9-1984

Weather Risk and Size Economies of Large Machinery in Wheat Production

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Research Bulletin 306

September 1984

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The Agricultural Research Division
Institute of Agriculture and Natural Resources
University of Nebraska-Lincoln
Irvin T. Omtvedt, Director

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Issued September 1984, 600

SUMMARY

Study findings indicate that farms with up to 3,000 acres of harvested wheat generally have farm machinery size economies. The total machinery cost per acre declines as farm size increases. It cannot be shown conclusively from this research that farms larger than 3,000 acres have diseconomies of size.

Size economies are more pronounced at smaller farm machinery sizes. This confirms the generally observed size relationship from other studies that indicate most farm size economies are achieved at modest farm sizes.

Size economies are most dramatic at the higher completion probabilities. Similarly, evidences of diseconomies of size are evident only at lower completion probabilities. These relationships can be expected in that higher machinery investments are required at higher completion probabilities.

At lower farm sizes (2,000 or less acres), higher levels of completion probability always resulted in higher machinery costs. The difference in cost per acre between 90 percent completion and 60 percent completion ranged from about 1 to 3 dollars per acre depending on size examined. At moderate farm sizes (2,250 to 2,750 acres) similar significant cost differences occurred between 90 percent and 80 percent comletion probabilities, but essentially no differences in costs between 80 percent and 60 percent completion probability were observed. At large farm sizes (3,000 acres and higher), cost differences by completion probability were not consistent and tended to be small.

The research findings also show that, other things being equal, the risk aversion level of farmers may be an important factor determining the size of farm machinery selected. A risk averse farmer will select a set of farm machinery larger than that selected by a risk neutral individual. The difference in total machinery cost per acre between the various risk aversion levels varies by size. Whether the difference in cost per acre will induce farmers to accept risk will depend on the farmer's assessment of losses which may be incurred by not completing field operations in the assumed time frames. Research related to the estimation of magnitudes of yield loss resulting from untimely completion of field operations would be useful in determining the total machinery economies associated with size.

Expansion of farm size beyond the point where earlier studies indicated that size economies were exhausted may be due to technical economies of size resulting from technological change. However, this does not preclude expansion for reasons other than economies of size.

Weather Risk and Size Economies of Large Machinery in Wheat Production

Glenn A. Helmers and Romanus Monji[1/]

INTRODUCTION

The issue of firm size economies in agriculture attracts interest because of its structural implications. Unfortunately, the investigation into the existence and degree of size economies has encountered problems including definition, isolation of cause-effect relationships, and appropriate research techniques. It is difficult to separate the pure size aspect from related issues such as technology, management, etc., which impact farm size changes. Historical trends in farm size lead many observers to propose that such trends are caused by an active size economies force. However, farm enlargements may have been caused by other forces partially, if not completely.

Obviously, historical farm growth has occurred by size changes compared to scale change (particularly unit duplication) where size changes refer to non proportional changes in input levels and scale changes refer to proportional changes in inputs. This may be due to a preference for the single plant-family labor managed firm. Another possible explanation for the lack of unit duplication may lie in the financial constraints which limit growth to additions to an existing unit. More likely it is because of a lack of significant size diseconomies. Had such size diseconomies been reached, more growth in duplication may have occurred. That is, in such a setting of size diseconomies should a firm expand, it would do so in a scale manner through duplication of efficiently sized units.

For policy purposes the question of determining whether there are diseconomies of size for very large farms is important. Should significant technical diseconomies exist, they would set a limit to the expansion of farms despite government tax policies and/or the existence of pecuniary economies.

Miller, *et. al.*(29) points to the divergence of views regarding contributing factors to farm size changes. Should significant size or scale economies exist, the resultant pressure on farm enlargement is obvious. However, should no size or scale economies exist, farms may still increase in size because of a number of other forces such as income tax incentives.

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Stigler(38) has argued that firms must, under competitive conditions, achieve minimum costs to survive. Hence, firms will tend to be driven to the minimum point of the long run average cost function. Most studies of agricultural size economies conclude that nearly all size economies are achieved at moderate farm sizes; hence, society gains little from farm size expansion beyond such moderately sized farms. These studies included Ball and Heady(2), Carter and Johnston(7), Dean and Carter(10), Gardner and Pope(16), Hall and Leveen(12), Jensen(21), Martin(28), and Miller, *et al.*(29).

Some analysts have been uncomfortable with much traditional analysis of farm size economies. Ryan(35) suggests that management differences between farms have not received enough emphasis in cross-sectional examinations of cost differences between farms. Holland(20) is critical of much of the economic-engineering analyses used in most size studies, particularly fixed machinery complements and constant yields. Johnson(22) has also criticized much size economies research for its assumptions of fixed inputs for small-sized firms. Seckler and Young(36) point out that increasing farm size doesn't imply economies of size—only the lack of size diseconomies. In addition, management differences and varying income desires are forces which drive farm size changes according to Seckler and Young(36). Stanton(37) in a discussion of the size economies issue, points to a lack of studies of size diseconomies caused by factors such as timeliness. Kislev and Peterson(24) reach different conclusions regarding pressures on farm size caused by size economies compared to traditional analyses. They find that for the 1930-70 period farm size changes are related to relative factor prices and not size relationships.

In an associated issue, disagreement exists regarding the existence of pecuniary economies in agriculture. Krause and Kyle(26) suggest that large farms may have a lower per unit input price due to volume discounts and a higher price per unit of output due to their ability to eliminate the middleman. Yet in Hall and Leveen's study(17), they conclude that "the cost advantages associated with purchased inputs do not contribute in any substantial way to the overall advantages of large farms..." On the other hand, Faris and Armstrong(13) report that volume discounts for purchased inputs are significant for large farms.

Only in recent years has there been efforts to determine the impact of income taxes on farm structure. One aspect of the tax impact is its influence on relative prices or costs of capital relative to labor. The nature of investment credit, rapid depreciation, and capital gains provisions result in capital investments having after-tax costs significantly lower than their before-tax costs. The same does not hold nearly to the degree for labor; hence, taxes encourage the substitution of capital for labor with the result that farm size is increased. Still another tax force which may differentially affect farm size growth lies in the nature of the progressive income tax. In association with tax laws relating to land and depreciable assets, individuals in higher tax brackets are able to outcompete those in lower tax brackets. While the exact impact of this force on farm growth is not fully clear, it can be hypothesized that progressive income taxes have a structural result.

A report by the U. S. Department of Agriculture (A Time to Choose)(39) points out that tax laws "encourage the growth and expansion of existing farms either at the expense of other farms or at the cost of denying entry to persons who want to begin farming." (p. 92). A similar conclusion has been reached by Harrington(18). Other tax related research with size implications to agricultural firms includes Boehlje(3), Bravo-Ureta and Helmers(6), Davenport, *et al.*(9), Krause and Burbee(25), and Watts and Helmers(41). Summaries of economies of size research in agriculture are provided in Jensen(21) and also Madden(27).

OBJECTIVES

Major objectives of this study were to determine the existence of economies or diseconomies of size for large farms and to determine the impact of farmers' risk aversion level on the size of farm machinery selected.

The first objective was achieved by selecting the smallest set of farm machinery that can perform all farm operations within a specified time period for various farm sizes. The smallest size set was also assumed to be the least cost. The long-run average cost curve was derived by varying farm size and calculating the per acre cost of the machinery selected for each assumed farm size. The curve so derived was designated as a long-run average cost curve only because the smallest size of machinery was selected at each farm size.

To achieve the second objective, the expected time available to perform farm operations was considered a function of the farmer's risk aversion level. Thus, a risk averse farmer will select a lower percentage of expected available working days as the expected condition and make larger investments in machinery to enable him to complete operations in fewer days. The difference in attitude towards risk will be revealed in the size of farm machinery selected given the same farm size.

To contain the problem to one of machinery selection, management quality was held constant. Hence, there are neither economies or diseconomies of management as farm size increases (Johnson and Hvinden(23)). It was also assumed that cropping practices do not change with farm size.

RISK ANALYSIS

Traditionally, risk in production has been defined as the occurrence of an event whose probability distribution is known. In machinery selection models risk has been handled in a variety of ways. The most common way, however, has been to assume various levels of yield losses associated with untimely completion of an operation. The cost of such yield losses is imputed and the model selects a set of machines that minimizes total cost including yield losses (Boisevert,(4); Donaldson(11); Edwards and Boehlje(12); Fulton, *et al.*(15); and Heady and Krenz(19)).

In this study, another aspect of risk is considered—the number of working days available for a time period. Based on weather data, the number of working days for a climatic week was calculated for four probability levels—90, 80, 70, and 60 percent. At higher probabilities fewer working days are perceived probable in a week. A risk averse farmer will adopt a higher completion probability level thus relying on fewer working days in a week compared to a risk neutral farmer. This risk averse farmer will invest in sufficient capacity to complete his operations within those few days. In contrast, a risk neutral individual will assume a higher number of working days (presumably the mean). Thus, lower equipment capacity is selected relative to the risk average farmer. Greater risk aversion is achieved at increased cost. However, this increased cost can only be assessed after the costs (yield losses) of lower probability completions are considered. That is, the incentive to complete field operations in a given time period depends upon the costs of yield losses which result when such operations are not completed. No yield losses due to failure to achieve the completion of operations in a time interval were included in this model. Hence, cost differences resulting from different completion probabilities must be compared to expected yield losses before conclusive estimates of risk premiums can be made.

DESCRIPTION OF THE STUDY AREA AND FARMING SYSTEM

Dictated mostly by the availability of daily weather data (81 years), the study is based on Kimball County of northwestern Nebraska. A previous study (1968) of size economies in the Nebraska Panhandle showed significant size economies to 250 acres of wheat and little size economy thereafter (Vollmar, *et al.*(40)). Wheat is the most important crop of the county, occupying about 90 percent of total cultivated area. Because of its importance, the study is based on wheat producing farms.

Two main tillage systems are practiced in Kimball County. These are black fallow and stubble mulch. A third not so widely practiced system is minimum till. Fallow efficiency for moisture and soil conservation and yield per acre varies among tillage systems (Fenster, and Peterson(14)). This study is limited to the black fallow system of farming. The inclusion of other tillage systems requires no methodological changes, only different cultivation practice assumptions.

The farming operation for the black fallow system is divided into three preharvest operations: primary tillage, secondary tillage, and grain drilling. Primary tillage is undertaken during the spring. The most common implements used are the one-way disk and moldboard plow. For best weed control, primary tillage has to be completed by mid-May. Time available for primary tillage will depend on assumed earliest tillage date which is in turn determined by the soil thaw date.

For secondary tillage a chisel plow or field cultivator can be used to control weed growth. For seedbed preparation a field cultivator or rod weeder can be used. There are about 15 weeks available for secondary tillage (mid-May to September 1). For optimum wheat yield, grain drilling has to be completed between the first and fourteenth of September (Neild, 1968(31)).

It has been assumed that harvesting is custom operated. Whereas this assumption may be valid for the relatively small farm sizes, it is not so tenable for the large scale farms. The case farms in this study range from 1,000 to 3,500 harvested acres in 250-acre increments.

It has also been assumed that labor is not constraining. The amount of labor employed in production is determined by the number of power units (tractors) that the farm operator will use. The quality of labor is invariant with farm size; hence, the wage rate per hour is equal for all employees. It is assumed that there are 12 working hours in a work day.

WEATHER MODEL

Based on 81 years of daily temperature and precipitation data from the Kimball weather station, a weather model was used to predict the earliest tillage week and the number of working days in a week that field operations were permissible.

The earliest tillage week was determined by the soil thaw date. A soil temperature model (Neild, 1971)(37) was used to predict soil temperature:

$$\text{1)} \quad \begin{aligned} Y &= 19.15 + 0.31X + 1.78X_2 \\ S\,E &= 3.31 \\ R_2 &= 0.92 \end{aligned}$$

Where

Y = weekly average soil temperature 8 inches deep in °F,
X_1 = weekly main air temperature in °F, and
X_2 = climatological week number.

It was assumed that tillage can begin when the soil temperature is 40°F.

The earliest tillage week at 90, 80, 70, and 60 percent probability levels was calculated using the mean and standard deviation of the estimated earliest tillage week, and the value from the normal table for the specified probability level. An implicit assumption made was that the frequen-

Table 1. Workdays per week.

Climatological Week no.[a]	Completion probability level				Farm operation
	90%	80%	70%	60%	
4	---	---	---	6.0	
5	4.9	5.5	5.7	5.8	
6	4.6	5.2	5.5	5.6	
7	4.5	5.2	5.4	5.6	Disking
8	4.3	5.0	5.3	5.5	
9	4.1	4.9	5.1	5.3	
10	3.6	4.4	4.8	5.0	Plowing
11	3.2	4.1	4.5	4.7	
12	2.9	3.8	4.2	4.5	
13	3.0	3.9	4.3	4.6	
14	2.6	3.7	4.0	4.3	
15	2.4	3.5	3.9	4.2	
16	2.2	3.3	3.7	4.0	Chisel
17	2.6	3.6	4.0	4.3	plowing
18	3.4	4.2	4.5	4.8	
19	3.7	4.5	4.8	5.0	
20	3.1	4.0	4.3	4.6	
21	2.7	3.7	4.0	4.3	
22	2.9	3.8	4.2	4.5	Field
23	3.4	4.3	4.6	4.9	cultivation
24	3.6	4.4	4.8	5.0	
25	4.1	4.8	5.1	5.3	
26	4.5	5.2	5.4	5.6	
27	4.5	5.2	5.4	5.6	Grain
28	4.5	5.2	5.4	5.6	drilling

[a] Note: The first climatological week begins the first of March.

cy distribution of the earliest tillage week is normal. The predicted earliest tillage weeks are presented in Table 1.

For the prediction of working days in a week, a working day is defined as one with less than .10 inches of precipitation on the day in question, less than .25 inches the day before and less than .50 for the previous two days (Pfeiffer and Peterson(34)). The search for tillage days is limited to weeks after the earliest tillage week. Soil temperature is, therefore, neglected as a factor that determines a work day. This process is assumed to describe average conditions although it is obvious that working days vary depending upon conditions such as cover, slope, texture, etc. Also, some inaccuracy occurs because of definition. Should it rain in the afternoon, an entire day is assumed unavailable for field operations. Hence, the estimates are underestimates of true work days. Partially balancing this effect is the assumption that a long period of mist or rainfall totalling less than .1 inch does not impede field operations.

The process of predicting the number of working days involves counting the number of working days in week n (for n = 1...52) over the 81 years of data and calculating the mean μ_n and standard deviation σ_n. Assuming a normal distribution, the number of working days Y for week n at the desired probability level is given by:

$$Z = \frac{Y_n - \mu_n}{\sigma_n} \quad (2)$$

Where

Z = standard normal variable whose value is predetermined by the desired probability level,

μ_n = average number of working days for week n, and

σ_n = standard deviation of working days for the n^{th} week.

The above process is repeated for all weeks. The estimated number of working days is reported in Table 1.

By assuming that a tractor will run 12 hours a day, working days are converted into tractor hours. Given recommended farm management practices, the earliest tillage date and the number of working days, the number of tractor hours available to perform a particular farm operation is calculated. It was assumed that seven working days were available per week. Assuming six days per week as available for work only reduces the working days by six-sevenths but does not change the basic relationships derived.

MACHINERY SELECTION MODEL

In the selection of machinery combinations, limiting farm operations in terms of power requirement and time available dictate the selection of the power source. In this case, primary tillage (plowing) is the operation that requires the most power (ASAE, D230.3)(1) and grain drilling is the most time limiting operation. After selecting the source of power, other implements are matched to the available tractor.

The tractor and implements are determined in the following set of equations (O'Connell, Rodewald and Folwell(33), and Bowers(5)):

$$TD = \frac{(P)(CF)(375)}{s} \quad (3)$$

Where

TD = total draft (lbs.) the tractor can pull,

P = tractor power take-off (P70) in horsepower,

CF = conversion factor,

375 = a conversion constant, and

s = travel speed in miles/hour.

The power take-off for the tractors in the model is taken from Nebraska Tractor Test Results, 1980(30). The conversion factor converts a tractor's power take-off (PTO) measured on concrete to usable drawbar horse-power given soil conditions. The travel speed is based on recommended farm management practices (Fenster(14)).

4) $$W = \frac{TD}{D}$$

Where

W	=	**implement width,**
TD	=	**total draft from equation 1, and**
D	=	**implement draft/foot of cut.**

The above equation specifies the width of the implement that each tractor in the model can pull. The calculated implement width has to be adjusted downward to the nearest implement width available in the market. The draft of the implement was taken from the Agricultural Engineers Year Book (ASAE EP391):

5) $$Ac = \frac{(W)(FE)(s)}{8.25}$$

Where

Ac	=	**acres per hours,**
W	=	**implement width from equation 2,**
s	=	**travel speed for the operation,**
8.25	=	**a constant that converts miles/hour and feet of width to acres/hour, and**
FE	=	**field efficiency.**

Equation 5 is used to determine the capacity in acres per hour of the implement whose width has been calculated in equation 4. A measure of field efficiency takes care of time lost due to turning; irregular fields, adjusting implements; filling grain drills, etc.; and the inability of the operator to take advantage of the theoretical width of the implement. The field efficiency was taken from the Agricultural Engineers Year Book (ASAE D230.3):

6) $$Ac/H = \frac{Fs}{TH}$$

Where

Ac/H	=	**acres that have to be handled per hour,**
Fs	=	**farm size in acres, and**
TH	=	**tractor hours available for the farm operation from the weather model.**

Equation 6 calculates the number of acres that must be operated per hour to complete the operation within the time available.

7) $$Ac \geq \frac{Ac}{H}$$

Equation 7 states the selection criterion, i.e., select a tractor and implement that has a capacity in acres per hour from equation 5 that is at least equal to required capacity from equation 6. An excess capacity of not more than five percent has been allowed to accommodate situations where equality cannot be achieved due to indivisibility.

Secondary tillage equipment is sized to the selected tractor using the previous set of equations except that for the assumed farm size, the power source would be known. The width of the implement that the tractor can pull is calculated by equation 4 and the implement's capacity is calculated by equation 5. Since secondary tillage has a low draft per foot of width relative to primary tillage, sizing the equipment to the tractor insures that the condition stated in equation 7 holds. The five percent excess capacity limit was not imposed.

In a situation where two or more tractors are required, the selection process is modified slightly. Two or more tractors are required either when total power required for primary tillage is greater than can be generated by the largest tractor in the model or when grain drilling requires more drills than can be hooked to a single tractor.

In the selection of a combination of two tractors, the largest tractor is selected first, and is then combined with the smallest tractor. If this combination does not satisfy capacity requirement (equation 7) the next smallest tractor is combined with the largest. If the capacity generated exceeds that required by more than 5 percent, the second smallest and the second largest tractors are combined. The process is repeated until a combination of tractors is found that generates capacity at least equal to but not exceeding 5 percent of required capacity. The process of selecting more than two tractors is similar to the above though more combinations are involved.

It has been assumed implicitly that the selection of the smallest tractor with adequate capacity to perform all farm operations satisfied simultaneously the least cost criteria. But such an assumption is not valid when two or more tractors are required and are selected only on the basis of capacity. To insure that the selected combination of farm machinery is also the least cost, three combinations were tested. Combination 1 consists of the largest and smallest tractor. Combination 2 consists of intermediate size tractors, i.e., next largest and next smallest, and combination 3 considers tractors of the same size. All three combinations generate the same total amount of horsepower and are matched to moldboard plows and grain drills that have the same total capacity per acre. As earlier indicated, these two activities are constraining in terms of horsepower requirement and time available.

MACHINERY COST

The prices of tractors and implements used in this study were obtained from an implement dealer. The dealership carries a complete line of agricultural equipment and there is no reason to believe that the prices deviate substantially from other dealers serving the same market areas. The prices were in 1981 dollars.

Machinery costs are divided into ownership and operation costs. Ownership costs are composed of depreciation, interest on investment, property tax, insurance, and housing. Operating costs include labor, maintenance, and fuel and lubrication costs.

Conventional machinery budgeting was used to estimate machinery costs. All machinery costs were placed on a real basis. This involved the annualization of costs at a real discount rate. The rate selected was four percent. For those costs expressed originally in nominal terms, such flow items were discounted by the appropriate nominal discount rate to achieve a present value which was then annualized with a real (four percent) discount rate.

Depreciation and Interest Expense

To determine annual depreciation and interest on invested capital, a capital recovery approach was used for the 10-year period and the assumed real discount rate of four percent.

The salvage value of farm machinery is calculated using the following (Ag Engineers Yearbook - 1977):

- for tractor: percent $= 68(0.920)^n$
- all other equipment: percent $= 60(.0885)^n$

The above determine the remaining farm value of equipment at the end of year n as percent of purchase price.

Sales and Property Tax

A sales tax of four percent of list price has been added to the list price to get the purchase price of machinery. No property tax on farm machinery exists; hence, none has been considered.

Insurance

Though insurance payments depend on the type coverage and may vary between farmers, a rate of \$5.00 per \$1,000 of real machinery value was assumed. The remaining machinery value is calculated by the same formula used to calculate salvage value except that n ranges from one to ten.

Housing

Housing investment costs are assumed to be 10 percent of machinery purchase price. Housing costs do not change over time and also are in real terms.

Repair and Maintenance Costs

Annual repair and maintenance costs are estimated using the formulas (ASAE Agri. Machinery Management Data - D230.3):

For Tractors:

8) $$Amc = 0.12\left[\frac{(n)(h)(100)}{W}\right]^{1.5}\frac{P}{100}$$

Where

n	**=**	**year 1,...10,**
h	**=**	**annual hours of use,**
W	**=**	**estimated wear-out life in hours = 1200 hours, and**
P	**=**	**purchase price.**

For grain drills

9) $$Amc = 0.159\left[\frac{(n)(h)(100)}{W}\right]^{1.4}\frac{P}{100}$$

Where

W = 1200 hours.

For other equipment

10) $$Amc = 0.301\left[\frac{(n)(h)(100)}{W}\right]^{1.3}\frac{P}{100}$$

Where

W = 2500 hours.

The above equations give total accumulated repair and maintenance costs. Subtracting the accumulated cost for year n-1 from the total accumulated cost for year n, gives the annual repair and maintenance cost for year n.

Fuel Costs

Fuel cost estimates are based on fuel consumption rates as given by the Nebraska tractor test results:

11) **Fuel costs = number of tractor hours X rate of consumption/hour**

X price/gallon

A price of $1.10 per gallon for diesel fuel has been assumed. For lack of basis to estimate travel time, the fuel cost estimates do not include traveling expenses.

To the extent that the rate of fuel consumption on test ground is less than on tilled soil, the estimates understate actual *fuel costs. Since that* underestimate of fuel costs is uniform over all farm sizes, the results derived from the analysis are valid.

Oil and Lubricants

Oil and lubricants costs are estimated at 15 percent of fuel costs.

Wages

The number of labor hours for the production period are estimated based on tractor hours. Fifteen percent of tractor hours have been added to take care of travel time to and from the field, to prepare and service machines, and for rest periods. A wage rate of $5.00 per hour has been assumed.

Results

The number of working days per week as predicted by the weather model are presented in Table 1. The weeks have been divided into five blocks for each farm operation. The predicted earliest tillage week for the 90, 80, and 70 percent completion probability level is the fifth week. For the 60 percent probability it is the fourth week. The number of working days in a week increases as the completion probability level declines. These results are consistent with expectations, i.e., a risk neutral individual will count on their being more working days relative to a risk averse farmer.

Table 1 shows that the number of working days decrease and then increase over the 28 weeks. This is consistent with the rainfall season in western Nebraska. The probability of rain increases and then decreases over the 28 weeks (Colville and Myers(8)).

Though the number of working days was considered an integer quantity, the process of deriving the average number of working days gives the impression that it is a continuous variable. Because rounding to the nearest day would have, in many cases, resulted in the same number of working days for 90 and 80, or 80 and 70, or 70 and 60 percent probability levels, the number of weekly working days was not rounded to the nearest whole number (Table 1).

The least cost machinery selected at the 90, 80, and 60 percent completion probability levels are shown in Tables 2, 3, and 4. The total machinery costs per acre are in Table 5 and are graphed respectively on Fig. 1, 2, and 3. Fig. 1, 2, and 3 were fitted with a cubic function excepting "outlyers" which were 2,750 acres for Fig. 1, 2,250 and 3,250 acres for Fig. 2 and 3,000 acres for Fig. 3. These "outlyers" were caused by machinery indivisibilities resulting from assumptions of the study. The functions for Fig. 1, 2, and 3 are:

Figure 1. Cost per acre at 90 percent completion probability level.

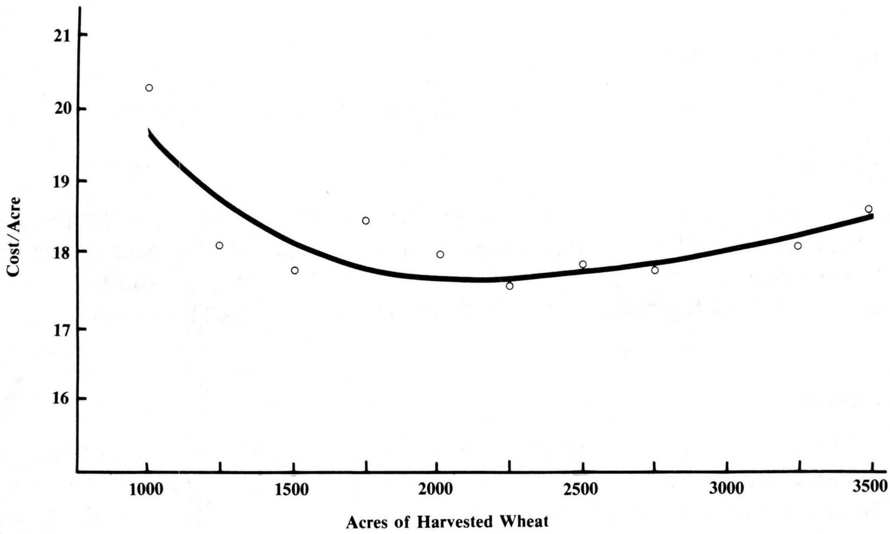

Figure 2. Cost per acre at 80 percent completion probability level.

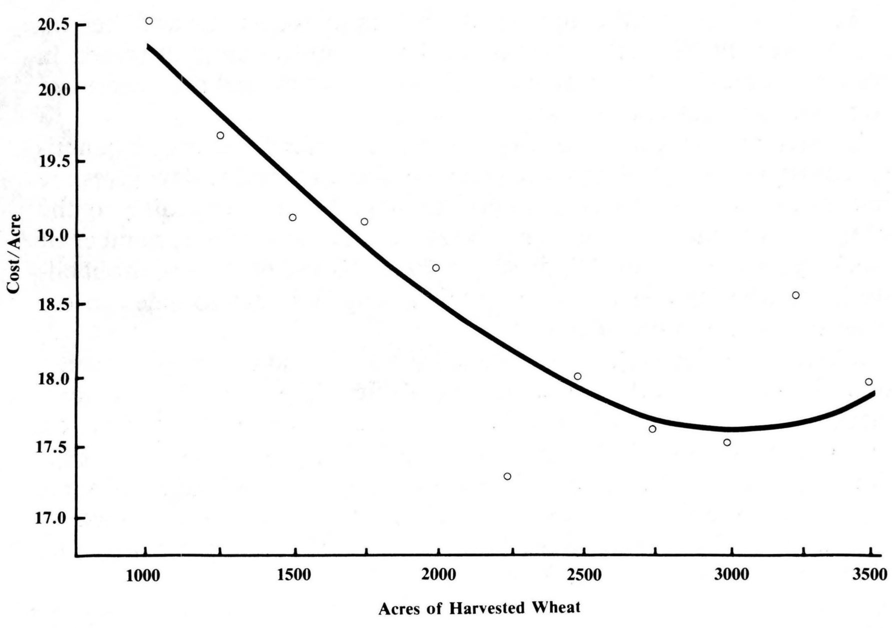

Figure 3. Cost per acre at 60 percent completion probability level.

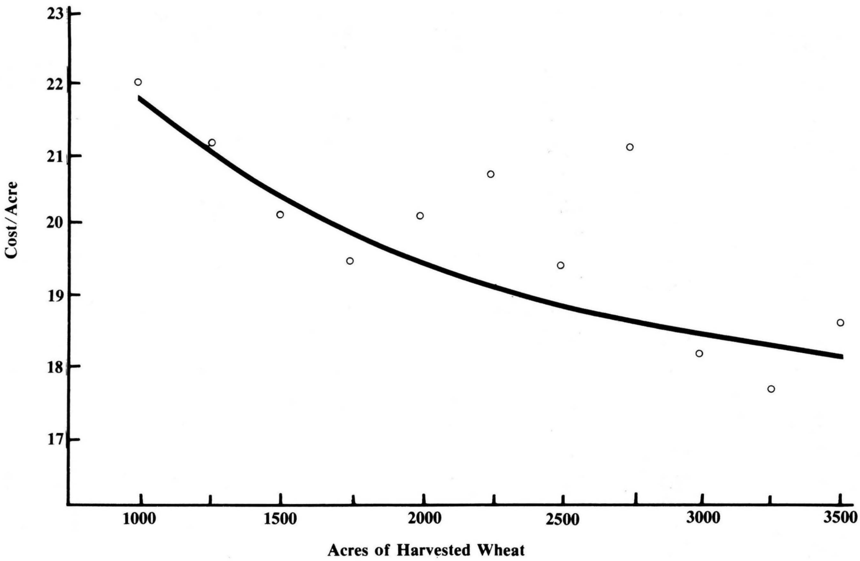

Fig. 1. $y(\text{cost/acre}) = 26.2552 - 0.56215A + 0.01383A^2 - 0.00013A^3$ $(r^2 = .8923)$

Fig. 2. $y(\text{cost/acre}) = 21.7288 - 0.08322A - 0.00778A^2 + 0.00020A^3$ $(r^2 = .9710)$

Fig. 3. $y(\text{cost/acre}) = 27.1061 - 1.09677A + 0.04073A^2 - 0.00047A^3$ $(r^2 = .7025)$

Where a is harvested wheat acres divided by 100

An examination of the machinery selected at each probability level (Tables 2, 3, and 4) indicates that the machinery complements selected for a given farm level at 90 percent are larger than those selected at 80 percent which, in turn, are larger than those selected at 60 percent. The difference in implement size between 80 percent and 60 percent is notable. Table 5 shows that in general the cost per acre declines as the completion probability decreases. It should be pointed out that acreage refers to harvested wheat acreage.

Conventionally, risk and returns are positively correlated. Similarly, risk and costs are expected to be and are negatively correlated.

To observe technical economies of size, either fixed costs per acre or variable costs per acre have to decline as farm size increases. Fixed costs will decline if the per acre purchase price of the selected equipment declines as the farm size increases. The per acre purchase price will decline if the price per unit capacity of the equipment does not rise as the

Table 2. Least cost farm machinery at 90 percent completion probability level.

Farm size acres	Tractor -Hp-	Disk -Ft-	Moldboard -Bottom-	Chisel -Ft-	Field cultivator -Ft-	Grain drill -Ft-
1000	150	25.7	7	19	29.5	39
1250	170	30.1	8	21	34.5	46
1500	130	22.9	6	16	26.5	30
	85	—	4	—		30
1750	130	22.9	6	16	26.5	32
	130	22.9	6	—		32
2000	150	25.7	7	19	29.5	39
	150	25.7	6	—		39
2250	170	30.1	8	21	34.5	42
	170	30.1	7	—		42
2500	170	30.1	8	21	34.5	46
	170	30.1	8	—		46
2750	190	32.1	9	23	38.5	52
	190	32.1	9	—		52
3000	150	25.7	7	19	29.5	39
	150	25.7	7	8		39
	150	—	6	—		39
3250	150	25.7	7	19	29.5	42
	150	25.7	7	8		42
	150	—	7	—		42
3500	170	30.1	8	21	34.5	44
	170	30.1	8	8		44
	170	—	7	—		44

equipment capacity increases. The purchase price of equipment depends only in part on its size. The features of the equipment and pricing strategy adopted by the dealer are also important in determining price.

90 Percent Probability

An examination of Fig. 1, Table 5, and Table 6, cost per acre at 90 percent level, indicates that in general the per unit machinery cost declines as farm size increases. The per unit cost declines from $22.08 per acre for 1,000 acres of harvested wheat to $17.63 per acre for 3,250 acres. Though the per unit cost of 3,500 acres is larger than that of 3,250 acres, it cannot be concluded on the basis of that one point that diseconomies of size are exhibited.

Table 5 shows that 2,000- and 2,250-acre farms have higher per acre costs than 1,750-acre farms. Similarly, a 2,750-acre farm has a higher per acre cost than a 2,500-acre farm. This can be explained by examining the variable and fixed costs of the 2,000, 2,250, and 2,750-acre farms on Table 6. The fixed costs per acre of the 2,000-acre farm are *higher than* those of the 1,750-acre farm. Because maintenance costs of the equip-

Table 3. Least cost farm machinery at 80 percent completion probability level.

Farm size acres	Tractor -Hp-	Disk -Ft-	Moldboard -Bottom-	Chisel -Ft-	Field cultivator -Ft-	Grain drill -Ft-
1000	130	22.9	6	16	26.5	36
1250	150	25.7	7	19	29.5	39
1500	170	30.1	8	21	34.5	50
1750	130	22.9	6	16	26.5	30
	85	—	4	—	—	30
2000	130	22.9	6	16	26.5	36
	130	22.9	5	—	—	36
2250	130	22.9	6	16	26.5	36
	130	22.9	6	—	—	36
2500	150	25.7	7	19	29.5	42
	150	25.7	6	—	—	42
2750	170	30.1	8	21	29.5	44
	170	30.1	7	—	—	44
3000	170	30.1	8	21	34.5	50
	170	30.1	8	—	—	50
3250	228	40.6	11	23	38.5	52
	150	25.7	7	—	—	52
3500	150	25.7	7	19	29.5	39
	150	25.7	6	—	—	39
	150	—	6	—	—	39

Table 4. Least cost farm machinery at 60 percent completion probability level.

Farm size acres	Tractor -Hp-	Disk -Ft-	Moldboard -Bottom-	Chisel -Ft-	Field cultivator -Ft-	Grain drill -Ft-
1000	110	18.6	5	14	22.5	30
1250	130	22.9	6	16	26.5	36
1500	150	25.7	7	19	29.5	44
1750	170	30.1	8	21	34.5	52
2000	130	22.9	6	16	26.5	30
	85	—	4	—	—	30
2250	130	22.0	6	16	26.5	36
	130	—	5	—	—	36
2500	170	30.1	8	21	34.5	42
	85	—	4	—	—	36
2750	150	25.7	7	19	29.5	42
	150	—	6	—	—	42
3000	150	25.7	7	19	29.5	44
	150	—	7	—	—	44
3250	170	30.1	8	21	34.5	50
	170	—	8	—	—	50
3500	190	32.1	9	23	38.5	52
	190	—	8	—	—	52

Table 5. Total machinery cost per acre of harvested wheat.

Farm size harvested wheat	Completion probability level		
	90%	80%	60%
acres		Dollars	
1000	22.08	20.49	20.23
1250	21.14	19.69	18.11
1500	20.15	19.14	17.79
1750	19.47	19.11	18.48
2000	20.13	18.77	17.99
2250	20.72	17.34	17.56
2500	19.39	18.01	17.83
2750	21.09	17.65	17.77
3000	18.13	17.53	16.24
3250	17.63	18.59	18.05
3500	18.58	17.98	18.57

Table 6. Total machinery cost per acre of harvest wheat at 90 percent completion probability level.

Farm size acres	Variable cost	Fixed cost	Total cost
1000	10.03	12.04	22.08
1250	9.49	11.48	21.14
1500	10.63	9.52	20.15
1750	9.03	10.44	19.47
2000	9.30	10.70	20.00
2250	9.44	11.59	21.03
2500	8.86	10.71	19.57
2750	9.45	11.60	21.05
3000	8.08	10.05	18.13
3250	8.27	9.36	17.63
3500	8.36	10.22	18.58

ment are calculated as percent of purchase price, variable costs are influenced by changes in fixed costs. Hence, on Table 6, the variable costs for the 2,000-acre farm are also higher than those for the 1,750-acre farms. It can be seen that the 2,000-acre farm has higher fixed costs per acre than the 1,750-acre farm because of a higher purchase price of selected machinery from Table 9, column 8. The table shows that the higher per acre purchase price for the 2,000-acre farm is due to the purchase price of grain drills.

The higher average total cost of the 2,250-acre and 2,750-acre farms

Table 7. Total machinery cost per acre at 80 percent completion probability level.

Farm size acres	Variable cost	Fixed cost	Total cost
1000	10.59	9.90	20.49
1250	10.01	9.68	19.69
1500	9.59	9.55	19.14
1750	10.95	8.16	19.11
2000	9.69	9.08	18.77
2250	9.07	8.27	17.34
2500	9.23	8.78	18.01
2750	8.14	9.51	17.65
3000	8.93	8.60	17.53
3250	9.17	9.42	18.59
3500	9.53	8.45	17.98

Table 8. Machinery cost per acre at 60 percent completion probability level.

Farm size acres	Variable cost	Fixed cost	Total cost
1000	11.33	8.90	20.23
1250	10.09	8.02	18.11
1500	9.71	8.08	17.79
1750	9.76	8.72	18.48
2000	10.85	7.14	17.99
2250	10.09	7.47	17.56
2500	10.69	7.26	17.95
2750	10.43	7.34	17.77
3000	8.96	7.50	16.46
3250	10.35	7.70	18.05
3500	10.70	7.87	18.57

can also be explained by higher average fixed cost resulting from higher purchase prices of the machinery selected. Table 9 shows that for the 2,250-acre farm, the higher fixed cost per acre is due to the higher per acre purchase price of the selected tractor and disk, and for the 2,750-acre farm, the higher fixed cost is due to the purchase price of the selected tractor, moldboard plow and grain drill.

This analysis indicates that given the assumed wage rate and fuel cost, fixed costs are more critical than variable costs in determining machinery cost per acre. It is conceivable, however, that higher wage rates or fuel prices would make variable costs more important in determining machinery cost per acre.

Table 9. **Purchase price in dollars per acre of the machinery selected at 90 percent completion probability level.**

Farm size acres	Tractor	Disk	Moldboard plow	Chisel plow	Field cultivator	Grain drill	Total
1000	47.80	14.98	8.70	7.80	10.75	16.97	107.00
1250	45.68	18.72	7.60	6.37	9.58	15.51	103.46
1500	44.13	9.16	9.49	2.05	6.80	13.47	85.10
1750	49.03	15.70	9.04	1.75	5.83	12.00	93.35
2000	47.80	14.98	8.31	3.90	5.37	16.97	97.33
2250	50.76	20.80	8.08	3.54	5.32	15.47	103.97
2500	45.68	18.72	7.60	3.18	4.79	15.51	95.48
2750	50.98	18.15	9.78	3.02	4.51	18.39	104.83
3000	47.80	9.99	8.44	3.15	3.58	16.97	89.93
3250	44.12	9.23	8.03	2.91	3.31	16.07	83.67
3500	48.94	13.37	9.23	2.75	3.42	15.13	92.84

Table 10. **Purchase price per acre of the machinery selected at 80 percent completion probability level.**

Farm size acres	Tractor	Disk	Moldboard plow	Chisel plow	Field cultivator	Grain drill	Total
	dollars						
1000	42.90	13.74	7.91	3.07	10.20	11.50	89.32
1250	38.24	11.98	6.96	6.24	8.60	13.58	85.60
1500	38.07	15.60	6.33	5.31	7.98	15.70	88.99
1750	37.83	7.85	8.13	1.75	5.83	11.54	72.93
2000	42.90	13.74	7.51	1.54	5.10	11.50	82.29
2250	38.13	12.21	7.03	1.36	4.53	10.22	73.48
2500	38.24	11.98	6.64	3.12	4.30	13.93	78.21
2750	41.53	17.02	6.62	2.89	3.91	12.84	84.81
3000	38.07	15.60	6.33	2.65	3.99	15.70	82.34
3250	41.91	14.53	7.30	2.56	3.81	15.56	85.67
3500	40.97	8.56	7.01	2.23	3.07	14.55	76.39

80 Percent Probability

Fig. 2, Table 5, and Table 7 show machinery cost per acre at the 80 percent completion probability level. Except for 2,250 acres, economies of size are clearly exhibited through 3,000 acres although the declines are not as great as for 90 percent completion. Results indicate that the cost per acre rises for farms larger than 3,000 acres. Table 7 shows that the higher total per acre cost for the 3,250- and 3,500-acre farms can be at-

Table 11. **Purchase price per acre of the machinery selected at 60 percent completion probability level.**

Farm size acres	Tractor	Disk	Moldboard plow	Chisel plow	Field cultivator	Grain drill	Total
	Dollars						
1000	38.80	10.71	7.11	2.91	9.66	10.10	72.29
1250	34.32	10.99	6.33	2.46	8.16	9.20	71.46
1500	31.87	9.99	5.80	5.20	7.17	11.77	71.80
1750	32.63	13.37	5.43	4.55	6.84	14.45	77.27
2000	33.10	6.87	7.12	1.54	5.10	10.10	63.83
2250	38.13	6.11	6.68	1.36	4.53	10.22	67.03
2500	32.16	9.36	6.63	3.18	4.79	11.56	67.68
2750	34.76	5.45	6.04	2.84	3.91	12.66	65.66
3000	31.87	4.99	5.80	2.60	3.58	11.77	60.61
3250	35.14	7.20	5.85	2.45	3.68	14.49	68.61
3500	40.06	7.13	6.55	2.38	3.54	14.45	74.11

Table 12. Machinery cost per acre at 90 percent completion probability level.

Farm size acres	Combination 1	Combination 2	Combination 3	Least cost combination
	Dollars			
1000	22.08	NA[a]	NA	
1250	21.14	NA	NA	
1500	21.45	20.15	21.00	2
1750	22.67	20.50	19.47	3
2000	21.36	20.46	20.00	3
2250	21.82	20.79	21.03	3
2500	21.28	19.87	19.57	3
2750	21.52	20.43	21.05	3
3000	20.67	18.20	18.13	3
3250	19.98	19.33	17.63	3
3500	19.85	19.49	18.58	3

[a]NA = Not applicable. Only one tractor is required.

tributed to their higher variable costs per acre. Though the cost per acre has risen for 3,250-and 3,500-acre farms, it cannot be concluded on the basis of two points that diseconomies of size set in at those farm sizes.

The lower than expected total cost per acre of the 2,250-acre farm is explained by the lower purchase price and therefore lower per acre fixed cost of the machinery selected. Due to machinery indivisibility, the 2,000- and 2,250-acre farms have the same least cost machinery combina-

Table 13. Machinery cost per acre at 80 percent completion probability level.

Farm size acres	Combination 1	2	3	Least cost combination
	----------	Dollars	----------	
1000	20.49	NA[a/]	NA	
1250	19.69	NA	NA	
1500	19.14	NA	NA	
1750	20.19	19.11	19.76	2
2000	20.33	19.01	18.77	3
2250	20.71	18.90	17.34	3
2500	19.36	18.15	18.01	3
2750	20.11	19.04	17.65	3
3000	19.91	18.34	17.53	3
3250	19.32	18.59	19.58	2
3500	18.32	17.98	18.37	2

[a/]NA = Not applicable. Only one tractor is required.

Table 14. Machinery cost per acre at 60 percent completion probability level.

Farm size acres	Combination 1	2	3	Least cost combination
	----------	Dollars	----------	
1000	20.23	NA[a/]	NA	
1250	18.11	NA	NA	
1500	17.79	NA	NA	
1750	18.48	NA	NA	
2000	18.91	17.99	19.04	2
2250	19.20	18.04	17.56	3
2500	19.34	17.83	17.95	2
2750	18.74	18.05	17.77	3
3000	18.28	18.78	16.46	3
3250	19.10	18.35	18.05	3
3500	18.93	18.57	19.25	2

[a/]NA = Not applicable. Only one tractor is required.

tion; hence, the fixed costs per acre of the latter will be lower than those of the former farm.

60 Percent Probability

An examination of Fig. 3, Table 5, and Table 8 indicates that the machinery cost per acre at 60 percent completion probability level declines as the farm level increases at 2,750 acres. As with 80 percent the cost declines are not as dramatic as 90 percent completion. Cost increases as farm size increases beyond 2,750 acres. The relatively lower per acre cost of 2,750-acre farms can be explained in terms of machinery purchase price.

Machinery Combinations

Three alternative combinations[2] were tested for each farm size that required two or more tractors. The per acre cost for the three alternative combinations at 90, 80 and 60 percent completion probability levels are presented in Tables 9, 10, and 11. Tables 12, 13, and 14 indicate that combinations 2 or 3 are least cost alternatives. Remember that labor is assumed unrestrictive. Hence, labor is assumed available for two machinery units. The same results may not occur where limits on labor exist. In such cases, one larger power unit may be more efficient than combinations of two units or more of equal size. For this setting, the rather consistent choice of combination 3 (equal size tractors and equipment) shows that a combination of medium sized machinery has advantages over larger farm machinery.

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[2]Combination 1 consisted of the largest and smallest tractor and equipment; combination 2 had the next largest and next smallest tractor and equipment; and combination 3 had equal size tractors and equipment.

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