery might be required because fewer acres would need to be tilled in each time period and thus, tractor use would be spread more evenly throughout the year. This is not the case however, as more tractor power and higher costs typify the diversified situation.

Summary of Chapter

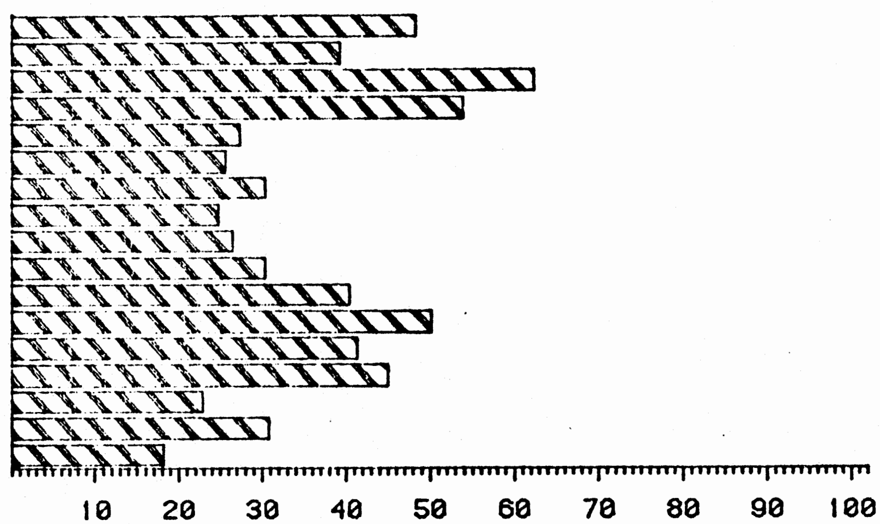
Figure 17, summarizes the total per acre costs for all farms analyzed using an $8.00 wage rate and 85% timeliness level. In general clay loam soil farms have the highest cost per acre, followed by the farms with irrigation, and then by the diversified dryland farms. The lowest average annual machinery cost per acre is found on specialized dryland farms.

The Texas County dryland wheat farm has a smaller average annual machinery cost per acre than the Canadian County dryland wheat farm. This results because Texas County has less rainfall and more hours at each timeliness level. The farms with 12 hours available per day have a slightly smaller cost per acre than do farms with 10 hours available per acre.

An attempt was made in this chapter to capture the effects of many of the factors which influence both machinery costs and machinery selection. Hopefully guides can be taken from these results which will help farmers with their machinery selection problems. Every farm is different with unique mixtures of soils and crops, as a result, it is not likely that the information reported in this chapter will be directly usable on any farm.

SITUATION					TOTAL COST
CA[1]	480[2]	S.L.[3]	D.D.[4]	10[5]	48.36
CA	960	S.L.	D.D.	10	39.28
CA	480	C.L.	D.D.	10	62.39
CA	960	C.L.	D.D.	10	53.97
CA	960	S.L.	S.D.	10	27.34
CA	1440	S.L.	S.D.	10	25.57
CA	480	S.L.	S.D.	10	30.33
CA	1440	S.L.	S.D.	12	24.74
CA	960	S.L.	S.D.	12	26.42
CA	480	S.L.	S.D.	12	30.33
CA	960	S.L.	D.I.	10	40.52
CA	480	S.L.	D.I.	10	50.13
MU	450	S.L.	D.D.	10	41.35
MU	450	S.L.	S.D.	10	45.05
TE	1280	S.L.	D.D.	10	22.90
TE	1280	S.L.	D.I.	10	30.79
TE	1280	S.L.	S.D.	10	18.15

TIMELINESS = 85%



1. CA = Canadian County; MU = Muskogee County; TE = Texas County

2. Farm Size in Acres

3. Soil Type; S.L. = Sandy Loam Soil; C.L. = Clay Loam Soil

4. Crop Mix D.D. = Diversified Dryland; S.D. = Specialized Dryland; D.I. = Diversified Irrigated.

Figure 17. Total Cost Per Acre for all Situations with 85% Timeliness Level and $8.00 Wage Rate

CHAPTER IV

Summary and Implicaitons

Three areas of Oklahoma (Texas county, Canadian county, and Muskogee county), were studied by varying the timeliness level, crop mix, farm size and wage rate. The optimal machinery complements for different farm resource situations were determined and analyzed with comparisions made on the important factors that affect machinery selection.

In reviewing the methodology of this study several different types of information were gathered. First rainfall data was gathered in order to come up with the timeliness factors used. Types and sizes of machinery were selected depending on the crops being grown. This information was input into a computer model to determine the optimal machinery complements.

Implications

The purpose of this section is to draw generalized implications from the results presented in the previous chapter. Total hours of labor per acre varied directly with the size and number of the implements used in the machinery complement. The number of hours available for work per time period increased from east to west accross the state because of less annual rainfall expected in the west. The annual average machinery cost per acre decreased as the timeliness level decreased. As the time contraints for performing the necessary field operations are relaxed, the cost of the machinery complements decreased due to using fewer machines and/or smaller machines. In addition, the annual average machinery cost per acre decreased as the wage rate decreased. As wage rates were lowered smaller implements were used to perform the necessary field operations.

In Figure 15 the diversified dryland farm in Texas county is shown to have had the lowest average annual machinery cost per acre in the state at any given wage rate and timeliness level. Muskogee county and Canadian county had the highest average annual machinery cost per acre for any given wage rate and timeliness level. The specialized dry land farms in Texas county had the lowest cost per acre followed by Canadian county and then Muskogee county.

Overall, the diversified irrigated farms in Texas county had lower average annual machinery cost per acre than irrigated or dryland farms in Canadian county. This was attributed primarily to the number of hours available to perform the necessary field operations during the critical summer time periods.

The largest average annual machinery cost per acre increase resulted when the soil type was changed from a sandy loam soil to a clay loam soil. Clay loam soils not only drastically cut the hours available per work period but also required more energy to pull implements through the soil. As a result larger tractors were required for clay soils which resulted in significantly higher fixed costs.

In Canadian county, the average annual machinery cost per acre for specialized dryland farms was considerably less than the costs for diversified farms. The size of implements used on specialized dryland farms was generally much larger so that necessary machinery operations could be performed in the given time period. This resulted because each operation requires all the acreage to be covered in a given time period instead of just part of the acreage. The diversified irrigated farms fell between these two extremes in terms of average annual machinery cost and machinery size.

Some optimal machinery solutions had a piece of machinery which was used only a very few hours per year due to a timeliness constraint in a particular time period. To obtain more realistic machinery complements some field operations were allowed to shift to a succeeding or preceding time period at a cost. This transfer procedure allowed machinery implements to be more efficient and eliminated the problem of machines being used only a few hours per year. The machinery selection model was forced to choose machinery discretly and therefore if all field work could be completed in a given time period the selection algorithm had to purchase an additional machine. The transfer procedure utilized successfully handles this problem.

Further Applications

One possible use of the model would be to determine the effects on optimal machinery complement selection on the adoption of new production technologies. For example, if a farmer were switching to minimum tillage how could the farmer best order the purchase of his new equipment?

A very important part of the machinery selection model is correct days available information. Additional work on collecting and updating rainfall data in order specify more accurate timeliness levels for the model operation would be beneficial. Since rainfall is so varied throughout the state and so crucial in the operation of the model, more work is needed. A situation not handled in the model concerns time periods when the soil is too dry to work. Information could be collected and used to determine days lost because of this condition. This information could then be incorporated into days available distributions.

There is always a need for the machinery complements, especially machinery prices, to be as current as possible.

There is always a need for the machinery complements, especially machinery prices, to be as current as possible. The choice of machinery available to farmers is so diverse it is hard to maintain current and complete complements.

More effective and accurate procedures for matching implements to tractors would be helpful. Matching is dependent on travel speed, soil type, soil texture and depth of operation, all of which can be so varied from farm to farm that considerable bias is introduced trying to generalize the matching of implements to tractors in the model.

Additional verification of model results could be accomplished by cooperation with the extension service. Results of the model could be compared to complements on farms. Such a study may lead to conclusions on the timeliness level farmers use as well as indicate how much excess capacity typical farmers build into their machinery complements. The model could also be used to help farmers upgrade their current machinery complements towards the optimal machinery complement when replacing outdated machinery.

Cost equatons used in the model are outdated. Considerable effort should be expended to develop current parameters for tractors and implements cost equations. Information is needed on repair cost, fuel consumption, and depreciation. Tax implications of trading machinery should also be considered.

One desirable major revision in the model would be the incorporation of machinery selecton with crop organizaton determination. The ability to combine the selection of a cropping organization and a corresponding machinery complement would show simultaneously which cropping organization and machine complement would provide the highest return.

Summary

Many variables were considered when selecting each machinery complement. Example considered were personal preferences concerning the size, number, and kind of machinery as well as the depth of tillage, soil type, and desired tillage speed. All of these considerations lead to choosing different tractors for one farm than for another. Machinery costs per hour varied with several factors. Perhaps the most important single factor affecting costs was annual hours of use. Fixed costs per hour were shown to be reduced significantly by increasing the annual use of machines. Time required for specific field operations decreased with the use of larger machines. Economics of size were shown to be possible if the value of time saved with a larger machine more than offset the increased operating cost of the larger machine.

The effects of changing the wage rate, timeliness level, crop mix, soil type, farm size, hours available and area of the state were compared with each other and their resulting machinery complements were shown. With a little work this model could be adapted to different areas of the state. Farmers could then incorporate their particular situations and obtain a machinery complement tailored to their farm. Without accurate weather data, soil type, implement speed, tillage depths, and technical coeficients, an accurate machinery complement cannot be determined but only generalized. It is hoped that this study has shed more light upon this ever growing and demanding area.

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VITA

Scott Morris Hininger

Candidate for the Degree of

Master Of Science

THESIS: EXPANSION OF AN OPTIMAL MACHINERY COMPLEMENT SELECTION SYSTEM

Major Field: Agricultural Economics

Biographical:

Personal Data: Born in Clinton, Oklahoma, January 23, 1956, the son of Mr. and Mrs J.R. Hininger.

Education: Graduated from Sheridan High School, Sheridan, Wyoming in May, 1974; received the Bachelor of Science in Agriculture degree from Oklahoma State University, Stillwater, Oklahoma in May, 1979, with a major in Agricultural Education; completed requirements for the Master of Science degree at Oklahoma State University in May, 1982.

Professional Experience: Employed as a Graduate Research Assistant in the Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, 1979-1981.