Farm Size and Cost Relationships in Relation to Recent Machine Technology

An Analysis of Potential Farm Change
By Static and Game Theoretic Methods

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RESEARCH BULLETIN 504 MAY 1962 AMES, IOWA

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SUMMARY

This study includes estimates of the relation of more recent machine technology to per-unit costs of crop production for farms of different sizes. The types of new machine technology of particular interest include large-capacity equipment such as 4- and 6-row corn planting and cultivating equipment and picker-sheller harvesting machines. A hypothesis generally held by persons concerned with agriculture is that these large-capacity machines, with high fixed costs which must be spread over more acres, stand to cause an important increase in farm size.

This study is based on data for the Carrington-Clyde soils in northeast Iowa and the Ida-Monona soils in western Iowa. Cost functions are estimated for farms of different sizes or acreages by budgeting procedures. More specifically, cost curves are derived as a function of acreage per farm. Losses in crop production resulting from untimely field operations are considered as costs for different acreages and are related to particular machine combinations. Parametric linear programming is used to permit analyses of livestock optimum enterprises and to consider the effect of subjective discounting of returns on size considerations. For decision making under risk and uncertainty, game theory models were employed to incorporate consideration of weather variations on optimal machinery-land or farm-size relationships.

The results, assuming average weather and current cropping methods, indicate that cost advantages associated with 6-row cropping equipment and field corn shellers are small relative to more standard sizes and types of machines. An expansion of farm size from 200 crop-acres operated with 2-row equipment to 400 crop-acres operated with 4-row equipment is estimated to reduce costs by 6 cents per $1 of crop product produced. Expansion to 600 crop-acres operated by 6-row equipment would further reduce costs by only 1.5 cents per dollar of crop product.

Under a farm organization including cash cropping and current rotations, minimum per-unit production costs (per dollar of product) are attained in the range of 600 to 680 crop-acres. However, the reduction in per-unit costs is small as acreage is extended from 400 to 800 crop-acres. With a continuous-corn rotation, minimum per-unit costs are attained at a size of 320 crop-acres.

The static budgeting analysis indicates that, while small cost reductions are possible as machinery investment is increased and as crop acreage is expanded beyond 320 acres, these savings alone probably are not great enough to "force" much larger farms. The greatest reduction in cost per unit of product is attained at approximately 320 acres. Up to this point, the high fixed costs of modern machinery decline rapidly as acreage and output are extended. For example, with fixed costs of $1,000, an expansion in acreage from 10 to 20 lowers fixed cost per acre from $100 to $50. An expansion from 400 acres to 800 acres, however, with fixed costs remaining at $1,000, lowers per-acre fixed cost from $2.50 to $1.25, a reduction of much less absolute importance, even though of the same relative magnitude. Too, cost functions were calculated on the basis of a charge for all labor. On smaller farms, a greater proportion of the labor would be provided by the family at a lower opportunity cost. This is a general type of finding under the static cost analysis of this study. While slight cost reductions can be attained by larger machine combinations and greater acreages, considerations such as capital availability and ability of farmers to withstand risks will be more important than current cost reduction possibilities in bringing about larger farms. Or, the possibilities might be stated otherwise: Just as a farm with 320 crop-acres has no great cost advantages when compared with a larger acreage, large farms also have no particular cost disadvantages when compared with smaller ones which may rely on more unpaid family labor.

A consideration of the yearly weather variation and days suitable for field operations indicated that an analysis based on average weather causes long-run per-unit production costs to be underestimated. Low per-unit costs in favorable weather are outweighed by extreme crop losses in years of unfavorable weather if only average weather is assumed. Hence, optimal machinery investment per acre to meet weather variations is higher than would be necessary if weather were static among years. The use of field corn shellers, found not to be profitable with less than 800 crop-acres when average weather is assumed, is estimated to be profitable on 450 acres when variations in weather are considered in cost and return calculations. These machines may prove profitable even on smaller acreages when decision is based on uncertainty criteria.

Several game theoretic criteria were applied in the examination of optimum farm size under uncertainty. The strategy selected by the Wald maximin criterion, a conservative model, is that which gives maximum expected profits under supposition of the least favorable weather. The specified acreage is 520. The Savage minimax-risk criterion, a strategy which minimizes the maximum risk, specifies a farm size of 560 acres. The Hurwicz pessimism-optimism index specifies different acreages, depending on the particular index, α, chosen. The index, α, is an indication of the degree of optimism (or pessimism) held by the decision maker. With values of 0.4 to 1.0 assigned to α, the optimum size is 520 acres. But with minimum pessimism and a value of zero assigned to α, the optimum acreage is 720 with investment in machinery accordingly.

When these same game theoretic techniques were applied to decision making under uncertainty, it was found that a larger machine investment proved optimal than was true when analysis was based on static budgeting approaches. For example, the static budget approach specified only 2-row machinery for a 200-acre farm. When game models were applied under assumptions of weather variation and uncertainty, however, 4-row machinery proved to be optimal.

Farm Size and Cost Relationships in Relation to Recent Machine Technology[1]

An Analysis of Potential Farm Change by Static and Game Theoretic Methods

by Earl O. Heady and Ronald D. Krenz

Farmers operate in a dynamic environment which is characterized by continual change and adjustment. One of the problems of change which confronts farmers is that of determining the proper combination of resources to use in production. Machines of large capacity, such as 6-row field equipment and picker-shellers for corn, are now on the market and are in use on numerous Corn Belt farms. Hence, farmers are faced with the question: "What combination of land, labor and machinery (i.e., what size of farm) is optimum or desirable in this situation?" This study includes analyses to provide quantitative information on the relationship of unit costs of production for farms of different sizes when operated with farm machinery of varying capacities. This information should be useful to farmers making decisions on whether to adopt machine technology such as that represented by 4-row and 6-row corn equipment and field corn shellers. It should provide data indicating sizes of farms which are optimum for machine combinations with varying field capacities, investment costs and possibilities in labor substitution.

In addition, to aid in individual farmer decisions, empirical analyses of the type explained in this study provide information suggestive of the upcoming structure of farming. While the process is slow and gradual, farm size has continuously adjusted to new cost structures and the substitutability of machine capital for labor. This study, designed to indicate acreage ranges over which new machine technology gives lowest unit costs of production, should suggest the minima toward which farm size may trend. There are, of course, other variables which affect both machine and farm sizes. For example, revolutionary changes in farm size did not occur in the shift from horse power to tractors because not all farmers were inclined, or forced, to change their scale of operations. Farmer age, lack of capital and other variables restrained the rate at which these techniques were adopted. The same is likely for other machine techniques now appearing.

OBJECTIVES

The major purpose of this study is to determine per-unit cost relationships associated with various machinery techniques. Unit costs of production are determined for farms of different acreages under more recent machine technology as well as under the types and sizes of crop equipment and power units now in use on the majority of Iowa farms. Comparison is made of cost functions under upcoming and existing machine technology to suggest the cost advantages which may or may not exist between them. The data generated are used to analyze both the acreage which results in lowest per-unit costs of production and the optimum farm size in terms of profit maximization.[2] Use of recent machinery techniques, such as 6-row corn equipment and picker-shellers, requires relatively large farms for profitable crop production. Hence, it is possible that minimum per-unit costs for these newer machines may or may not differ greatly from the minimum per-unit costs possible with more conventional machinery on farms of typical sizes in Iowa, depending on the size of farm on which the machines are employed.

As part of the more general objective of this study, the following are specific objectives in relating machine techniques to cost relationships and farm size:

1. To determine the magnitude of cost economies associated with various machinery techniques.
2. To determine the sizes of farms which allow attainment of minimum per-unit production costs for each of the several sizes of machinery analyzed. (The study also includes determination of farm size necessary to allow attainment of the majority of the cost economies associated with various types of machines.)
3. To compare information on costs and farm size for various soil, rotation and fertilizer situations.
4. To compare residual returns to labor and land for farms operated with various sets of machinery, under various price conditions and for various cropping techniques. (This information is provided to suggest the size of operations necessary to give returns on farm resources comparable with rates of returns for resources employed in nonfarm industries.)
5. To examine the effects of weather variations upon the optimal level of machinery investments and optimal farm size.

The purpose of this study is not that of specifying the size of farm which "ought to exist" in Iowa or the Corn Belt. Neither is it to predict the average size or

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[1] Project 1328, Iowa Agricultural and Home Economics Experiment Station, Center for Agricultural and Economic Adjustment cooperating.

[2] The criterion of optimum farm size used is defined as the size at which the marginal costs incurred with the last acre added are equal to the marginal returns from this last acre. At this acreage, profits are maximized. In the long run, under pure competition and adequate knowledge, this also would be the size of farm with minimum average total costs.

the distribution of sizes which might exist at some future time. Rather, it is to provide general information relating to per-unit production costs when farms of different sizes are operated with different combinations of machines and power units. Cost and related estimates are not made for farms of discrete sizes. Instead, costs are estimated in the manner of cost curves or functions as acreage is increased against given combinations of machinery.

BUDGET TECHNIQUE

This section describes the budget method used in estimating cost relationships for farms organized to produce only cash crops. Cost curves are developed for eight complete sets of farm machinery. Each set includes a slightly different combination of equipment. Together, the various machine combinations cover a wide range of field capacities and investment costs.

The cost curves apply to the soil areas shown in fig. 1. Emphasis in this study is on Carrington-Clyde soils in northeast Iowa. Land in this soil association has a relatively high agronomic rating for corn production. Intensive cropping is possible since the soil is not greatly subject to erosion.

The Ida-Monona area included in the study represents somewhat the opposite extreme. It borders the Missouri River bottoms and includes a belt of hilly land with steep slopes. The erosion hazard is severe on these soils, and the agronomic rating for corn production is considerably below that of the Carrington-Clyde soils. Hence, a greater proportion of the cropland must be kept in meadow, and cash-grain farming is not as suitable as in the Carrington-Clyde area. Cost curves developed for Ida-Monona soils are based on the use of conservation practices necessary to control erosion and to maintain crop yields over the long run.

Cost curves for the various sets of machinery on Carrington-Clyde soils are developed under three cropping systems. These cropping systems include the current cropping system as indicated from the 1954 census, a 5-year rotation and a continuous-corn system. A combination of two rotations is used in budgeting cost curves for Ida-Monona soils. The current cropping system places approximately 51 percent of the land in row crops; the 5-year rotation calls for 60 percent in row crops, and the continuous-corn program calls for placing all land in row crops. Table 1 outlines the cropping systems, fertility levels and machinery combinations for which cost curves are developed.

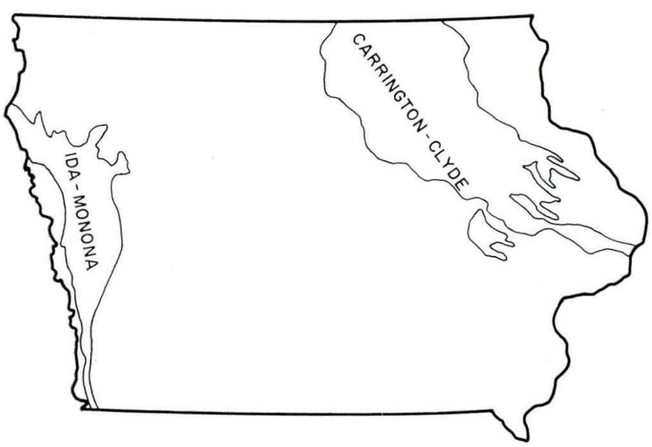

Fig. 1. Soil association areas of Iowa considered in this study.

Table 1. Combinations of soil type, cropping systems and sets of machinery for which cost curves are developed in this study.

Carrington-Clyde Soil Association

A. Current cropping system[a]
   1. Eight sets of machinery
   2. Two fertilizer levels

B. 5-year rotation[b]
   1. Eight sets of machinery
   2. Two fertilizer levels

C. Continuous corn
   1. Three sets of machinery
   2. One fertilizer level

Ida-Monona Soil Association

A. Combination of CCOM[c] and CCOMM[d]
   1. Three sets of machinery
   2. One fertilizer level

[a] Based on U. S. Census of Agriculture: 1954. 1,part 9. 1956.
[b] Includes 2 years of corn, 1 year of corn or soybeans, 1 year of oats and 1 year of meadow.
[c] Corn-corn-oats-meadow rotation assumed for slopes of 0-13 percent.
[d] Rotation assumed for slopes of 14 percent or more.

Total cost curves are developed for each set of machinery under the various cropping systems. Expansion of acreage for a given set of machinery requires that some field operations be performed at unfavorable times. If acreage is increased sufficiently, crops must be planted, tended and harvested so late that yields are depressed. Such "untimeliness" losses are included in the calculation of cost per unit of production for the various acreage ranges. Total costs include annual fixed machinery costs, variable machinery inputs and costs of other variable inputs. A description of these costs and a description of the method of estimating untimeliness losses follow.

Per-Unit Cost Curves

Per-unit cost curves are determined for eight sets of machinery with current cropping methods and the 5-year rotation on Carrington-Clyde soils. Each set of machinery has a somewhat different capacity for field crop operations. All machinery combinations assume the same hay harvesting operations, with the exception that baling is custom hired for the smallest set of machinery. Three of the machine combinations have one tractor and are designed for operation by one man. The remaining five sets include two tractors. For the two-tractor machinery combinations, hourly labor is hired to operate the second tractor. The key to these machine combinations is given in table 2. The numbers and

Table 2. Legend and machine combinations used.

Key	No. of tractors	Tractor capacity	Planting & cultivating equipment	Corn harvesting equipment
1. 2-plow, 2-row	1	2-plow	2-row	1-row pull type
2. 3-plow, 4-row	1	3-plow	4-row	2-row mounted
3. 4-plow, 4-row	1	4-plow	4-row	2-row mounted
4. 3- & 3-plow, 4-row	2	3-plow	4-row	2-row mounted
5. 3- & 4-plow, 4-row	2	4-plow	4-row	2-row mounted
6. 3- & 4-plow, 6-row	2	4-plow	6-row	2-row mounted
7. 3- & 4-plow, combine-picker	2	4-plow	4-row	Combine-picker
8. 3- & 4-plow, picker-sheller	2	4-plow	4-row	Picker-sheller

references at the left are those used later to identify the several machine combinations. Information in other columns refers to the number of tractors included in each set, the plow capacity of the tractors, the size of machinery and the harvesting equipment.

Cost curves also are developed with three machinery combinations for a continuous-corn cropping program on Carrington-Clyde soils. These three sets of machinery differ from the eight sets previously discussed since machinery is only required for corn operations. Three sets of machinery are also designed for use on Ida-Monona soils. These combinations differ from any combinations designed for Carrington-Clyde soils since some special machines are required for erosion control.

Costs of Inputs

For the calculations which follow, input costs are divided into **annual** fixed costs, which vary with the number of crop-acres operated, and variable costs, which vary with the amount of product produced per acre. The curves so developed are short-run cost curves where machinery is the fixed resource or restraint. Fixed costs which do not vary with acreage or output include annual fixed machinery expenses and depreciation, as well as the overhead labor required for machine maintenance. Variable costs include those for machinery, fuel, land taxes, labor, cropping expenses (such as seed and fertilizer) and others which vary with the numbers of acres operated and the yield levels attained. Variable costs per unit of output, including transportation and corn drying, are not constant per acre since untimeliness of operations causes yields to decrease as acreage is expanded for a given set of machinery.

FIXED COSTS

Fixed machinery costs include interest, taxes, insurance, housing and depreciation. An interest charge of 7 percent on machine investments is used in this study since it is the typical rate on loans for machinery purchases. The 7-percent charge is assessed against the "average value" of all machinery. The average value is defined as equal to half of the sum of the purchase price, less 10 percent of the purchase price (trade-in value). An annual charge, varying by type of equipment but averaging approximately 2 percent of the original purchase price of machinery, is made for housing, taxes and insurance.

Depreciation charges include fixed and variable components. The fixed component is based on obsolescence and "normal annual depreciation" and is obtained by dividing 90 percent of the purchase price by the estimated maximum years of service. Dividing 90 percent of the purchase price by maximum units of service gives the depreciation charge per service unit.

VARIABLE COSTS

Variable costs relative to the number of acres operated include property tax on land, variable machinery costs, labor costs and cropping costs. Property taxes are $2.01 per crop-acre in the Carrington-Clyde area and $2.95 per crop-acre in the Ida-Monona area.[3]

[3] Iowa State Tax Commission. Annual report, 1956-57.

Variable machinery costs include fuel, repairs and extra depreciation charges for above-normal annual use. Annual charges for repairs and service are determined as percentages of the machine investment.

Variable labor costs include labor required for maintenance and repair in addition to the actual field operations. Variable maintenance requirements are based on estimates prepared by Hinton.[4] Labor required for actual field operations is equal to the number of tractor hours required. All labor, both maintenance and field operations, for operator or hired labor, is charged at the rate of $1 per hour.

Variable cropping costs include seed, fertilizer and any custom charges required. Variable handling costs include costs of transporting products to market and drying or shelling corn. The transport cost is estimated at 3 cents per bushel on all grain crops and 3 cents per bale of hay or straw. For machinery combinations which include field shelling of corn, the drying cost is 10 cents per bushel. With conventional corn picking, drying costs are replaced by shelling costs of 3 cents per bushel. All per-unit costs are assessed to the production remaining after subtracting losses resulting from untimely field operations.

Prices and Yields

The per-unit cost curves formulated in this study measure costs per dollar value of crop product, instead of costs per physical unit of product since several crops or products are involved. Hence, prices are needed to determine total value of output. Three sets of prices are used in estimating sizes of farms which are optimum in terms of profit maximization. The three price levels, averages of recent periods, are for 1953-57, 1956-58 and for 1958. Prices during the 1953-57 period average the highest of the three levels chosen. In this period, corn price averaged $1.30 per bushel. During the 1956-58 period, the corn price averaged $1.13 per bushel. The 1958 average prices are lowest of the three levels with corn price at 97 cents per bushel. Average prices for other crop products for each period are provided in the appendix.

Yields assumed for the current cropping program on Carrington-Clyde soils are the average of 1953-57 actual yields in the area. Yields and fertilizer requirements for other rotations on Carrington-Clyde soils were provided by agronomists.[5]

Timeliness of Operations

The only factor considered in this study which can result in rising per-unit costs and thus limit the expansion of farm size is the untimeliness element of field operations. No other factors are included which result in increasing costs per acre with the expansion of farm size. Other factors which, in practice, will limit farm size (such as limitations of management, land supplies or labor supplies), are omitted from this analysis because these items cannot be readily measured.

Estimates of total production include losses in

[4] R. A. Hinton Farm management manual. Ill. Agr. Ext. Serv. Bul. AE-3349. 1959.

[5] See footnotes to Appendix table A-6 for details on sources of data.

yields because of untimely operations which may arise during the following operations: (1) corn planting, cultivating and harvesting, (2) oats planting and harvesting, (3) soybean planting and (4) hay harvesting. Estimates of the rate of loss occurring when operations are performed during a suboptimal period were obtained from various agronomic and engineering sources. Loss functions were developed to consider both a "no loss" period and the subsequent crop yield losses which occur as operations are extended beyond this "no loss" period (i.e., if operations are extended into a suboptimal period with respect to seasons of the year).

Several items of information are needed to determine the losses resulting from untimely operations: (1) hours of machinery input required per acre for each cropping operation, (2) hours available in each day for field operations, (3) the period over which operations can be performed without losses (the optimal period) and (4) estimates of the losses that occur as an increasing function of time if operations are performed during the suboptimal period.

Average dates for beginning each operation and the time limitations on the optimal period for operations were obtained from a survey among county extension directors in the respective soil areas. Estimates of the number of days available for field operations were obtained from records of the Agronomy Farm at Ames and were adjusted to the conditions of northeastern and western Iowa.

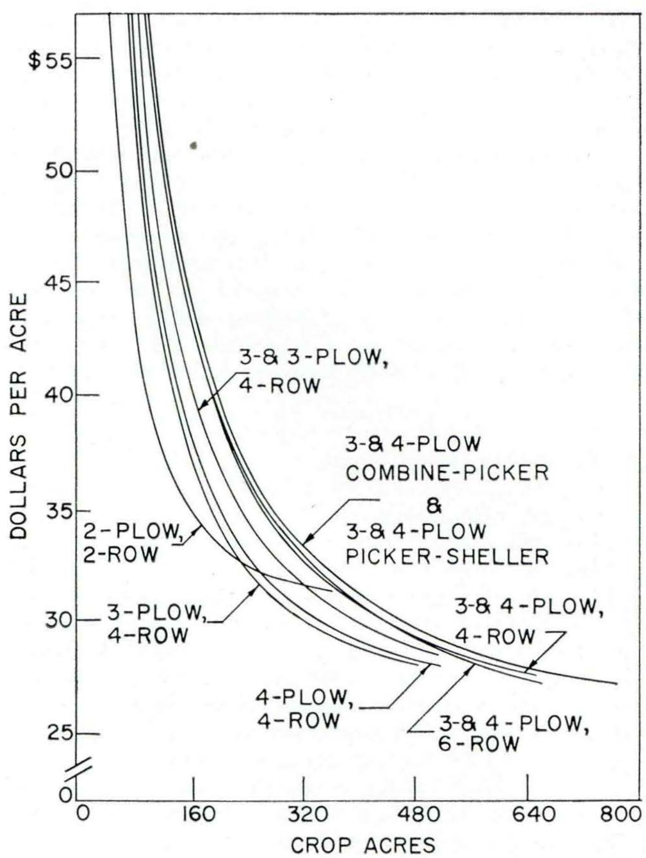

Fig. 2. Average costs per acre with current cropping programs and assuming no crop losses.

COST FUNCTIONS FOR VARIOUS MACHINERY COMBINATIONS AND CURRENT CROPPING SYSTEMS

Cost curves for eight sets of machinery, based on current cropping methods in the Carrington-Clyde area and 1953-57 prices, are presented in this section. The first cost curves presented are on a per-acre basis and merely show the costs per acre as the number of acres is increased for a given set of machinery. Account is not taken of loss resulting from untimeliness of operations. Per-acre cost curves fall rapidly over small acreages because of the dominance of fixed costs. As acreage is extended, however, per-acre costs are composed of an increasing proportion of variable costs. The slope or decline in the cost curves decreases accordingly. The mathematical limit of per-acre costs is the constant per-acre mix of variable costs. The cost curves "flatten out" accordingly for each set of machinery. The total fixed costs, which provide the per-acre fixed costs when divided by the number of acres, range from $1,092 to $3,349, depending on the particular combination of machinery.

The cost curves, on a per-acre basis, are presented in fig. 2. The legend indicates the machine combination. For example, "2-plow, 2-row" refers to a single 2-plow tractor and 2-row equipment; "3- and 4-plow and 4-row" refers to a 3-plow tractor and a 4-plow tractor with 4-row planting and cultivating equipment for each, but a conventional corn picker and a stationary sheller.

The lower limit to per-acre costs is the constant variable cost per acre. This lower limit to per-acre costs is not the same for all machinery combinations. Variable costs, including the value of labor used, are considerably higher with the 2-plow, 2-row combination than with the other combinations.[6] The 2-plow, 2-row combination does not include grain-combining or hay-baling equipment-operations which would have to be hired on a custom basis. Hence, fixed machine costs are lower, but variable costs are considerably higher because of the custom charges. With this 2-plow, 2-row combination, per-acre costs approach a lower limit of approximately $31.50 at 320 crop-acres, an acreage extending far into the suboptimal range as far as timeliness is concerned. For the other machinery combinations, costs approach a minimum of approximately $27-$28 per acre (see fig. 2).

While differences in the cost limit approached for the several machine combinations are not great, there is wide variation in the acreage at which this limit is approached. It is in the neighborhood of 800 acres for the combination which includes 3-plow and 4-plow tractors, 6-row equipment and a combine-picker or picker-sheller. It is approached at 480 acres or less for a 3-plow or a 4-plow tractor with 4-row equipment. Hence, it would appear that farms using the latter combinations would not be at any great cost advantage, compared with those using larger equipment with field shelling. The smaller 2-plow tractor with 2-row equip-

[6] Machine combinations presented in this section are referred to by the plow capacity and type of corn equipment.

ment would, however, have a more definite cost disadvantage. It should be remembered, of course, that the curves in fig. 2 refer only to per-acre costs. They do not take into account losses resulting from untimeliness and would suggest that to attain major cost advantages, farms need to be larger than is actually the case when weather and timing of operations are considered.

With 160 crop-acres, the minimum per-acre costs attained by the smallest machinery combination are approximately $35, whereas $27 is the practical minimum for larger acreages operated with other machine combinations. The majority of the cost economies gained from increasing acreage is attained at 440 acres with other machine combinations. While per-acre costs continue to decline because of the fixed-cost component, the decrease becomes unimportant beyond 440 acres — regardless of the machine combination used. Increasing farm size from 440 to 960 crop-acres, for example, would reduce per-acre costs by about $1.50. This amount is insignificant as a factor affecting farm size, particularly in light of the added investment involved and the uncertainty associated with it.

The cost curves presented in fig. 2 do not include a charge for land investments. Hence, they do not measure all costs. However, land costs per acre are constant, including interest, and would not change the curvature of the cost functions.

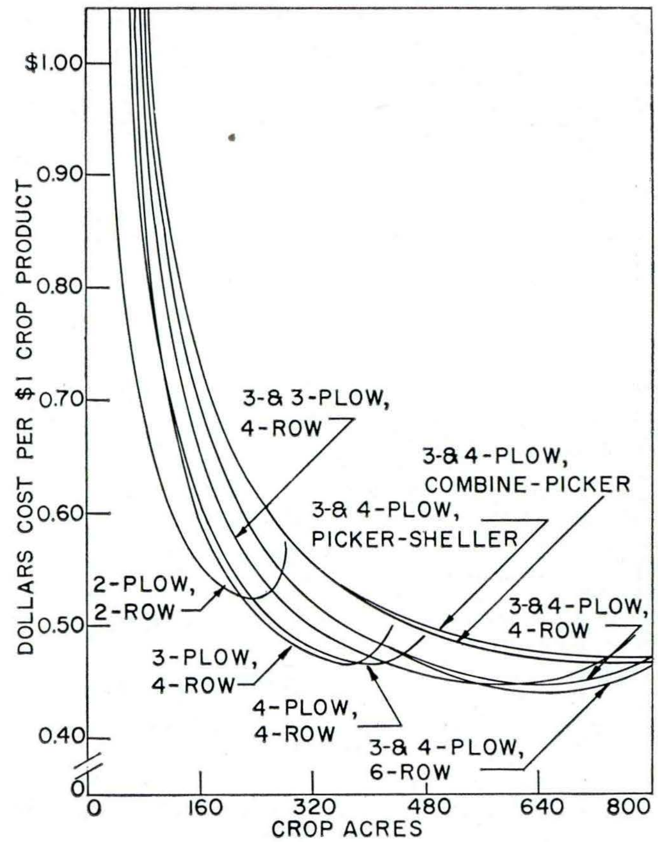

Fig. 3. Average costs of producing $1 worth of crop product with eight machinery combinations based on current cropping methods.

Costs Per Unit of Product

Since the cost curves of fig. 2 ignore crop losses resulting from untimeliness of operations, they do not answer the question of optimal farm size. Figure 3 includes per-unit cost curves when losses from untimeliness of operations are considered. These are U-shaped, since per-unit costs increase as acreage is increased to sufficient magnitude for each machine combination. The curves turn upward, denoting that the acreage of minimum cost has been attained, when the losses from untimeliness more than offset the decline in average costs because of spreading fixed costs over a larger acreage.

Generally, in economic textbooks, physical quantity is presented on the horizontal axis; dollar cost per unit of physical output, on the vertical axis. The cost curves presented in fig. 3, however, do not measure cost against physical output. Aggregation of the individual products is necessary in determining average cost for a multiproduct firm. The most feasible and meaningful procedure is to aggregate the physical quantities by their respective prices. This procedure results in the measurement of costs per dollar of output, instead of costs per physical unit of output. The main disadvantage of this change in axis is that the cost schedules vary vertically with level of product prices.

A second difference between these cost curves and those typically included in economic textbooks deals with the quantity axis. In the cost curves presented here, the quantity measured on the horizontal axis is land input rather than output. The cost curves are presented in this manner to facilitate analysis and interpretation of the data in terms of farm size. Since some detail is lost in using land input rather than product output on the horizontal axis, average per-unit costs are presented in fig. 4 for one set of machinery and one cropping system, with both land input and dollar of output measured on the horizontal axis. The two average cost curves are identical at small acreages where crop losses resulting from untimely operations are negligible. With expanding acreage, crop losses gradually become more severe, and dollar output per acre declines. Hence, costs per dollar of output rise more sharply when measured against dollar output than when measured against acreage.

MINIMUM COST PER DOLLAR OF CROP OUTPUT RELATIVE TO ACREAGE

Minimum average costs for the 2-plow, 2-row combination are attained at 240 crop-acres, as shown in fig. 3. Below 200, and above 240 acres, average costs rise quite sharply for this machine combination. Farmers with 210 crop-acres or less would minimize per-unit costs by using this set of machinery. (The 2-plow, 2-row combination includes a complete line of field equipment except for crop-harvesting machines.)

The 3-plow, 4-row combination includes a complete complement of machinery for a 3-plow tractor. Of the machinery combinations studied, this set gives lowest average per-unit costs on acreages ranging from 210 to 370 crop-acres. The results illustrated in fig. 3 indicate that it would be unwise for a farmer with the

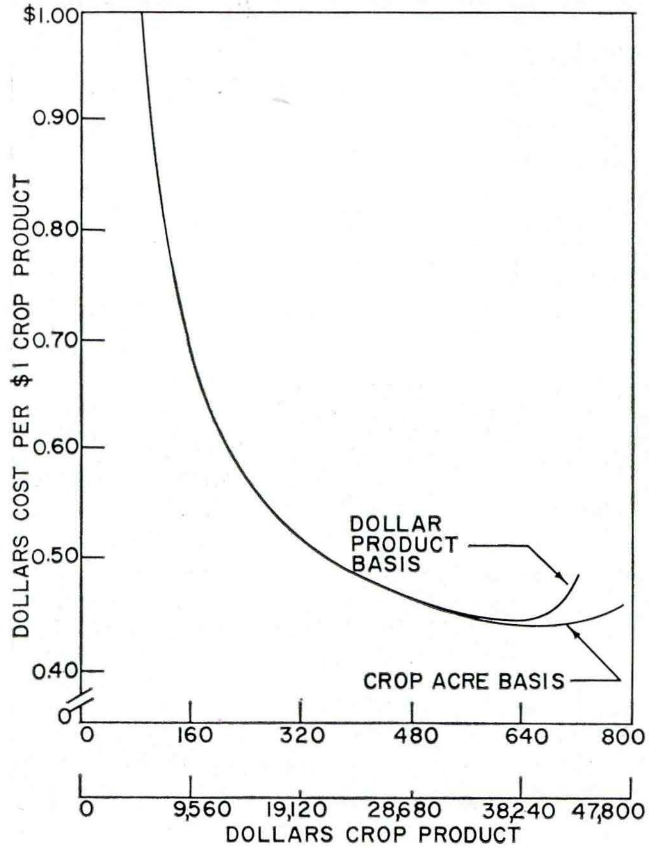

Fig. 4. Average costs of producing $1 worth of crop product with crop-acres and total dollars product on the quantity axis (3- and 4-plow, 6-row machinery combination).

2-plow, 2-row combination to expand acreage to the point where average per-unit costs are a minimum. If this farmer is operating 210 or more acres of cropland, he would be wise to increase machinery investment instead of land investment. Between 200 and 280 crop-acres, untimeliness losses increase rapidly with the 2-plow, 2-row machine combination. At 240 acres (the minimum average cost acreage for the 2-plow combination), a shift to the 3-plow, 4-row combination would increase total annual costs by $68 but would increase total value product by $241.

The 4-plow, 4-row machinery combination includes the same machine items as the 3-plow, 4-row combination except for a 4-plow tractor and a 4-bottom plow in place of a 3-plow combination. On farms with less than 370 crop-acres, per-unit costs are higher with the 4-plow than with the 3-plow combination. This is because fixed costs are higher, and the additional field capacity with a 4-plow combination is not needed at these acreages. With 370 to 430 crop-acres, average per-unit costs are less with the 4-plow combination since severe untimeliness losses are avoided with the equipment of larger capacity.

All remaining machine combinations studied include two tractors and 4- or 6-row corn equipment. The 3- and 3-plow, 4-row combination includes two 3-plow tractors, 4-row corn equipment and a 2-row mounted corn picker. With this set of machinery, average costs are minimized at 640 acres. On a unit-cost basis, this is the optimal set of machinery for farms ranging from 430 to 560 crop-acres. As with the 2-plow, 2-row combination, it would not be profitable to operate at the acreage which gives minimum per-unit costs with this set of machinery. Other sets of machinery give lower per-unit costs at 640 acres than are attained with this combination.

The 3- and 4-plow, 4-row machinery combination does not give lowest per-unit costs at any acreage. This set of machinery includes one 3-plow and one 4-plow tractor and 4-row corn equipment. Per-unit costs are lower with this combination than with the 3- and 3-plow combination on farms with 600 or more crop-acres. However, average per-unit costs are still lower with the machinery combination which includes 6-row corn equipment. The combination which includes 6-row equipment has nearly the same fixed costs as the 3- and 4-plow combination. Since it has a larger corn cultivating capacity, it results in lower untimeliness losses and, hence, in lower average costs per dollar of output.

Two sets of machinery also were studied which include equipment for field shelling of corn. The combine-picker combination includes a 12-foot, self-propelled combine-harvester with a corn-picker head, while the picker-sheller combination has a 12-foot, pull-type combine and a 2-row mounted corn picker with sheller attachment. Fixed costs are nearly the same for these two machinery sets. Calculated unit costs are slightly higher with the picker-sheller combination, however, because of higher repair costs per acre and slightly greater losses in oats harvesting. The minimum unit costs attainable with either of these two sets of machinery is higher than the minimum per-unit cost attainable with machinery sets which do not include field shellers.

With field shellers, corn harvesting is estimated to begin 26 days earlier, thus greatly reducing corn harvesting losses and also leaving more time for fall disking and plowing. Without field shellers, much less plowing or disking can be done in the fall, resulting in more planting untimeliness in the spring and in a definite limit to farm size. These savings in harvesting and planting losses are outweighed, however, by the 10-cent-per-bushel drying charge required for field-shelled corn. As a result, minimum per-unit costs are estimated to be about 3 cents per dollar higher than with combinations which have conventional harvesting equipment. Actually, drying of corn may be required in some years with conventional harvesting methods. Hence, the difference in minimum per-unit costs is probably less than 3 cents. This is a relatively small difference, and experienced operators may use picker-shellers or combine-pickers to gain a cost advantage, based on added value of product. Too, they may be able to get harvesting out of the way sooner and spend their time profitably on livestock.

Certain of these results are summarized in table 3. With current cropping systems, large acreages are needed to obtain cost benefits from recent machinery innovations such as large-scale equipment and field shelling of corn. Also, the cost advantages to be gained are quite small. (The cost estimates in table 3 do not include a charge for land or management and, hence, do not attempt to estimate total costs as a suggestion of profit per acre.)

Table 3. Costs per dollar product for all machinery combinations with current cropping systems and 1953-57 prices.

Machinery combination	Range in acreage with lowest average total costs	Minimum average cost acreage	Minimum average cost
1. 2-plow, 2-row	0-210	240	$0.52
2. 3-plow, 4-row	210-370	360	0.47
3. 4-plow, 4-row	370-430	400	0.46
4. 3- and 3-plow, 4-row	430-560	640	0.45
5. 3- and 4-plow, 4-row	none	680	0.45
6. 3- and 4-plow, 6-row	560-800	680	0.44
7. 3- and 4-plow, combine-picker	800-960	760	0.47
8. 3- and 4-plow, picker-sheller	none	760	0.47

From the data in table 3 and fig. 3, it appears that a machinery combination including one 4-plow tractor and 4-row corn equipment allows attainment of most cost economies from expanded farm size. With this set of machinery, 400 crop-acres results in minimum costs per dollar of product. Six-row equipment gives lower per-unit costs only if farm size is expanded to 560 crop-acres. Although the possibility of using 6-row equipment with a 1-tractor combination was not examined, such a possibility would not appear to be profitable. The budgeting of timeliness of field operations indicated that with the 4-plow, 4-row combination, most of the untimeliness losses stem from delays in fall and spring disking and plowing. The extra corn planting and cultivating capacity possible with 6-row equipment would be worth very little in reducing losses. The budgeting procedures indicated that some balance is needed in expanding machinery capacity. The expansion of field capacity in only one direction — for example, corn cultivating — may not be profitable since other operations may provide the real bottleneck to profitable expansion of farm size.

Use of 4-row corn equipment is estimated to result in cost savings of about 10 percent as compared with 2-row equipment (with comparison at the acreage of minimum cost for each). This difference may cause pressure toward larger farms. Further expansion in machinery capacity to include 6-row equipment would reduce per-unit costs by an additional 1 or 2 cents per dollar of product. Acreage would have to be increased accordingly. This cost reduction alone may not be sufficient to serve as a "pushing force" toward farm enlargement. For prices sufficiently above per-unit costs, however, the greater income generated from farm enlargement and a volume of output could be an important "pulling force" in this direction.

Field-shelling equipment alone does not give cost economies sufficiently great to induce greater farm size. Per-unit costs are generally higher with field shellers than with conventional harvesting equipment, even on larger farms. Here again, however, with sufficiently high product prices, the large volume that can be produced with combinations which include field shellers may favor the larger farm.

Results of this analysis indicate that, for any size farm, investment in machinery solely to eliminate all untimeliness losses is not profitable. For example, with 160 crop-acres, crop losses in all years are estimated to be zero only with the machinery combinations which include field corn shellers. With these combinations, average costs per dollar of product are 4 cents above the next best combinations and 18 cents above the least-cost set of machinery for a unit of 160 acres. Similar results are indicated at other acreages.

A farmer with a given set of machinery should expand the size of his farm beyond the point where no losses from untimely operations would occur. If, in so doing, he incurs small untimeliness losses which are more than offset by reduction in fixed costs per unit of output, profits will be increased. At some level of acreage per machine, however, the marginal losses from untimeliness become greater than the marginal cost of machinery for these purposes.

PER-UNIT COST FUNCTIONS

Regardless of the set of machinery under consideration, the structure of per-unit costs is similar. Figure 5 presents the various cost functions for the 3- and 4-plow, 6-row machinery combination. Results are similar for other sets of machinery; only the scales of measurement differ.

Average fixed costs per unit of output continue to decline as long as output increases. Average variable costs are almost constant for small acreages and increase slowly with increasing acreage. (Variable inputs per acre are nearly constant regardless of acreage. With increasing acreage, the only additional charges are for extra wear and tear on machinery.) The rise in the variable cost curve is due to the decrease in yields which results from untimely field operations as acreage grows sufficiently for a particular machine combination. This rise in variable costs per unit of output also is char-

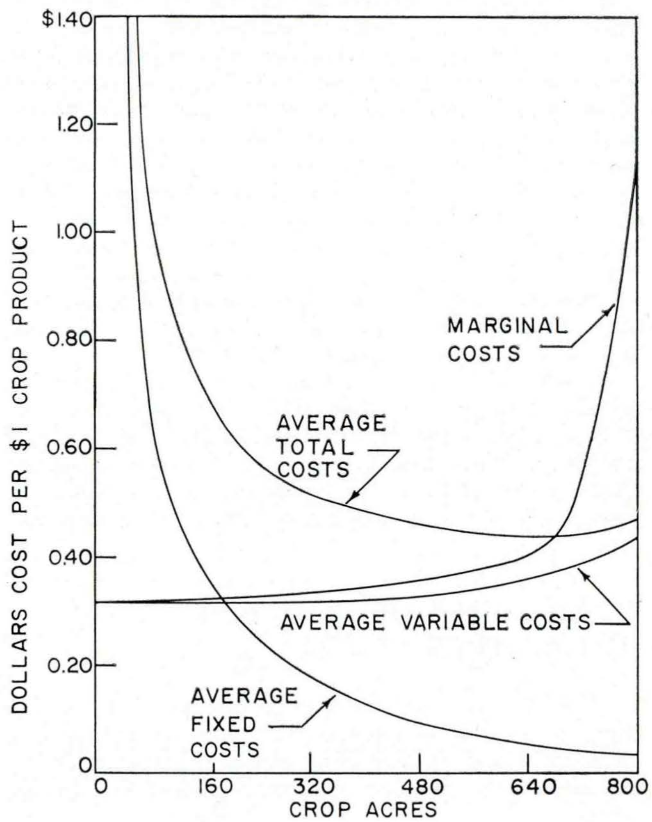

Fig. 5. Per-unit cost functions for the 3- and 4-plow, 6-row machinery combination based on current cropping methods.

acterized in the marginal cost function. A marginal cost function of the shape shown in fig. 5 results for all of the machinery combinations studied. The marginal cost function "turns up" sharply where further expansion of farm size results in large losses from untimely operations. With current cropping systems, this increase in losses occurs especially at the acreage where corn planting interferes with soybean planting, resulting in very heavy losses in soybean production or vice versa.

The average total cost curves for all two-tractor combinations are quite flat near the minimum-cost point.[7] For example, with the 3- and 4-plow, 6-row combinations, per-unit costs vary less than 5 cents per dollar of product between 400 and 840 crop-acres. With two-tractor combinations, losses from untimely operations increase quite slowly over a wide acreage range. In this same acreage range, fixed costs per unit of output decline only slowly. For example, with a total fixed cost of $10 per acre, per-unit fixed cost is cut by 50 cents per acre as acreage is extended from 10 to 20. For this same total fixed cost, however, per-acre fixed cost declines by only 1¼ cents as acreage is increased from 400 to 800 acres. Hence, average total costs remain nearly constant.

LONG-RUN FUNCTION

A long-run average cost curve, or envelope curve, is presented in fig. 6. This envelope curve is based on the eight sets of machinery discussed earlier and on current cropping techniques; the curve also is based on an approximation of the relevant points, selected from the separate short-run curves. As indicated in fig. 6, the acreage of minimum per-unit cost for the long-run curve is approximately 680 crop-acres. With free resource mobility, and with the resource prices assumed in this study, a farm of 680 acres could survive at the lowest product prices. Yet, average total costs vary less than 2 cents per dollar of product between 400 and 800 crop-acres. This small difference in per-unit costs over a wide acreage range would allow survival of farms of many sizes at about the same price level.

Per-unit costs increase quite sharply for acreages of less than 320 crop-acres. Cost economies are relatively large as acreage is extended to 320 acres.

The envelope curve also indicates rapidly increasing per-unit costs at farm sizes above 800 crop-acres. The long-run or envelope curve refers not to a single machinery combination but to all possible machine combinations. It shows the lowest cost, at any particular acreage, for the most economical machine combination.

RELATIONSHIP OF COST FUNCTIONS TO CROPPING SYSTEM

The cost curves presented in the previous section only apply to a situation which meets the following specifications: Soil association area is Carrington-Clyde; cropping system includes current methods; fertilization is at current levels; product prices are at 1953-57 average; input prices are at current market rates; and weather is "average." In this and following sections, cost functions are estimated when these restricting conditions are relaxed in a singular fashion. Costs are estimated under two additional cropping systems and two fertilizer levels.

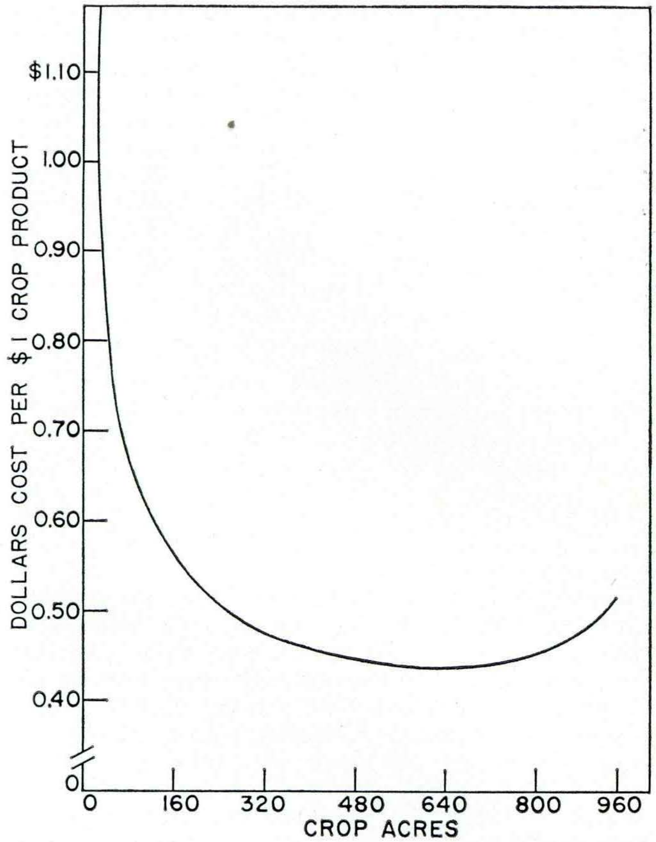

Fig. 6. Long-run average cost or envelope curve based on current cropping methods and 1953-57 prices.

Costs Under a 5-Year Rotation Program

Cost curves are presented in this section for the eight sets of machinery (explained previously) used with a 5-year crop plan. This crop pattern includes 1 year of oats, 1 year of meadow, 2 years of corn and 1 year of half corn and half soybeans. Sixty percent of the cropland is in row crops. The first set of cost curves, presented in fig. 7, is based on current fertilization rates

Table 4. Comparisons of minimum per-unit costs with current cropping systems and a 5-year rotation for six machinery combinations.

Machinery combination	Minimum average cost[a] Current cropping system	Minimum average cost[a] 5-year rotation	Minimum cost acreage Current cropping system	Minimum cost acreage 5-year rotation
2-plow, 2-row	$0.52	$0.52	240	200
3-plow, 4-row	0.47	0.46	360	320
4-plow, 4-row	0.46	0.46	400	360
3- and 3-plow, 4-row	0.45	0.45	640	560
3- and 4-plow, 6-row	0.44	0.44	680	600
3- and 4-plow, combine-picker	0.47	0.47	760	720

[a] Minimum average cost of producing $1 worth of crop product with 1953-57 average product prices.

[7] In this section, the term "average total cost" is used to indicate the sum of the variable and fixed costs. It is not inferred that all costs have been considered.

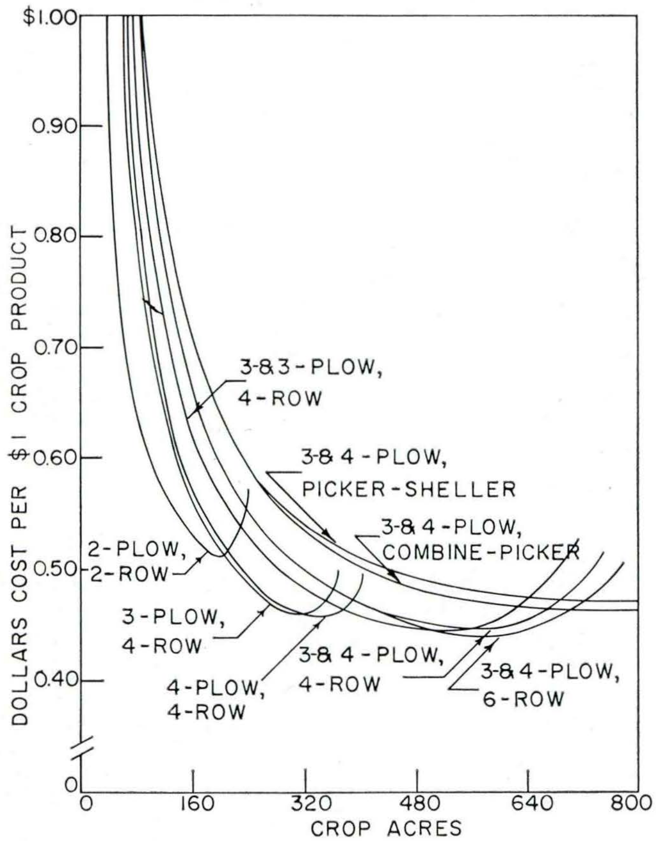

Fig. 7. Average costs of producing $1 worth of crop product with eight machinery combinations based on the 5-year rotation.

and 1953-57 prices. The relative cost relationships among machinery combinations are almost identical to results obtained for the current cropping system.

Table 4 summarizes relevant cost and acreage data for both a 5-year rotation plan and current cropping methods. The main effect of the change in cropping system is a reduction in the number of acres to provide a cost minimum (i.e., the acreage associated with the low point on the cost curve). For example, the acreage associated with the acreage of cost minimum declines from 240 to 200 acres for the 2-plow, 2-row machinery combination and from 360 to 320 acres with the 3-plow, 4-row combination. With more intensive use of row crops, labor and other input requirements per acre are increased. Yields per acre also are increased. Thus, the size of farm necessary to give minimum costs is reduced. Minimum per-unit costs with the 5-year rotation are almost identical to those estimated for current cropping systems. Profit from total inputs is greater under the former system, however, because land investment is smaller.

As suggested in fig. 7, the main cost advantages of different crop acreages and machine combinations is attained by the time acreage is expanded to around 300 acres. As indicated in table 4, the minimum cost with a 3-plow, 4-row combination is attained at 320 acres. Other combinations give slightly lower costs at larger acreages. However, the extremely large reductions in per-unit costs have been attained at 300 acres even by the 3-plow, 4-row combination. Cost savings per dollar of crop product alone are not great enough, beyond this acreage, to result in extreme pressure toward larger farms. Actually, the larger acreages and bigger machine combinations do little more than duplicate the level of per-unit costs attained at 300 crop-acres by the 3-plow, 4-row combination. Too, remember that all labor (operator, family and hired) is charged as an expense or cost in these calculations. The larger units would need to use some hired labor, while farms of smaller acreages would not. Hence, with lower cost for some family labor, the actual out-of-pocket cost would generally be as low with 300-320 crop-acres and a 3-plow, 4-row combination as at 600 acres with two 3-plow tractors and 4-row equipment. This same general conclusion would apply to other cost combinations which follow. Under both cropping systems, cost advantages for combinations including two tractors are small.

Effect of Fertilizer Application Level on Per-Unit Costs for Carrington-Clyde Soils

The cost curves presented thus far are based on fertilization rates representing an average of those used in the Carrington-Clyde soil area at the time of the study. These rates approximated an 8-20-20 (pounds of active ingredients of N, P_2O_5 and K_2O per acre) mixture on corn and a 0-20-0 mixture on oats. Cost curves presented in this section, for three sets of machinery only, are based on a higher fertilization rate. Yields are increased accordingly and amount to 7 bushels for corn, with proportional increases in the yields of other crops.

Figures 8, 9 and 10 include the resulting per-unit cost curves, with land charges excluded, for two cropping systems and two fertilizer levels with three sets of machinery. The shape of the cost curve is affected relatively little by a change in the rate of fertilizer application. The slope, particularly on the upward sloping portion of the curve, is especially determined by losses from untimely field operations. Since untimeliness losses are determined largely by the same acreages against a given set of machinery, the shape of the cost curves remains nearly the same regardless of the fertility level.

Under high fertilization, per-unit costs of crop output are generally lower than under the lower fertilization rates. In absolute amounts, the total value of product increases considerably more than does cost of fertilizer application. The optimal amount of fertilizer input is, of course, best determined by marginal analysis, rather than by comparison of farm cost functions. With the 5-year rotation, use of the high fertilizer level increases costs of fertilizer by $2.95 per acre but increases value product, with no untimeliness losses, by $7.51 per acre at 1953-57 prices. The optimum fertilizer level is represented by a rate at which marginal return is equal to marginal cost. Return and cost levels depend, of course, on the price of fertilizer and the prices of the products. Marginal value return, for the rates indicated, is double the cost of the additional fertilizer even at product prices as low as those which existed in 1958.

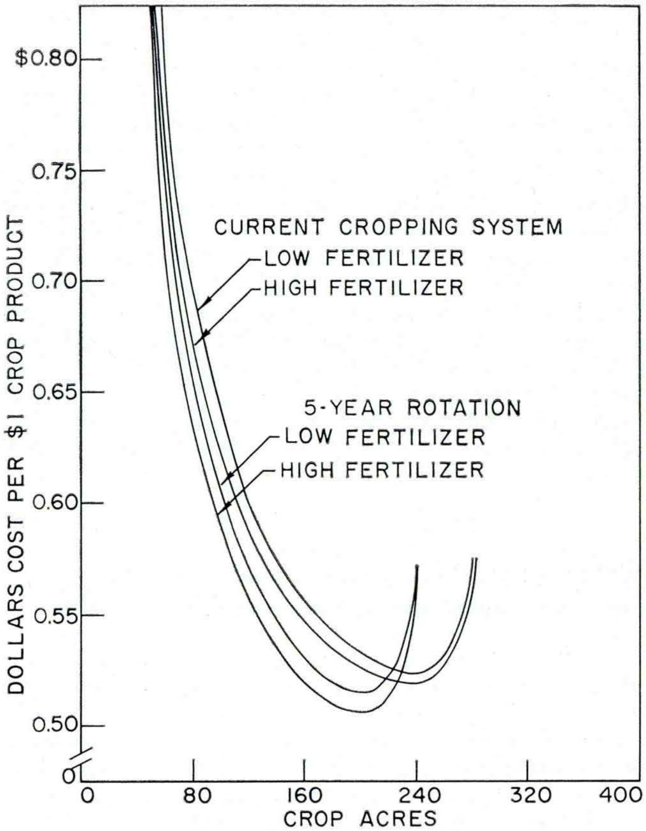

Fig. 8. Average costs of producing $1 worth of crop product with the 2-plow, 2-row machinery combination for two cropping systems and two fertilizer levels.

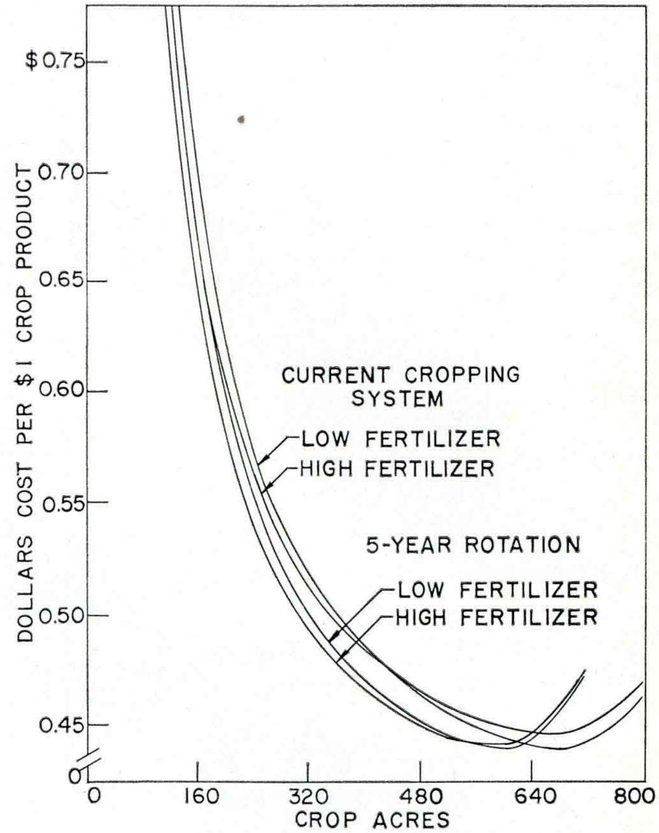

Fig. 9. Average costs of producing $1 worth of crop product with the 4-plow, 4-row machinery combination for two cropping systems and two fertilizer levels.

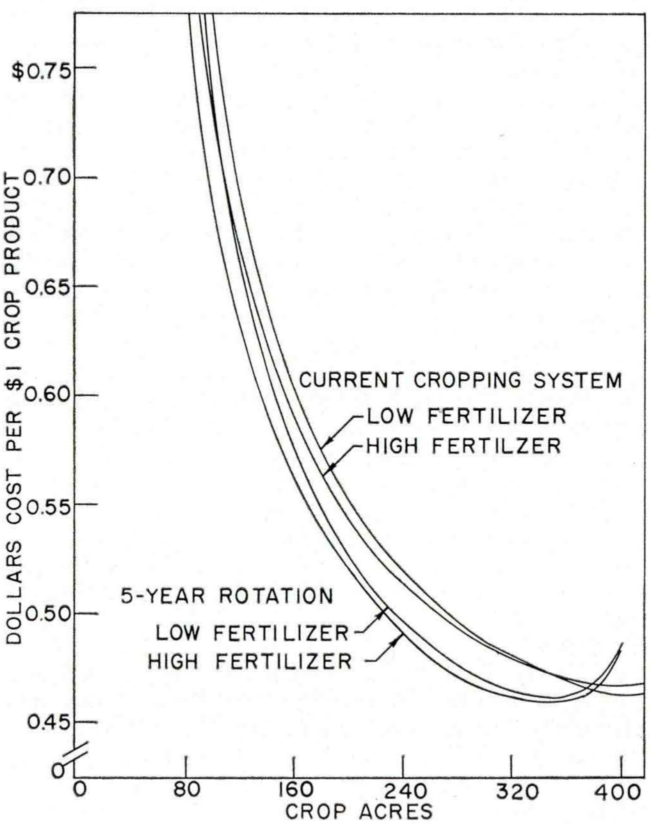

Fig. 10. Average cost of producing $1 worth of crop product with the 3- and 4-plow, 6-row machinery combination for two cropping systems and two fertilizer levels.

Per-Unit Costs Under a Continuous-Corn Program on Carrington-Clyde Soils

Cost functions are developed in this section for a continuous-corn cropping program on Carrington-Clyde soils. Somewhat different machinery combinations are required since hay harvesting is eliminated. Three such sets of machinery, all including 6-row corn equipment, have been used for these calculations. The first set is designed for operation by one man. It includes a 4-plow tractor, 6-row corn equipment and a 2-row mounted picker with sheller attachment. A second set, designed for operation by two men, includes one 4-plow and one 3-plow tractor, 6-row and 4-row corn equipment and a 2-row mounted corn picker. A third set, also for operation by two men, is a duplicate of the second set with the addition of a sheller attachment on the corn picker. Only one plow would be needed with the 2-tractor combinations; the second tractor would be used for other operations such as disking, harrowing and planting.

A corn yield of 71 bushels per acre is assumed with continuous corn, with total fertilizer input of $9.77 per acre per year. The resulting average cost curves for the three sets of machinery on Carrington-Clyde soils are presented in fig. 11. The vertical axis is cost per bushel of corn, rather than costs per dollar of product, since aggregation of products is not necessary. Under the continuous-corn program, the one-man operation gives lowest per-unit costs only on farms of less than 96 crop-acres. At 96 acres, average costs per unit of output still are declining quite rapidly, indicating that such small farms would be uneconomical.

The two-man or 2-tractor operation without a field sheller attachment gives lowest per-unit costs for farm units over a range of approximately 100 to 400 acres. The two-man operation with a picker-sheller has lower unit costs for more than 400 acres.

Table 5 provides a comparison of certain cost and acreage quantities for the continuous-corn and 5-year rotation systems. Both cropping programs are based on the same general level of fertilization, adjusted for the rotations and the same price levels. Per-unit production costs with the continuous-corn program are expressed in costs per dollar product to facilitate comparison. (The price of corn used is $1.30 per bushel.) Again, the acreage at which costs are at a minimum is smaller under continuous corn than under the rotation. The major per-unit cost gains are attained at 240 crop-acres with the continuous-corn program. The comparable size is 320 acres under the 5-year rotation and 400 acres under current cropping programs.

The structure of fixed and variable costs differs considerably between the continuous-corn and the other two cropping programs. Total machinery investment is considerably lower with machinery combinations for the continuous-corn program. Fixed machinery costs per acre, at the acreages of minimum cost, average slighly higher with continuous corn since optimal farm size is smaller. However, variable machinery costs per dollar of output are lower. Average costs (the sum of fixed and variable costs per unit) per $1 of output are, in total, slightly less for continuous corn, mainly because of the larger value of output per acre. Corn produces a greater value product per acre than do oats, hay and soybeans.

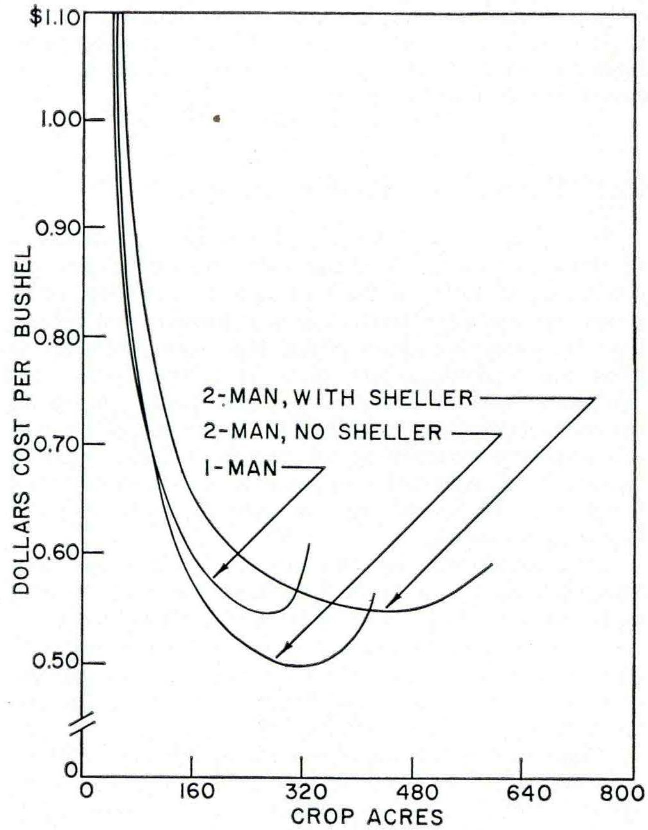

Fig. 11. Average costs of producing corn with a continuous-corn cropping system.

Table 5. Minimum per-unit costs of producing $1 worth of crop product with the continuous-corn program and the 5-year rotation on Carrington-Clyde soils.

Machinery combination	Acreage of minimum cost	Minimum cost per dollar of product
Continuous-corn		
One-man	280	$0.42
Two-man (no sheller)	320	0.39
Two-man (sheller)	440	0.43
5-year rotation		
4- plow, 4-row	360	0.46
3- and 4-plow, 6-row	600	0.44
3- and 4-plow, picker-sheller	720	0.47

COMPARISON OF COST FUNCTIONS FOR TWO SOIL TYPES

This section deals with cost functions for Ida-Monona soils. While these soils are relatively fertile, the topography differs greatly from that of the Carrington-Clyde area. Only 20 percent of the farmland in the Ida-Monona area has a slope of 4 percent or less, and 22 percent has a slope of 14 percent or more.

Under these conditions, terraces, contouring and other conservation practices must be used if soil erosion is to be controlled and yields are to be maintained. Topography also limits the selection of rotations and cropping machinery. Four- and 6-row corn equipment is less well adapted. Erosion-control practices also favor use of some special machine equipment, such as two-way plows and lister-planters.

Cost Curves for Ida-Monona Soils

Cost curves are developed for three machinery combinations on Ida-Monona soils. One set, a one-man operation, includes a 3-plow tractor, two-way plow, 2-row lister-planter and a 2-row mounted corn picker. One set designed for two-man operation includes 4-plow and 3-plow tractors, both 4-row and 2-row corn equipment and a 2-row mounted corn picker. A second two-man operation includes the same machines plus a field-sheller attachment. In determining the required implements for 2-tractor operations, it is assumed that 4-row corn equipment can be used only on slopes of less than 14 percent.

Cost functions for Ida-Monona soils have been computed on the basis of a CCOM rotation for land with less than 14 percent slope, and a CCOMM rotation on slopes of 14 percent or more. Hence, each 40 crop-acres includes 19.1 acres of corn, 9.5 acres of oats and 11.3 acres of meadow. High levels of fertilization are assumed on these rotations.

Cost curves for three sets of machinery on Ida-Monona soils are presented in fig. 12 along with average cost curves for two machinery combinations designed for Carrington-Clyde soils. The two cost curves for Carrington-Clyde soils are for the 5-year rotation and high levels of fertilization.

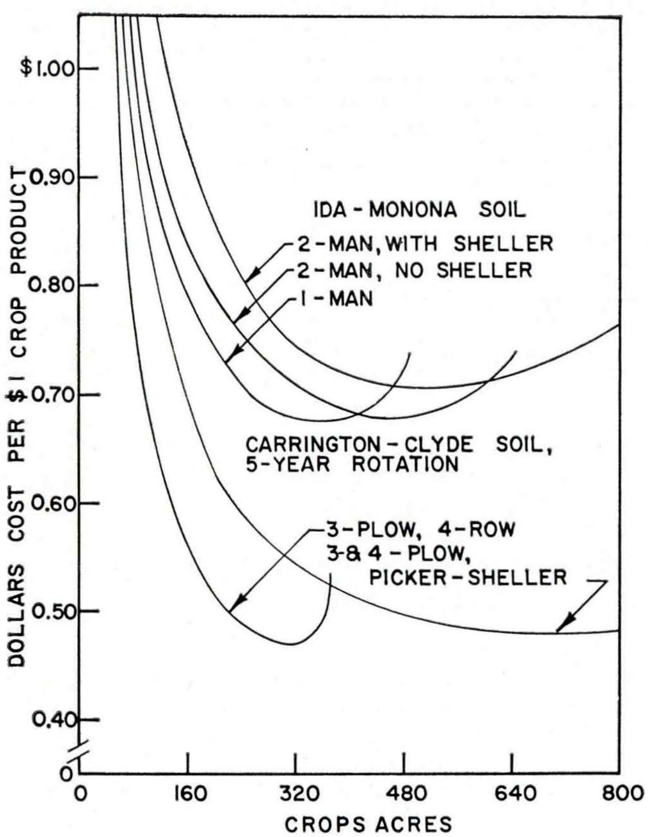

Fig. 12. Average costs of producing $1 worth of crop product with Ida-Monona soils and with two machinery-cropping combinations on Carrington-Clyde soils (1953-57 prices).

With one-man operation on Ida-Monona soils, average costs reach a minimum at 340 crop-acres. The one-man operation gives lower per-unit costs than do two-man operations up to approximately 400 acres. The two-man operation without field sheller gives lowest per-unit costs over a range of 410 to 600 crop-acres. It has minimum per-unit costs at 480 acres. For more than 600 crop-acres, the two-man operation with field sheller gives lowest per-unit costs.

With comparable rotations and with land charges excluded, minimum average costs per dollar product on Ida-Monona soils are approximately 20 cents greater than the minimum average costs on Carrington-Clyde soils. This difference in costs is partly due to lower yields and less intensive row-cropping on Ida-Monona soils. If a land charge were included in the calculations, this difference would be partly or entirely eliminated because of difference in the price of land and, hence, in interest charges.

Machinery items included in the one-man operation for Ida-Monona soils are quite similar to the machinery included in the 3-plow, 4-row combination established for Carrington-Clyde soils. As shown in fig. 12, however, the per-unit cost curves for these two sets of machinery are of slightly different shape. The cost curve for this machinery combination on Carrington-Clyde soils reaches a minimum at a smaller acreage and has a steeper upward slope than the cost curve for Ida-Monona soils.

With the one-man operation on Ida-Monona soils, losses for untimely operations increase slowly with expanding acreage because the proportion of row crops is smaller. Extension of acreage causes corn planting to interfere with soybean planting or vice versa on Carrington-Clyde soils. Hence, the average cost curves for the latter soil type bend up quite sharply. On Ida-Monona soils, soybeans are not included in the rotation, and the proportion of row crops is lower. Consequently, planting losses tend to be lower than on Carrington-Clyde soils as acreage is expanded against the given set of machinery.

Losses from delays in hay harvesting are more severe on Ida-Monona soils since more meadow is required in the rotation. With expanding acreage, however, corn planting losses generally become serious before haying losses become important. The season for planting and harvesting is slightly longer in western Iowa than in the northeast part of the state. For these reasons, a one-man operation can expand to larger acreages on Ida-Monona soils than on Carrington-Clyde soils before losses from untimeliness become important.

With two-man operations, untimeliness of haying operations is more of a problem at the larger acreages consistent with this set of machinery. Capacities of hay harvesting equipment used are identical for one-man and two-man operations, regardless of soil type. With two men, however, more effective use of haying machinery is possible, and haying can be started and conducted on time at larger acreages. With more meadow in the rotations on Ida-Monona soils, expanding acreage causes hay losses and becomes more serious than on Carrington-Clyde soils. Hence, the optimum acreage, in a cost-minimum sense, is smaller for two-man operation on Ida-Monona soils than on Carrington-Clyde soils.

Most of the cost economies from acreage expansion on Ida-Monona soils are attained at 320 crop-acres. Ignoring field size, which differs between the two soil types, the acreage needed to attain the main economies of size is affected little by topography or soil type. The results of this study indicate that the main economies of size for both soils are attained with farm machinery of sizes now used on some farms. The acreage best adapted to these machines is, of course, considerably greater than the average size of farm found in the two areas. As a general statement, we could say that farms must have about 320 crop acres to realize the major cost economies associated with modern machine combinations and capacities. Larger farms with machines of greater capacity would have slightly lower costs, but this further cost advantage probably has no great importance in causing farms to expand beyond 320 acres. Too, farms requiring two men would have a hired labor expense not found on one-man farms. If labor charges are included in cost calculations, the larger acreages have no cost disadvantage when operated with larger capacity machine combinations. Availability of capital and ability to shoulder the consequences of uncertainty thus may be more important than cost advantages for farms larger than 320 crop-acres. In both areas, of course, a farm of 320 crop-acres generally will have more total acres because some land is in permanent pasture or similar uses.

EFFECTS OF PRICE CHANGES ON COST SCHEDULES

Cost curves presented thus far are based on 1953-57 average product prices. Cost curves based on other price levels are now presented for Carrington-Clyde soils to illustrate the effects of price changes on per-unit costs and on the optimum acreage. The results also are used to determine minimum or "break-even" prices needed for the various machinery combinations and rotations.

A 5-percent interest charge on land investments is included in costs of this section. Land is valued at $361 per acre in the Carrington-Clyde area.[8] Land is treated as a variable input in estimation of cost curves, hence, interest charges on land also serve as a variable cost.

Cost Functions at Different Price Levels on Carrington-Clyde Soils

Figure 13 includes average total and marginal unit cost curves for the three price levels on Carrington-Clyde soils. The three price levels are averages for the periods 1953-57, 1956-58 and 1958. The average price of corn declined from $1.37 per bushel in 1953 to 97 cents in 1958.[9]

[8] D. M. Gadsby. Results of farm land price survey in 1959. (Unpublished data.)
[9] Prices of Iowa farm products (1930-1958). Iowa Farm Science 13:24. 1959.

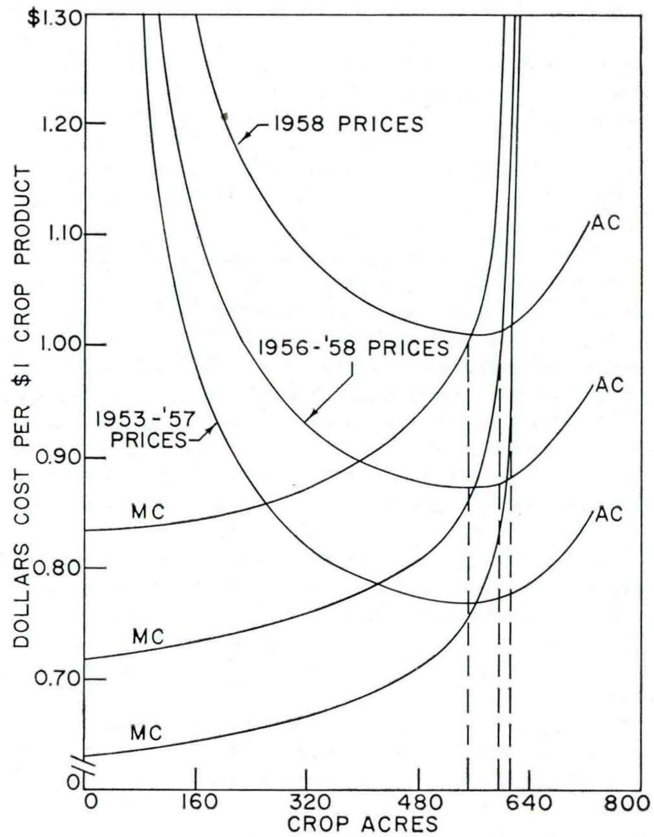

Fig. 13. Marginal and average total costs of producing $1 worth of crop product with the 3- and 4-plow, 6-row machinery combination based on the 5-year rotation, low fertilization and for three price levels, Carrington-Clyde soils. (The marginal cost curves are indicated by MC, while the average cost curves are indicated by AC.)

As indicated in fig. 13, the cost curves shift upward with falling product prices. This vertical movement results since costs are measured as costs per dollar of product rather than costs per physical unit of output. As indicated earlier, per-unit costs include charges for labor and land as well as other fixed and variable costs.

The 5-percent interest charge for land has the effect of changing the slope of the cost curve slightly, as well as raising it vertically. With inclusion of losses from untimely field operations, land costs per dollar of product rise with increasing acreage. Hence, the charge for land raises the "right-hand" portion of the cost curve more than the "left-hand" portion. With this change in the shape of the cost curve, the minimum per-unit cost point occurs at a smaller acreage than when land charges are not included. The change in acreage required for a cost minimum is not great, however, and the general conclusions relative to machinery, cost economies and acreage still apply in the manner outlined previously.

Size in Acreage With Product Price Changes

The minimum per-unit cost acreage is not necessarily the acreage which will maximize profits. Maximum profits are obtained with the farm size at which marginal cost of acreage expansion equals marginal revenue. Optimal farm size, measured from the standpoint of profit maximization, thus decreases with falling prices. With the 3- and 4-plow, 6-row machinery combination for Carrington-Clyde soils (fig. 13), optimal farm size is 610 crop-acres with 1953-57 prices, 598 crop-acres with 1956-58 prices and 536 crop-acres with 1958 prices. With 1958 prices, the minimum average total cost is $1.01 per dollar of product.

Thus, with land and labor costs at market rates included in the calculations, costs are higher than prices. The difference between price and costs would not result in lack of net income for a farmer, but would provide him with a return for his labor and capital at rates lower than those charged in the market. The average total cost curve is not the relevant curve for short-run planning. With falling prices, it is still profitable to produce, as long as return per unit is above variable cost per unit. Losses are then minimized, or returns above fixed costs are maximized.

The optimum farm size for attainment of maximum profit changes only slightly with price variations which leave return per unit above average costs. This condition holds true because the marginal cost curve is very inelastic above the minimum point of the average cost curve. When prices (returns per unit) fall below the minimum average total cost, optimal farm size declines relatively more because the elasticity of the marginal cost curve is greater at smaller acreages.

Break-Even Prices on Carrington-Clyde Soils

In this section, minimum corn prices needed for profitable production are estimated. The prices stated are those necessary to cover total costs per unit when both land — priced at the level mentioned previously and prevailing at the time of this study — and labor charges are included in the cost functions. These "break-even" prices are computed under the condition that prices of other crops maintain their historic relationship to corn price. The minimum "break-even" prices are specified to be those equal to minimum per-unit cost acreages. The results shown in table 6 for Carrington-Clyde soils indicate a price of $1.02 for the current cropping system and a low level of fertilization. Under a high fertilization level and the 5-year rotation, the "break-even" price is 94 cents per bushel of corn at the lowest cost minimum. With the continuous-corn program, the lowest "break-even" corn price is 80 cents with a 320-acre, two-man operation. Of course, with lower prices, land value would decline, and different break-even prices would exist over the long run.

RESIDUAL RETURNS TO LABOR AND LAND

Some farmers consider labor as a fixed factor in the short run. Hence, labor receives only those profits remaining after all other expenses have been paid and a return has been imputed to capital. Residual returns to labor are determined in this section in this manner: All costs excluding labor, but including interest on capital and land investment, are subtracted from the total value product. The residual return so calculated is then divided by hours of labor input to determine residual returns per hour. The rates of return determined in this manner apply only to the hours actually used in cropping operations.

Residual returns per hour of operator's labor input are presented in table 7 for some of the price, machinery and cropping combinations studied on Carrington-Clyde soils. For simplification, residual returns are computed only at minimum cost acreages. (Residual returns to labor are lower at other acreages.) Under 1953-57 and 1956-58 product prices, residual returns are greater than $1 per hour for all combinations of machinery or cropping systems. Under 1958 prices, residual returns are considerably less than $1 per hour except for the rotation system with high fertilization. As suggested in table 7, variations in product prices have much more effect on residual returns to labor than do variations in machinery or cropping programs.

Comparison With Nonfarm Labor Incomes for Carrington-Clyde Soils

Labor returns in possible farm and nonfarm family employment are compared by relating residual returns to labor and the earnings from manufacturing employment. In 1956, annual nonfarm wages averaged $3,935 in Iowa, or approximately $1.96 per hour.[10] Total hours worked by nonfarm laborers was approximately 2,000 per year. Total input of operator's labor varies from 1,700 to 2,200 hours at the minimum cost acreages for the eight machine combinations included in this study.

Table 7 shows residual returns, at minimum per-unit cost acreages greater than $2 per hour for all cropping and machinery combinations studied on Carrington-Clyde soils at 1953-57 prices. This level of return to labor is not attained for any of the cropping systems and machinery combinations under 1958 prices. With the minimum per-unit cost acreage for each machinery combination, a corn price between $1.30 and 97 cents is necessary to return $2 per hour of labor input. The corn price necessary to give this return for six machinery combinations and two cropping systems is included in table 8. (Again it is assumed that other product prices maintain a relationship with corn price equal to the average of the past, while input prices are at the 1959 level.) These prices also assume the price per acre of land equal to $361. At a lower price for land, the corn price necessary to return $2 per hour for labor would decline accordingly.

On the basis of the data in table 8, with corn price at $1, a farmer must choose the 3- and 4-plow, 6-row machinery combination and operate 560 crop-acres under the 5-year rotation with high fertilizer application to obtain $2 per hour for his labor. The corn price must be above $1 to bring this return to labor with any other machinery or cropping combination.

[10] Earl O. Heady and Laurel Loftsgard. Farm planning for maximum profits on Cresco-Clyde soils in northeast Iowa and comparision of farm and nonfarm incomes for beginning farmers. Iowa Agr. Exp. Sta. Res. Bul. 450. 1957.

Table 6. Corn price at which per-unit costs equal returns at minimum cost acreage for Carrington-Clyde soils.

Cropping system	Machinery combination[a] 1	2	3	4	5	6	7	8
Current cropping system								
Crop acres (A)	240	360	400	520	600	680	680	720
Low fertilizer ($)	1.11	1.03	1.03	1.03	1.03	1.02	1.04	1.05
High fertilizer ($)	1.05	0.98	0.98	0.97	0.98	0.97	0.99	1.00
5-year rotation system								
Crop acres (A)	200	320	320	480	520	560	640	640
Low fertilizer ($)	1.03	1.00	1.00	0.99	0.99	0.98	1.00	1.01
High fertilizer ($)	1.02	0.96	0.95	0.95	0.95	0.94	0.97	0.98
Continuous corn		One-man			Two-man (no sheller)		Two-man (sheller)	
Crop acres (A)		280			320		440	
Corn price ($)		0.84			0.80		0.85	

[a] See table 2 for titles of machinery combinations corresponding to given numbers.

Table 7. Residual return per hour at the minimum-cost acreages for eight machine combinations on Carrington-Clyde soils.

	Machinery combination[a] 1	2	3	4	5	6	7	8
Current cropping system								
Crop acres (A)	240	360	400	520	640	680	680	720
Low fertilization								
1953-57 prices ($)	2.21	3.11	3.19	4.41	4.54	4.83	4.46	4.37
1956-58 prices ($)	1.16	1.84	1.87	2.44	2.44	2.69	2.29	2.16
1958 prices ($)	0.05	0.52	0.50	0.40	0.31	0.47	0.05	—0.09
High fertilization								
1953-57 prices ($)	2.77	3.80	3.89	5.44	5.54	5.77	5.51	5.48
1956-58 prices ($)	1.62	2.38	2.45	3.30	3.30	3.60	3.16	3.07
1958 prices ($)	0.36	0.89	0.88	0.99	0.87	1.01	0.59	0.50
5-year rotation system								
Crop acres (A)	200	320	320	480	520	560	640	640
Low fertilization								
1953-57 prices ($)	2.42	3.42	3.51	4.70	4.91	5.18	4.95	4.78
1956-58 prices ($)	1.37	2.08	2.12	2.74	2.78	3.01	2.70	2.29
1958 prices ($)	0.32	0.64	0.72	0.75	0.78	0.82	0.41	0.17
High fertilization								
1953-57 prices ($)	3.00	4.08	4.29	5.78	6.01	6.38	6.11	5.80
1956-58 prices ($)	1.83	2.58	2.74	3.60	3.65	3.96	3.61	3.30
1958 prices ($)	0.65	1.08	1.16	1.37	1.25	1.50	1.01	0.76

[a] See table 2 for titles of machinery combinations corresponding to given numbers.

Table 8. Corn price needed to give residual returns to labor of $2 per hour for six machinery combinations on Carrington-Clyde soils.

Cropping system	Machinery combination[a] 1	2	3	4	6	7
Current cropping system						
Low fertilizer	$1.27	$1.15	$1.15	$1.10	$1.08	$1.10
5-year rotation						
High fertilizer	1.16	1.07	1.06	1.02	1.00	1.03

[a] See table 2 for a description of the machinery combinations corresponding to given numbers.

In interpreting table 8, again it must be remembered that these prices are determined for the minimum-cost acreages; at any other acreage, the appropriate corn price would be higher.

With the continuous-corn operation, a corn price of 97 cents (1958 average price) would still give residual returns to labor of $3.48 with the two-man operation on 320 crop-acres. Residual returns to labor would be above $1 per hour with all continuous-corn operations, assuming operations at minimum-cost acreages, as long as the corn price is above 84 cents per bushel.

Land Returns

We compute residual returns to land in this section. The procedure used is the same as that for labor. All factors excluding land are assumed to be paid the market rates. The remaining net returns are then imputed to land. Since costs were calculated by using land as a variable resource, the total residual returns to land can be used to compute the marginal residual returns for each increment of land. Starting from zero, the first acres have large losses since all fixed machinery and labor costs are charged to them. As acreage is expanded further, however, marginal residual returns become positive if marginal costs are less than the marginal value product of land. Although net income from a particular acreage is negative, the marginal residual returns to land are positive under these conditions.

Figure 14 includes curves of marginal imputed value for land when marginal residual returns to land are capitalized at 5 percent for two machinery combinations on Carrington-Clyde soils under the current cropping system and two price levels. The schedules of imputed values for land parallel the marginal profits

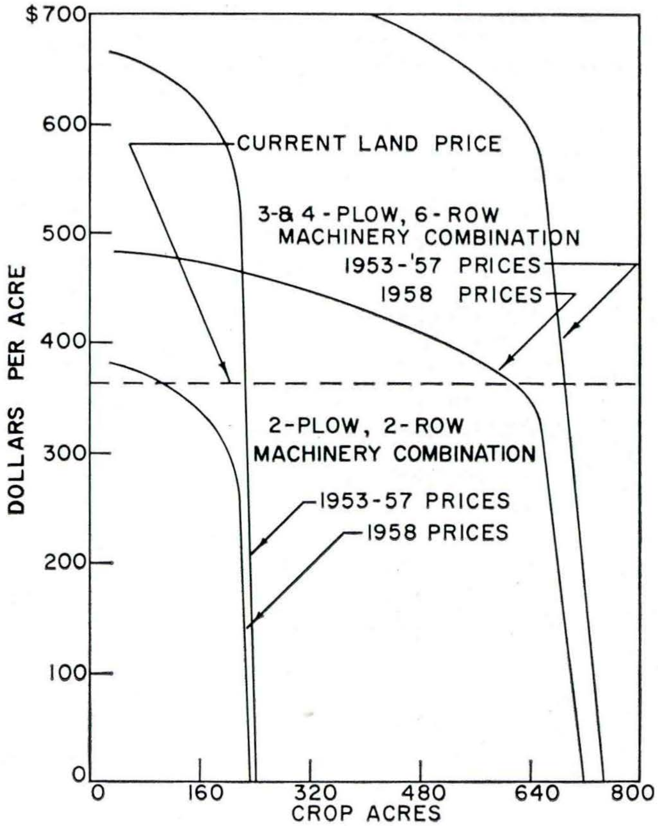

Fig. 14. Marginal imputed values of land with current cropping systems capitalized at 5 percent on Carrington-Clyde soils for two machine combinations.

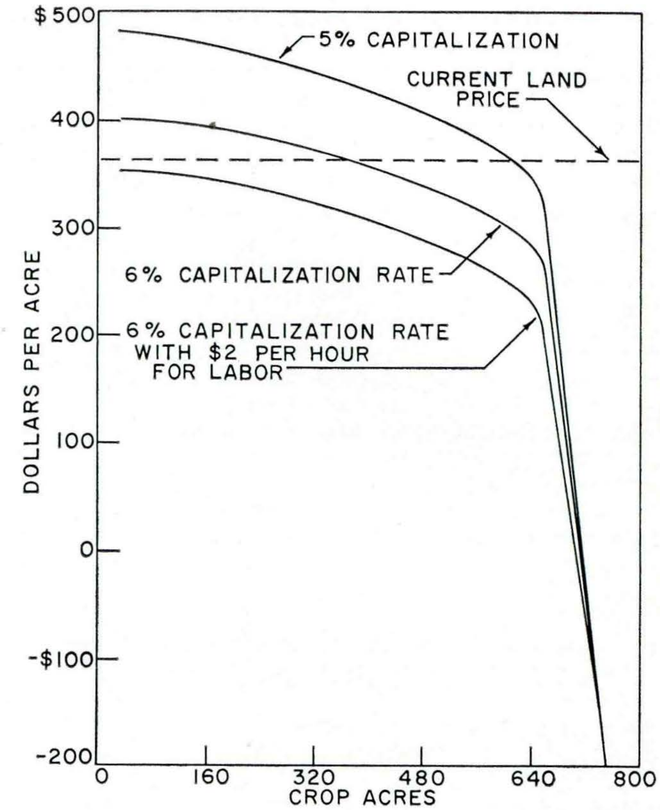

Fig. 15. Marginal imputed values of land with 3- and 4-plow tractors and 6-row machinery for current cropping systems on Carrington-Clyde soils.

associated with increasing acreage and, hence, are essentially the inverse of the marginal cost curves previously examined. At acreages where the marginal cost of producing $1 worth of product is less than $1, the capitalized residual return to land is greater than the current land price.

The schedules presented in fig. 14 demonstrate the effect of changes in product prices on marginal imputed land values. With a given set of machinery, the marginal imputed value of land varies from $7 to $9 with each 1-cent change in the price of corn. Figure 14 also indicates differences in marginal imputed land values resulting from two machine combinations. In general, these imputed values continue to be greater than current land prices over an extended acreage for the higher capacity machine combination. At either set of prices, a farmer with the 3- and 4-plow tractors with 6-row equipment could pay more for added acreage than a farmer with a 2-plow tractor and 2-row equipment. The curves of marginal imputed land values thus suggest one reason why land prices have risen over the last decade, even while product prices were falling.

An imputed resource value, figured as a residual, depends both on the prices of commodities and on the returns attributed to other resources. Figure 15 has been developed for one machinery combination to illustrate the effects on the marginal imputed value of land of different (a) capitalization rates for land and (b) imputed rates for labor. Calculations are based on 1958 prices and the current cropping system on Carrington-Clyde soils. The marginal imputed value of land declines as both the capitalization rate is increased to 6 percent and the imputed return to labor is raised from $1 to $2 per hour.

OPTIMUM ACREAGE UNDER WEATHER VARIATIONS, CARRINGTON-CLYDE SOILS

Cost curves presented previously in this study were based on "average weather" for Carrington-Clyde soils. Cost calculations assumed average yields and a number of days available for field operations in each year equal to the average over an 18-year period. In this section, untimeliness losses are based on "other than average number of days" available for field operations in each year.

Figure 16 presents average total cost curves for the machinery combination of 3- and 4-plow tractors, 6-row field equipment and a combine-picker for three weather conditions: (a) weather equal to the average over 18 years, (b) weather equal to the "worst" 2 years out of the 18 years and (c) weather equal to the "best" 2 years out of the 18. "Worst" refers to the 2 years with the least number of days available for field operations. Similarly, "best" refers to the 2 years with the most days suitable for field operations.

A decrease in the number of days available for field operations lowers the acreage at which average

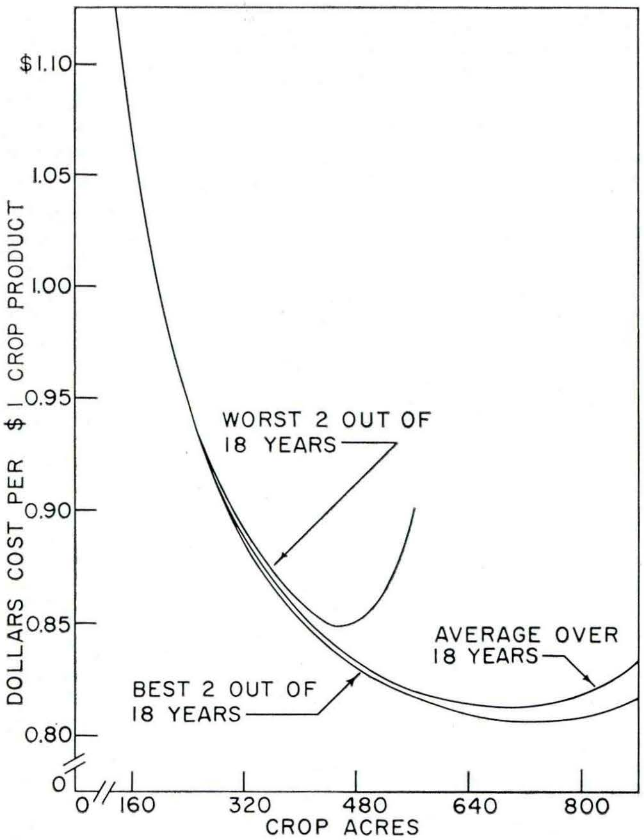

Fig. 16. Effects of variations in weather on the average costs of producing $1 worth of crop product on Carrington-Clyde soils.

costs reach a minimum. With 197 days available per year (best weather), per-unit costs reach a minimum at 760 acres. Under average weather (170 days), per-unit costs are a minimum at 680 acres. With only 143 days available (worst weather), the same machinery combination has a minimum per-unit cost at 460 acres. A farmer who has based his production plans on average weather and committed himself to operating 680 acres would have serious losses from untimely operations in several years out of the 18. His average cost of producing $1 of product with 680 acres would be $1.12, or a net loss for 1 year of $3,134. His total receipts would actually be higher if he reduced crop-acres.

Optimum Acreage Under Weather Variation

Cost curves of the types presented in previous sections are of the static type since they do not consider decision making with respect to variablity. We now consider some aspects of variability as they relate to selection of acreage. We do so only in a simplified framework where certain of the alternatives in acreage and machine combinations are placed in a game-theory framework.

To bring weather variations closer to farm-size determination, information is needed on magnitude of net profits resulting from various acreages operated under different weather conditions. To simplify these calculations, we have classified years into five groups on the basis of weather over 18 years. Category A in table 9 signifies the "best" weather, and category E signifies the "worst" weather as explained in the preceding section. Other categories fall between these, with category C taken as the "middle 6 years" with respect to weather and days available for field operations. To determine optimal farm size for the 3- and 4-plow combine-picker combination on Carrington-Clyde soils, net profits are budgeted for each weather category over the acreage range considered likely to contain the optimal acreage. Multiplying estimated net profit by the frequency of occurrence of each type of weather gives an **expected value of net return** (mathematical expectation) for each acreage. The acreage giving the highest expected value of net return is now designated as the optimal acreage. On the basis of this criterion, the optimal acreage for the 3- and 4-plow combine-picker machinery combination is 600 acres. It has an **expected value of net return** of $5,242 at 1953-57 prices (return above all costs when labor is included as expense but interest on land investment is not subtracted). This compares with 823 acres as the optimum size farm for this set of machinery under average weather (i.e., where cost and return are calculated as if weather in each year would be equal to the average of the 18 years).

Table 9. Weather categories.

	Weather categories				
	A	B	C	D	E
Years occurrence in 18 years	2	4	6	4	2
Probability of occurrence	0.11	0.22	0.33	0.22	0.11
Total number of days available per year	197	181	170	160	143

By comparing the **expected value of net return** with net profits under weather category C (quite similar to average weather), we note the differences resulting from averaging unit costs over all weather and per-unit costs computed on the basis of near-average weather (table 10). At any acreage, the **expected value of net returns,** where costs and net returns are averaged over all weather, is lower than profits under category C. Production costs per dollar value of output are higher when averaged over all weather than when based on average weather (category C).

Table 10. Net profits for various acreages with five categories of weather and the 3- and 4-plow, combine-picker machinery combinations (Carrington-Clyde soils and 1953-57 prices).

Crop-acres	Net profits for the five categories of weather ($/yr.)					Expected value of net return ($/yr.)
	A	B	C	D	E	
440	4,151	4,130	4,107	3,788	3,694	3,960
480	4,846	4,803	4,753	3,802	3,791	4,412
520	5.546	5,416	5,371	3,832	3,828	4,828
560	6,031	5,990	5,947	3,842	2,961	5,115
600	6,619	6,541	6,451	3,701	1,195	5,242
640	7,155	7,068	6,947	2,756	—467	5,189
680	7,677	7,544	7,379	1,439	—3,134	4,910
720	8,121	7,982	7,774	—173	—7,907	4,307

GAME THEORETIC CRITERIA APPLIED TO CARRINGTON-CLYDE SOILS

A decision criterion based on expected values is described as decision making under risk. Luce and Raiffa[11] point out that the mathematical expectation of the monetary value, as computed here, may not be the relevant decision criterion for many individuals. Not only the mean, but perhaps the variance of expected returns also should be considered. Some individuals on Carrington-Clyde soils may prefer the strategy (crop acreage) which minimizes income, variance (440 acres), or the strategy with the largest expected value for 1 year (720 acres). Numerous criteria of selection are possible, depending on the individual's risk-security preference schedule.[12]

Although the frequencies of occurrence of the various types of weather may be known, uncertainty still exists as to what the weather will be in any one year. Decisions on farm size and machinery investment are of a relatively long-run nature, and arrangements cannot be changed for each year. The uncertainty of weather in a given year may, of course, be the relevant point for a beginning farmer, for example. It is necessary for him to select courses of action so that he can "stay in the game," especially for the first year. The proper criteria for determining farm size and machine investment under these conditions will depend upon the individual's pessimistic or optimistic outlook, as well as his ability to rent farms of different sizes and to obtain corresponding amounts of capital for machinery.

Decision Criteria

Numerous game theoretic criteria can be used as a basis for decisions under uncertainty. Several of them are used here as a basis for specifying farm size in acreage when weather is presumed uncertain for the decision-making period.

Under the Wald maximin criterion,[13] a very conservative model, one would choose the strategy giving the largest minimum return. In this case, it would be the acreage giving maximum profits under the worst weather conditions, or 520 acres on Carrington-Clyde soils. For the Savage minimax-risk criterion, which is less pessimistic, one would choose 560 crop-acres. This criterion specifies choice of the event (strategy) which minimizes the maximum risk. Risk in this case would refer to the amount of loss resulting from operating too many crop acres, should be worst weather actually occur.

A third criterion, the Hurwicz pessimism-optimism index, gives solutions only after a particular pessimism-optimism index is chosen for an individual making a decision. This criterion is based on the weighted sum of the worst and best possible outcomes of each strategy (alternative in farm sizes and machine investments). In this case, the outcome is examined for each acreage under the worst and the best weather conditions thought to be possible. All intermediate results are ignored. For each act, or acreage, A_i, let m_i be the minimum (worst weather) and M_i the maximum (best weather). Some number α between 0 and 1, called the pessimism-optimism index, is chosen. The weight given to the worst outcome is α, and the weight given to the best outcome is $1 - \alpha$. For each act, the α index for A_i is equal to $\alpha \, m_i + (1 - \alpha) \, M_i$. Using this criterion the strategy (acreage) which gives the maximum α index is chosen. Optimum acreages have been computed when various values have been assigned to α. The results are presented in table 11.

Table 11. Optimal farm size with various levels of the Hurwicz pessimism-optimism index.

Level of α	Optimal farm size (maximum α-index) (crop-acres)
0.0	720[a]
0.1	680
0.2	640
0.3	560
0.4 to 1.0	520

[a] Results on units larger than 720 acres were not included in the above analysis; hence, for a state of complete optimism, the proper answer in this case is not 720 acres but 840 acres.

Table 11 indicates that optimal farm size decreases with increasing pessimism regarding weather (α increasing). The individual with extreme optimism ($\alpha = 0$) would be willing to gamble on the weather and expand acreage to the maximum in a given year in hopes of a maximum return. This strategy, however, would not maximize returns in the long run. Individuals with this high degree of optimism may be few in number. Selection of the proper farm size would depend upon the individual's risk-security preference schedule. For example, few beginning farmers would likely follow the results based on average weather.

A similar analysis was carried out with the 3- and 3-plow, 4-row machinery combination. This, or a quite similar machinery combination, is frequently found in northeast Iowa. The results indicated that, when variations in weather are considered, long-run expected returns would be maximized with 400 acres on Carrington-Clyde soils. Estimates based on average weather and with the same product prices indicated minimum per-unit costs at 520 acres and optimum farm size, in a profit-maximizing sense under 1953-57 prices, of 640 acres.

These examples show that farm businesses might not survive if they expanded acreage to a point equating marginal cost and marginal revenue in an average year. In these two examples, when considering weather variations, the optimum farm size is 12 to 22 percent smaller than the acreage which gives minimum per-unit costs, and 27 to 37 percent smaller than the optimum farm size under the supposition of marginal cost and marginal revenue equated under acreage expansion.

[11] R. Duncan Luce and Howard Raiffa. Games and decisions. John Wiley and Sons, Inc. New York. 1957.

[12] The term "risk-security preference schedule" is used here to refer to an individual's desire for, or aversion to, risk. It is not inferred that a quantitive index of this attitude is possible.

[13] The several decision criteria are discussed in Luce and Raiffa, **ibid.**, pp. 278-285; and John L. Dillon and Earl O. Heady. Theories of choice in relation to farmer decisions. Iowa Agr. and Home Econ. Exp. Sta. Res. Bul. 485. 1960.

Table 12. Net profits for 200 acres of Carrington-Clyde soil with three machinery combinations and variations in weather (1953-57 prices).

Machinery combinations[a]	Weather categories A	B	C	D	E	Expected value of net return
No. 1 combination						
2-plow, 2-row	$1,473	$1,473	$1,470	$ 822	$—1,260	$1,013
No. 2 combination						
3-plow, 4-row	1,444	1,444	1,441	1,376	1,120	1,378
No. 3 combination						
4-plow, 4-row	1,329	1,329	1,324	1,311	1,221	1,298

[a] See table 2 for a more complete description.

Determination of Optimum Machinery Investment for a Given Acreage

A similar decision problem exists for a farmer with a fixed acreage and with choice in the amount of capital to invest in machinery. He is faced with the alternatives of excessive crop losses in years of poor weather or excess machinery costs in years of good weather. The problem can be constructed as a game matrix, much the same as the acreage problem just discussed. Table 12 provides such a matrix where net profits for three sets of machinery and five categories of weather have been computed for 200 acres. These particular sets of machinery are the smaller capacity combinations and were considered more likely to be optimum on 200 acres (on the basis of the previous analysis based on average weather). The weather categories are those explained earlier. Profit estimates are based on the current cropping system and 1953-57 product prices.

On the basis of average weather, estimated average costs of producing a dollar of crop product are 87.5 cents with the 2-plow, 2-row set of machinery, 87.9 cents with the 3-plow, 4-row combination and 88.9 cents with the 4-plow, 4-row machinery combination. Hence the budgeting results based on average weather in each year would call for the use of the 2-plow, 2-row combination on 200 crop-acres. However, the data in table 12 indicate that the 3-plow, 4-row combination would give maximum **expected value of net returns** in the long run. Losses are quite severe in poor weather years with the 2-plow, 2-row machinery combination. With the 3-plow, 4-row combination, losses during the 2 years of worst weather are much less (only $320 per year), while fixed machine costs are only slightly higher. With the 4-plow, 4-row set, crop losses are only about $100 per year during the worst weather years, but fixed machinery costs increase by more than this amount.

The machinery investment problem just posed can also be examined in an uncertainty framework. As stated previously, the type of weather which will occur in any one year is uncertain, although the distribution of weather may be known. A farmer usually has greater opportunity to vary machinery investments than to vary land investments. Actually, changing from the 3-plow, 4-row combination to the 4-plow, 4-row combination involves only a change of the tractor and plow. Similarly, a farmer with the 2-plow, 2-row combination could avoid most of his crop losses by using a 4-plow tractor and corresponding plow instead of his 2-plow arrangement.

The several criteria for decision making under uncertainty are now used in analyzing the machinery investment problem. The results obtained from application of these decision criteria to the 200-acre example are given in table 13. In general, investments in machinery increase with increasing pessimism regarding weather. According to the Hurwicz pessimism-optimism critrion, only the most extreme optimist (α less than 0.009) would try to operate 200 acres with the 2-plow 2-row machinery combination. This is the set of machinery designated as optimal for 200 acres by the analysis based on average weather in every year.

Table 13. Decisions on optimal machinery combination for 200 crop-acres (Carrington-Clyde soils and 1953-57 prices).

Criterion	Decision on machinery combination
Static cost analysis	1>2>3[a]
Risk (expected value)	2>3>1
Uncertainty	
Maximin	3>2>1
Minimax risk	2>3>1
Pessimism-optimism index	
α less than 0.009	1>2>3
α between 0.009 and 0.055	2>1>3
α between 0.055 and 0.532	2>3>1
α greater than 0.532	3>2>1

[a] For machinery combinations, see table 2. The symbol > means "preferred to."

A second example of the determination of optimal machinery investments deals with a farm unit of 560 acres. Net profits were estimated for three alternative machinery combinations (see table 14). All machinery combinations include two tractors. Cropping programs and prices are those used for the 200-acre example.

As indicated in table 15, an individual who is extremely optimistic about the weather (an α index less than 0.135) would minimize machinery investments and choose the 3- and 3-plow, 4-row machinery combination. Most farmers, however, would probably order the alternatives 7>6>4. In a year with best weather, the 3- and 4-plow combine-picker combination shows $659 less profit than the 3- and 4-plow, 6-row combination. In a year with poorest weather, however, profits are $4,343 higher with the combination which includes the field sheller.

With 560 acres, the budgeting (static cost) analysis calls for a larger machinery investment than do the uncertainty criteria. However, the machinery set chosen under uncertainty criteria does not give minimum per-

Table 14. Net profits with 560 crop-acres for three machinery combinations with variations in weather.

Machinery combination[a]	Minimum cost per $1 product with average weather	Weather categories A	B	C	D	E	Expected value of net returns
No. 4 combination							
3- and 3-plow, 4-row	$0.799	$6,774	$6,691	$6,494	$ 346	$—1,800	$4,238
No. 6 combination							
3- and 4-plow, 6-row	0.796	6,690	6,642	6,612	1,164	—1,382	4,483
No. 7 combination							
3- and 4-plow, combine-picker	0.820	6,031	5,990	5,947	3,842	2,961	5,115

[a] See table 2 for additional detail on the machinery combinations.

Table 15. Decisions on optimal machinery combination for 560 crop-acres (Carrington-Clyde soils and 1953-57 prices).

Criterion	Decision on machinery combination[a]
Static cost analysis	6>4>7
Risk (expected value of net returns)	7>6>4
Uncertainty	
Maximin	7>6>4
Minimax risk	7>6>4
Pessimism-optimism index	
α less than 0.132	4>6>7
α between 0.132 and 0.135	4>7>6
α between 0.135 and 0.167	7>4>6
α greater than 0.167	7>6>4

[a] For machinery combinations, see table 2. The symbol > means "preferred to."

unit costs for average weather. The set chosen by the uncertainty criteria includes field shelling of corn. As shown earlier, field shelling requires the extra cost of drying and results in higher per-unit costs with average weather assumptions. Field shelling provides much more field capacity in corn harvesting, also allowing more time for fall field work. This extra capacity results in a per-unit cost curve which rises more slowly under "average weather in each year" assumptions. In the case where variations in weather are considered, however, this capacity reduces crop losses considerably in years of bad weather.

A general conclusion which can be drawn from the several sets of computations is: The set of machinery which gives lowest per-unit costs under assumptions of "average weather in each year" has too little capacity to be optimum when variations in weather are considered. Where decisions are based on risk or uncertainty criteria, the capacity of the machinery specified is greater than the optimum indicated for "average weather in each year" assumptions. Under the latter assumption, field corn shellers would not have any profit advantage on farms of less than 800 acres. Under the uncertainty analysis, however, the optimum machinery combination for 560 acres is one which includes a field sheller. The 560-acre size represents a simple discrete example. The same finding might even have held true had the analysis been applied to smaller acreages. (A field sheller was not included in machine combinations for 200 acres, analyzed under uncertainty criteria.) Even from the 200-acre example, we can conclude that 4-row corn equipment is profitable on a smaller acreage than would be indicated by the static budgeting analysis of costs.

APPENDIX

Table A-1. Variable machinery costs and field capacities of individual machines.

Machine	Depreciation per service unit	Repairs per service unit[a]	Power cost per acre	Minimum annual depreciation	Acres per hour[b]
Tractors					
2-plow	$0.252	$0.236	—	$210.74	—
3-plow	0.309	0.289	—	258.29	—
4-plow	0.379	0.354	—	316.26	—
Plows					
2-14″	0.174	0.246	$1.08	20.86	0.67
3-14″	0.166	0.239	0.88	29.81	1.00
4-14″	0.163	0.230	0.74	39.02	1.33
3-14″-2-way	0.282	0.239	0.88	50.72	0.92[c]
8′ tandem disk	0.103	0.080	0.40	17.96	3.10
10′ tandem disk	0.098	0.076	0.40	20.48	3.88
20′ drag harrow	0.034	0.013	0.17	10.62	7.76
24′ drag harrow	0.036	0.017	0.12	13.02	9.31
Endgate seeder	0.037	0.020	0.20	7.42	9.0
Fertilizer spreader	0.140	0.100	0.25	31.00	4.1[c]
Corn planters (check row)					
2-row	0.240	0.096	0.33	30.00	1.40
4-row	0.228	0.114	0.23	45.54	2.80
6-row	0.243	0.121	0.20	72.78	4.20
Lister planters					
2-row	0.204	0.20	0.50	30.00	1.40[c]
4-row	0.270	0.20	0.50	54.00	2.50[c]
Cultivators					
2-row	0.116	0.062	0.46	29.10	2.04
4-row	0.093	0.049	0.24	54.30	4.08
6-row	0.105	0.056	0.22	87.45	6.12
2-row rotary hoe	0.130	0.069	0.29	9.75	4.08[c]
4-row rotary hoe	0.130	0.069	0.16	19.49	8.16
7′ power mower	0.206	0.320	0.36	27.82	2.72
8′ side delivery rake	0.220	0.205	0.34	33.00	3.10
Baler (medium capacity)	0.410	0.150	0.42	272.85	3.78
Corn pickers					
1-row pull type	1.355	0.093	1.08	101.62	0.83
2-row mounted	1.276	0.851	0.82	191.39	1.66
2-row mounted with sheller	1.615	1.077	1.23	242.32	1.66
Combines					
7′ motor mounted	1.328	0.944	0.70	239.04	1.66
12′ pull type	1.397	0.869	0.62	419.13	2.84
12′ self propelled with corn picker attachment	1.480	0.829	1.12	739.90	1.66
Wagon with flair box and flat rack	—	—	—	21.69	—
40′ grain and bale elevator	—	—	—	30.75	—

[a] Includes grease and oil expense.
[b] Applies to Carrington-Clyde soils unless otherwise indicated.
[c] Applies to Ida-Monona soils.

Table A-2. Quantities of fertilizer input for various rotations and fertility levels (pounds per acre active ingredients).

	N	P_2O_5	K_2O
Carrington-Clyde soil			
Low fertility level			
Corn	8	20	20
Oats	0	20	0
Total per 40 crop-acres			
Current cropping system	130.4	520	326
5-year rotation system	160	568	400
High fertilizer level			
1st-year corn	5	42	51
2nd-year corn	41	26	17
Oats after soybeans	25	20	0
Oats after corn	10	3	0
Meadow	0	7	38
Total per 40 crop-acres			
Current cropping system	482.8	744.7	983.9
5-year rotation system	612.0	728.0	916.0
Continuous corn			
Per acre	43.3	25.7	17.1
Total per 40 acres	1,730	1,028	681
Ida-Monona soil			
CCOM rotation			
1st-year corn	34	24	0
2nd-year corn	42	24	0
Oats	12	23	0
CCOMM rotation			
1st-year corn	21	39	0
2nd-year corn	40	39	0
Oats	16	47	0
Total per 40 acres	823.4	733.8	0

Table A-3. Composition of crops in rotations and resulting yields per acre (no untimeliness losses assumed).

	Corn	Oats	Soybeans	Hay
Carrington-Clyde soil				
Current cropping system				
Acres per 40 acres of cropland	16.3	9.5	4.1	10.1
Yield per acre				
Low fertilization	64 bu.	44 bu.	23 bu.	2.3T.
High fertilization	71 bu.	47.2 bu.	26 bu.	2.8T.
5-year rotation system				
Acres per 40 acres of cropland	20	8	4	8
Yield per acre				
Low fertilization	64 bu.	44 bu.	23 bu.	2.3T.
High fertilization	71 bu	47.2 bu.	26 bu.	2.8T.
Continuous corn				
Yield per acre	71 bu.	—	—	—
Ida-Monona soil				
Acres per 40 acres of cropland				
CCOM (0-14% slope)	15.6	7.8	—	7.8
CCOMM (15-24% slope)	3.52	1.76	—	3.52
Total	19.12	9.56	—	11.32
Yields per acre				
CCOM	64.3 bu.	37.4 bu.	—	2.5T.
CCOMM	53.3 bu.	32.7 bu.	—	1.8T.

Table A-4. Prices used in budgeting cost schedules.

	Unit	1953-57 Prices ($)	1956-58 Prices ($)	1958 Prices ($)
Corn	bu.	1.30	1.13	0.97
Oats	bu.	0.69	0.63	0.56
Soybeans	bu.	2.47	2.19	2.12
Hay	ton	17.89	16.30	13.50
Straw	bale	0.34	0.30	0.26
Phosphoric acid	cwt.	—	10.00	—
Nitrogen	cwt.	—	13.50	—
Muriate of potash	cwt.	—	12.00	—
Seed corn	bu.	—	12.00	—
Seed oats	bu.	—	1.10	—
Soybean seed	bu.	—	2.75	—
Alfalfa seed	cwt.	—	45.00	—
Ladino clover	cwt.	—	80.00	—
Bromegrass	cwt.	—	25.00	—

Table A-5. Normal date of beginning of field operations.[a]

Operation	Soil area: Carrington-Clyde	Soil area: Ida-Monona
First field work in spring	April 1	March 24
Plant oats	April 7	April 1
Plant corn	May 7	May 11
Plant soybeans	May 18	(no soybeans)
Cultivate corn		
1st time	June 2	June 3
2nd time	June 19	June 20
3rd time	July 1	July 1
Cultivate soybeans		
1st time	June 7	(no soybeans)
Cut meadow for hay		
1st cut	June 9	June 9
2nd cut	July 11	July 10
3rd cut	Sept. 3	Sept. 1
Harvest oats	July 18	July 11
Harvest soybeans	Sept. 25	(no soybeans)
Pick corn		
30% moisture	Oct. 1	Sept. 24
20% moisture	Oct. 27	Oct. 14
Last field work in fall	Nov. 15	Nov. 20

[a] Based on a survey of county extension directors in the areas studied.

Table A-6. Functions used in estimating crop losses resulting from untimely field operations.[a]

Field operation	Date when losses begin: Carrington-Clyde area	Date when losses begin: Ida-Monona area	Losses per day late
Corn planting	May 16	May 20	First 16 days....0.4 bu.[b] Next 15 days....0.84 bu. Remaining days....1.4 bu.
Corn cultivating			
1st time	5 days after starting date		0.5 bu.[c]
2nd time and 3rd time	5 days after starting date		0.25 bu.[c]
Corn harvesting	Oct. 31	Oct. 19	0.6 percent[d]
Oats planting	April 11	April 6	Loss = $Y_0 - .346x - .0203x^2$ (Y_0 = maximum yield[e] x = days late)
Oats harvest	July 21	July 14	0.71 bu.[f]
Soybean planting	May 26	—	0.60 bu.[g]
Hay harvesting			
1st cut	June 12	June 12	First 5 days....3.5%[h]
2nd cut	July 14	July 13	Same as for 1st cut
3rd cut	Sept. 6	Sept. 4	Same as for 1st cut

[a] Loss estimates given apply to Carrington-Clyde area. These losses were adjusted on a percentage basis for the Ida-Monona area.
[b] W. A. Russell, Ames, Iowa. Estimates on losses from late planting of corn. (Private communication.) 1959.
[c] Kenneth K. Barnes, Ames, Iowa. Estimates on losses from late cultivation of corn. (Private communication.) 1959.
[d] David Alan Link. Farm machinery selection from system economics. Unpublished M.S. thesis. Iowa State University Library, Ames, Iowa. 1958. (p. 136).
[e] K. J. Frey, Ames, Iowa. Data on trials on late planting oats at Independence, Iowa. (Private communication.) 1959.
[f] Link, ibid. (p. 134).
[g] C. R. Weber. Guide to higher soybean yields. Iowa Coop. Ext. Serv. Pamphlet Pm. 202. 1953.
[h] Based on results obtained by Dawson. Yield, composition and feeding value for milk production of alfalfa hay cut at three stages of maturity. U.S. Dept. Agr. Tech. Bul. 739. 1940.