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Abstract

Optimal farm machinery complements were developed, using mixed-integer programming techniques, for several farm sizes, cropping patterns and different methods of financing (lease and credit-purchase). Financing methods did not affect machinery complement selection but did have an impact on farm profitability and cash flow.

An Economic Analysis of Farm Machinery Complement Selection

Machinery represents a major investment and is an important financial component on modern U.S. farms. In early 1985, machinery values (tractors and equipment) represented 38 percent of U.S. farm non-real estate asset values while machinery-related expenses were 19 percent of total farm production expenses in 1984 (15). From 1979 to 1984 capital expenditures for farm machinery declined 38 percent ($11.75 to 7.28 billion) reflecting depressed farm economic conditions (15). During this same period, an increased variety of machinery financing alternatives became available and Federal tax legislation emphasized the use of accelerated cost recovery and investment tax credit for machinery purchases.

Many machinery complement studies have focused on cost minimization. Machinery operating and ownership costs were minimized while considering labor, machine size, and the sequence and timeliness of field operations (10,12). Other studies have used mixed integer programming models to simultaneously solve for machinery selection and crop production (6,7). An integer program selected machinery size and then the best crop plan was selected, given this set of machinery.

Investment credit, accelerated depreciation, and the general rate structure of the income tax schedule were analyzed to determine the effects of tax policy on machinery investment (3,16). The effects of the 1981 and 1982 Federal tax law changes on machinery acquisition decisions have also been studied (14). Findings indicated the advantage of the credit-purchase alternative has declined.

In today's farm economy careful planning of machinery investment and financing decisions can have a major impact on the financial success or failure of a farm operation. In this study, optimal machinery complements were developed for several farm sizes, cropping patterns and different methods of financing machinery acquisitions (lease and credit-purchase). The different financing methods did not affect machinery complement selection but did impact farm profitability and cash flow.

The Machinery Complement Selection and Financing Model

This study extends previous research by developing a machinery selection and financing model which combines new and proven approaches to machinery complement selection and financing. The models developed in this study, using mixed integer linear programming (MILP) algorithms, build machinery complements from many possible power and implement combinations instead of selecting from alternative fixed machinery sets. Alternative financing and taxation considerations are incorporated using annualized cost capital budgeting approaches. Annualized costs were used to retain the advantages of a single period model. This general modeling approach was used to meet the following objectives:

1. To determine optimum machinery complements for farms of different size and crop enterprise combinations, and
2. To examine the impacts of alternative acquisition, financing, and tax strategies on least cost machinery complement decisions.

Assumptions and Constraints

The study region selected was southeastern South Dakota, which is on the western edge of the Cornbelt region of the United States. Based on agricultural census data (4) farm sizes of 400, 800, and 1600 cropland acres were chosen for the study. The census data (4) were also used to determine the fixed cropping pattern on each farm--45 percent corn, 15 percent oats, 30 percent soybeans, and 10 percent alfalfa. Variable production costs per acre for each crop were obtained from regional crop budgets developed by Aanderud (1).

The field operations assumed in the model were conventional tillage and harvesting methods. Conventional tillage methods were assumed because conventional tillage is used on 70.4 percent of South Dakota cropland, while various conservation tillage practices are used on remaining cropland (5).

The calculation of tractor hours available each month for completion of field operations was a two step process. First, field working days available during each month of the production season were calculated--based on probable non-wet days permitting field operations (9). Second, working days were multiplied by a 14 hour work day to compute tractor hours available for each month.

Tractor sizes of 80, 100, 125, 165, and 220 horsepower were specified based on recent retail tractor sales data by horsepower (8) and from discussions with area farmers. Equations from the Agricultural Engineers Yearbook (2) were used to calculate the maximum size implements for each tractor. Tractor horsepower, along with assumptions of soil type, implement speeds, and depth of field activity were incorporated into equations to calculate tractor pulling capacity in pounds of force. Additional equations, one for each field operation being considered, were used to calculate implement draft in pounds of force per unit of implement size. The maximum implement size was computed by dividing implement draft into tractor pulling capacity.

Once maximum implement size was determined for each tractor, tractor-implement combinations were developed. When possible, each tractor was assigned two implement sizes for each field operation and in many cases a specific implement size could be used with more than one tractor. The end result was a broad range of tractor and implement sizes representative of those used by farmers in eastern South Dakota.

Annualized costs, using capital budgeting procedures, were calculated for each tractor and implement (11,13). Annualized costs are the average cost of acquiring and using a capital asset over its useful life after accounting for the time value of money. Annualized costs were calculated for credit-purchase and lease financing alternatives, creating two separate models. Calculating annualized costs made it possible to use single period machinery selection models.

Finance terms used in annualized cost calculations were representative of 1984-85 conditions in eastern South Dakota. The credit-purchase agreement assumes a 5 year loan, annual payments, a 30 percent downpayment, and a 15 percent annual interest rate. The lease agreement assumes a 0.225 payment factor, the lessor keeping the investment credit, annual payments at the beginning of the year, and purchasing the equipment at the end of the lease. Both agreements assume using the equipment for 8 years, a 22 percent marginal tax bracket, ACRS depreciation, and a 12 percent after-tax rate of return.

Model Structure

The model was designed to use mixed integer linear programming techniques (MILP) so tractors and other machinery would enter into the solution in whole number values rather than as fractions of a tractor or machine. The MILP approach also meant that annualized costs would enter the model in their entirety.

The MILP algorithm was used to maximize profits of the farm. The profit function represents annual gross returns less all annualized fixed and variable costs (Figure One). The profit function was subject to various constraints: (a) matching tractors to implements, (b) restricting total hours of labor per month, (c) restricting maximum hours of tractor use per month, (d) restricting implement hours of use, (e) restricting each crop's acreage planted, and (f) restricting tractors and implements to integer values. In this model, maximizing the profit function results in selection of the least cost machinery complement.

The rows section contains eight general subsections: costs, total hours, tractor hours, implement hours, tractor use, field operations, transfer rows, and the profit objective (Figure Two).

The cost subsection contained annualized ownership/leasing costs for tractors and implements, variable costs per acre for tractors and implements, and other crop production costs per acre, including interest expense of an operating loan.

The hours subsections of the model are linked together and set up in a similar way. The total hours subsection specifies the maximum man hours available to operate the farm each month. The tractor and implement hours subsections constrain the hours of use per month and year, respectively, that each machine could be used. If one tractor, and the implements that are selected with it, cannot complete all field operations within the time constraints, another tractor, of the same or different size, would also be selected. Labor hiring activities were linked with the monthly total hours constraints and selection of additional tractors.

The tractor use subsection constrains the model from selecting more than one implement per tractor for a specific field operation.

The model was structured such that completion of one field operation led to the next operation in the logical sequence of activities needed to produce specific crops. This method allowed for variable crop production costs as well as variable machine costs to be allocated to specific crops according to actual use rather than prorating the costs over total farm acres.

The final two subsections are transfer rows and the objective function. The transfer rows linked crop production and sales activities. The profit row accounted for all costs and returns expected on the cash grain farm.

The columns section of the model contains all of the activities under consideration. The tractor, implement, and tractor-implement activities were all linked by machine hours per acre coefficients. This was done so that tractors would be matched only with implements they could pull and the appropriate annualized machinery costs and variable costs per acre would be matched accordingly for use in the profit maximization procedure.

Crop production and sales activities were included in the profit function and determined the number of acres on which tractors and implements would be used. In fact, pre-specified crop acreages determined the acreage of each field operation and the model multiplied the appropriate tractor-implement variable machine costs per acre by this number of acres. The labor hiring activities were included in case more man power was needed during any month to operate additional machinery.

Empirical Results

Machinery complements selected and the systems of implements used for the 400, 800, and 1600 acre farms are shown in Table One. The implements selected by the model are given in the fist column and the slash with a number following it indicates which tractor the implement was used with. Under the acres columns the slash between numbers means the implement was used on two different occasions.

For all farm sizes, identical machinery complements were selected for both credit-purchase and lease option models. This suggests that either the financing terms of credit-purchase and leasing agreements are relatively competitive, and the differences in financing terms was not sufficient to affect complement selection, or the marginal relationships of the coefficients were similar. Profit differences between lease and credit-purchase alternatives varied from $2300 for the 400 acre farm to $4400 for the 1600 acre farm. The credit-purchase alternative was more profitable in each case.

An 80 HP tractor and the appropriate sizes of implements were selected for the 400 acre farm. Since the farm is relatively small, the selection of one tractor was not surprising.

In the larger acreage farms machinery complements were selected based primarily on hours of use, with annualized cost the secondary consideration. First the model examined annualized and variable costs for an implement in a particular field operation. Second the machine hours per acre for the implement were multiplied by the number of acres in the field operation. If the hours of available use were not exceeded the implement with the lowest annualized cost was selected; otherwise, a different sized implement not exceeding hours of available use was chosen. Sometimes two implements, each supplying hours and being used with separate tractors, were needed to complete a field operation. Then two tractors were used individually or in combination for all remaining field operations.

For the 800 acre farm, two tractors--an 80 HP and 125 HP--were selected along with the specific implements used with these tractors. Although the selection of two tractors was anticipated, using the smaller tractor for tillage operations was not. The larger tractor was expected to be used for heavy field operations such as tillage and the smaller tractor on lighter operations like baling. However, profit maximization was the objective and complements were selected based on that criteria.

Two medium sized tractors--a 125 HP and 165 HP--were selected for the 1600 acre farm and they were used more according to traditional farm practices. The larger 165 HP tractor was used for the majority of tillage work and the 125 HP tractor handled lighter work such as drilling and baling.

The selection of swathers and combines was unchanged for all farm sizes except the 1600 acre farm. On the 1600 acre farm the combining could not be completed in the 180 hours of available use by the 13 foot combine and a bigger combine was selected because it could complete the job faster.

Conclusions

The model presented in this study can be an aid in machinery investment decisions. The model contains the basic components of annualized machine costs, variable machine costs, production costs, and crop returns. These components, together with the provisions for timeliness of operations, produce a model that is capable of aiding in many machinery related decisions.

The model built in this study can select the entire machinery complement for a farm, given applicable time constraints and crop production patterns. In addition this model selects implements for all machine operations from field preparation to final crop harvest. The model also allocates the acres of use for each tractor-implement combination to maximize profits.

Researchers may be the primary beneficiaries of the kind of analysis made in this study. The fact that different financial agreements (credit-purchase and lease) in this study selected the same optimal machinery complement suggests that machinery complement selection is not a precondition to analysis of financing. It seems that machinery complement selection and financing strategies can be a sequential process. Least cost financing alternatives must be studied irrespective of the machinery complement employed. However, optimum machinery complement selection is important to avoid investment in power units and equipment in excess of that necessary for the production process. Complement selection affects the level of investment while financing alternatives are concerned with least cost financial strategies.

In today's farm economy it is particularly important that farmers watch their financial concerns much more closely. Since many models (6,7,10,12) do an adequate job of selecting machinery complements, perhaps greater attention should be directed toward studying different variations in machinery financing alternatives and how they will affect farm profitability and cash flow.

Figure One -- Model Objective Function and Constraints

Maximize: $R - AC_t - AC_m - VC_{tm} - PC_c$

Subject to:

$T_t - M_m \leq 0$ (a)

$L_j \leq H_j$ (b)

$LT_{tj} \leq HT_{tj}$ (c)

$LM_m \leq HM_m$ (d)

$XC_c \leq A_c$ (e)

$T_t, M_m \leq 0,1,2,\text{etc.}$ (f)

Where:

R = annual gross returns from crop sales

AC_t = annualized ownership/leasing costs of all tractors selected

AC_m = annualized ownership/leasing costs of all implements selected

VC_{tm} = variable costs per acre of all tractor-implement combinations selected

PC_c = crop production costs per acre (excluding machinery and labor expenses)

T_t = tractor size t = 1 to 5

M_m = implements to be used only with tractor_t

L_j = hours of equipment use in month j

H_j = total hours of equipment use available in month j

LT_{tj} = hours of use for tractor t in month j

HT_{tj} = total hours of use available for tractor t in month j

LM_m = hours of use for implement m during the year

HM_m = total hours of use available for implement m during the year

XC_c = acres planted of crop c

A_c = maximum acres to be planted of crop c

Figure Two--Description of Machinery Selection MILP Matrix
(+,- are sign of coefficient in model)

Rows \ Colns	Row Type	Tractors	Implements	Tractor-Implement Combinations	Crops	Crop Sales	Labor Hiring
Costs	N	(+) Annualized	(+) Annualized	(+) Variable Costs Per Acre	Prodn Costs		(+) Per Hour
Total Hours	L			(+)			(-1)
Tractor Hours	L	(-) ←	Hours Provided By Machine	(+) ↖			
Implement Hours	L		↓ (-)	↖ Machine Hours Per Acre ↙ (+)			
Tractor Use	L	(-)	(+)				
Field Operations	E			-1 -1 +1 +1 -1 -1 +1 +1 -1 -1 +1 +1 -1 -1	(+1)		
Transfer Rows	E				(-)	(+1)	
Profit	N	(-)	(-)	(-)	(-)	(+)	(-)

Table One--Machinery Complement Results by Farm Size and Financing Method

Selected	400 Acre Lease Units	Acres	400 Acre Purchase Units	Acres	800 Acre Lease Units	Acres	800 Acre Purchase Units	Acres	1600 Acre Lease Units	Acres	1600 Acre Purchase Units	Acres
80 HP Tractor	1.0		1.0		1.0		1.0					
125 HP Tractor					1.0		1.0		1.0		1.0	
165 HP Tractor									1.0		1.0	
Plow 5-16/80	1.0	340	1.0	340	1.0	680	1.0	680				
Plow 10-18/165									1.0	1360	1.0	1360
Chisel 8 ft/80	1.0	60	1.0	60	1.0	120	1.0	120				
Chisel 10 ft/125									1.0	240	1.0	240
Disk 10 ft/80	1.0	400	1.0	400	1.0	483	1.0	483				
Disk 12 ft/125					1.0	317	1.0	317				
Disk 15 ft/125									1.0	683	1.0	683
Disk 19 ft/165									1.0	917	1.0	917
Harrow 24 ft/80	1.0	400	1.0	400	1.0	800	1.0	800				
Harrow 66 ft/165									1.0	1600	1.0	1600
Drill 10 ft/80	1.0	100	1.0	100	1.0	200	1.0	200				
Drill 20 ft/125									1.0	400	1.0	400
Planter 4 row/80	1.0	300	1.0	300								
Planter 8 row/125					1.0	600	1.0	600	1.0	625	1.0	625
Planter 8 row/165									1.0	575	1.0	575
Cultivator 4 row/80	1.0	300	1.0	300								
Cultivator 6 row/80					1.0	600	1.0	600				
Cultivator 12 row/165									1.0	1200	1.0	1200
Swather 16 ft	1.0	40/60	1.0	40/60	1.0	80/120	1.0	80/120	1.0	160/240	1.0	160/240
Baler Small/80	1.0	40	1.0	40	1.0	80	1.0	80				
Baler Big/125									1.0	160	1.0	160
Combine 13 ft	1.0	180/180	1.0	180/180	1.0	360/360	1.0	360/360				
Combine 20 ft									1.0	720/720	1.0	720/720
Profit	14064.96		16346.82		46866.65		49888.32		116215.29		120617.42	
Annualized Machine Costs	27484.50		25202.64		36427.65		33405.98		53059.50		48657.37	

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