FARM SIZE AND COSTS IN RELATION TO FARM MACHINERY TECHNOLOGY

by

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INTRODUCTION

Farmers operate in a dynamic rather than a static environment - an environment characterized by continual change and adjustment. One of the problems farmers constantly face in such an environment is that of determining the proper combination of resources to use in production. With continual change in agricultural machinery, the farmer is constantly faced with the question "What combination of land, labor, and machinery should be chosen?". This study is an attempt to provide quantitative information on cost relationships with various capacity sets of farm machinery. It is hoped that this information will be useful to farmers making decisions on the adoption of recent machinery innovations such as four-row and six-row corn equipment and field corn shellers.

In the present American economy two main forces are operating which require constant change and adjustment in agricultural production. One force operates on the demand side while the other force effects the supply side of agricultural production. On the demand side, the low income elasticity for farm products indicates that with a growing level of per capita income, the demand for agricultural products will increase less than the demand for other goods and services (3, p. 11). This relative change in demand will induce changes in the industry pattern of demand for resources. High income elasticity industries will enjoy a good demand for their products and will be able to outbid the low income elasticity industries, such as agriculture, for use of resources. Hence the prices of some factors used by farmers will rise relative to farm product prices.

Also, with this change in the demand structure, there will be changes in relative factor costs. Some resources will become more scarce than others. With a changing demand structure, non-agricultural demand for land will incur much less increase than non-agricultural demands for labor. These changing relative factor costs will encourage adjustments on the part of farm operaters in the combination of resources used in production.

On the supply side, the major cause of maladjustment in a developing economy is that of technological advancement. Most new techniques serve to change the marginal rates of physical substitution among resources (5). In the American economy, a technological innovation will generally encourage the use of less labor and more capital or land. Examples of such innovations in the past include corn and cotton pickers, combines, tractors, and many others. Farmers have responded to these technological improvements with a high rate of mechanization (4, p. 5).

However, despite the production adjustments made by farmers, farm incomes are still low relative to incomes of non-farm people. In 1955 the per capita income of non-farm people was $1,935 compared to $881 for farm people (3, p. 7). Hence, further adjustments in agriculture are required before resource returns in agriculture will equal resource returns in other industries.

A considerable time lag exists between the development and the general adoption of most technological improvements in agriculture. This time lag is partially due to the uncertainty involved. With an entirely new production process the probabilities of results are quite uncertain. For example, four-row and six-row corn equipment and field corn shellers have recently been developed but the adoption of these techniques has certainly not been general. Farmers are quite uncertain as to what effect the adoption of these techniques may have on per unit production costs and on their personal income. Farmers are also uncertain as to what combination of land, labor, and machinery investments will best utilize these new machinery techniques.

The relationships of land and machinery investments can be examined from two viewpoints: (1) What size farm is required to gain the benefits in cost reduction of the new machinery techniques? or (2) To what extent do new machine techniques change the structure of per unit costs which in turn will tend to influence farm size? Further changes in farm size can be expected with further mechanization as has occurred in the past (4, p. 6).

This study is designed to provide information on the effects of such machinery innovations as four- and six-row corn equipment and field corn shellers on per unit production costs. If the uncertainty surrounding the use of these new techniques can be reduced, farmers will be permitted to make better decisions and hence improve their income positions.

OBJECTIVES

The major purpose of this study is to determine the per unit cost relationships associated with various machinery techniques. In so doing, this study will attempt to describe what difference in per unit costs and optimum farm size[1] can be expected with the adoption of recent machinery innovations. This study is based on the hypothesis that the use of recent machinery innovations, such as six-row corn equipment and picker-shellers, will require relatively large farms for profitable crop production. It is also hypothesized that the minimum per unit costs possible with these newer machines will differ little from the minimum per unit costs possible with more conventional farm machinery on smaller-sized farms. In other words, the long-run average total cost curve is expected to be quite flat around its minimum point. These hypotheses are suggested by the fact that large capital investments in machinery will be required with such machine items. Accordingly, annual fixed costs will be proportionately higher, which will require large operations to attain low per unit costs.

This study will attempt to verify or reject these hypoth-

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[1]Optimum farm size is here 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 this is also the size of farm with minimum average total costs.

eses and also provide quantitative information which will be useful to farmers making decisions on investments in land or farm machinery.

Specific objectives of this study are:

1. To determine the nature of cost economies associated with various machinery techniques.
2. To determine what farm size will attain minimum per unit production costs with each of the various sets of machinery. Also of interest is the determination of the size farm which achieves the majority of the cost economies, i.e., at what size farm will further expansion in acreage produce only insignificant cost economies.
3. To provide such cost information for operations on various soil, rotation, and fertilizer conditions. These procedures will provide information usable to a greater number of farm operators.
4. To compare residual returns to labor and land resulting from operations carried on with various sets of machinery, under various price conditions, and for various cropping techniques. Such information may be of value to operators in comparing the returns to their resources with returns to resources employed in non-farm industries.
5. To examine the effects of weather variations upon the

optimal level of machinery investments and/or optimal farm size.

6. To incorporate the information gained on cost relationships under cash-grain operations into a determination of optimal long-run farm plans. In this phase of the study it will be possible to consider livestock opportunities and certain aspects of capital rationing.

The determination of optimum long-run farm plans in this study will allow consideration of subjective discounting of returns and a consideration of the quantity of capital available. As mentioned above, the amount of available capital is an important factor in determining individual farm size.

REVIEW OF LITERATURE

Derivation of Cost Schedules

Most of the literature on the estimation of per unit production costs revolves around theoretical aspects, or statistical pitfalls. Few empirical results are available (44, ch. 6; 45, ch. 3; 43). There are perhaps several reasons for this void. Tintner (45) points out that the range of available data on the output of a given firm is often not sufficient for statistical estimation of cost functions. When only one firm is examined, data are in time series form. Hence, the data describe the dynamic aspects whereas the cost curves to be estimated are static. Staehle (43) discusses other estimation problems involved in time series data, such as changes in technology, changes in scale of operation, and measurement problems in multi-product firms.

Many of these estimation problems could be avoided through the use of cross-sectional data. However, cross-sectional data would be difficult to obtain for the purposes of this study. The objectives of this study are to examine the effects of new machinery innovations on cost relationships and on optimal farm size. Hence, data would be required for farms of a wide variety of acreages. It is not likely that data would be available on per unit costs resulting from the operation of large machinery combinations on small acreages or the operation of small machinery combinations on large acreages.

An alternative empirical approach to estimation of cost relationships is suggested by Bressler (6), Heady (15) and Olson (38). They suggest a budgeting or "synthesis" approach by which total production and total costs are estimated on the basis of agronomic, engineering and other technical data. Beginning with such basic data as crop yields, required fertilizer inputs, machine capacities and machine input costs; estimates of total production and costs are developed. Such estimates can be developed for various scales of operation for a given set of fixed inputs or for various sets of fixed inputs. These estimates can thus be used to derive short-run or long-run per unit cost functions.

Scoville (41) used this approach in studying the economies of size of Nebraska corn-livestock farms. He synthesized efficient combinations of 1-, 2-, 3- and 4-man farms which would allow maximum use of resources without interfering with timely performance of field operations. Fellows (11) used a similar budgeting procedure to estimate returns-to-scale in potato farming. Fellows et al. (12, 13) also used this method to estimate the economies-to-scale in dairy farming in New England. In this study all resources were varied except labor. Gibbons (14) used a budgeting procedure to estimate costs per acre for crop production in north-central

Iowa. McKee (34) carried this same analysis a step further by making allowance for some losses due to untimely field operations and obtained estimates of costs per $100 crop product. However, McKee estimated untimeliness losses from only corn planting and oats planting, thus omitting the consideration of other critical periods of field work. Hence, the resulting cost schedules leave room for considerable improvement.

Link (30) utilizes estimates of losses from untimeliness of operations, along with estimates of the retail cost of machines as a function of machine capacity to derive an optimum set of machinery for a given farm. Link treated the various field operations and machines independently in assuming that each operation began on time. This assumption of independence may prove to be quite unrealistic and a serious limitation of his study.

Implications to Farm Size

McKee (34) concludes that most of the cost economies to be gained from farm expansion occur at relatively small acreages and diseconomies will not likely occur until extremely large acreages are attained. Heady, referring to McKee's study, arrives at the following conclusion:

> It is doubtful that technical conditions and cost economies are of a nature in most segments of American agriculture to endanger the units typically operated by farm families. We are willing to speculate that beyond a limited size, cost differ-

> entials and scale returns are less important than other considerations in limiting farm size or in allowing a varied pattern of farm size. (17, p. 363)

Similar conclusions were arrived at by Miller and Back (37). In their analysis of effects of technical change on farm size in the plains states, they concluded thusly:

> Perhaps technical progress, particularily mechanization was a necessary accompaniment to size increase . . . . However, we decline to assign the role of prime mover to technology in explaining actual changes in size made by farmers. _Technology created the potential for increase in size; other variables explained the actual size changes_. (37, p. 1260)

BUDGETING PROCEDURE

This section presents a description of the budgeting method used in studying the cost relationships with cash-grain farming. Cost curves developed for eight complete sets of farm machinery are used to study the effects of various machinery innovations on the structure of per unit costs. Each set of machinery includes a slightly different combination of equipment. These sets are designed to cover a wide range of possible combinations and field capacities, thus allowing comparisons of new machine innovations to conventional size equipment.

The cost curves developed in this investigation apply to the soil areas shown in Figure 1. The major portion of this study will apply to the Carrington-Clyde soil association in north-east Iowa. Most of the land in this soil association has a good agronomic rating for corn production. Intensive row-cropping is possible since the soil is generally not subject to erosion. The Carrington-Clyde area was selected to represent a soil type which would allow cash-grain farming on an extensive scale.

The Ida-Monona area was selected to represent the opposite extreme. The Ida-Monona association covers a belt of hilly and steep land bordering the Missouri river bottoms. The erosion hazard is quite severe on these soils, and the agronomic rating for corn production is below that of the

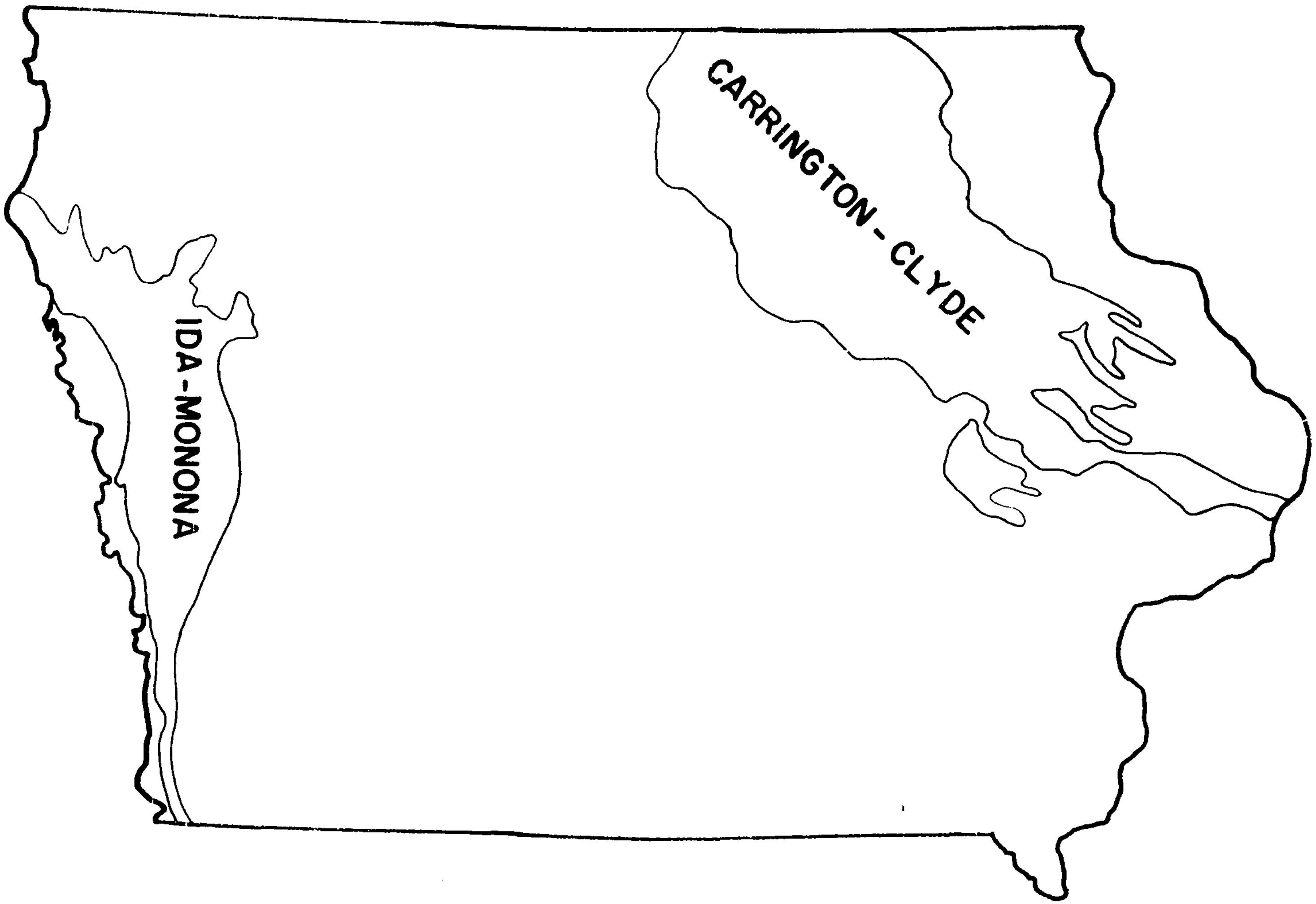

Figure 1. Soil association areas of Iowa considered in this study

Carrington-Clyde soils. Hence, more crop land is kept in meadow and cash-grain farming is not as common in the Ida-Monona area (47). Cost curves developed for Ida-Monona soils assume levels of conservation practices required to control erosion and maintain crop yields.

Sets of cost curves are developed for three cropping systems on Carrington-Clyde soils. These cropping systems include the current cropping system, as determined from 1954 census data (47); a five-year rotation; and a continuous-corn system. A combination of two rotations is assumed in budgeting cost curves for Ida-Monona soils. Table 1 outlines the cropping systems, fertility levels, and machinery combinations for which cost curves are developed.

The analysis of various rotations is performed to determine the effect of intensity of row-crops on per unit costs. Current cropping systems include approximately 51 percent of the crop land in row-crops, the five-year rotation includes 60 percent in row-crops and the continuous-corn program is of course all row-crops.

The various per unit cost curves are developed by budgeting total costs and total crop production at 40 crop acre intervals for each set of machinery. With a given set of machinery and with expanding acreage, the necessity of performing some field operations at sub-optimal times will eventually result in some yield losses. Such "untimeliness"

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
  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[b] and CCOMM[c]
  1. Three sets of machinery
  2. One fertilizer level

[a]Census (47).

[b]Corn-corn-oats-meadow rotation assumed for slopes of 0-13 percent.

[c]Rotation assumed for slopes of 14 percent or more.

losses are estimated for each 40 crop acre interval. 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 will follow.

Per unit cost curves are determined for eight sets of machinery with current cropping methods and the five-year rotation on Carrington-Clyde soils. Each set of machinery is designed with slightly different capacity in operations on row-crops. All machinery combinations assume identical hay harvesting operations with the exception that baling is custom hired with one set of machinery. Three machine combinations have one tractor and are designed for one-man operations. The remaining five sets include two tractors. With two-tractor machinery combinations, it is assumed that hourly labor is hired to operate the second tractor. A complete description of these machinery combinations is presented in Tables 35 through 41 of the Appendix.

Cost curves are also developed with three machinery combinations for a continuous-corn program on Carrington-Clyde soils. These three sets of machinery differ from the eight sets previously discussed since with continuous-corn, 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. Complete lists of the machinery included in all combinations are given in Tables 35 through 45 of the Appendix.

Costs of Input Requirements

For the calculations which follow, input costs are divided into annual fixed costs, variable costs per crop acre, and variable costs per unit of output. The cost curves so developed are short-run cost curves where machinery is the fixed item. Hence, fixed costs include annual fixed machinery costs and fixed overhead labor required for machine maintenance. Variable costs per acre include variable costs for machinery, land taxes, labor, and cropping expenses such as seed and fertilizer. Variable costs per unit of output, including transportation and corn drying, are not constant per acre since untimeliness of operations causes decreases in yields.

Fixed machinery costs include interest, taxes, insurance, housing and depreciation. A charge on machine investments of 7 percent is used in this study. Seven percent is approximately the current rate on loans for machinery purchases. This is a case of opportunity cost since capital outlays in the form of machinery may decrease the amount of capital available for investments in other farm opportunities. The 7 percent charge is assessed against the "average value" of all machinery. The average value is here defined as being equal to one half the sum of the purchase price plus 10 percent of the purchase price (trade-in value) (20, p. 75). An annual charge of 2 percent of the original purchase price of the machine is made for housing, taxes, and insurance (7). The 2 percent charge includes 1.4 percent for housing, 0.4 percent for personal property taxes and 0.2 per cent for insurance. These charges were found to be comparable with current costs.

In this study, depreciation charges include fixed and variable components. The fixed component is based on obsolescence and "normal annual use". The variable depreciation components are added when normal annual use is exceeded. Husain presents estimates of the maximum life of machines in years and service units[1] (26, p. 60). Maximum service units divided by maximum years of machine life gives "normal annual use". The fixed, annual depreciation component is obtained by dividing 90 percent of the purchase price by maximum years of service. Dividing 90 percent of the purchase price by maximum units of service gives the depreciation charge per service unit. Depreciation charges, itemized for all machines, are given in Table 24 of the Appendix.

Fixed labor overhead covers such items as off-season repair and overhauling of equipment which would be required regardless of acreage operated. It is estimated at 250 hours per year with a charge of $1 per hour (25).

Variable costs per acre 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 (28, p. 11 and pp. 175-177).

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[1]A service unit is an hour for tractors and an acre for other implements.

Variable machine costs include fuel, repairs, and extra depreciation charges for above-normal annual use. Fuel costs are obtained from a study by Epp (10) and are summarized in Tables 24 and 25 of the Appendix. Repair costs are based on estimates by Husain (26, p. 60). Husain established annual charges for repairs and service as percentages of the retail prices of the machine. These percentages of the retail prices were divided by the normal annual use to arrive at a repair cost per service unit. These data are also presented in Tables 24 and 25 of the Appendix.

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 (25, p. 7). It is estimated that maintenance labor is 50 hours per 40 crop acres per year for the first 400 acres, 40 hours per 40 acres from 400 to 600 acres and 25 hours per 40 acres above 600 acres. Labor required for actual field operations is equal to the number of tractor hours required. All labor, both maintenance and field operations, for operator's or hired labor, is charged at the rate of $1 per hour (47).

Cropping costs include seed, fertilizer and any custom charges required. Seed and fertilizer costs are itemized by cropping systems in Tables 24, 27 and 29 of the Appendix. Custom charges only apply to one set of machinery and are itemized in Table 24 of the Appendix.

Variable per unit costs include costs of transporting products to market and drying or shelling of corn. The transport cost is estimated at 3 cents per bushel on all grain crops and 3 cents per bale of hay or straw. With machinery combinations which include field corn shelling, 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 accessed on the production remaining after subtracting losses from untimely field operations.

Prices and Yields

The per unit cost curves formulated in this study measure costs per dollar value of crop product. Hence, at least one set of prices is needed to determine total value of output. However, three sets of prices are used to indicate the effect of changes in prices on costs per dollar output, and to determine at what price level per unit costs will equal returns. The three price levels chosen are averages of recent historical prices as reported in Iowa Farm Science (40). These price levels are averages for the years of 1953-57, and 1956-58 and for the single year 1958. Prices averaged for the 1953-57 period are the highest of the three levels chosen. In this period the 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 per bushel. Average prices for other crop products for each period are given in Table 30 of the Appendix.

Yields assumed for the current cropping program on Carrington-Clyde soils are the average of 1953-57 actual yields in the area (27). Yields and fertilizer requirements for other rotations on Carrington-Clyde soils are estimated by Pesek.[1] Yield data on Ida-Monona soils was obtained from Dean, _et al_. (9). All data on yields are given in Table 28 of the Appendix.

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 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.

[1]J. T. Pesek, Ames, Iowa. Estimates of fertilizer requirement levels for specified crop rotations on Carrington-Clyde soils. Private communication. 1959.

Hence the cost curves here developed are based on the assumption that such factors as management, labor, and land are unlimited in supply. The results must be interpreted accordingly.

In this study, estimates of total production are based on the assumption that losses in yields due to untimely operations occur with the following operations: (1) corn planting, (2) corn cultivating, (3) corn harvesting, (4) oats planting, (5) oats harvesting, (6) soybean planting and (7) hay harvesting. Estimates of the rate of loss occurring when operations are performed during a sub-optimal period were obtained from various agronomic and engineering sources. These loss functions include time limits on the no-loss period, and the estimated loss resulting each day from operations after this period. These loss functions, along with their source, are presented in Table 32 of the Appendix.

To determine the losses resulting from untimeliness of operations, several items of information are needed, including: (1) the hours of machinery input required per acre specified for each cropping operation, (2) the number of hours available in each day for field operations, (3) estimates of the optimal date to perform each operation, and (4) estimates of the losses that occur if operations are performed during a sub-optimal period. To determine machinery requirements per acre, a schedule of field operations is first established for each crop. This schedule approximates current operations by farmers in the Carrington-Clyde area and is presented in Table 34 of the Appendix. Effective field capacities of machinery were determined as follows (2, p. 26):

$$C = \frac{5280 \times S \times W \times Ef}{43,560 \times 100}$$

where C = effective field capacity, in acres per hour,

S = speed of travel, in miles per hour,

W = rated width of implement, in feet, and

Ef = field efficiency, in percent.

The field efficiencies (Ef) used in this study are estimates derived from time and motion studies of field operations (2, p. 53). The resulting field capacities are given in Table 24 of the Appendix.

A schedule of machine hours required per 40 crop acres is next established. This schedule is based on the effective field capacities of machines, schedules of operations performed on each crop, and the acres of each crop grown on 40 crop acres.

Average dates for beginning each operation and the time limitations on the optimal period for operations were obtained from a survey of County Extension Directors in the respective soil areas. McKee (34, p. 81) presents a table of days available for field operations by weeks obtained from work records of the Agronomy Farm at Ames, Iowa. McKee's schedule of available days was adjusted to fit conditions in north-east and western Iowa through the use of climatology date (42). These schedules of available days are given in Table 33 of the Appendix.

STRUCTURE AND RELATIONSHIPS OF PER UNIT COSTS WITH VARIOUS MACHINERY COMBINATIONS

This section will present cost curves determined for eight sets of machinery with current cropping methods in the Carrington-Clyde area and based on 1953-57 prices. In this section, attempts are made to estimate the effect of specific machines on per unit production costs and on optimal farm size. The cost structures will be first examined on a per acre basis. Figure 2 presents total costs per acre for the eight basic machinery combinations. These curves are derived with the assumption that no losses due to untimely field operations have occurred. Such losses would lower some cost items such as shelling and drying corn, and transporting the products to market, and hence lower the costs per acre. The curves in Figure 2 were extended to cover the range of acreage which can be operated with the particular set of machinery, given the average number of days available for field operations.

With any set of machinery, costs per acre would be constant, regardless of farm size, if all costs were variable. However, a large part of the total cost involved in crop production is the fixed annual machinery costs. In the machine combinations here studied, fixed machine costs vary from $1092 to $3349. Hence, total costs per acre will decline as acreage is increased.

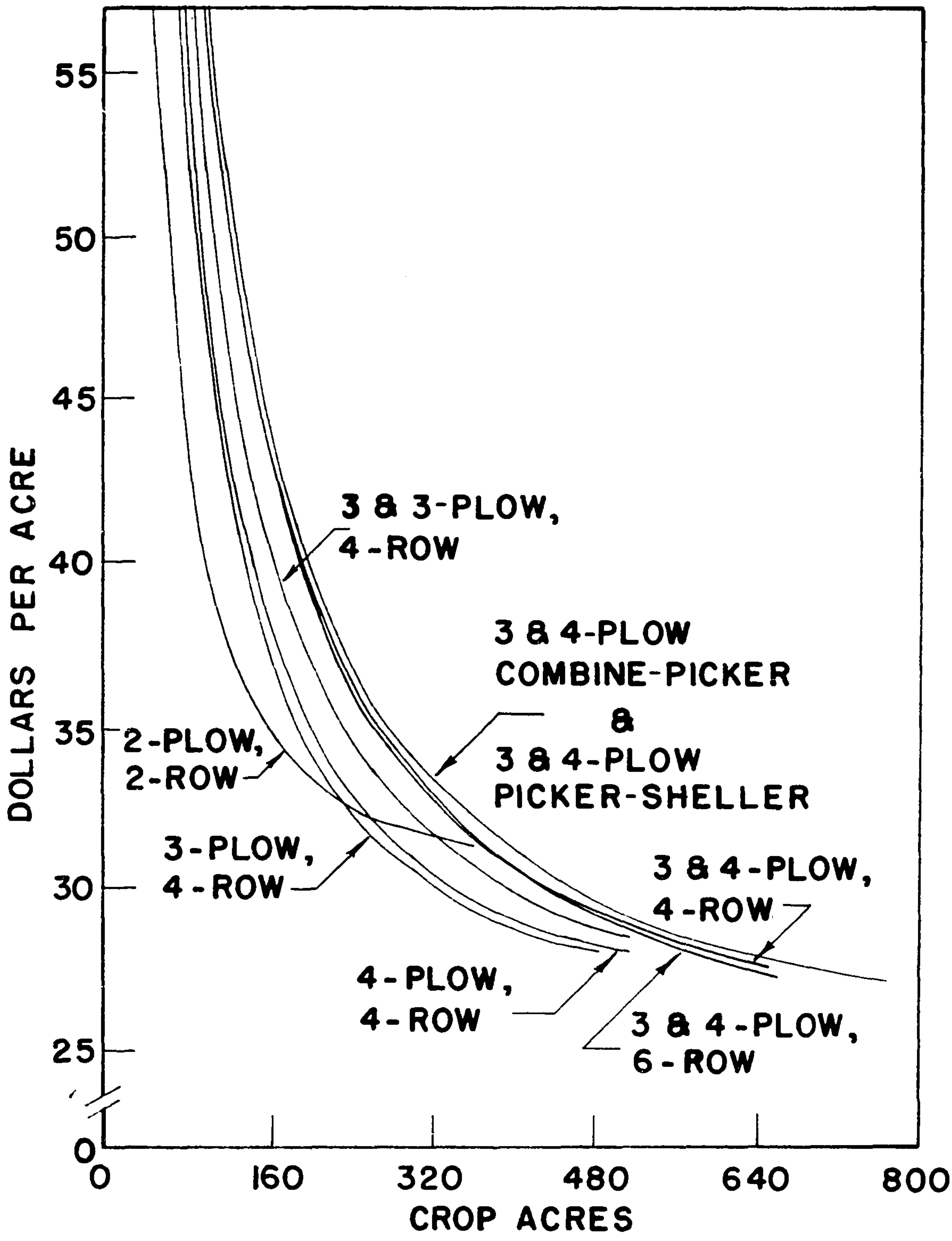

Figure 2. Average costs per acre with current cropping programs and assumed no crop losses

With expanding acreage, the lower limit to per acre costs is variable costs. At very large acreages, the fixed cost component becomes an insignificant part of total per acre costs. The reader will note from Figure 2 that this lower limit to per acre costs, variable costs, is not the same for all machinery combinations studied. Variable costs are considerably higher with the two-plow, two-row combination.[1] Higher variable costs result with this combination since it does not include grain combining or hay baling equipment. Hence fixed machine costs are lower but variable costs are considerably higher because of the necessary custom operations. With this two-plow, two-row combination, per acre costs reach a lower limit of $31.40 at 360 crop acres. Further farm expansion is not possible with this set of machinery. With other machinery combinations, costs reach a minimum of approximately $27-$28 per acre.

Figure 2 indicates that the majority of farmers are presently operating in an area of decreasing per acre costs. With 160 crop acres, the minimum per acre costs would be approximately $35, whereas $27 is the minimum for larger acreages. At 440 acres, the majority of the cost economies to be

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[1]Machine combinations presented in this section are referred to by the plow capacity and type of corn equipment. A complete listing of all machine items included in each combination is given in Tables 35 to 45 of the Appendix.

gained from increasing farm size is already attained. Increasing farm size from 440 to 960 crop acres would reduce per acre costs by only $1.60.

The cost curves presented in Figure 2 do not contain any charge for investments in land. Hence, the estimates presented do not measure all costs. However, land costs would, by definition, be constant per acre and hence, including interest on land would not change the curvature of these cost curves.

These cost curves, however, ignore crop losses due to untimeliness of operations and hence cannot give answers to questions of optimal farm size. Figure 3 presents a set of average per unit cost curves when losses from untimeliness of operations are considered.

The reader will note from Figure 3 that the cost curves presented in this study are not of the usual type. The usual average cost curve presents physical quantity on the horizontal axis and dollars cost per unit of physical output on the vertical axis. To determine average cost with a multi-product firm when all products are to be considered, aggregation of the individual products is necessary. The only feasible aggregation procedure is to weight the physical quantities by their respective prices. This procedure results in the measurement of costs per dollar value of output instead of costs per physical unit of output. The main disadvantage of this change in axis is that the cost schedules will move vertically as

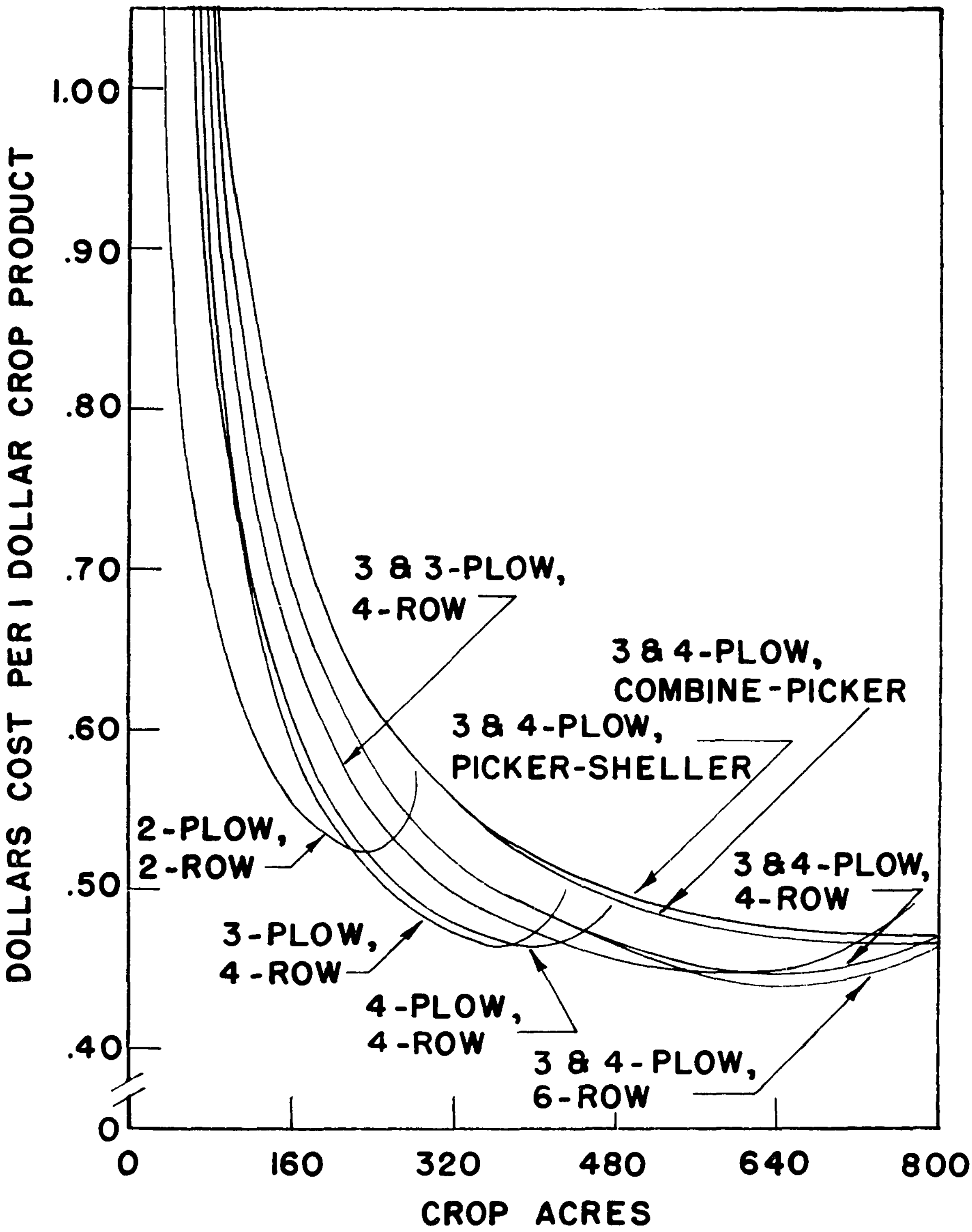

Figure 3. Average costs of producing $1 worth of crop product with eight machinery combinations based on current cropping methods

product prices vary. With rising product prices and constant costs, the cost curve will fall.

A second difference between these cost curves and the type found in economic textbooks deals with the quantity axis. In the cost curves here presented, the quantity measured on the horizontal axis is not output but land input. The cost curves are presented in this manner to facilitate discussion in terms of farm size. However, some accuracy is lost by using land input instead of output on the horizontal axis. Figure 4 presents average per unit costs with one set of machinery and one cropping system on both the land input axis and the dollars of output axis. The two average cost curves are identical at small acreages where crop losses due to untimely operations are negligible. With expanding acreage, crop losses gradually become more severe, and dollar output per acre falls, hence, costs per dollar output rise more than costs measured on the acreage axis.

As shown in Figure 3, with the two-plow, two-row combination, minimum average costs are attained at 240 crop acres. Below 200, and above 240 acres, average costs rise quite sharply. Farmers with 210 or less crop acres would minimize per unit costs by using this set of machinery. The two-plow, two-row combination includes a complete line of comparable size equipment excluding a combine-harvester and hay baler.

The three-plow, four-row combination includes a complete

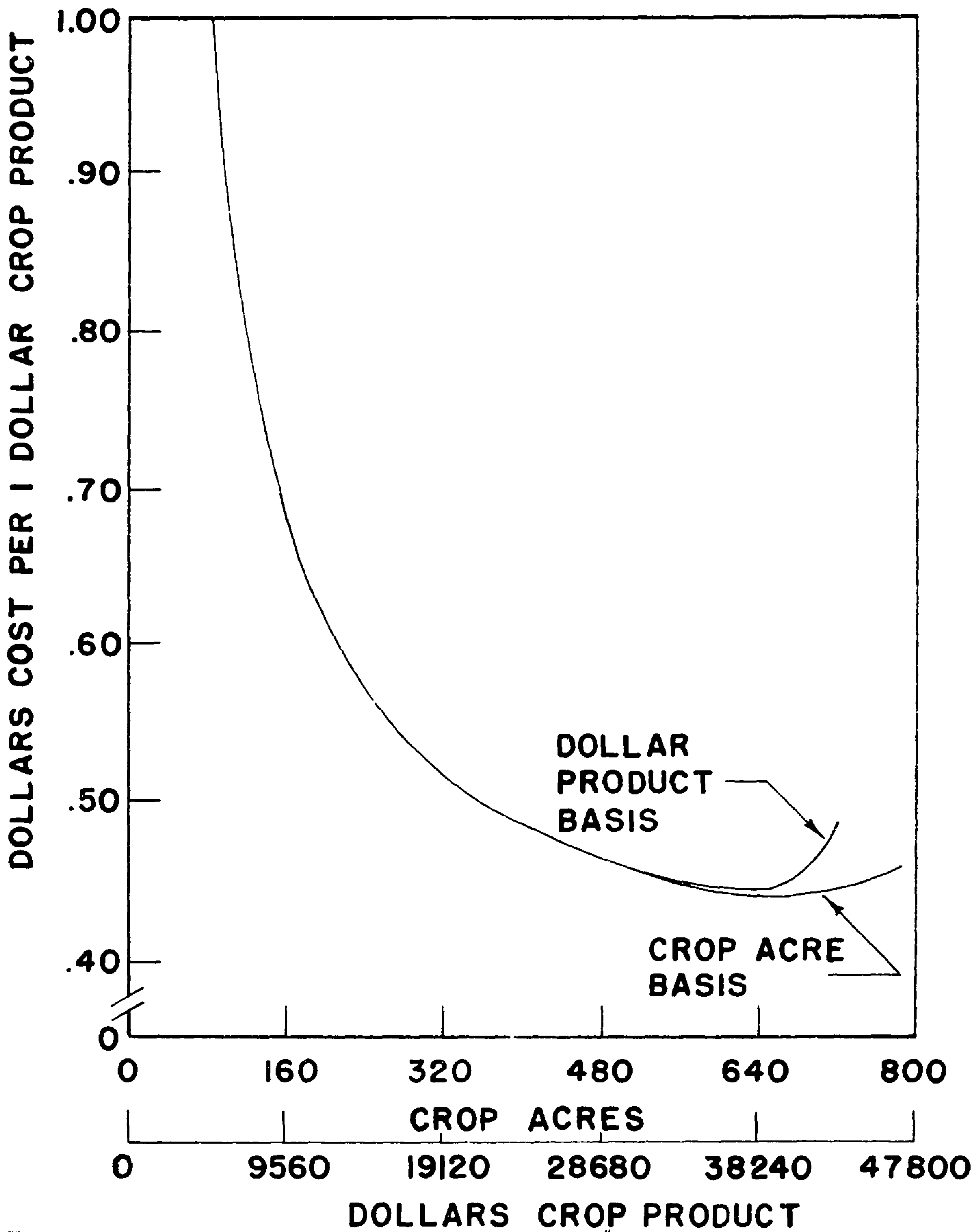

Figure 4. Average costs of producing $1 worth of crop product with crop acres and total dollars product on the quantity axis (three- and four-plow, six-row machinery combination)

complement of machinery for a three-plow tractor. Of the machinery combinations studied, this set gives lowest average per unit costs on farms with 210 to 370 crop acres. The results included in Figure 3 indicate that it would be unwise for a farmer with the two-plow, two-row combination to expand acreage to where average per unit costs are a minimum. If this farmer is operating 210 or more acres of crop land he would be wise to increase machinery investments instead of land investments. Between 200 and 280 crop acres, untimeliness losses are increasing rapidly with the two-plow, two-row combination. At 240 acres (the minimum average cost acreage for the two-plow combination), changing to the three-plow, four-row combination would increase total annual costs by $68 but would increase total value product by $241.

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

All remaining machine combinations studied include two tractors and four- or six-row corn equipment. The three and three-plow, four-row combination includes two three-plow tractors, four-row corn equipment and a two-row mounted corn picker. With this set of machinery, average costs are a minimum at 640 acres. This would be the optimal set of machinery for farms ranging in size from 430 to 560 crop acres. As with the two-plow, two-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 three and four-plow, four-row machinery combination does not give lowest per unit costs at any acreage. This set of machinery includes one three-plow and one four-plow tractor, four-row corn equipment and a four-row rotary hoe. Per unit costs are lower with this combination than with the three and three-plow combination on farms with 600 or more crop acres. However, average per unit costs are still lower with the machinery combination which includes six-row corn equipment. The combination which includes six-row equipment has almost the same amount of fixed costs as the three and four-plow combination, but due to larger corn cultivating capacity, results in less untimeliness losses and hence, lower average costs per dollar output.

Two sets of machinery were also studied which include equipment for field shelling of corn. The combine-picker combination includes a 12' self-propelled combine-harvester with a corn picker head; while the picker-sheller combination has a 12' pull-type combine and a two-row mounted corn picker with sheller attachment. Fixed costs are nearly the same for these two machinery sets. However, per unit costs are slightly higher with the picker-sheller combination due to higher repair costs per acre and slightly more losses in oats harvesting. The minimum in per unit costs attainable with either of these two sets of machinery is higher than the minimum per unit costs 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 spring and a definite limit to farm size. However, these savings in harvesting and planting losses are outweighed by the 10 cent per bushel drying charge required for field shelled corn. As a result, minimum per unit costs are 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.

Table 2 presents a summary of the results discussed above. It is evident from Table 2 that with the current cropping system, quite large acreages are needed to obtain any cost benefits from recent machinery innovations. Also, the cost advan-

Table 2. Costs per dollar product for all machinery combinations with current cropping system and 1953-57 prices

Machinery combination	Range in acreage with lowest average total costs	Minimum average cost acreage	Minimum average cost
2-plow, 2-row	0-210	240	$.52
3-plow, 4-row	210-370	360	.47
4-plow, 4-row	370-430	400	.46
3 and 3-plow, 4-row	430-560	640	.45
3 and 4-plow, 4-row	none	680	.45
3 and 4-plow, 6-row	560-800	680	.44
3 and 4-plow, combine-picker	800-960	760	.47
3 and 4-plow, picker-sheller	none	760	.47

tages to be gained are quite small. The cost estimates in Table 2 do not include a charge for land or management and hence do not attempt to estimate total costs. However, they do indicate the cost relationships that do exist. According to Table 2, and Figure 3, a machinery combination including one four-plow tractor and four-row corn equipment attains almost all cost economies possible. With this set of machinery, 400 crop acres would be the minimum cost acreage. The use of six-row equipment would not give lower per unit costs unless farm size is expanded to 560 crop acres. Although the possibility of using six-row equipment with a one-tractor combination was not examined, such possibilities would not appear to be profitable. The budgeting of timeliness of field operations indicated that with the four-plow, four-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 six-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, say corn cultivating, may not be profitable since other operations may be the real bottleneck to the expansion of farm size.

Table 2 also indicates that field shelling of corn is not a profitable activity unless a farm has at least 800 crop acres. The advantage of such machine items in getting harvesting done on time is outweighed by the higher fixed costs and drying costs involved.

The use of four-row corn equipment is expected to result in significant cost economies compared to two-row equipment, which may cause economic pressures to expand farm size. Further expansion in machinery capacity to include six-row equipment would reduce per unit costs by an additional 1 or 2 cents per dollar product. This cost reduction is probably not sufficient to induce further farm enlargement. However, if prices are above per unit costs, considerably more income would result from farm enlargement due to the increase in volume of output.

Field shelling will not induce farm enlargement from the standpoint of per unit costs; per unit costs are generally higher with field shellers than with conventional harvesting equipment. However, here again, with sufficiently high product prices, the large volume that can be produced with combinations which include field shellers may induce further farm enlargement.

These results indicate that a farmer with any size farm could not profitably invest in machinery solely to eliminate all untimeliness losses. For example, with 160-crop acres, crop losses are zero only with the machinery combinations which include field corn shellers. With these combinations, average costs per dollar product are 4 cents above the next best combinations and 18 cents above the least cost set of machinery. Similar results are indicated at other acreages.

It is evident that 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. In so doing, he may incur small untimeliness losses but would be reducing fixed costs per unit of output.

These interpretations are, of course, based on "average weather". With variations in weather taken into account, some modification of these results may be necessary. These possibilities are dealt with later.

Regardless of the set of machinery under consideration, the structure of per unit costs is very similar. Figure 5 presents the various cost functions for the three- and four-plow, six-row machinery combination. Results are similar for other sets of machinery, only the scales of measurement would differ.

Average fixed costs per unit of output continue to decline as long as output increases. Average variable costs are almost constant at small acreages and increase slowly with increasing acreage. Actual inputs per acre are almost constant regardless of acreage. With increasing acreage the only additional charges are for extra wear and tear on machinery. The rise in variable costs is due to the decrease in average yields which result from untimely field operations. This rise in variable costs per unit of output is exemplified by the marginal cost function. A marginal cost function of this shape results with 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

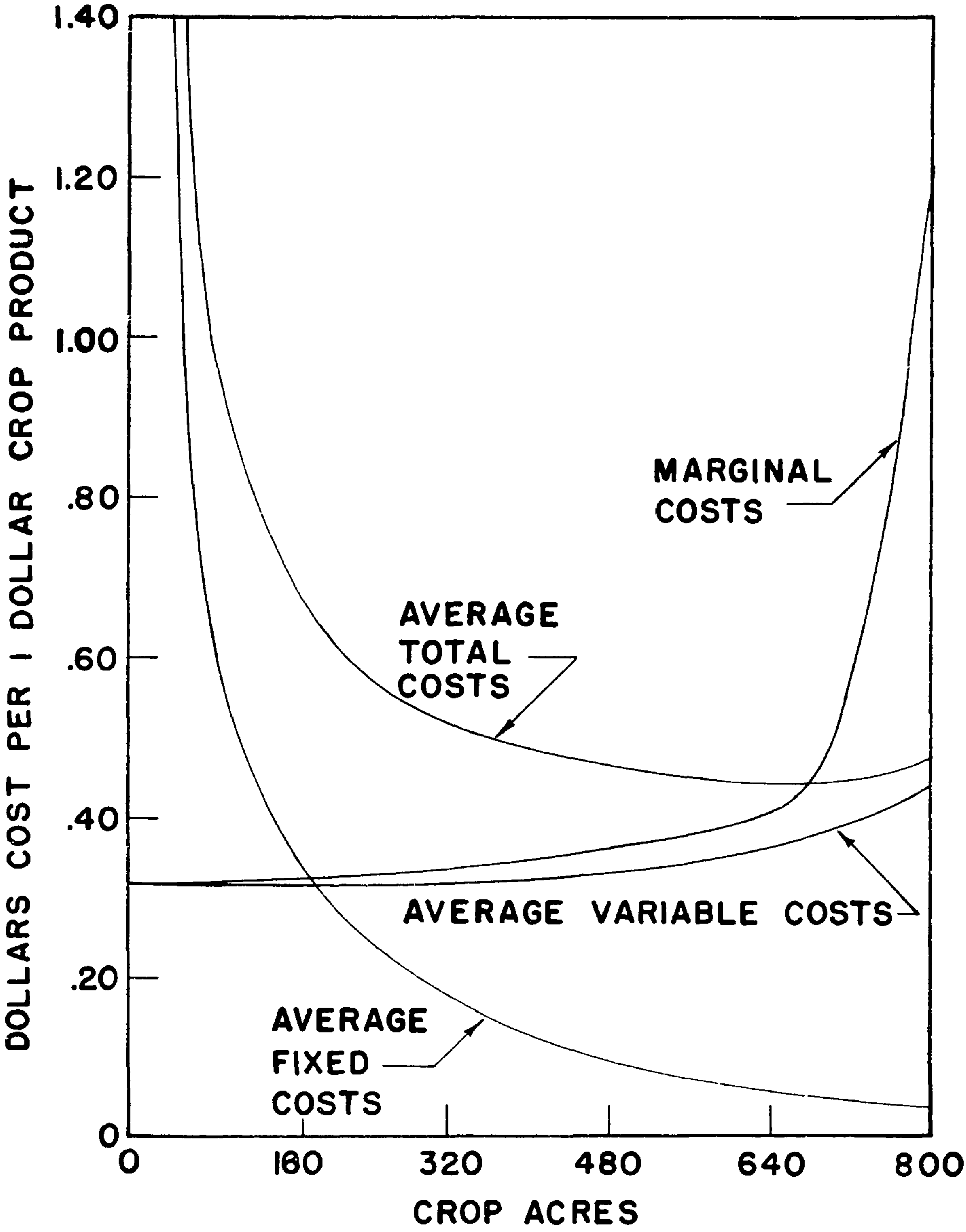

Figure 5. Per unit cost functions for the three- and four-plow, six-row machinery combination based on current cropping methods

operations. With current cropping systems this increase in losses generally occurs when corn planting begins to interfere with soybean planting, resulting in very heavy losses in soybean production.

In the real world, the marginal cost function may have a more gradual upward slope with no sharp break as here indicated. This sharp break is partly a result of the assumption of constant input requirements regardless of acreage operated. The budgeting analysis allows decreasing yields by considering losses from untimely operations, but the budgeting procedure assumes constant labor and machinery requirements per acre regardless of farm size. Under actual farming conditions, it is more likely that input requirements per acre will vary with expanding acreage.

Table 3 lists percentage value losses due to untimely field operations. Since no other factors are considered which reduce yields, the marginal cost schedule is quite directly related to percent losses. With no losses, marginal costs are constant and equal to average variable costs. Small percentage losses are mainly due to untimely corn harvesting. These losses have little effect on marginal costs and in themselves would never limit farm size. Larger product losses, (1 percent or more), begin to appear when planting difficulties arise. As farm size is further increased, planting losses increase quite rapidly and result in steeply inclined marginal cost

Table 3. Percentage value losses due to untimely field operations for selected machinery combinations (current cropping system, 1953-57 prices)

Crop acres	Machinery combination: 2-plow, 2-row	3-plow, 4-row	3- and 3-plow, 4-row	3- and 4-plow, 6-row	3- and 4-plow, combine-picker
40	0	0	0	0	0
80	0.21	0	0	0	0
120	0.63	0.07	0	0	0
160	1.11	0.25	0.06	0.06	0
200	1.81	0.50	0.20	0.18	0
240	2.46	0.78	0.40	0.36	0.03
280	15.33	0.91	0.66	0.60	0.11
320		1.52	0.96	0.88	0.21
360		2.02	1.28	1.18	0.32
400		5.70	1.63	1.50	0.47
440			2.01	1.83	0.64
480			2.46	2.17	0.82
520			2.96	2.53	1.04
560			3.51	2.90	1.28
600			5.81	3.33	1.64
640			6.32	3.74	2.03
680			7.11	4.26	2.49
720			10.41	6.12	2.92
760			13.90	8.99	3.41
800				11.92	4.07
840				15.34	5.26
880					6.53
920					8.06
960					10.21

curves. The cost analysis indicates that farm expansion should cease when losses due to untimely operations reach 2 to 4 percent of the total value of the crop.

The average total cost curves for all two-tractor combinations are quite flat near the minimum cost point.[1] For example, with the three- and four-plow, six-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 are slowly declining, hence, average total costs remain nearly constant.

A long-run average cost curve or envelope curve is presented in Figure 6. This envelope curve is based on the eight sets of machinery considered and on current cropping techniques. As indicated by Figure 6, the minimum per unit cost acreage in the long run is approximately 680 crop acres. With free resource mobility, and with the resource prices assumed in this study, a farm of 680 acres would survive the lowest product prices. On the other hand, average total costs vary less than 2 cents per dollar product between 400 and 800 crop acres. Such a small difference in per unit costs would allow survival of farms of quite a variety of acreages. Considerably higher per unit costs are incurred on farms of less than 400 crop acres. Thus considerable cost economies exist

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[1]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.

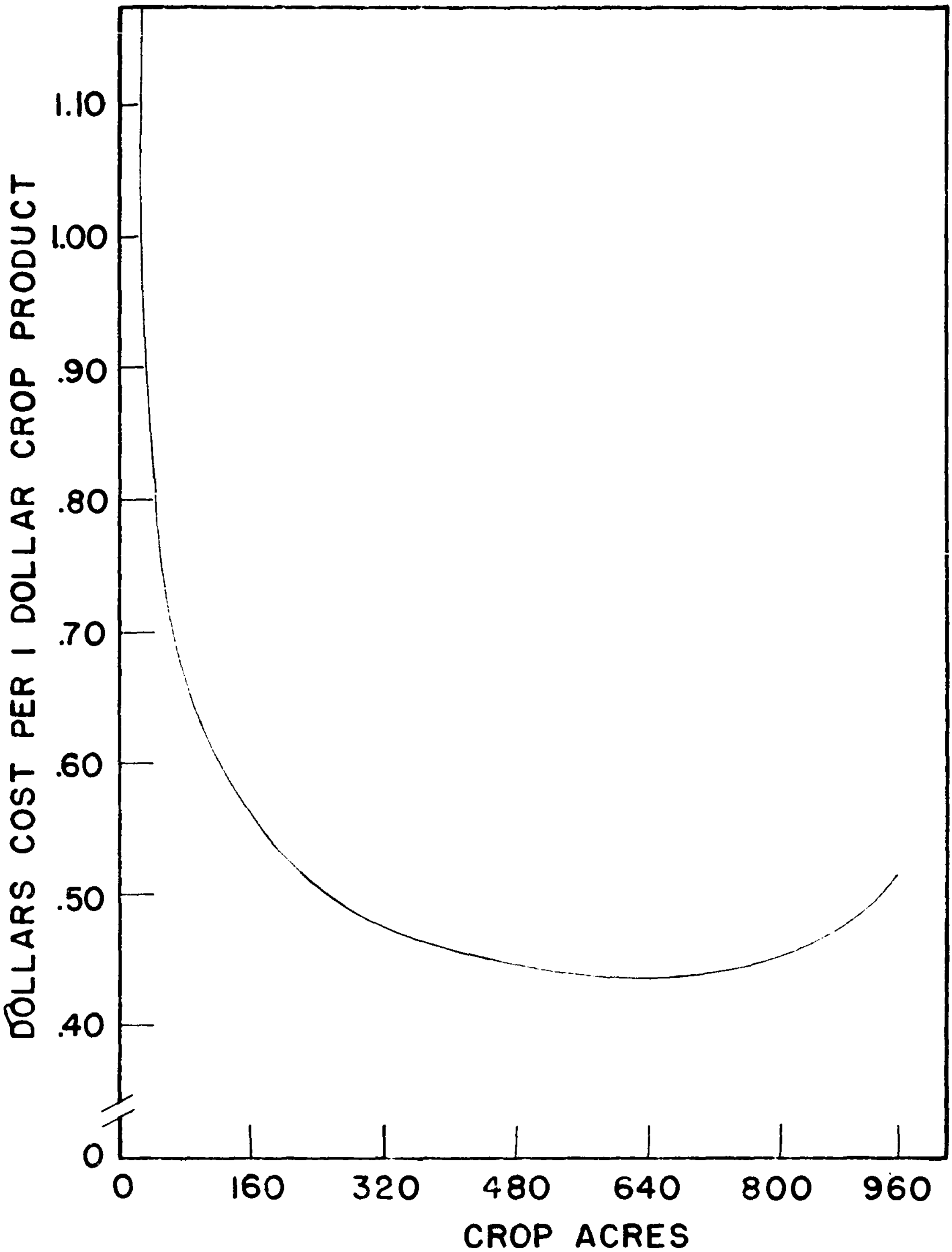

Figure 6. Long-run average cost or envelope curve based on current cropping methods and 1953-57 prices

to expand farm size to at least 400 acres. Whether the average size of farm will actually reach this level depends on many other factors besides costs.

The envelope curve indicates rapidly increasing per unit costs for farm size above 800 crop acres. This rise in per unit costs can perhaps be avoided through the use of three- or four-tractor machinery combinations. Such large sets of machinery would probably not attain minimum per unit costs below 800 crop acres.

With the assumptions used in budgeting techniques, farm size could be expanded indefinitely at approximately the same per unit costs through increasing machinery investments. The same minimum in per unit costs could result since management inputs are assumed to be unlimited. Realistically, with expanding acreage, per unit costs would probably be more and more a function of managerial ability.

With farms of less than 400 crop acres, smaller capacity combinations of machines would probably not reduce average total per unit costs. Although fixed costs would be lower, they would be averaged over few acres.

RELATIONSHIP OF THE CROPPING SYSTEM TO PER UNIT COSTS OF CROP PRODUCTION

The determination of the cost curves presented in the previous section was possible only through restricting the analysis to one very limited situation. The above results apply only to the situation which meets the following specifications:

1. One soil type - Carrington-Clyde,
2. One cropping system - current methods,
3. One fertilization level - current levels,
4. One set of product prices - 1953-57 average,
5. One set of input prices - current market rates,
6. Only for "average weather".

In this and following sections, attempts are made to obtain results when these restricting conditions are relaxed in a singular fashion. This section will deal with two additional cropping systems and two fertilizer levels.

Per Unit Costs Under a Five-Year Rotation Program

Budgeted cost curves are here presented for the same eight sets of machinery previously studied but based on a five-year rotation plan. This rotation includes one year of oats, one year meadow, two years corn and one year of half corn and half soybeans. In this rotation plan 60 percent of the crop land is in row crops. The first set of cost curves presented in this section is also based on current fertilization rates and 1953-57 prices.

Figure 7 presents the average per unit cost curves obtained from budgeting with the five-year rotation system. The resulting cost relationships between machinery combinations are almost identical with results obtained for the current cropping system. Table 4 presents the results obtained

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

Machinery combination	Minimum average cost[a] Current cropping system	Minimum average cost[a] Five-year rotation	Minimum cost acreage Current cropping system	Minimum cost acreage Five-year rotation
2-plow, 2-row	$.52	$.52	240	200
3-plow, 4-row	.47	.46	360	320
4-plow, 4-row	.46	.46	400	360
3 and 3-plow, 4-row	.45	.45	640	560
3 and 4-plow, 6-row	.44	.44	680	600
3 and 4-plow, combine-picker	.47	.47	760	720

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

with the five-year rotation compared to results with current cropping methods for six sets of machinery. The results in Table 4 indicate the main effect of the change in cropping systems, which is a reduction in the number of acres that can

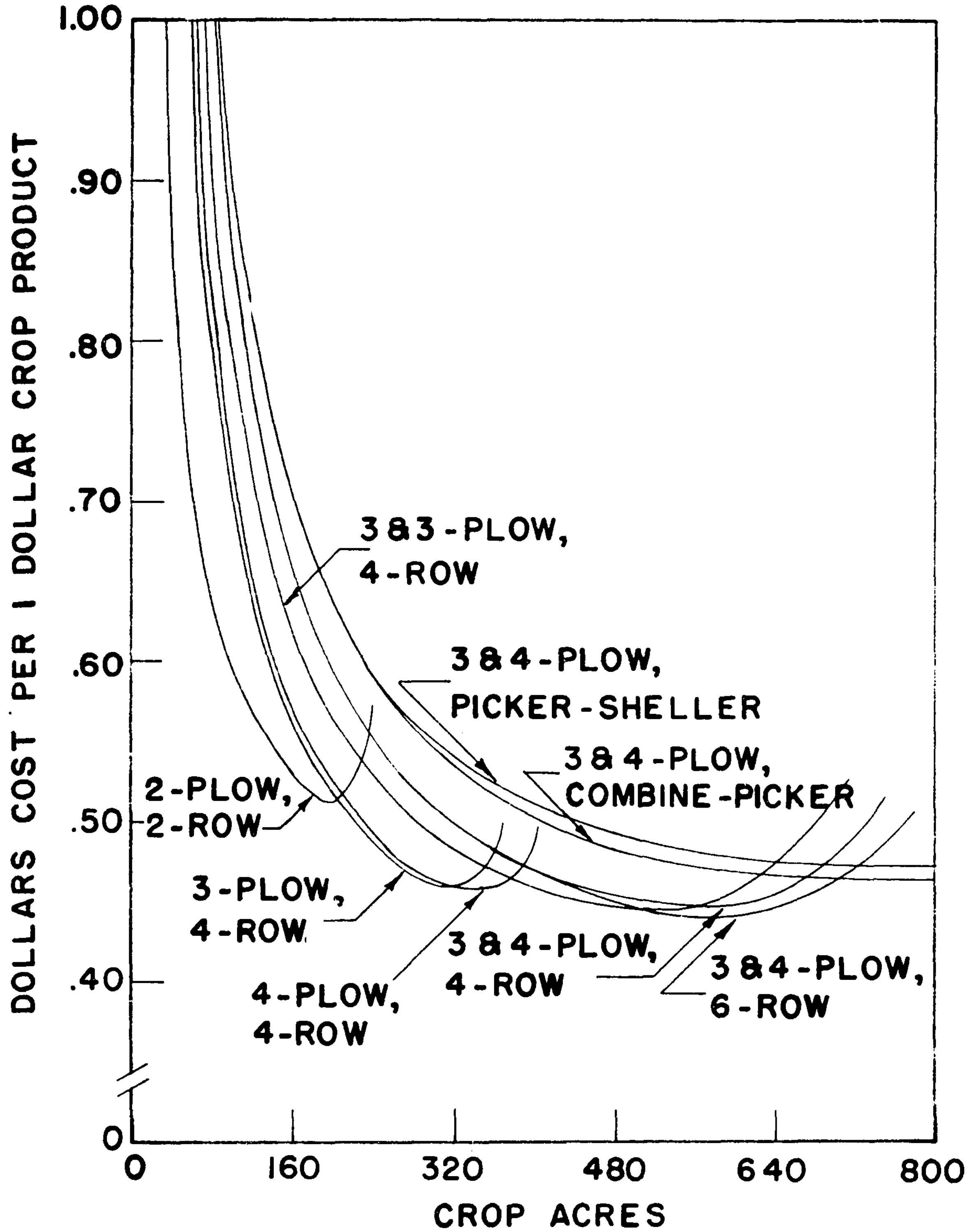

Figure 7. Average costs of producing $1 worth of crop product with eight machinery combinations based on the five-year rotation

profitably be operated with a given set of machinery. With more intensive use of row-crops, labor and other input requirements per acre are increased. Thus, with a given supply of operator's labor, optimal farm size is reduced.

Minimum per unit costs with the five-year rotation are almost identical to those estimated for current cropping systems. At any acreage, below that of minimum average costs, per unit costs are slightly less with the five-year rotation. However, per unit costs begin to rise at smaller acreages with the five-year rotation system.

One conclusion from this comparison of cropping systems is that farmers limited in acreage can better utilize their machinery capacity by intensifying the cropping system to include more row crops. If capital limitations restrict farm expansion, a given set of machinery can be more fully utilized by more intensive use of row crops. Factor inputs per acre are thus increased and resource returns would be nearly the same. Total value product per acre is higher with the five-year rotation system than with current cropping systems. Hence, if any charge is made for land, per unit costs would be lower with the rotation system.

With the five-year rotation system, cost advantages would result in economic pressures to increase farm size to at least 320 crop acres. This compares with 400 acres with current cropping systems. Cost economies would be relatively insignificant with further expansion of farm size. Under both cropping systems, only small cost advantages are indicated for two-tractor operations. The majority of the economies of size are attained with the four-plow, four-row combination. Any possible advantage to be gained from going to two-tractor combinations would come from the increase in volume of output and not from reductions in per unit costs. If prices are above per unit costs, a larger income would result with a larger volume of output.

Effects of an Increase in Fertilizer Application on Per Unit Costs

All average cost curves thus far presented are based on current average fertilization rates used in the Carrington-Clyde area (47). These current rates of application were estimated at 8-20-20 (pounds of active ingredients of N-P_2O_5-K_2O per acre) on corn and 0-20-0 on oats.

In this section, cost curves are presented for three sets of machinery with production and cost estimates based on much higher fertilization rates and higher yields. The additional fertilizer input is assumed to give a seven bushel increase in corn yields and proportional increases in the yields of other crops. Details on fertilizer inputs and yields are given in Tables 27, 28 and 29 of the Appendix.

Figures 8, 9 and 10 present the resulting average cost

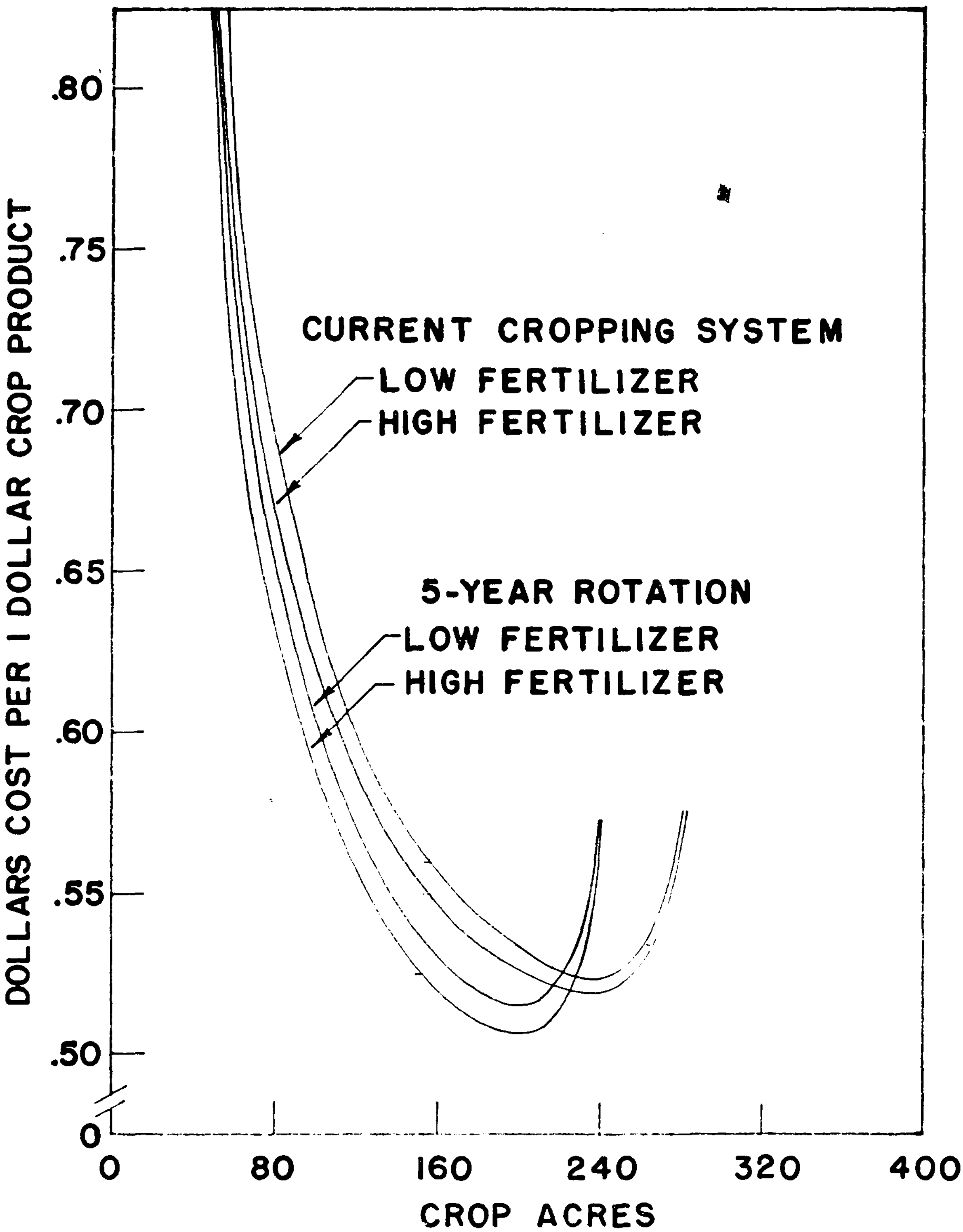

Figure 8. Average costs of producing $1 worth of crop product with the two-plow, two-row machinery combination for two cropping systems and two fertilizer levels

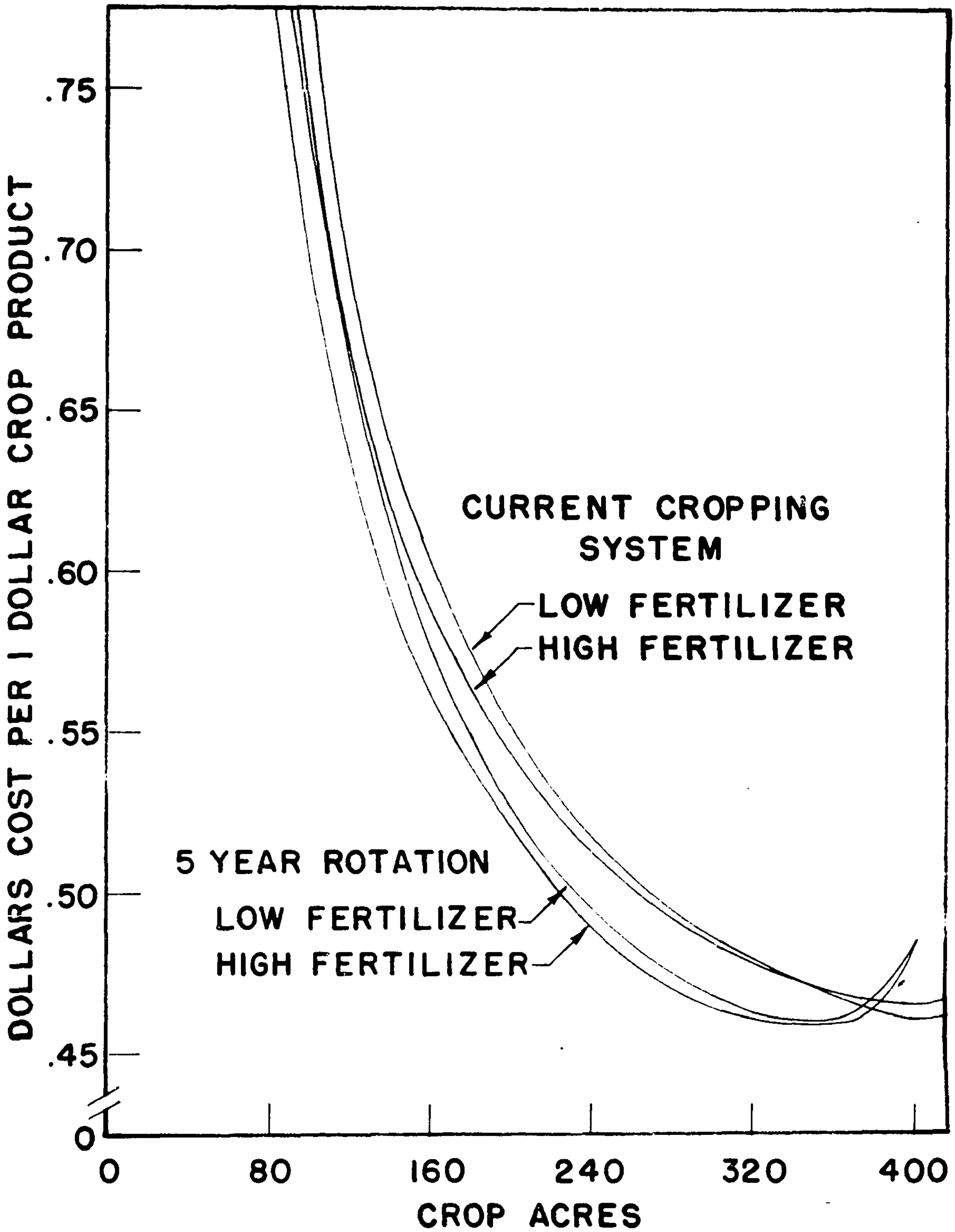

Figure 9. Average costs of producing $1 worth of crop product with the four-plow, four-row machinery combination for two cropping systems and two fertilizer levels

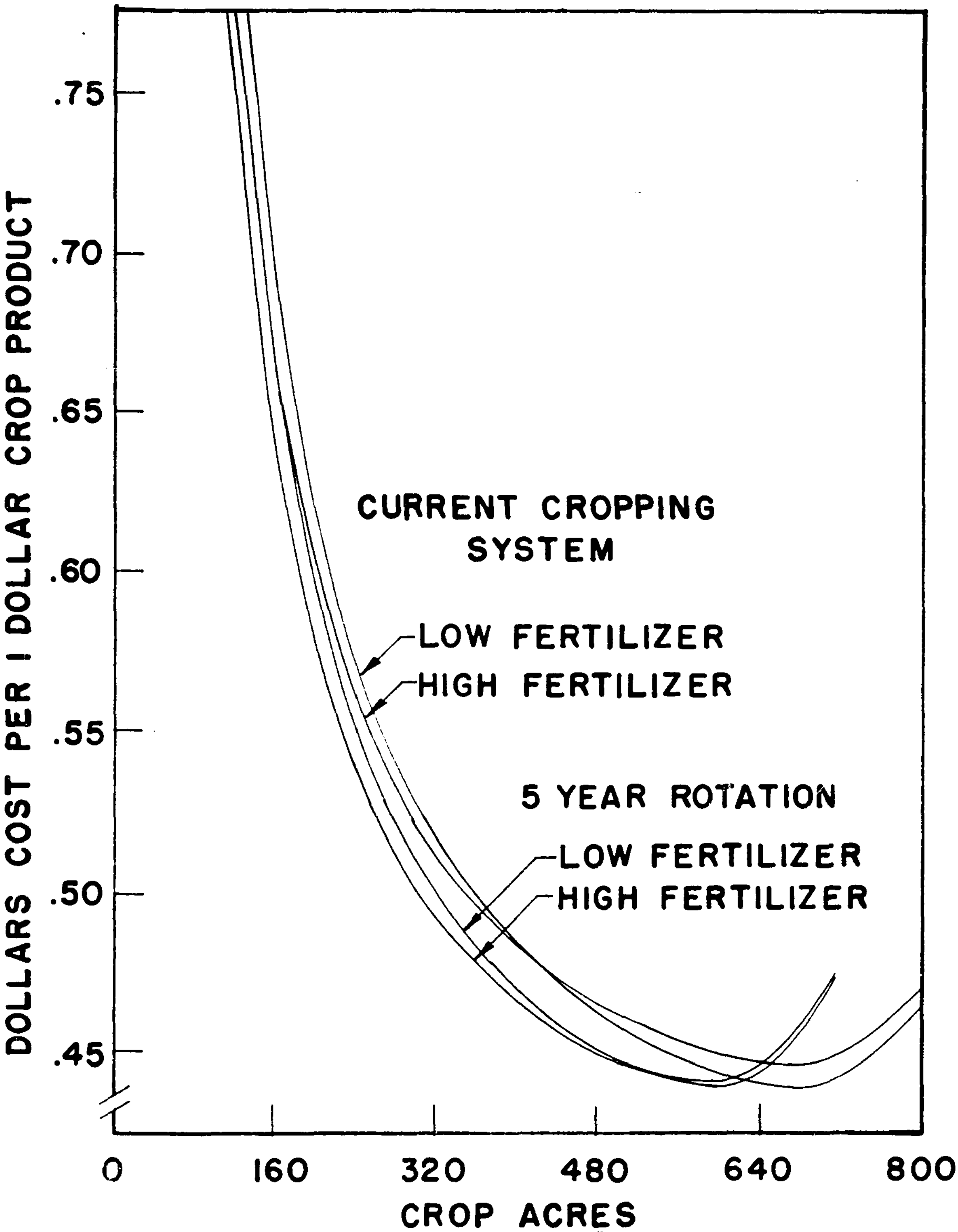

Figure 10. Average costs of producing $1 worth of crop product with the three- and four-plow, six-row machinery combination for two cropping systems and two fertilizer levels

curves for two cropping systems and two fertilizer levels with three sets of machinery. The shape of the cost curve is affected very little by a change in the rate of fertilizer application. The shape of the cost curve is partly determined by the amount of losses from untimely field operations. Since these losses are determined largely on a percentage basis, the shape of the cost curve will remain nearly the same regardless of the fertility level.

The results presented in Figures 8, 9 and 10 indicate that higher fertilization has very little effect on per unit costs. With high fertilization, per unit costs are lower at acreages below the minimum cost point but the reverse is true at and above the minimum per unit cost point. However, these results do not permit the conclusion that the use of more fertilizer is not profitable. Per unit costs are similar under both fertilizer levels only because total value product and the costs here considered increase by the same percentage (approximately 12 percent) when more fertilizer is used. This similarity in rates of increase occurred mainly by accident. In absolute amounts, total value product increases considerably more than do costs with the application of more fertilizer. Only the change in absolute values is relevant since some costs, especially land costs, have not been included in cost estimates made above. When a 5 percent interest charge on land investments is included in the cost estimates, per unit costs are generally 3 to 5 cents lower with the high fertilization level.

The comparison of per unit costs is a crude method for determining optimal fertilizer levels. The optimal amount of fertilizer input is best determined by marginal analysis. With the five-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, based on 1953-57 prices. These results indicate a very high return on the marginal input. The optimum fertilizer application is determined where marginal expected return is equal to marginal expected costs. Returns and costs would, of course, depend upon the prices of fertilizer and the prices of the products. Actually, marginal value receipts are double the costs of additional fertilizer even with product prices as low as those in 1958.

Per Unit Costs Under a Continuous-Corn Program

Cost functions are also developed for a continuous-corn cropping program on Carrington-Clyde soils. Different combinations of machinery are here required since no haying or grain harvesting operations are needed with continuous corn. Three such sets of machinery were established; all include six-row corn equipment. One set is designed for one man operations. It includes a four-plow tractor, six-row corn equipment and a two-row mounted picker with sheller attachment. A second set, designed for two-man operations, includes one four-plow and one three-plow tractor, six-row and four-row corn equipment and a two-row mounted corn picker. A third set, also for two-man operations, is a duplicate of the second set with the addition of a sheller attachment on the corn picker. It was found that only one plow would be needed with the two-tractor combinations. One tractor would be used full time on other operations such as disking, harrowing and planting. Complete descriptions of these sets of machinery are given in Tables 42 and 43 of the Appendix.

A corn yield of 71 bushels per acre is assumed with continuous-corn, with total fertilizer input of $9.77 per acre per year. This fertilization level provides the same amount of plant nutrients as the previous high level fertilizer cropping systems. However, without meadow in the rotation, more of the nutrients must be applied artificially.

Figure 11 presents the resulting average cost curves for the three sets of machinery. In Figure 11, the vertical axis is cost per bushel of corn rather than costs per dollar product since no aggregation of products is 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 are still declining quite rapidly, indicating that such small farms would

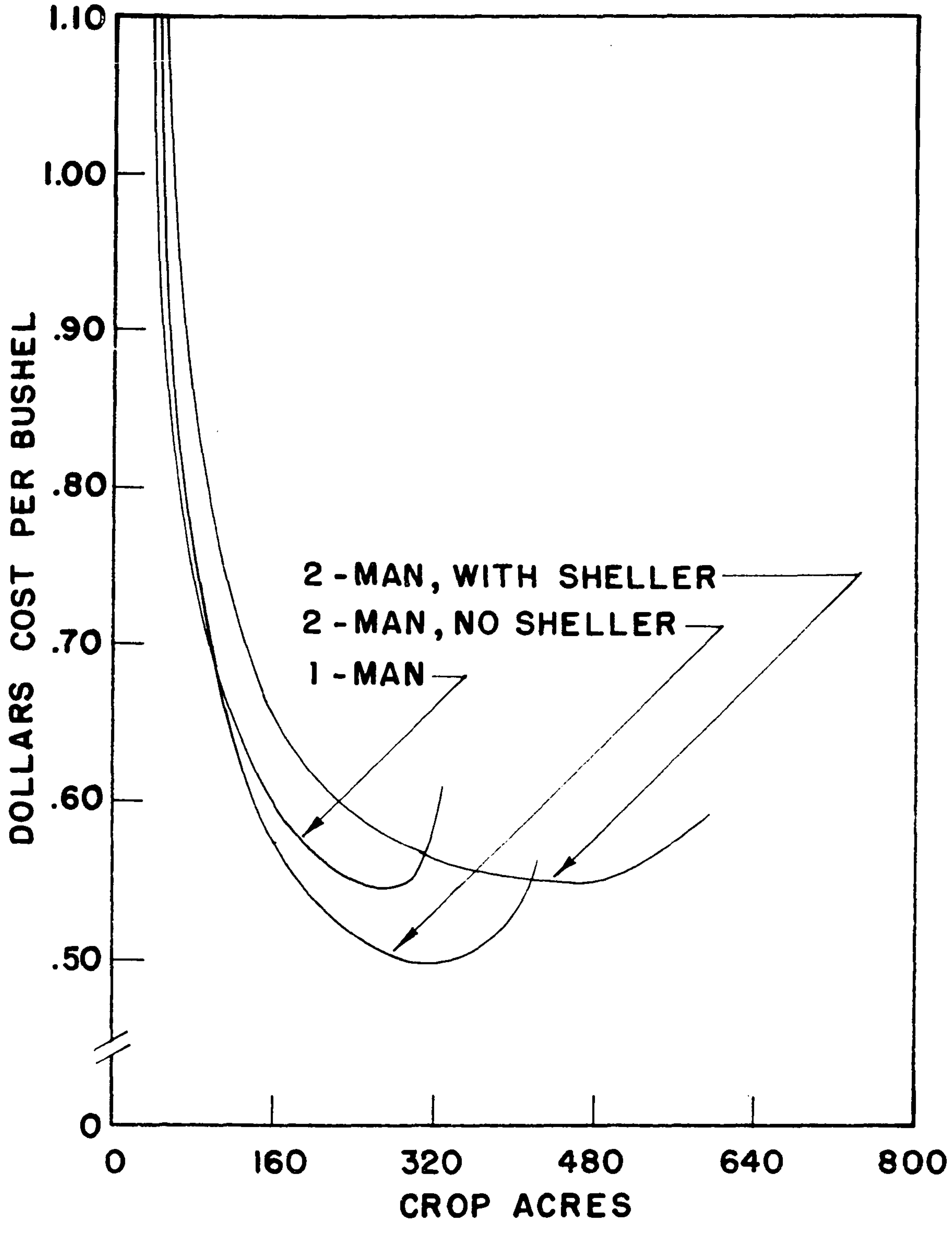

Figure 11. Average costs of producing corn with a continuous-corn cropping system

be uneconomical. Hence a two-man operation is preferred. With the one-man operation, no serious losses from untimely operations result with less than 280 crop acres; however, per unit costs are higher partly because of the 10 cent drying cost with field shelled corn.

A one-man operation on continuous-crop does not appear to be the most profitable arrangement due mainly to harvesting difficulties. With a two-row picker, two men can pick an estimated 1.7 acres per hour whereas one man with the same corn picker can only pick 1.2 acres per hour. This difference becomes quite crucial under continuous-corn programs. Even with picker-shellers, although harvesting begins approximately 26 days earlier, too much time must be spent picking corn, leaving little time for other fall field work. Hence, even with six-row corn equipment and a picker-sheller, one man alone could not profitably operate more than 280 crop acres.

The two-man operation without a field sheller attachment gives lowest per unit costs for farm units ranging from 96 to 415 crop acres. Up to 280 crop acres, total crop losses from untimeliness of operations are greater with two-man operations than with the one-man operation. However, the two-man operation has a conventional corn picker and hence no drying costs. Drying costs become relatively important under a continuous-corn program.

The two-man operation with a picker-sheller has lowest average costs only on farms with 415 or more crop acres. The field shelling operation permits considerable expansion of farm size but at a higher per unit cost.

Table 5 presents a comparison of the continuous-corn program and the five-year rotation system. Both cropping

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

Machinery combination	Minimum cost acreage	Minimum cost per dollar product
	Continuous-corn	
One-man	280	$.42
Two-men (no sheller)	320	.39
Two-men (sheller)	440	.43
	Five-year rotation	
4-plow, 4-row	360	.46
3- and 4-plow, 6-row	600	.44
3- and 4-plow, picker-sheller	720	.47

programs are based on the same fertilization and price levels (corn price of $1.30). Per unit production costs with the continuous-corn program are here expressed in costs per dollar product to facilitate comparisons. Here again, more intensive use of row crops calls for smaller optimal farm size. Most of the cost economies are attained at 240 crop acres with the continuous-corn program. This compares with 320 acres under the five-year rotation and 400 acres under current cropping programs.

Comparisons of per unit costs under the two cropping systems are made difficult by the fact that fewer machines are needed with continuous-corn. Total machinery investments are considerably lower with machinery combinations designed for the continuous-corn program. However, fixed machinery costs per acre at the minimum cost acreages would average slightly higher with continuous-corn since optimal farm size is considerably smaller. With continuous-corn, variable machinery costs are lower. Fuel inputs are higher but repair expense per acre is slightly less. Average costs per unit of output are in total slightly less for continuous-corn mainly due to the larger value of output per acre.

COMPARISON OF PER UNIT COSTS ON TWO SOIL TYPES

The Carrington-Clyde soil association is well adapted to intensive row-cropping and the use of large capacity equipment. However, this study will next examine results obtained when the same budgetary techniques are used to study cost relationships on an extremely different type of soils. These are the Ida-Monona soils found in western Iowa. Although the fertility rating of these soils is good, the topography is quite different from Carrington-Clyde. It has been estimated that only 20 percent of the farm land in the Ida-Monona area has a slope of 4 percent or less, and 22 percent has a slope of 14 percent or more (48).

Under these conditions, the use of terraces, grassed waterways, and other conservation practices are required if soil erosion is to be kept within bounds, and yields are to be maintained. The topography also limits the selection of rotations and cropping machinery. With this type of topography, the use of four- and six-row corn equipment is limited. Reasonable erosion control practices also include the use of some special machine equipment such as two-way plows and lister-planters (29).

Cost curves are here developed for three sets of machinery on Ida-Monona soils. One set, a one-man operation, includes a three-plow tractor, two-way plow, two-row lister-planter, and a two-row mounted corn picker. One set designed for two-man operations includes four-plow and three-plow tractors, both four-row and two-row corn equipment, and a two-row mounted corn picker. A second two-man operation includes the same machines with the addition of a field-sheller attachment. In determining the required implements for two-tractor operations, it is assumed that four-row corn equipment can be used only on slopes of less than 14 percent. Complete descriptions of these machinery combinations are given in Tables 44 and 45 of the Appendix.

Per unit costs are budgeted for Ida-Monona soils assuming a CCOM rotation on land with less than 14 percent slope, and a CCOMM rotation on slopes of 14 percent or more. Thus 40 crop acres would include 19.12 acres of corn, 9.56 acres of oats, and 11.32 acres of meadow. High levels of fertilization are assumed on these rotations. Cost and yield data for the Ida-Monona area are given in Tables 25, 27, 28 and 29 of the Appendix.

Cost curves for three sets of machinery on Ida-Monona soils are presented in Figure 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 five-year rotation and high fertility levels.

With the one-man operation, average costs reach a minimum

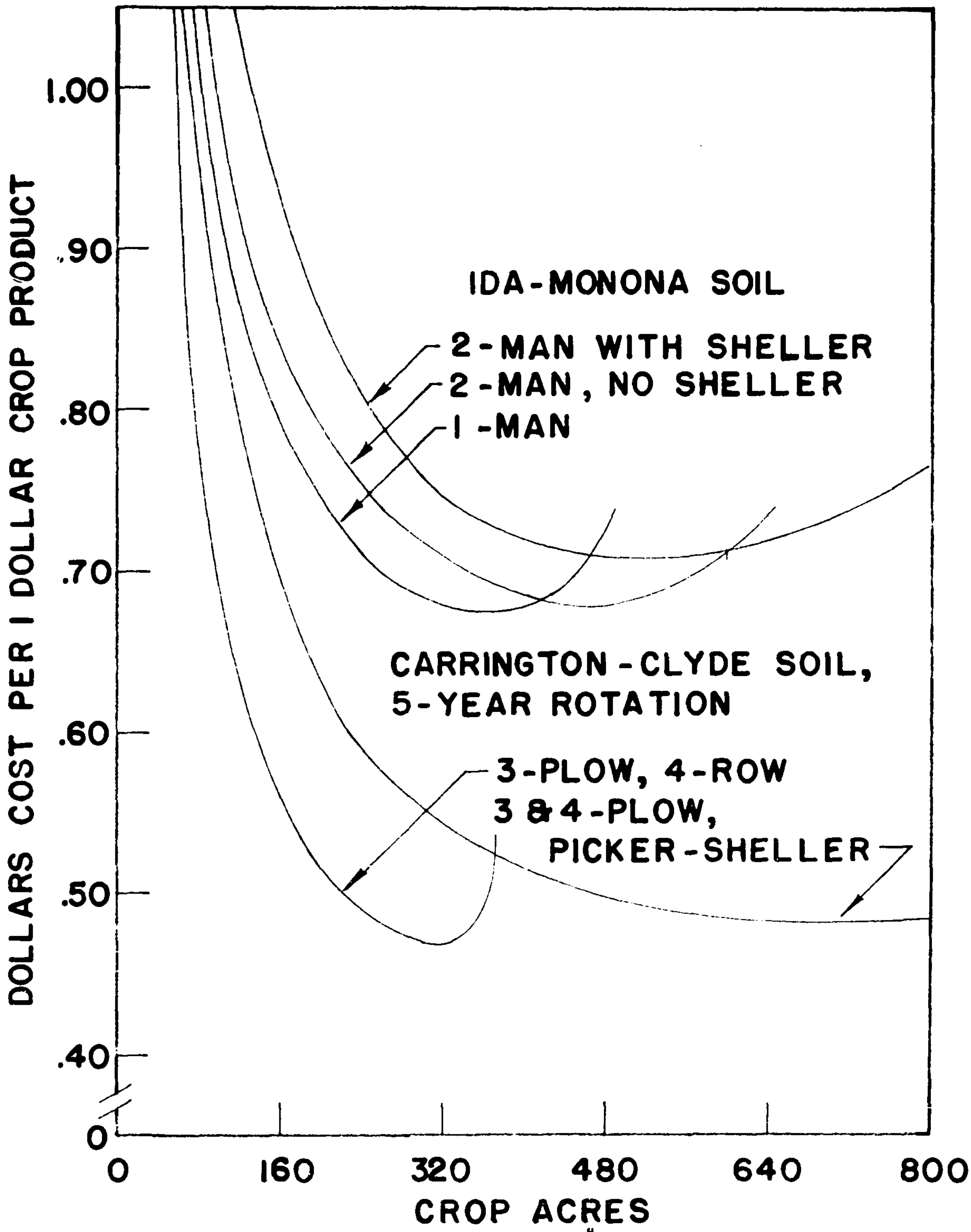

Figure 12. Average costs of producing $1 worth of crop product with Ida-Monona soils and with two machinery-cropping combinations on Carrington-Clyde soils (1953-57 prices)

at 340 crop acres. The one-man operation gives lower per unit costs than do two-man operations on farms of less than 410 crop acres. The two-man operation without field sheller gives lowest per unit costs on farms of 410 to 600 crop acres and minimum per unit costs at 480 acres. On farms with more than 600 crop acres, a two-man operation with field sheller gives lowest per unit costs.

With comparable rotations, minimum average costs per dollar product on Ida-Monona soils are approximately 20 cents above the minimum average costs on Carrington-Clyde soils. This large difference in costs is partly due to lower yields and less intensive row-cropping on Ida-Monona soils. However, land costs per unit of output would be considerably higher on Carrington-Clyde soils. The difference in costs per dollar product between the two soil areas is only 9 to 12 cents when total costs include a 5 percent interest charge on land investments.

Machinery items included in the one-man operation for Ida-Monona soils are quite similar to the machinery included in the three-plow, four-row combination established for Carrington-Clyde soils. However, as shown in Figure 12, the per unit cost curves for these two sets of machinery are of slightly different shape. The cost curve for the machinery combination on Carrington-Clyde soils reaches a minimum at a smaller acreage and has a steeper upward slope than the cost curve developed for Ida-Monona soils. With the one-man operation on Ida-Monona, losses from untimely operations increase slowly with expanding acreage. On Carrington-Clyde soils, interference of corn planting with soybean planting usually results in extreme losses of soybeans. Hence, the average cost curves bend up quite sharply. On Ida-Monona soils, soybeans are not included in the rotation and consequently planting losses tend to be lower than on Carrington-Clyde soils. Losses from delays in hay harvesting are more severe on Ida-Monona since more meadow is required in the rotation. However, with expanding farm size, planting losses generally become serious before haying losses. For these reasons a one-man operation can expand to larger acreages on Ida-Monona soils than on Carrington-Clyde soils.

With two-man operations, untimeliness of haying operations is more of a problem. Capacities of hay harvesting equipment are identical for one-man and two-man operations, regardless of soil type. However, with two men, more efficient use of haying machinery is possible and haying is likely to be started on time. Regardless, with more meadow in the rotations on Ida-Monona soils, with expanding acreage, hay losses become more serious than occurs on Carrington-Clyde soils. Thus the optimum size of farm with two-man operations is smaller on Ida-Monona soils than on Carrington-Clyde soils.

Most of the cost economies to be gained from expansion of farm size on Ida-Monona soils are attained on farms of 340 crop acres. Similar results were obtained for Carrington-Clyde soils with the five-year rotation. However, one cost factor has been omitted which may be more important on Ida-Monona soils. No consideration was made of the time required for travel between fields. This cost would occur on any soil but would be more important where much of the land is too steep or wooded to crop. Consequently, field size is smaller and more field time is lost traveling between fields.

Ignoring the field size factor, one would conclude that the size of farm needed to attain the main economies of size is affected little by topography or soil type. This conclusion may be correct since the results of this study indicate that the main economies of size are attained with conventional farm machinery. This is true even on soils easily adaptable to extensive operations. The attainment of large size farms and the use of larger capacity equipment is more likely to occur on level land than on hilly, steep land, but these large farms will probably not have lower per unit costs.

A more important effect of topography is on the type of rotation required. Hilly, steep land would require more meadow in the rotation. With more meadow in the rotation, costs per dollar of crop product may be higher since row crops generally produce more revenue per acre.

EFFECTS OF PRICE CHANGES ON COST SCHEDULES

All cost curves previously presented are based on the average product prices from 1953 to 1957. As previously stated, a set of prices is needed for aggregation purposes since several products are involved. This section will examine cost curves based on other levels of product prices to determine the effects of price changes on per unit costs and on the optimum size farm. The results are also utilized to determine the minimum or "break-even" prices needed for the various machinery combinations and rotations.

In this section, a 5 percent interest charge on land investments is included in costs. Land is valued at $361 per acre in the Carrington-Clyde area and $202 per acre in the Ida-Monona area.[1] Land has been treated as a variable input in estimation of cost curves, hence interest charges on land are here considered as variable costs.

The cost curves presented in this study would not be affected by changing product prices if the prices of all inputs maintain a constant relationship to product prices. In this section, the analysis is performed by varying product prices with input prices held constant. With this approach, some information can be obtained on the effects of a "cost-

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[1]Dwight M. Gadsby, Ames, Iowa. Information on current land prices by counties. Private communication. 1959.

price squeeze" on farm profits.

Figure 13 presents average total and marginal unit cost curves for the three- and four-plow, six-row machinery combination with the five-year rotation plan, low fertilization, and for three price levels. The three price levels are averages for the periods 1953-57, 1956-58 and the single year 1958. Prices of crop products declined between 1953 and 1958. The average price of corn was $1.37 in 1953 and $.97 in 1958 (40). Prices of all crop products considered in this study are itemized for each period in Table 30 of the Appendix.

As indicated in Figure 13, with falling product prices, the cost curves shift upward. This vertical movement results since costs are measured as costs per dollar product rather than costs per physical unit of output. Little or no horizontal movement of these cost functions result with changes in prices. A horizontal shift may occur if the price of one product changed relative to the price of other products, since percentage losses from untimeliness are not uniform over all crops at all acreages considered. Actually, the prices of corn, oats, hay and soybeans maintained very nearly the same relationships with each other over the six-year period considered. Hence, the acreage giving the minimum average total cost remains very nearly the same with all three sets of prices.

Including a 5 percent interest charge on land in total

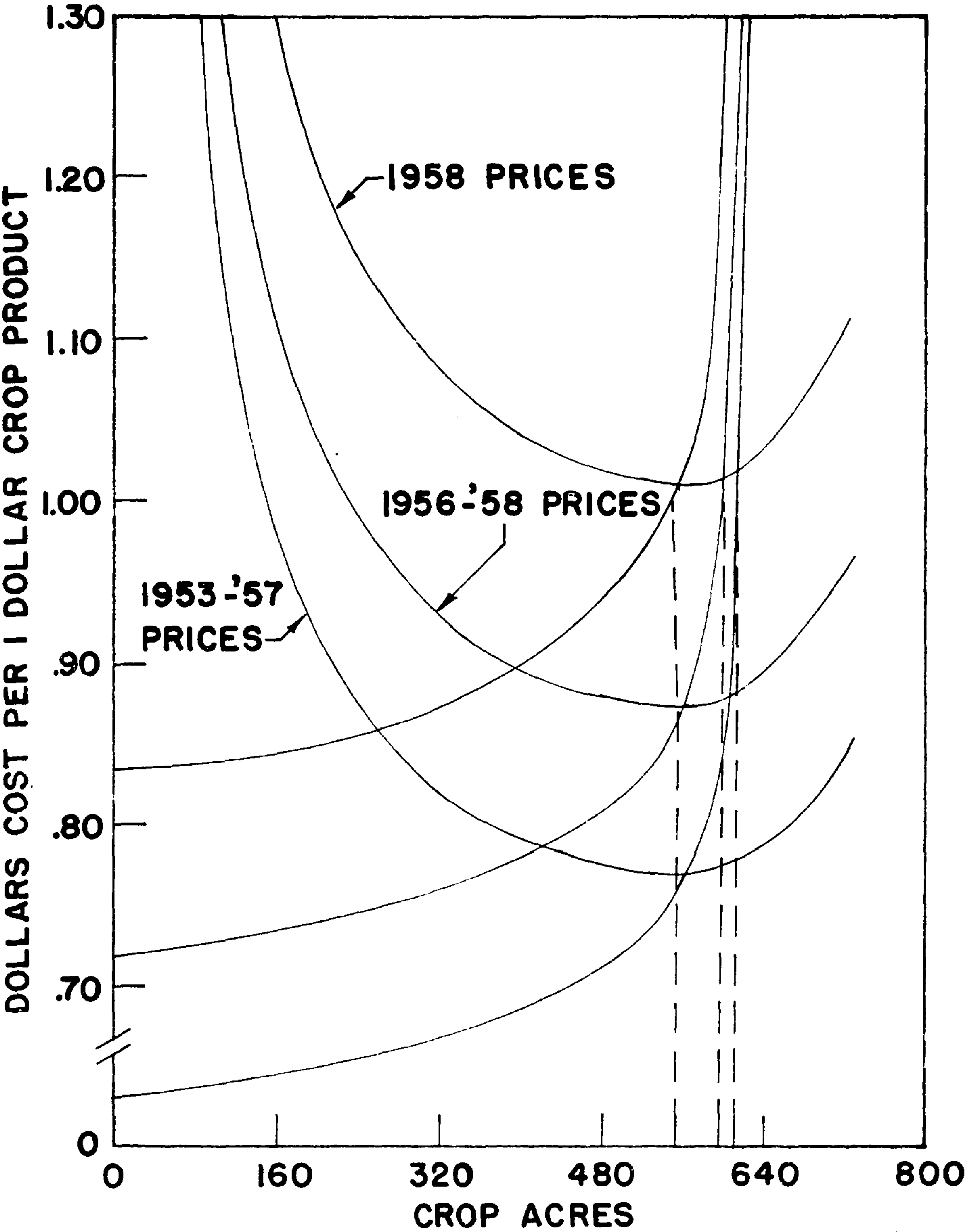

Figure 13. Marginal and average total costs of producing $1 worth of crop product with the three- and four-plow, six-row machinery combination based on the five-year rotation, low fertilization and for three price levels

costs has the effect of raising the cost curve vertically and also a slight change in shape. With consideration of losses from untimely field operations, land costs per dollar product rise with increasing acreage. Hence, including a 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 will possibly occur at a smaller acreage. However, the results obtained when a charge for land is included do not greatly differ from the results previously presented. The conclusions regarding the use of machinery and cost economies are still valid.

The minimum per unit cost acreage is not necessarily the acreage which will maximize profits. Maximum profits are obtained at the acreage where marginal cost equals marginal revenue. With this type of cost curve, optimal farm size is determined where the marginal cost of producing $1 worth of product equals $1. Hence, optimal farm size will decrease with falling prices. With the three- and four-plow, six-row machinery combination (Figure 13), optimal farm size is 610 crop acres for 1953-57 prices, 598 crop acres for 1956-58 prices, and 556 crop acres with 1958 prices. With 1958 prices, the minimum average total cost is $1.01, thus profits would be negative. In the short run, production would continue as long as variable costs are met. The average total cost curve is not the relevant planning curve for the short run. With falling prices, it would still pay to produce as long as receipts are above variable costs in the sense that losses would be minimized. Any returns above variable costs can be applied to fixed costs, thus reducing total loss.

Results presented in Table 6 indicate that changes in optimum farm size would be small with price changes occurring above the minimum average total cost (for example, 1956-58 prices vs. 1953-57 prices). These small changes in acreage result with very steep, or inelastic, marginal cost curves

Table 6. Optimum farm size with three levels of product prices for eight machinery combinations (current cropping system - low fertilization)

Machinery combination	Price level 1953-57	1956-58	1958
		(crop acres)	
1. 2-plow, 2-row	244	242	130
2. 3-plow, 4-row	378	365	345
3. 4-plow, 4-row	411	403	382
4. 3- and 3-plow, 4-row	640	625	491
5. 3- and 4-plow, 4-row	688	666	533
6. 3- and 4-plow, 6-row	693	671	624
7. 3- and 4-plow, combine-picker	823	819	566
8. 3- and 4-plow, picker-sheller	817	815	545

above the average total cost curves. When prices fall below the minimum average total cost (1958 prices), optimal farm size would decrease considerably. In this area of prices the marginal cost curve is very elastic.

The determination of optimal farm size in this manner is based on the assumption that all variable inputs receive the same minimum rates of return. With a fall in prices a farmer may prefer to maintain a larger than optimal acreage temporarily and sacrifice returns on labor or investments. This decision may be logical if prices are expected to soon rise.

Realistically, farmers probably are not likely to adjust farm size with short-run changes in product prices. Farmers probably adjust farm size when the new level of prices is expected to persist for a considerable length of time. Accordingly, if long term expected prices are being considered, variations in machinery investments should also be considered.

The preceding cost curves are based on the assumption that machinery investments are fixed while land inputs are variable. This assumption is necessary to determine untimeliness losses with various acreages, but it is not inferred that land inputs are in practice more easily varied than machinery inputs. Actually the reverse is probably true.

Probably of greater practical significance is the determination of average total costs at various levels of product prices and the various "break-even" prices. Table 7 presents average total costs[1] of producing $1 worth of product at the minimum cost acreage for the eight basic machinery combinations studied. These estimates include a 5 percent interest charge on land investments.

The results in Table 7 point out the small difference in minimum per unit costs between machinery combinations for a given cropping system. Only the two-plow, two-row set of machinery gives significantly higher minimum average costs. According to Table 7, the current cropping program with current fertilizer inputs results in highest per unit costs.

The only cropping program which meets total per unit costs with low, 1958 product prices is the five-year rotation plan with high level fertilizer application; and even with this cropping system, total returns would be less than total costs with two sets of machinery. These estimates of total per unit costs indicate that with current cropping methods, farmers' profits were negative in 1958, even if they operated at least cost acreages. Negative profits indicate that returns to labor or capital fell below the rates here assumed in determining costs. In other words, even if farmers oper-

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[1]These estimates of average total costs include estimated costs of all factors excluding management.

Table 7. Average total costs of producing crops at minimum cost acreage on Carrington-Clyde soils (dollars per $1 crop product)

	Machinery combination[a]							
	1	2	3	4	5	6	7	8
				Current cropping system				
Crop acres	240	360	400	520	640	680	680	720
Low fertilization								
1953-57 prices	$.87	.81	.81	.80	.80	.79	.81	.82
1956-58 prices	$.98	.91	.91	.91	.91	.90	.92	.93
1958 prices	$1.14	1.06	1.06	1.05	1.05	1.04	1.07	1.08
High fertilization								
1953-57 prices	$.83	.77	.78	.77	.77	.76	.78	.79
1956-58 prices	$.93	.87	.87	.86	.87	.86	.88	.89
1958 prices	$1.08	1.01	1.01	1.00	1.01	1.00	1.03	1.04
				Five-year rotation system				
Crop acres	200	320	320	480	520	560	640	640
Low fertilization								
1953-57 prices	$.84	.79	.79	.78	.78	.77	.79	.80
1956-58 prices	$.95	.90	.89	.88	.88	.87	.90	.91
1958 prices	$1.10	1.04	1.03	1.02	1.02	1.01	1.04	1.05
High fertilization								
1953-57 prices	$.80	.76	.75	.74	.75	.74	.76	.77
1956-58 prices	$.90	.86	.85	.84	.85	.84	.86	.88
1958 prices	$1.05	.99	.98	.97	.98	.97	1.00	1.01

[a]See Table 6 for titles of machinery combinations corresponding to given numbers.

ated at the least cost acreage, their returns to labor in 1958 were less than $1 per hour or their returns on land investments were less than 5 percent. However, farmers could have received these returns to resources in 1958 with more intensive row cropping and higher fertilization.

Results in Table 7 have been summarized, translated into the minimum corn price needed for profitable production, and presented in Table 8. These estimates of "break-even" prices are based on the assumption that all other prices maintain their present relationship to the price of corn. These estimates again are for the minimum per unit cost acreages. The results in Table 8 indicate that $1.02 is the minimum corn price needed for profitable production with current cropping systems and current low levels of fertilization. With high fertilization levels and the five-year rotation, a minimum price of $.94 is needed to break even. With the continuous-corn program, the corn price would have to fall to $.80 to eliminate profits with a 320 acre, two-man operation. On the other hand, on Ida-Monona soils, $1.11 is the minimum break-even price.

If prices fall below these break-even prices, production would still continue in the short-run as was shown in Figure 13. Farmers would continue producing as long as variable costs are met. With the five-year rotation system and low fertilizer inputs, a corn price of $.85 to $.90 would cover

Table 8. Corn price at which per unit costs equal returns at minimum cost acreage

	Machinery combination[a]							
	1	2	3	4	5	6	7	8
Current cropping system								
Crop acres	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	$1.06	.98	.98	.97	.98	.97	.99	1.00
Five-year rotation system								
Crop acres	200	320	320	480	520	560	640	640
Low fertilizer	$1.03	1.00	1.00	.99	.99	.98	1.00	1.01
High fertilizer	$1.02	.96	.95	.95	.95	.94	.97	.98
Continuous-corn	One-man			Two-man (no sheller)			Two-man (sheller)	
Crop acres	280			320			440	
Corn price	$.84			.80			.85	
Ida-Monona								
Crop acres	340			480			480	
Corn price	$1.11			1.11			1.15	

[a]See Table 6 for titles of machinery combination corresponding to given numbers.

all variable costs, including land, with any machinery combination. When machinery investments must be replaced, production would probably cease unless the long-run expected prices are at least as high as those shown in Table 8.

RESIDUAL RETURNS TO LABOR

In this section the budgeting results are utilized in estimating residual returns to labor. The residual procedure here used is identical to methods frequently used to determine the "value" of land or other inputs. However, no assertion is here made that residual returns to labor equal the value productivity of labor. Such statements are often invalid as shown by Heady (16, p. 407). The purpose of this section is simply to determine what rate of return farm operators would receive on their labor input with various prices and cropping and machinery combinations. This rate of return on farmers' labor can then be compared to non-farm wage rates.

No doubt some farmers consider labor as a fixed factor. Hence, labor receives only what profits remain after all other expenses have been paid. Residual returns to labor are here determined in a similar manner by subtracting all costs excluding costs of own labor from the total value product. The total residual return is then divided by the hours input of operator's labor to determine residual returns per hour. The rates of return determined in this manner apply only to the hours actually used and not to all labor available.

Figure 14 presents schedules of residual returns to labor with the two-plow, two-row and the the three- and four-plow, six-row machinery combinations for two cropping and

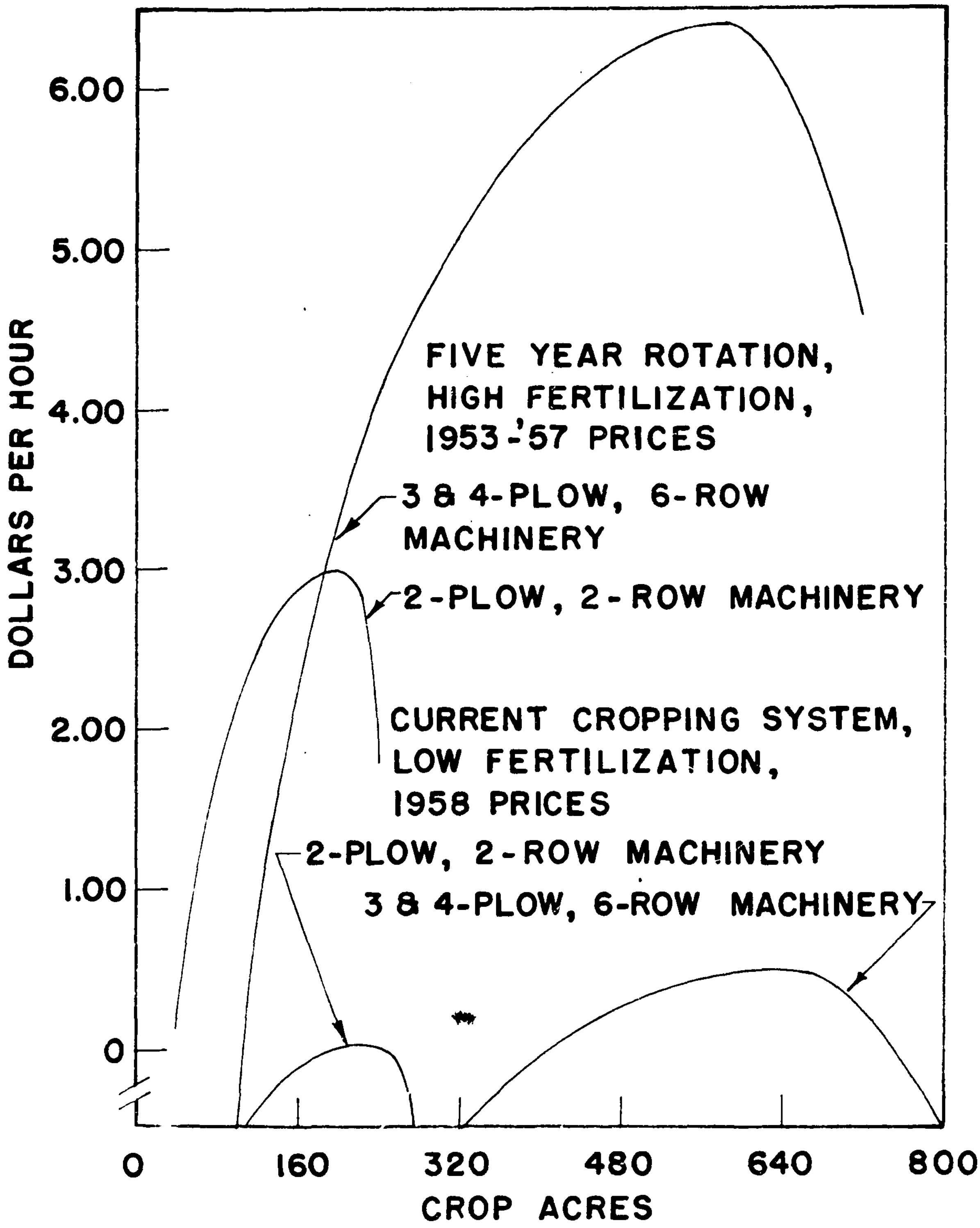

Figure 14. Average residual returns per hour of operator's labor used in producing crops with two machinery combinations

price situations. Highest residual returns to labor, with any set of machinery, are obtained with 1953-57 prices and the five-year rotation at high fertilizer levels. The extreme low in returns occurs with 1958 prices, current cropping systems, and current, low fertilizer inputs. As shown in Figure 14, the schedule of residual returns per hour is almost an inverse of the average total cost function. Residual returns are generally increasing over the same range of acreage as total average costs are declining. However, residual returns reach a maximum at the acreage where the marginal cost of producing $1 worth of product equals $1. Profits are maximized at this acreage; and profits[1] plus charges for own labor are equal to total residual returns to labor (see Figure 15). At acreages where total average costs per dollar output are greater than $1, residual returns per hour labor input are less than $1; and where total average costs are less than $1, residual returns to labor are greater than $1 per hour.

According to the results presented in Figure 14, at optimal acreages, residual returns per hour of operator's labor input would vary from $.50 to $6.40 with the three- and four-plow, six-row machinery combination. With the two-plow, two-row set of machinery, residual returns vary from $.05

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[1]Profit is here defined in the classical economic sense, the difference between total receipts and total costs. Hence costs of labor are also subtracted from receipts in determining profit.

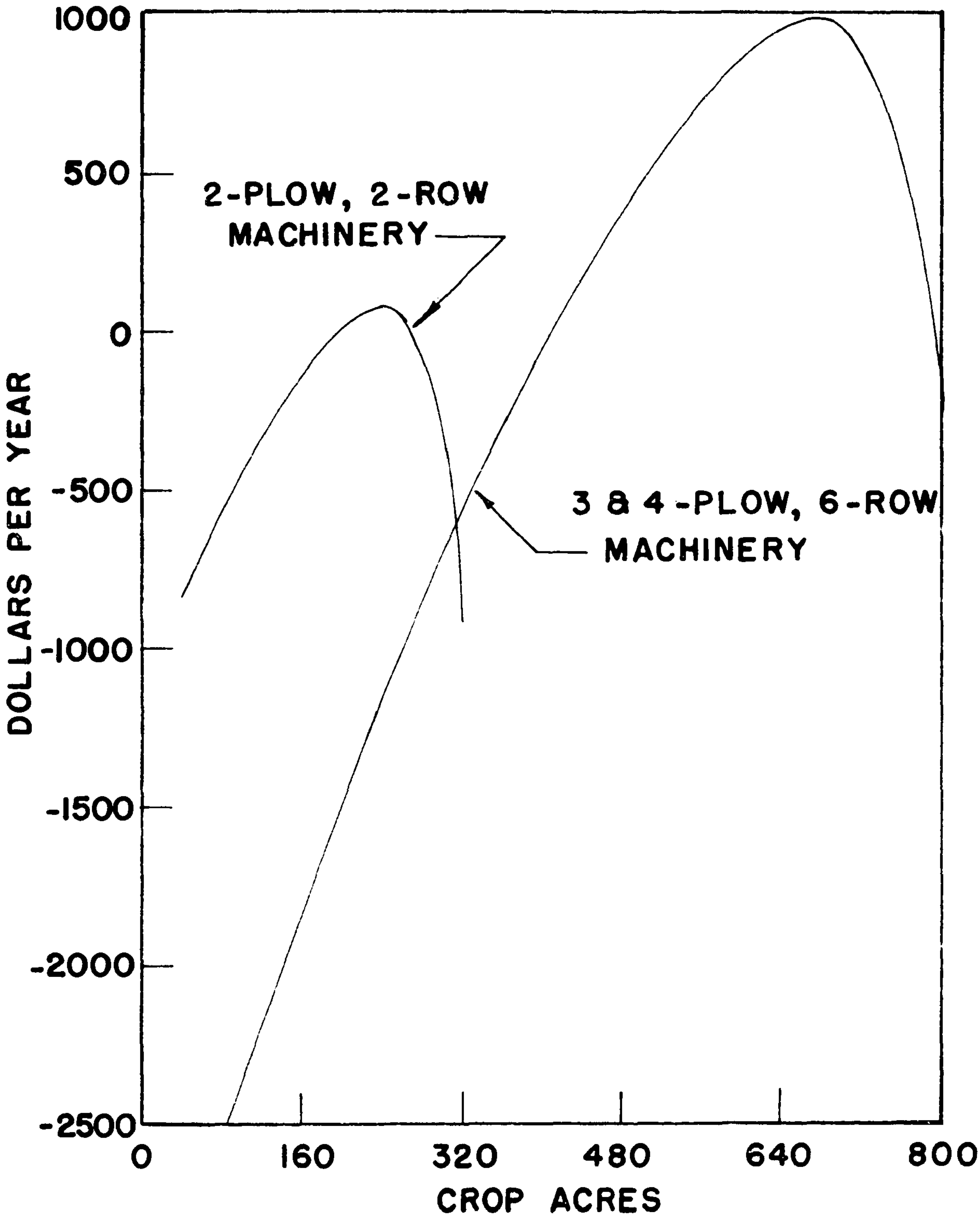

Figure 15. Total residual returns to labor with the current cropping system, low fertilizer and 1958 prices

to $3. The implication is that residual returns to labor will show more variation on larger farms. A larger variation could be expected since the volume of output increases with acreage; and with the residual procedure, all profits or losses accrue to labor.

Residual returns per hour of operator's labor input are presented in Table 9 for some of the price, machinery and cropping combinations studied on Carrington-Clyde soils. For simplicity's sake, these returns are presented only for the minimum cost acreages. Hence, as shown in Figure 14, the residual returns to labor will generally be lower at other acreages. With 1953-57 and 1956-58 product prices, residual returns are greater than $1 per hour for all combinations of machinery or cropping systems. With 1958 prices, residual returns are very low except for the rotation system with high fertilization. As indicated in Table 9, variations in product prices have more effect on residual returns to labor than do variations in machinery or cropping programs.

Comparison to Non-Farm Incomes

The farm family's income normally consists of returns from labor, from management, and returns from owned capital in the form of land or machinery. "Profits" or "total residual returns to labor" as used in this study are not identical with net farm income. Profit is the remainder after all

Table 9. Average residual returns per hour of operator's labor input at the minimum cost acreages

	Machinery combination[a]							
	1	2	3	4	5	6	7	8
	(dollars per hour)							
	Current cropping system							
Crop acres	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	.05	.52	.50	.40	.31	.47	.05	-.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	.36	.89	.88	.99	.87	1.01	.59	.50
	Five-year rotation system							
Crop acres	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	.32	.64	.72	.75	.78	.82	.41	.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	.65	1.08	1.16	1.37	1.25	1.50	1.01	.76

[a]See Table 6 for titles of machinery combinations corresponding to given numbers.

costs, including costs of operator's labor, land investments and machinery investments, have been subtracted from total receipts. Total residual returns to labor are equal to profits plus the charge for operator's labor. Net farm income would be equal to profits plus the charge for own labor, plus the interest charge on that portion of the capital investment owned by the farm family. The total amount of return from investments would depend upon the individual farmer's equity position.

Comparisons of farm and non-farm family incomes can best be made by comparing the residual returns to labor with the earnings of manufacturing workers. This manner of comparison eliminates questions of returns from investments or managerial inputs.

Heady and Loftsgard (21, p. 83) have compared farm incomes to the average annual wage rate for manufacturing workers in Iowa for 1955. In that year, average annual non-farm wages were $3,935 or approximately $1.96 per hour. Total hours worked by non-farm 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 with the eight machine combinations studied.

Examination of Table 9 will show that residual returns are greater than $2 per hour with any cropping or machinery combination at minimum per unit cost acreages with 1953-57 prices. On the other hand this return is not attained under any circumstances with 1958 prices. Accordingly, with each machinery combination operating at the minimum per unit cost acreage, some corn price between $1.30 and $.97 will bring residual returns of exactly $2 per hour of labor input. The corn price which will give this return is determined for six machinery combinations and two cropping systems. The results are presented in Table 10. Again it is assumed that all other product prices maintain a constant relationship to the price of corn.

Table 10. Corn price needed to give residual returns to labor of $2 per hour

	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 6 for titles of machinery combinations corresponding to given numbers.

These results can be compared with Table 8 where labor is included at a cost of $1 per hour. Thus the corn price must increase by 6 to 16 cents per bushel to increase labor returns by $1 per hour. The smaller the acreage, the greater the increase needed in corn price. Hence, a $2 charge for labor would shift the average total cost curves upward by 6 to 16 cents. The reader is cautioned against interpreting these estimates as the value of labor. A rise in the corn price of 6 to 16 cents does not increase the value of labor by $1. With rising product prices the value product of all factors will normally increase. The residual procedure, however, wrongly imputes all net profits to the one residual factor.

According to Table 10, with corn price at $1, a farmer must choose the three- and four-plow, six-row machinery combination and operate 560 crop acres under the five-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. In interpreting Table 10, 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 (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.

The above discussion will also serve to show the fallacy of interpreting residual returns to labor as the value of labor. These residual returns fluctuate with changes in cropping systems and machinery investments although the labor input may be the same. In effect, the residual procedure assumes that market prices are the proper accounting prices for all factors except the factor under study. Hence, the residual return to this factor, labor in this case, will depend on the market price used for all other factors. For instance, increasing the required return on land investment from 5 percent to 6 percent would decrease residual returns to labor by $.40 to $1.10 per hour.

RESIDUAL RETURNS TO LAND

The same procedure utilized previously to determine residual returns to labor is used in this section in determining residual returns to land. All factors excluding land are paid the market rates. The remaining net proceeds are imputed to land. However, since budgeting procedures were performed by varying land in 40-acre increments, the total residual returns to land can be divided into the marginal residual returns of each increment of 40-crop acres. Starting with zero acres, operating the first 40 acres results in tremendous losses since all fixed machinery and labor costs would accrue to the first 40-acre unit. With following 40-acre units, residual returns are positive as long as marginal costs are less than the marginal value product. Although net farm proceeds are negative, the marginal residual returns to land may still be positive.

The estimated marginal residual returns can then be capitalized into land prices. Such a procedure results in a schedule of land prices for successive 40-acre units. With the assumption that the residual return is equal to marginal value product, such a schedule would represent the demand for land of a farmer with that particular machinery combination. The assumption that residual returns are equal to the marginal value product, however, is probably not legitimate for reasons stated previously. These schedules of capitalized residual returns will here be used only to further illustrate the effects of variations in machinery combinations, cropping systems and prices on the resulting profits.

Figure 16 presents the marginal residual returns to land capitalized at 5 percent for two machinery combinations beginning with the second 40-acre increment. The schedules of capitalized returns to land indicate marginal profits associated with increasing farm size 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 capitalized return to land is equal to the current land price at the optimum acreage, as determined by the marginal cost function. This result occurs since a 5 percent interest charge on land was also used in budgeting costs. With the three- and four-plow, six-row machinery combination and 1958 product prices, optimum farm size is 624 crop-acres, the same result as obtained earlier.

The schedules presented in Figure 16 demonstrate the effect of changes in product prices on residual returns to land. With a given set of machinery, the capitalized value of returns to land varies $7 to $9 with each one cent change in the price of corn. Such a conclusion may seem quite extreme. This type of change can be expected with changes in

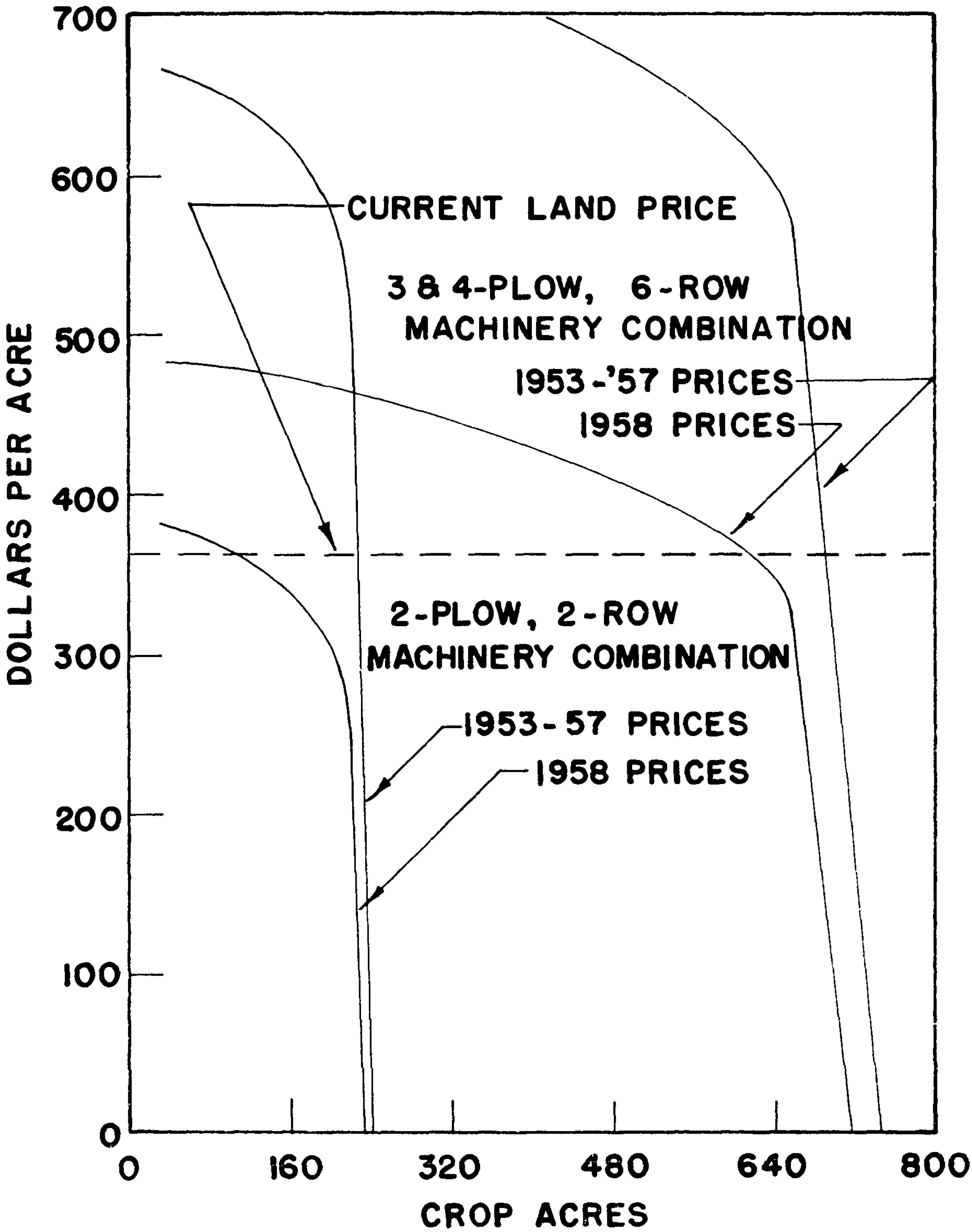

Figure 16. Marginal residual returns to land with current cropping systems capitalized at 5 percent

product prices. With constant physical output per acre, the value productivity of land will vary with a change in the product price. However, this effect is here overemphasized. With the residual procedure, all changes in profits resulting from changes in product prices are capitalized into land values. With a change in product prices, the value product of labor and other factors would also vary.

Figure 16 also indicates the change in residual returns to land resulting from a change in machinery. These schedules demonstrate that the value of additional land to an individual operator depends upon the original farm size and available machine capacity. If machinery capacity is fixed, the value of additional land to the operator soon falls below the market land price.

These differences in land values associated with different sets of machinery point out one weakness of the residual approach. Estimates of resource value through residual procedures are quite precarious. Such estimates of resource values are largely predetermined by the assumptions regarding the level of other inputs and input prices.

The schedules of capitalized marginal residual returns to land suggest one hypothesis as to why land prices are currently rising while product prices are falling. Realistically, the marginal value of land falls as product prices fall.

However, many farmers probably capitalize all profits into land values. This is essentially what is being done when marginal residual returns are used as estimates of the marginal value product of land. If farmers plan in these terms, the result will be a continued demand for land for farm enlargement unless product prices fall drastically.

The capitalized marginal value of land may be higher than market value even when total profits are negative. For example, with the three- and four-plow, six-row machinery combination and 1958 prices, profits are negative with the current cropping system even at the least-cost acreage. However, Figure 16 indicates that capitalized marginal residual returns to land are greater than current land prices up to 640 crop-acres. It is evident that it pays to expand farm size as long as marginal returns are greater than marginal costs even though total receipts are less than total costs. This type of farm enlargement is profitable when land is properly valued. However, the demand for land is larger than warranted when land is overvalued. Farmers will not be maximizing profits if they invest in land when other investments would bring higher returns.

Such estimates of residual returns are more useful when all other factor inputs are properly evaluated. With the input prices assumed in budgeting, the capitalized value of marginal residual returns are well above market land prices even with 1958 product prices. Possibly some farmers would demand a higher return on their land investment. Figure 17 presents marginal residual returns capitalized at both 5 and 6 percent. Increasing the capitalization rate from 5 percent to 6 percent calls for reducing farm size from 624 crop-acres to 380 crop-acres. Or if a farmer demands $2 per hour for his labor and 6 percent on land investments, optimum farm size would be zero. In other words, with current land prices, such resource returns are not possible at any acreage with 1958 product prices.

Any number of combinations of specified returns to labor, capitalization rates, and product prices could be dealt with. These particular rates were chosen mainly to illustrate the procedure. The determination of proper input prices is partly a matter of individual reservation prices or alternatives, and thus would differ between individual farmers.

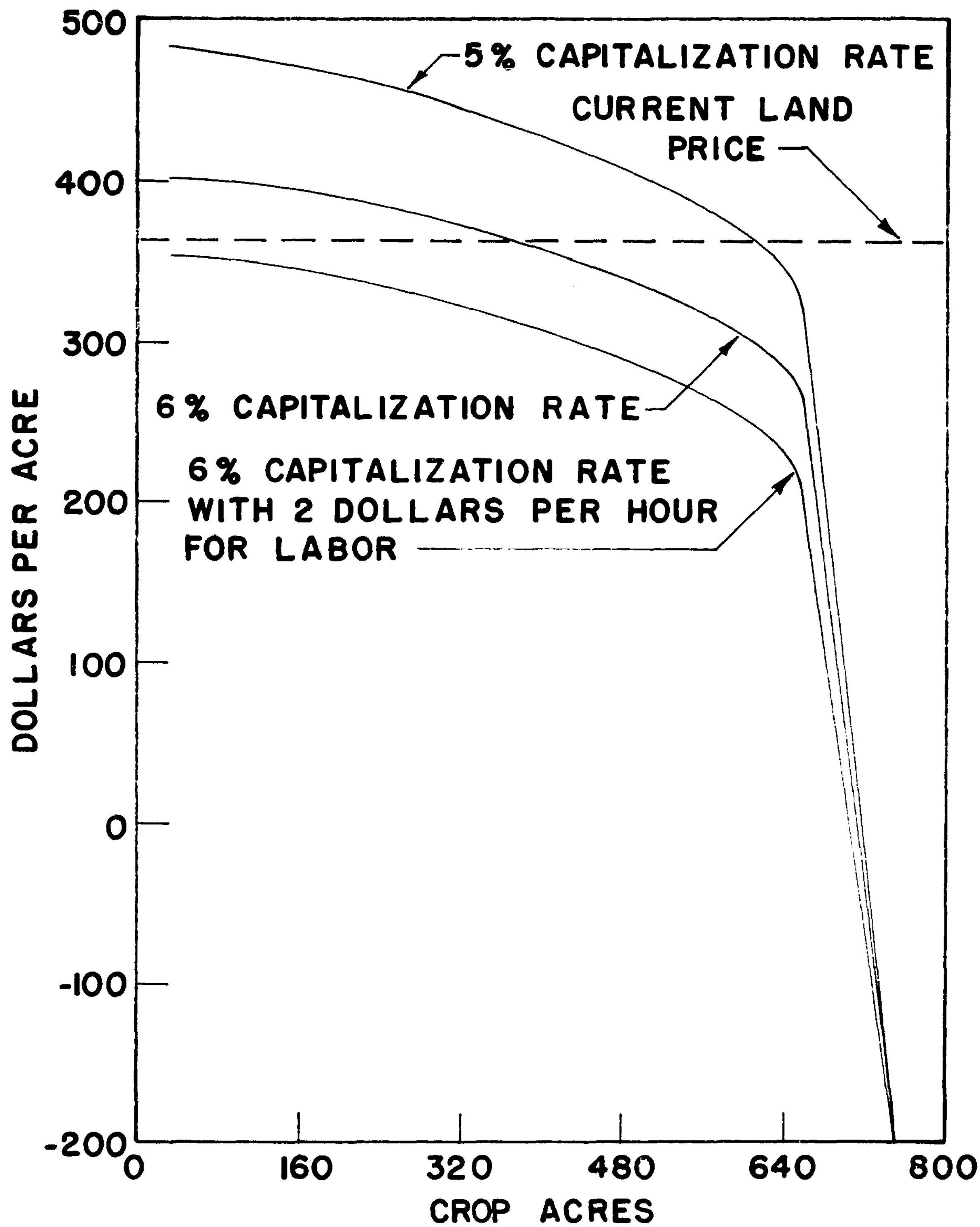

Figure 17. Marginal residual returns to land with the three- and four-plow, six-row machinery combination, higher factor prices, and 1958 product prices

OPTIMUM LONG-RUN FARM PLANS

The previous analysis of per unit costs has been based on a cash-crop farming arrangement with inputs and products priced at historical market levels. Such analysis essentially assumes that the market prices are the proper planning prices for allocation of resources within the farm firm. This assumption may not be correct when livestock opportunities are considered. Individual ability in livestock production may call for a higher planning price on an input, such as labor, or a higher price on hay or corn. Also, the use of market rates on capital ignores any subjective discounting that a farmer may make on returns from investments. A more realistic estimate of the optimum cropping program is possible if the relevant planning prices are known.

The possibilities for livestock production and subjective discounting of returns are included in this analysis by integrating the budgeting results into a linear programming problem. Given a set of production alternatives, linear-programming techniques determine the relevant planning prices of inputs and the level of each production alternative which will maximize the objective function. The usual objective function in linear programming is profit maximization. However, in this study maximum returns to capital is chosen as the objective function. This choice was made since we are interested in farm size, and the availability of capital is an important factor in this respect. With this objective function, the linear programming solutions indicate the amount of capital required and the marginal value of capital for each of several plans. Hence, the individual farmer can select from these plans the one which best utilizes all the capital he has available, or he can select the plan which will give the rate of return on capital which he requires.

This type of linear programming technique is termed "variable resource" or "continuous" programming in the literature (18, ch. 7). The variable resource technique is desirable where the analysis is based on farms that are very homogeneous except for one resouce since this technique provides solutions for an unlimited number of levels of this one resource. In this section, optimum farm plans are obtained for various levels of capital. Capital is gradually increased in supply with programming techniques determining the optimal production plan at each of many capital levels. In these optimum plans, capital is increased in supply until its marginal value is less than 5 percent. All plans with a marginal return to capital of less than 5 percent are assumed to be impractical.

Three sets of optimum plans were obtained for Carrington-Clyde soils, each based on a different cropping program. The three cropping programs considered are those used in budgeting procedures. The higher level of fertilizer application is used in all three cases. Crop prices for 1956-58 are used for linear programming purposes. In that period, corn price averaged $1.13 per bushel.

In each program, three types of production opportunities are offered. These include investments in livestock, land or machinery. In many research studies of this nature the production alternatives offered include only livestock and a choice of cropping systems with land and cropping machinery investments fixed (9, 19, 21, 22, 33). Optimum farm plans presented in this section are based on linear programming solutions which include six livestock alternatives and the alternative to use any combination of land and machinery that was examined in the budgeting procedures.

Livestock alternatives include a two-litter-per-year hog system, beef cows with calf feeding, long-fed feeder calves, short-fed yearlings, grade B dairy, and a small poultry flock. Input-output data for livestock enterprises are based on estimates of Hinton (25). The monthly distribution of labor inputs required for livestock is obtained from Loftsgard (31). Available buildings provide space for 20 litters of hogs in spring and fall, 200 laying hens, and 20 grade B dairy cows (21).

A summary of the livestock activities[1] is given in Table 11. The input-output coefficients are based on one two-litter unit in the case of hogs, and per head plus replacements in the case of beef cattle, dairy cattle and poultry. In actual programming, two hog enterprises are included. Both are two-litter systems and otherwise identical except that one enter-

Table 11. Input-output coefficients for livestock used in linear programming

Resource requirements	Hogs	Beef calves	Year-lings	Beef cows	Grade B dairy	Poultry
Capital (dollars)	182.50	127.47	157.95	201.95	272.24	1.60
Spring labor (hours)	8.28	2.69	2.58	9.9	24.59	0
Summer labor (hours)	17.16	6.73	2.51	9.14	31.09	0
Fall labor (hours)	11.76	5.21	1.00	6.66	21.58	0
Winter labor (hours)	22.8	3.77	4.10	19.30	38.74	0
Total labor (hours)	60.0	18.4	10.2	45.	116.	1.00
Hay (tons)	0.7	1.4	1.3	5.5	5.2	0
Corn (bushels)	225.0	48.0	55.0	40.	61.	1.80
Net receipts[a] (dollars)	119.54	37.55	30.12	56.65	87.15	.863

[a]Net receipts before costs of labor or capital are deducted.

[1]In linear programming terminology enterprises or production alternatives are referred to as "activities".

prise utilizes available building space, while the other hog enterprise requires $220 additional capital for buildings and hence is not limited to present building space.

Livestock prices used in linear programming are also averages for 1956-58 and are presented in Table 30 of the Appendix. In the programs based on continuous-corn, forage for livestock is assumed to be purchased at the 1956-58 average price for hay.

With each of the three cropping systems, linear programming is performed beginning with 160 crop acres and the machinery combination which gives lowest per unit costs of producing crops for this size farm. For the current cropping system and five-year rotation, the two-plow, two-row combination gives minimum per unit costs. The two-man operation without field sheller is optimum on 160 acres of continuous-corn. Machinery investment activities involve changing from the machinery combination which is optimum for 160 crop-acres to some other set of machinery, still operating only 160 acres. Hence, all other machinery combinations which were examined in the budgeting procedures are considered as separate activities. These machinery activities indicate the differences in capital and labor requirements and the difference in crop losses resulting from operations on 160 crop-acres, comparing each set of machinery to the least-cost machinery combination. By establishing machinery activities in this manner, a set of land activities can be specified for each machinery combination.

One of the most limiting assumptions of the linear programming technique is that of linearity (18, p. 17). Linear programming is normally performed under the assumption that the real situation is approximated by constant input-output coefficients regardless of scale of operation. Such procedures, when applied to farm size, would give unrealistic answers as indicated by the results obtained with budgeting techniques. In this study, a type of non-linear programming is attained by entering land activities as 40 crop-acre incremental units. Fixed costs are all included in the first 160 crop-acres which are "forced" into the optimum plan. The land activities indicate the incremental changes in total inputs and outputs and hence approximate the marginal cost functions developed in budgeting techniques. Each activity is restricted to a particular 40-acre range. The input-output coefficients are assumed to be linear within each 40-acre interval but vary between the 40-acre units. Thus, the untimeliness losses, which were previously estimated, can be included in the linear programming solutions by specifying these losses by machinery combination and by 40 crop-acre increments.

Charges on capital and labor are omitted in determining the revenue of all land, machinery or livestock activities included in the programs. Instead, the amounts of labor and capital needed are entered as resource requirements, allowing the linear programming procedures to determine the proper accounting prices.

Plans developed with this type of programming are labeled "optimum long-run farm plans" in this study since investments in land, machinery, and livestock can be altered. Additional labor can be hired since machinery combinations which include two tractors assume hired labor to operate one tractor. The supply of hog buildings can also be expanded with the choice of the proper hog enterprise. The only inputs which cannot be increased in supply are the operator's labor and building space for poultry or dairy cows.

Analysis of Programming Results

Tables 12, 13 and 14 present the linear programming results for Carrington-Clyde soils with three alternative cropping systems. The first plan in each table represents the starting point for linear programming. This plan is obtained from budgeting procedures and not from linear programming.

Included in each of these tables is a list of the resources that are limiting (all utilized) in each farm plan, along with the marginal value of each resource. The marginal value is to be interpreted as the amount by which total net receipts would increase if one more unit of the particular

Table 14. Optimum farm plans with continuous-corn (beginning with 160 crop-

Plan	Marginal value of capital (%)	Net income (dollars)	Livestock program	Acres of cropland	Cap Land
1		6,614		160	60,822
2	65.5	9,005	20 (1:1) hogs	160	60,822
3	53.9	9,177	20 (1:1) hogs 200 hens	160	60,822
4	29.7	9,653	24 (1:1) hogs 200 hens	160	60,822
5	22.1	9,878	27 (1:1) hogs	160	60,822
6	19.5	10,144	20 (1:1) hogs 30 beef calves	160	60,822
7	13.9	10,155	20 (1:1) hogs 30 beef calves 1 yearling	160	60,822
8	12.4	11,903	20 (1:1) hogs 21 beef calves 2 yearlings	200	76,082
9	11.6	12,295	20 (1:1) hogs 38 yearlings	200	76,082
10	11.5	13,745	20 (1:1) hogs 23 yearlings	240	91,342
11	10.6	17,396	154 yearlings	280	106,602
12	9.7	18,617	139 yearlings	320	121,862
13	7.1	22,229	77 yearlings	480	183,166

.ng with 160 crop-acres and a two-man machinery combination)

.cres of ·ropland	Capital investments (dollars) Land	Machinery	Livestock	Total	Limiting resources and their marginal values
160	60,822	8,876		69,698	
160	60,822	8,876	3,650	73,348	Hog space-$21.11
160	60,822	8,876	3,970	73,668	Hog space-$61.12, Poultry space-$.35
160	60,822	8,876	5,570	75,268	Hog space-$62.64, Poultry space-$.33, All labor-$.08
160	60,822	8,876	6,591	76,289	Hog space-$42.94, All labor-$.68
160	60,822	8,876	7,951	77,649	Hog space-$30.50, All labor-$.85, Fall labor-$1.93
160	60,822	8,876	8,030	77,728	Hog space-$17.40, All labor-$1.25, Fall labor-$1.62
200	76,082	8,876	6,903	91,861	Hog space-$10.47, All labor-$1.47
200	76,082	8,876	10,278	95,236	Hog space-$9.64, All labor-$1.48
240	91,342	8,876	7,624	107,842	Hog space-$7.24, All labor-$1.53
280	106,602	8,876	26,722	142,200	All labor-$1.72
320	121,862	8,876	24,068	154,806	All labor-$1.90
480	183,166	9,250	13,450	205,866	All labor-$2.86

resource were made available. For instance in plan 2, Table 13, providing building space for one additional breeding sow would increase total receipts by $21.10. These marginal values are based on the assumption that other resources that are not fully utilized can be considered as free goods. These results must be interpreted accordingly.

These results indicate that regardless of the cropping program the same pattern of changes in the livestock program occur with increasing capital supplies. Regardless of cropping system, 20 litters of hogs, which initially bring a marginal return to capital of 65.5 percent, is the first livestock enterprise to be included in the optimum plans. Poultry is next included in the optimum plans. With current and five-year rotation cropping systems, one dairy cow is next added. At this point, labor becomes limiting and dairying is never expanded beyond one cow. As livestock investments increase, dairy is replaced by beef cattle, either cows or feeder calves. With a continuous-corn system, investments in hog buildings are made and additional hogs are included instead of a dairy cow. Realistically, keeping only one cow producing grade B milk would probably never be considered. When labor becomes a limiting factor, poultry and hogs begin to decline. They are placed by either beef calves or yearlings, which bring higher returns to labor. Livestock investments reach $8 to $10 thousand before any increase is made in land or machinery investments.

With current cropping methods (Table 12), the first increase in land investments brings a marginal return to capital of 10.7 percent. Such a high return on land investments is an apparent contradiction to results obtained earlier. However, in optimum plans for 160 crop-acres, livestock utilize all available corn and hay, raising the value of corn to $1.48 per bushel and hay to $18.71 per ton. Hence the high return on land investments are due to the high values placed on corn and hay.

With 160 crop-acres, it is not profitable to increase land investments with the two-plow, two-row machinery combination. Hence, increases in machinery investment accompany any increase in land investments. Changing to the three-plow, four-row set of machinery permits cultivation of more land with the same amount of labor. With additional investments in land and machinery, labor is also released for use in crop production by replacing hogs with feeder calves or yearlings. At the capital level where marginal returns to capital are 8 percent, the three- and three-plow, four-row set of machinery begins to replace the three-plow, four-row set. This change in machinery consists of adding a second tractor and includes hiring labor for crop use. In the remaining plans, land investments increase rapidly with small decreases in returns to capital. Feeder yearlings are the only remaining livestock enterprise. Each 40 crop-acre increment of land added to the plan replaces approximately 15 yearlings. The value of labor increases with increasing investments in land until at 480 crop-acres, labor at any time of the year is worth $2.90 per hour. This means that one additional hour of operator's labor would allow crop or livestock production to increase which would increase returns by $2.90.

With the five-year rotation system (Table 13), much the same pattern in plan changes occur with increasing capital supply. With this cropping system, the first investments in land bring a lower rate of return on capital than occurred with the current cropping program (9.1 percent vs. 10.7 percent). A lower return to capital results since 160 crop-acres under a five-year rotation supplies more corn than with current cropping methods. Hence, livestock production is limited by other resources rather than corn and a lower value is placed on corn, which decreases the importance of farm expansion. However, the five-year rotation system is more profitable than current cropping systems as reflected in the larger farm size and higher returns to capital in the final plans. Also, with the rotation system, more investments are made in machinery to enable farm size to expand. The last two plans in Table 13 call for the set of machinery which includes six-row corn equipment.

Under a continuous-corn program (Table 14), the first

160 crop-acres is based on a two-man machinery operation. The first additional investments in land bring a higher return to capital (12.4 percent) than with other cropping systems. Investments in machinery are not increased until the final plan where a field corn sheller attachment is added. Adding the sheller attachment reduces corn harvesting losses, making it profitable to expand farm size another 160 crop-acres.

Yearlings again are the only livestock included in large acreage plans. Although yearlings bring lowest returns to capital of any livestock considered, they are included in optimum plans because of the low labor requirements, especially in summer and fall. Yearlings give highest returns per hour of labor input of all livestock opportunities considered. The returns to labor are important since operator's labor is the main resource limiting farm size regardless of cropping system. The necessary off-season machine maintenance, along with livestock and actual field operations place a high value on labor available throughout the year.

With all cropping systems, incomes rise steadily with increasing investments. With 160 crop-acres and optimum livestock plans, incomes range from $7,182 to $10,155, with 35 to 45 percent of this income resulting from livestock production. Maximum incomes range from $16,748 to $22,229, the lowest occurring with current cropping systems and highest under continuous-corn. These income figures have been adjusted for all fixed costs except personal property taxes on livestock and livestock buildings. In interpreting these income figures it must be remembered that the discussion is in terms of crop acres. Actual farm size would be considerably larger.

Optimum Farm Size

Table 15 presents a comparison of the optimum farm size as determined by budgeting techniques and the linear programming results. With budgeting techniques, the optimal farm size for a given set of machinery and prices is determined where the marginal cost of producing $1 worth of product equals $1. If the prices assumed in budgeting were equal to the accounting prices or marginal productivities determined in linear programming, the optimal long-run farm size would be identical with both procedures. However, as indicated in Tables 12, 13 and 14 the marginal productivity of some resources, especially labor, is considerably above the prices assumed in cost budgets. Hence, it would be well to examine the effect of this change in input prices on the optimal size of farm.

The results indicate that with current cropping systems and the three- and three-plow, four-row machinery combination, optimal farm size, as determined from linear programming, is only 480 crop-acres compared to 630 crop-acres under budgeting

Table 15. Comparisons of optimal farm size determined with budgeting techniques and with linear programming

	Budgeting marginal cost of producing $1 worth of crop product = $1	Linear programming Required return on capital investments 5%	7%	9%	11%
Current cropping system					
Crop acres	630	480	351	172	160
Machinery investment	$10,865	$10,865	$9,601	$5,071	$4,665
Five-year rotation					
Crop acres	600	560	361	161	160
Machinery investment	$12,979	$12,979	$10,865	$4,690	$4,665
Continuous-corn					
Crop acres	480	480	480	320	240
Machinery investment	$9,250	$9,250	$9,250	$8,876	$8,876

analysis. Actually, opportunities were allowed in linear programming to move to any acreage or machinery combination to maximize profits. In the budgeting analysis, the minimum average cost point on the long-run average cost curve is 680 acres with the three- and four-plow, six-row machinery combination. Thus, in effect, the addition of livestock opportunities reduces optimal long-run farm size by 200 acres and also reduces optimal machinery investments.

With the five-year rotation system, optimal farm size with budgetary analysis is 600 acres with the three- and four-plow, six-row machinery combination. Linear programming results call for the same set of machinery but only 560 crop-acres. Here again the addition of livestock opportunities reduces optimal farm size.

Under the continuous-corn program, optimal farm size as determined by linear programming is identical to budgetary results. Returns on resources used in crop production with continuous-corn are much higher than returns with livestock production. Hence, the addition of livestock does not affect the cropping program. Livestock is only a supplementary activity being restricted to resources not needed for crop production.

As indicated above, the introduction of livestock alternatives has greater effect on farm size when the cropping system is less profitable. With current cropping methods, including livestock has a decisive effect on farm size, to the extent that six-row corn equipment or field shellers are not profitable under any conditions with current cropping rotations. However, increasing the intensiveness of row-crops increases the competition of crops for the use of resources and consequently lessens the effect of livestock on farm size.

Table 15 also indicates the resulting farm size with various required returns to capital. These results can be interpreted as the effect on farm size of subjective discounting of returns, or internal capital rationing. Loftsgard (31, p. 30) has reported a case where a farmer required rates of return of 11 to 26 percent on working capital. Such severe self-imposed capital rationing would have far greater effect on farm size than small differences in per unit costs.

In this case, a required rate of return of 11 percent would limit farm size to 160 crop-acres with the current or five-year rotation cropping systems. With continuous-corn, farm size would expand to only 240 crop-acres at this high interest rate. The required rate of return would have to fall to 7 percent before optimal farm size will show much increase with either the current cropping system or the rotation plan. These results are, of course, based on 1956-58 product prices. With lower product prices, say at 1958 levels, still lower rates of return would be required before optimal farm size would increase.

OPTIMUM FARM SIZE WITH CONSIDERATION FOR VARIATIONS IN WEATHER

Effects of Variations in Weather on Cost Curves

All cost curves previously presented in this study were based on "average weather". Budgeting procedures were based on average yields and on the average number of days available for field operations over an 18-year period (35). In this section, average yields are still assumed, but budgeting of untimeliness losses are based on other-than-average number of days available for field operations. Hence, this section will deal with variations in income resulting from variations in number of days available for field operations, but this analysis does not consider the income effects of variations in rainfall or length of growing season. Since the analysis in this section will be in terms of net farm profits, total costs include a 5 percent interest charge on land investments.

Figure 18 presents average total cost curves for the three- and four-plow, combine-picker machinery combination for average weather over 18 years, for the average weather in the "worst" two out of 18 years, and for the average weather in the "best" two out of 18 years (35). "Worst" weather refers to the two years with the least number of days available for field operations. Similarly, "best" weather refers to the two years with the most days fit for field

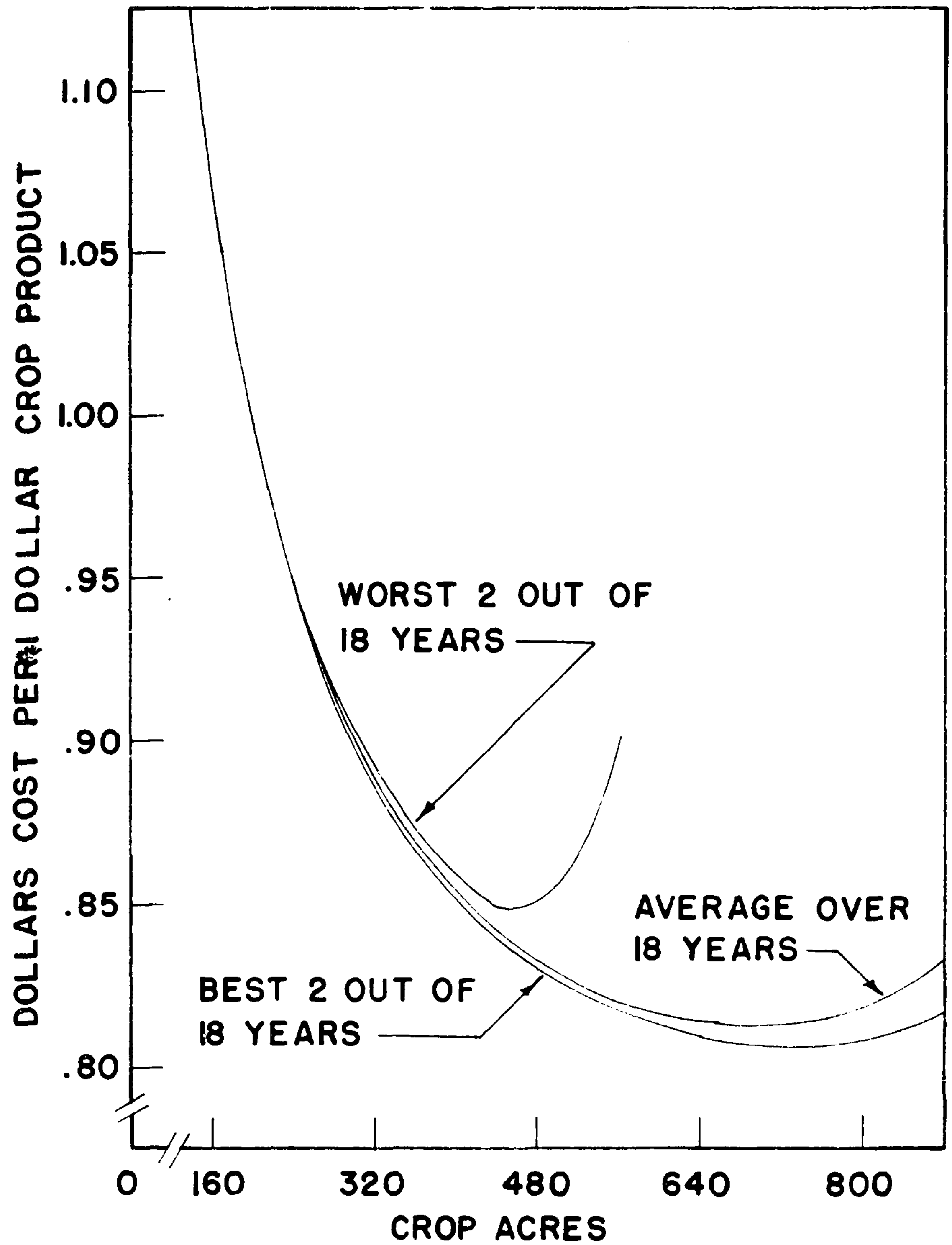

Figure 18. Effects of variations in weather on the average costs of producing $1 worth of crop product

operations.

Decreasing the number of days available decreases the acreage at which average costs reach a minimum. With 197 days available per year (best weather), per unit costs reach a minimum at 760 crop-acres. Under average weather (170 days), per unit costs are a minimum at 680 crop-acres. With only 143 days available (worst weather), the same set of machinery gives a minimum per unit cost at 460 crop-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 at least two out of 18 years. His average cost of producing $1 worth of product with 680 acres would be $1.12, or a net loss for one year of $3,134. His total receipts would actually be higher if he reduced crop acres. On the other hand, in the two best years, his average costs with 680 acres would decline from $.814 to $.808, less than one cent per dollar product. It is clear that per unit costs based on average weather are not identical to per unit costs averaged over all weather conditions. With extremely good weather, all the available field time cannot be utilized. Operations are completed largely on time leaving slack periods between operations. With poor weather, all available field time is utilized and operations become extremely untimely. No slack periods occur between operations.

Figure 18 indicates that optimal farm size for a given set of machinery varies considerably with variations in weather. These variations would make it extremely difficult to equate marginal costs and marginal returns. With current governmental agricultural price policies, a farmer should be able to make fairly good predictions of product prices but he would have considerable difficulty accurately predicting weather. Both weather and price variations must be considered in determining optimum farm size.

Determination of Optimum Acreage

The determination of the optimal acreage for a given set of machinery becomes more complex when variations in weather are considered. Planning on the basis of static cost analysis would call for equating marginal costs and marginal revenue. For the three- and four-plow, combine-picker machine combination (Figure 18), this criterion would give an optimal farm size of 823 crop-acres with 1953-57 prices for average weather. However, as stated above, per unit costs for average weather are not identical to per unit costs averaged over all weather.

To include the consideration of weather variations in the determination of optimal farm size, information is needed on net farm profits resulting from operating various acreages under all weather conditions. A simplification of this prob-

Table 16. Description of categories of weather

	Weather categories				
	A	B	C	D	E
Years occurrence in 18 years	2	4	6	4	2
Probability of occurrence	.11	.22	.33	.22	.11
Total number of days available per year	197	181	170	160	143

lem is here considered by classifying years into categories of weather. With weather data available for 18 years (35), five categories of weather are established based on total number of days available for field operations. Category "A" is identical to "best" weather and category "E" is identical to "worst" weather as discussed above. To determine optimal farm size for the three- and four-plow, combine-picker combination, 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 return for each acreage. The acreage giving highest expected returns is designated the optimal acreage. On this basis, the optimal acreage for the three- and four-plow, combine-picker machinery combination is 600 acres with expected annual net profits of $5,242. This compares with 823 acres, which is the optimum size farm for this set of machinery and 1953-57 prices as determined on the basis of average weather.

By comparing the expected value of net profits to net profits with weather category C (quite similar to average weather), the reader will note the discrepancy between per unit costs averaged over all weather and per unit costs with average weather (Table 17). At any acreage, the expected value is lower than profits with category C, indicating that actual production costs per dollar value of output are higher than the estimates based on average weather.

Table 17. Net profits for various acreages with five categories of weather and the three- and four-plow, combine-picker machinery combination

Crop-acres	Categories of weather A	B	C	D	E	Expected value
	(dollars per year)					
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

A decision criterion based on expected values is described in the literature as decision making under risk. Luce and Raiffa (32, p. 20) point out that the mathematical expectation of the monetary value may not be the relevant decision criterion for many individuals. Not only the mean, but perhaps the variance of expected returns should also be considered. Some individuals may prefer the strategy (crop acreage) which minimizes income variance (440 acres), or the strategy with the largest expected value for one year (720 acres). Any number of criteria are possible, depending on the individual's risk-security preference schedule.[1]

Although the frequencies of occurrence of the various types of weather may be known, uncertainty still exists as to what the weather will be like in any one year. Decisions on farm size are usually long-run decisions, however, the uncertainty of weather in a given year may be the relevant point for, say a beginning farmer or a tenant. Many beginning farmers cannot make plans for the long run. What is important to them is to stay in the game, especially the first year. The proper criteria for determining farm size under these conditions will again depend upon the individual's pessimistic or optimistic outlook.

Mixed strategies, or combinations of acreage or machinery are ruled out in this analysis since we are here trying to determine the proper strategy for one year. Only pure strategies can thus be dealt with.

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

The Wald maximin criterion (32, p. 278) which is very conservative, would have one choose the strategy with the largest minimum return. In this case it would be the acreage giving maximum profits under worst weather conditions, or 520 acres. The Savage minimax-risk criterion (32, p. 280), which is less pessimistic, would have one choose 560 crop acres. This criterion says to choose the act which minimizes the maximum risk. Risk in this case would mean the amount one could possibly lose by operating too many crop acres, given that the worst weather actually occurs.

A third criterion, the Hurwicz pessimism-optimism index (32, p. 282), gives solutions only after a particular pessimism-optimism index is chosen. This criterion looks at a weighted sum of the worst and best possible outcomes of each strategy. In this case we examine the outcome for each acreage for only the worst and the best weather conditions. 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 $\alpha m_i + (1 - \alpha) M_i$. This criterion says to choose the strategy (acreage) which gives the maximum α-index.

Table 18 indicates that with increasing pessimism regard-

Table 18. 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.

ing weather (α increasing), optimal farm size decreases. The individual with extreme optimism would be willing to gamble on the weather and expand acreage to the maximum in a given year in hopes of a maximum return. Table 17 shows us that this strategy would not maximize returns in the long-run. Individuals with this high degree of optimism may be few and far between. Selection of the proper farm size would depend upon the individual's risk-security preference schedule. However, few beginning farmers would be likely to follow the results based on average weather.

A similar analysis was carried out with the three- and three-plow, four-row machinery combination. This, or a quite similar machinery combination, is frequently found in north-east Iowa. The results indicated that when variations in weather are considered, long-run expected returns would be maximized with 400 crop-acres. Estimates based on average weather, and with the same product prices indicated minimum per unit costs at 520 acres and optimum farm size of 640 acres.

These two examples serve to show that farmers would probably not survive if they expanded acreage to where marginal cost equals 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 for average weather.

Determination of Optimum Investment in Machinery

A quite similar decision problem exists for an individual with fixed acreage but who has a choice as to the amount of capital to invest in machinery. This individual is faced with the alternatives of excessive crop losses in poor weather years or excess machinery costs in good weather years. The problem can be put into a game matrix much the same as the acreage problem. Table 19 gives net profits with 200 crop-acres for three sets of machinery and with variations in weather. These particular sets of machinery are the smaller capacity combinations and were considered more likely to be

Table 19. Net profits with 200 crop-acres with three machinery combinations and variations in weather

Machinery combinations	Weather categories A	B	C	D	E	Expected value
	(dollars)					
No. 1 - 2-plow, 2-row	1,473	1,473	1,470	822	-1,260	1,013
No. 2 - 3-plow, 4-row	1,444	1,444	1,441	1,376	1,120	1,378
No. 3 - 4-plow, 4-row	1,329	1,329	1,324	1,311	1,221	1,298

optimum on 200 acres on the basis of the analysis of average weather. The weather categories are the same as in prior discussion. Profit estimates are based on current cropping systems and 1953-57 product prices.

On the basis of average weather, estimated average costs of producing a dollar of crop product are \$.875 with the two-plow, two-row set of machinery, \$.879 with the three-plow, four-row combination, and \$.889 with the four-plow, four-row machinery combination. Hence the budgeting results for average weather would call for the use of the two-plow, two-row combination on 200 crop acres. However, Table 19 indicates that the three-plow, four-row combination would give maximum returns in the long-run. Losses are quite severe in poor weather years with the two-plow, two-row machinery combination. With the three-plow, four-row combination, losses during the two years of worst weather are much less, only $320 per year, while fixed machine costs are only slightly higher. With the four-plow, four-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 problem 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 may have more opportunity to vary machinery investments than land investments. Actually, changing from the three-plow, four-row combination to the four-plow, four-row combination involves only a change of the tractor and plow. Similarly, a farmer with the two-plow, two-row combination could avoid most of his crop losses by using a four-plow tractor and plow instead of his two-plow arrangement. Or a farmer could gamble that the weather will be ideal for cropping operation in a particular year and reduce his machinery investments for that year.

The same criteria for decision making under uncertainty are applied here as were used on the acreage problems above. The results obtained from application of these decision criteria to the 200-acre example are given in Table 20.

The criteria for decision making under uncertainty give varied results. In general, investments in machinery increase

Table 20. Decisions on optimal machinery combination for 200 crop-acres

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 .009	1>2>3
α between .009 and .055	2>1>3
α between .055 and .532	2>3>1
α greater than .532	3>2>1

[a]For machinery combinations, see Table 19. The symbol > means "preferred to".

with increasing pessimism regarding weather. According to the Hurwicz pessimism-optimism criterion, only the most extreme optimist (α less than .009) would try to operate 200 crop-acres with the two-plow, two-row machinery combination. This is the same set of machinery designated optimal by the analysis based on average weather.

A second example of the determination of optimal machinery investments deals with a farm unit of 560 crop-acres. Net profits were estimated for three alternative machinery combinations. All machinery combinations include two tractors. Cropping programs and prices are the same as were used

Table 21. Net profits with 560 crop-acres for three machinery combinations with variations in weather

Machinery combination	Minimum cost per $1 product with average weather	Weather categories A	B	C	D	E	Expected value
		(dollars)					
No. 4 - 3- and 3-plow, 4-row	$.799	6,774	6,691	6,494	346	-1,800	4,238
No. 6 - 3- and 4-plow, 6-row	.796	6,690	6,642	6,612	1,164	-1,382	4,483
No. 7 - 3- and 4-plow, combine-picker	.820	6,031	5,990	5,947	3,842	2,961	5,115

for the 200-acre example.

According to Table 22, an individual who is extremely optimistic about the weather (α-index less than .135) would minimize machinery investments and choose the three- and three-plow, four-row machinery combination. However, most

Table 22. Decisions on optimal machinery combination for 560 crop-acres

Criterion	Decision on machinery combination
Static cost analysis	6 > 4 > 7[a]
Risk (expected value)	7 > 6 > 4
Uncertainty	
Maximin	7 > 6 > 4
Minimax risk	7 > 6 > 4
Pessimism-optimism index	
α less than .132	4 > 6 > 7
α between .132 and .135	4 > 7 > 6
α between .135 and .167	7 > 4 > 6
α greater than .167	7 > 6 > 4

[a]For machinery combinations, see Table 21.

farmers would probably order the alternatives 7 > 6 > 4. In a year with best weather, the three- and four-plow, combine-picker combination shows $659 less profit than the three- and four-plow, six-row combination. However, in a year with poorest weather, profits are $4,343 higher with the combination which includes the field sheller.

With 560 acres, the budgeting analysis calls for a larger machinery investment than do the uncertainty criteria. However, the machinery set chosen by the uncertainty criteria does not give minimum per 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 resulting in higher per unit costs with average weather. However, field shelling provides considerable extra field capacity in corn harvesting, also allowing more time for fall field work. This extra capacity results in a much slower rising per unit cost curve with average weather and in the case where variations in weather are considered, this capacity reduces crop losses considerably in years of bad weather.

One common conclusion which can be drawn from both acreage examples is that the set of machinery which gives lowest per unit costs with average weather is of too small a capacity to be optimum when variations in weather are considered. All decisions based on risk or uncertainty aspects call for larger capacity machinery than was regarded optimum for average weather. The conclusion was made earlier that field corn shellers were not profitable on farms of less than 800 crop-acres; however, here it was found that the optimum machinery combination for 560 crop-acres is one which includes a field sheller. Also, from the 200-acre example, we can conclude that four-row corn equipment is probably profitable on smaller farms than was previously indicated. Hence, in terms of average weather, it appears profitable for a farmer to over invest in machinery. However, all cost and profit estimates, based on either average weather or all types of weather, are determined with the same budgeting procedures and are subject to the same limitations. The budgeting procedures assumed a fixed pattern of cropping rotation and field operations. In the real world a farmer could probably reduce the cropping losses in an unfavorable year by changing the rotation or pattern of field operations, by working longer hours when field work is possible, or by custom hiring additional machinery. It may be profitable to invest in a set of machinery which would be optimum for average weather and hire additional machinery in years of unfavorable weather. This possibility was not examined in the analysis and it may not be a likely solution since in unfavorable years most neighboring farmers would also be short on machinery capacity.

SUMMARY

This study was designed to provide information on the relationship of production costs to acreage operated with different capacity machinery combinations. Costs per dollar of crop product were obtained through a budgetary or "synthetic" approach. Data from numerous fields of study were utilized in estimating total costs and total crop production with several sets of machinery for a wide range of acreage. Total crop production was estimated with consideration for losses in yields which result when field operations are performed during suboptimal periods. Such losses eventually occur when farm size is expanded with a fixed capacity set of machinery. These cost relationships were examined for several rotations and fertilizer levels on Carrington-Clyde soils and for one cropping rotation on Ida-Monona soils.

The resulting cost schedules indicate that the large machinery investments required with current machinery methods result in very high production costs on small farms (less than 200 crop-acres). Fixed machinery costs can be reduced by the use of smaller capacity machines, or through custom hiring. However, this approach results in considerably higher variable costs and little or no decrease in total costs. With the cropping systems currently used in the Carrington-Clyde area (50-60 percent row crops), average total costs are min-

imized with a farm size of approximately 560 to 680 crop-acres. Per unit costs can be reduced 5 or 6 cents per dollar of crop product by increasing farm size from 200 crop-acres to 400 crop-acres. Under a continuous-corn program on Carrington-Clyde soils, average per unit costs are minimized at 320 crop-acres with the bulk of the savings in costs being gained at 240 crop-acres. These results indicate increasing per unit costs with expansion of farm size beyond 800 acres. However, only one- and two-tractor machinery combinations were analyzed.

Untimeliness of field operations limits the acreage that can be worked with a specific set of machinery. For a particular machinery combination, continued expansion of acreage will eventually cause severe crop losses due to untimely field operations. Hence, marginal cost curves have a very steep incline above the average total cost curve.

Results indicate that it is unprofitable to invest in enough machinery simply to eliminate all losses due to untimeliness of operations. With a given set of machinery further expansion of farm size would reduce fixed costs per unit of output. This reduction would be more significant than small crop losses from untimely operations.

Results also indicate that the cropping practices currently used on Carrington-Clyde soils do not minimize per unit costs. At any acreage and with any set of machinery, per unit costs could be reduced 5 to 6 cents per dollar crop product through more intensive row cropping and the application of more fertilizer. Marginal returns from fertilizer inputs on the average farm are at least 200 percent even with product prices as low as those of 1958. The cropping system which gives lowest average costs per dollar of output is continuous-corn. With continuous-corn, the average per unit cost is 20 cents below the per unit costs possible with current cropping systems. Intensifying the use of row crops also decreases the farm size which gives minimum per unit costs.

The analysis, based on average weather, indicates that quite large acreages are needed to justify use of six-row equipment or field shellers. With current cropping systems, six-row equipment is not profitable on farms with less than 560 crop-acres and field shellers or combine-pickers are not profitable unless farms include at least 800 crop-acres. The large fixed costs involved with such machine items restrict their use on smaller size farms.

The cost advantage to be gained from the use of larger sets of machinery is also small. Expanding operations from use of two-row equipment on 200 crop-acres to four-row equipment on 400 crop-acres would give a reduction in costs of 6 cents per dollar of output. Further expansion to the use of six-row equipment on 600 acres would further reduce costs by only 1.5 cents per dollar output. The use of field shellers results in higher minimum per unit costs and are profitable only when farm size is expanded to where untimeliness losses are too great with conventional corn harvesting equipment. Furthermore, on hilly, steep land, such as Ida-Monona soils, where six-row equipment cannot be utilized, machinery costs per unit of output are not necessarily higher. Machinery costs may be higher in such areas since more field time is probably lost traveling between fields but not because smaller equipment is required. Hence, six-row equipment and field corn shellers are not expected to result in much larger profits per acre. As long as prices are above production costs, the adoption of these large capacity machines will increase profits through increasing volume of output but will not increase profits per unit of output.

The analysis of cost relationships was extended to include livestock opportunities through the use of linear-programming techniques. Alternatives considered in programming optimum farm plans included investments in livestock, land and machinery. Optimum plans were obtained with returns to capital as the objective function. The results indicate that for a farmer with 160 acres of crop land, the best use of additional funds ($8,000 to $10,000) would be in livestock, primarily hogs and feeder cattle. However, if sufficient capital is available, profits would be increased by reducing investments in livestock and expanding investments in land and cropping machinery. With a required minimum return on capital of 5 percent, the optimal farm plan includes 77 to 116 short-fed yearlings and 480 to 560 crop-acres. The addition of livestock alternatives decreases the optimal farm size relative to results obtained with strictly cash-crop operations. The linear programming results also provide estimates of the optimal farm size for other levels of required returns to capital. Hence, the individual farmer can select the optimum farm plan consistent with his subjective discount rate on agricultural investments.

Effects of variations in weather on per unit costs and optimal farm size were examined by budgeting costs for five types or categories of weather. These categories classify years by the number of days available for field operations. It is apparent from this analysis that cost estimates based on average weather underestimate per unit costs averaged over time. This difference in per unit costs result since more field time is available in extremely favorable years than can be utilized, whereas extreme losses result in years unfavorable to field operations. Hence, the mathematical expectation of the monetary return is less than profit estimates based on average weather. It follows that optimum farm size with a given set of machinery is smaller when these variations in weather are considered. With two quite different sets of machinery, long-run expected returns are maximized with 27 to 37 percent less land than was found optimum with average weather.

Hence, with current cropping techniques, per unit costs would probably be a minimum at 500 to 550 crop-acres, with the bulk of cost economies gained by farms with 300 to 350 crop-acres. Similarly, the optimal machinery combination for any given size farm is of substantially larger field capacity than was indicated with average weather. Results indicate that, due to large losses in poor weather years, field corn shellers are probably profitable on much smaller farms than was previously indicated. A 12 foot self-propelled combine with corn picker head was found to be profitable on a 560-acre farm. When variations in weather are considered, investments in field corn shellers give greater return in terms of reduced crop losses than do investments in six-row corn equipment. However, even with consideration for variations in weather, at least 450-500 crop-acres are required for profitable use of either type of equipment.

Limitations of Study and Suggestions for Further Research

The budgeting procedure utilized in this study allows the consideration of only those factors that are measureable and for which reasonable estimates are available. Hence, no consideration is given to the possible limitations of the managerial factor. Untimeliness of field operations is essentially the only factor included which causes increasing per unit costs. However, the timing of operations is essentially a managerial function. The budgeting technique can reasonably be used only when a set pattern of operations is established, including dates and sequences of all field operations. Untimeliness losses result when this pattern is disrupted. However, it is the managerial function to deal with each situation in a manner to maximize profits or minimize losses. In practice, an alert manager may decide to change this pattern of operation according to the conditions at hand. This study indicated that there are many situations where costs or losses may be lowered by a change in this pattern. For instance with increasing farm size, with practically all machinery combinations, a situation arises where corn cultivating interferes with hay harvesting. The budgeting procedure called for a fixed pattern of operations. Realistically, farm managers would have a choice of which loss to incur and hence would try to minimize total value losses.

This analysis also assumed that all field operations would proceed in normal sequence with no increase in costs per acre regardless of farm size. This assumption may or may not be true. The skillful manager could possibly maintain this efficiency, but many managers would have difficulty organizing work to minimize costs. Another factor omitted in this analysis is the consideration of field size and loss of time from traveling between fields. Such losses would be partially a result of limitations of the management factor, but not entirely. Such costs would become more important with the expansion of farm size.

Hence, the cost curves presented in this study probably overestimate per unit costs for small acreages and underestimate per unit costs on large units. The budgeting technique fails to include many cost-saving changes that are possible at all acreages. However, the management factor would become more important and more limiting with increasing acreage. It is doubted that the average manager can maintain constant efficiencies in field operations with increasing farm size as was assumed in the budgeting technique.

The purpose of this study was not to predict future farm size. The purpose was mainly to estimate the cost relationships between production techniques and farm size. The attainment of a particular farm size will be a function of numerous factors in addition to costs. The results of this study indicate that cost advantages extend beyond the current average farm size but apparently other considerations are as important as per unit costs in the determination of optimal scale of operations.

As mentioned above, many factors which influence production costs were omitted in this study. Further study in the area of farm size should include time and motion studies of field operations on various size farms, better estimates of actual rates of repair and depreciation of farm machinery, and a more thorough analysis of alternative sequences and methods of field operations. Many cost estimates were used in this study not because they were considered accurate or satisfactory, but because they were the best or only ones available.

Further analysis of effects of variations in weather should prove beneficial. An inventory approach may be ideal with respect to farm machinery investments. Other variations in weather, besides number of days available, could also be examined; such as variations in growing season and precipitation. It is hoped that the results obtained in this study will prove helpful to farm operators; however, the lack of precision in the basic data and the limitations of this analysis leave room for considerable improvement.

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APPENDIX

Table 23. Costs new and annual fixed machinery costs for all machinery combinations

Machinery combination	Total value new	Minimum annual depre- ciation[a]	Fixed costs[b]	Total fixed machinery costs
Current cropping system and five-year rotation on Carrington-Clyde soils				
2-plow, 2-row	$8,481	$ 596.23	$ 496.14	$1,092.37
3-plow, 4-row	15,747	1,299.93	921.20	2,221.13
4-plow, 4-row	16,694	1,367.23	976.60	2,343.83
3- and 3-plow, 4-row	19,754	1,588.15	1,155.61	2,743.76
3- and 4-plow, 4-row	23,135	1,854.91	1,353.40	3,208.31
3- and 4-plow, 6-row	23,598	1,895.81	1,380.48	3,276.29
3- and 4-plow, combine-picker	23,324	1,984.29	1,364.51	3,348.80
3- and 4-plow, picker-sheller	23,814	1,905.84	1,393.12	3,298.96
Continuous-corn on Carrington-Clyde soils				
One-man	12,650	836.27	742.20	1,578.47
Two-man	16,139	1,097.93	946.31	2,044.24
Two-man with field sheller	16,818	1,148.86	986.03	2,134.89
Ida-Monona soils				
One-man	15,877	1,285.61	961.76	2,247.37
Two-man	21,287	1,668.54	1,245.29	2,913.83
Two-man with field sheller	21,966	1,719.47	1,285.01	3,004.48

[a]Based on Table 25.

[b]Includes taxes, insurance, housing, and interest on machinery investment.

Table 24. Variable machinery costs and field capacities of individual machines

Machine	Deprecia-tion per service unit[a]	Repairs per service unit[b]	Power cost per acre[c]	Minimum annual depre-ciation	Acres per hour[d]
Tractors					
2-plow	$.252	$.236		$210.74	
3-plow	.309	.289		258.29	
4-plow	.379	.354		316.26	
Plows					
2-14"	.174	.246	$1.08	20.86	.67
3-14"	.166	.239	.88	29.81	1.00
4-14"	.163	.230	.74	39.02	1.33
3-14"-2-way	.282	.239	.88	50.72	.92[e]
8' tandem disk	.103	.080	.40	17.96	3.10
10' tandem disk	.098	.076	.40	20.48	3.88
20' drag harrow	.034	.013	.17	10.62	7.76
24' drag harrow	.036	.017	.12	13.02	9.31
Endgate seeder	.037	.020	.20	7.42	9.0
Fertilizer spreader	.140	.100	.25	31.00	4.1[e]
Corn planter (check row)					
2-row	.240	.096	.33	30.00	1.40
4-row	.228	.114	.23	45.54	2.80
6-row	.243	.121	.20	72.78	4.20

[a]Depreciation and repair costs based on estimates by Husain (26).

[b]Includes grease and oil expense.

[c]From Epp (10).

[d]Applies to Carrington-Clyde soils unless indicated.

[e]Applies to Ida-Monona soils.

Table 24. (Continued)

Machine	Deprecia- tion per service unit	Repairs per service unit	Power cost per acre	Minimum annual depre- ciation	Acres per hour
Lister planter					
2-row	.204	.20	.50	30.00	1.40[e]
4-row	.270	.20	.50	54.00	2.50[e]
Cultivators					
2-row	.116	.062	.46	29.10	2.04
4-row	.093	.049	.24	54.30	4.08
6-row	.105	.056	.22	87.45	6.12
2-row rotary hoe	.130	.069	.29	9.75	4.08[e]
4-row rotary hoe	.130	.069	.16	19.49	8.16
7' power mower	.206	.320	.36	27.82	2.72
8' side delivery rake	.220	.205	.34	33.00	3.10
Baler (medium capacity)	.410	.150	.42	272.85	3.78
Corn pickers					
1-row pull type	1.355	.903	1.08	101.62	.83
2-row mounted	1.276	.851	.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	.944	.70	239.04	1.66
12' pull type	1.397	.869	.62	419.13	2.84
12' self pro- pelled with corn picker attachment	1.480	.829	1.12	739.90	1.66
Wagon with flair box and flat rack				21.69	
40' grain and bale elevator				30.75	

Table 25. Total variable costs by cropping systems and machinery combinations (per 40 acres of cropland)

Machinery combination	Machine repair[a]	Fuel[a]	Seed and ferti- lizer[b]	Labor[c]	Custom machine charges[d]	Total
			Carrington-Clyde soils			
Current cropping system						
2-plow, 2-row	85.62	140.85	225.19	165.08	170.99	1,590.13
3-plow, 4-row	101.70	139.24	225.19	135.70		1,404.23
4-plow, 4-row	108.54	136.38	225.19	130.64		1,403.15
3- and 3-plow, 4-row	102.65	142.83	225.19	139.01		1,412.08
3- and 4-plow, 4-row	102.86	137.47	225.19	128.47		1,396.39
3- and 4-plow, 6-row	101.38	137.20	225.19	123.55		1,389.72
3- and 4-plow, combine-picker	101.87	142.38	225.19	128.22		1,400.06
3- and 4-plow, picker-sheller	106.55	144.15	225.19	128.47		1,406.76
Five-year rotation system						
2-plow, 2-row	86.38	148.51	236.87	181.41	141.92	1,597.49
3-plow, 4-row	102.85	146.82	236.87	137.78		1,426.72
4-plow, 4-row	109.46	143.46	236.87	131.78		1,423.97
3- and 3-plow, 4-row	107.48	146.58	236.87	153.81		1,447.14
3- and 4-plow, 4-row	108.08	141.12	236.87	141.87		1,430.34
3- and 4-plow, 6-row	106.45	140.80	236.87	136.46		1,422.98
3- and 4-plow, combine-picker	107.08	146.20	236.87	141.64		1,434.19
3- and 4-plow, picker-sheller	112.60	148.40	236.87	141.87		1,442.14

[a]Based on Table 24.

[b]Refers to low fertilizer levels on current cropping systems and five-year rotation. Based on Table 29.

[c]Includes operator and hired labor for field operations only. No overhead labor included.

[d]From Armstrong (1).

Table 25. (Continued)

Machinery combination	Machine repair	Fuel	Seed and fertilizer	Labor	Custom machine charges	Total
Continuous-corn						
One-man	120.94	178.80	467.80	131.71		1,701.65
Two-man	113.42	163.36	467.80	150.77		1,697.75
Two-man with sheller	122.46	179.76	467.80	150.77		1,723.19
			Ida-Monona soils			
One-man	107.93	146.25	307.66	148.45		1,375.49
Two-man	111.64	138.16	307.66	152.35		1,375.01
Two-man with sheller	115.96	145.99	307.66	152.35		1,387.16

Table 26. Miscellaneous crop production costs

	Unit	Dollars
Seed[a]		
Corn	acre	1.93
Oats	acre	3.30
Soybeans	acre	4.25
Meadow	acre	5.30
Charges for transport to market[b]		
Corn	bushel	.03
Oats	bushel	.03
Soybeans	bushel	.03
Hay	bale	.03
Straw	bale	.03
Drying field shelled corn[c]	bushel	.10
Shelling corn	bushel	.03
Baling twine	per ton of hay or straw	1.03
Hay baling	bale	.11
Combining oats or soybeans	acre	4.00
Application of fertilizer on oat ground	acre	1.00
All labor	hour	1.00
Property tax on land		
Carrington-Clyde soil area	acre	2.01
Ida-Monona soil area	acre	2.95
Interest charge on machines	% of average value	7.0
Property tax on machinery	% of retail price	0.4
Machinery insurance	% of retail price	0.2
Housing of machinery	% of retail price	1.4

[a]From (36, p. 175).

[b]From Gibbons (14, p. 97).

[c]Source of information on all custom charges, Armstrong (1).

Table 27. 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[a]			
Corn	8	20	20
Oats	0	20	0
Total per 40 crop-acres			
Current cropping system	130.4	520	326
Five-year rotation system	160	568	400
High fertilizer level[b]			
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
Five-year rotation system	612.0	728.0	916.0
Continuous corn[b]			
Per acre	43.3	25.7	17.1
Total per 40 acres	1,730	1,028	681
Ida-Monona soil[c]			
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

[a]Estimated on basis of U. S. Census (47).

[b]J. T. Pesek, Ames, Iowa. Estimates of fertilizer requirements. Private communication. 1959.

[c]From Dean, *et al.* (9).

Table 28. 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 crop land	16.3	9.5	4.1	10.1
Yield per acre[a]				
Low fertilization[a]	64 bu.	44 bu.	23 bu.	2.3 tons
High fertilization[b]	71 bu.	47.2 bu.	26 bu.	2.8 tons
Five-year rotation system				
Acres per 40 acres of crop land	20	8	4	8
Yield per acre[b]				
Low fertilization[a]	64 bu.	44 bu.	23 bu.	2.3 tons
High fertilization[b]	71 bu.	47.2 bu.	26 bu.	2.8 tons
Continuous corn				
Yield per acre	71 bu.			
	Ida-Monona soil[c]			
Acres per 40 acres of crop land				
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.		2.5 tons
CCOMM	53.3 bu.	32.7 bu.		1.8 ton

[a]From (27).

[b]J. T. Pesek, Ames, Iowa. Yield estimates. Private communication. 1959.

[c]From Dean, et al. (9).

Table 29. Cropping inputs and costs (per 40 crop-acres)

	Current cropping system		Five-year rotation		
	Current fertilization	High fertilization	Current fertilization	High fertilization	Continuous corn
Seed cost[a]	$129.59	$129.59	$124.40	$124.40	$77.20
Fertilizer[b]					
lb. N	130.4	482.8	160.0	612.0	1,720
lb. P_2O_5	520.0	744.7	568.0	728.0	1,040
lb. K_2O	326.0	983.9	400.0	916.0	680
Total cost of fertilizer	$95.60	$218.27	$112.47	$230.77	$390.60

[a]Based on (36).

[b]Based on Table 28.

Table 30. Prices used in budgeting cost schedules and in linear programming[a]

	Unit	1955-57 prices ($)	1956-58 prices ($)	1958 prices ($)
Corn	bu.	1.30	1.13	.97
Oats	bu.	.69	.63	.56
Soybeans	bu.	2.47	2.19	2.02
Hay	ton	17.89	16.30	13.50
Straw	bale	.34	.30	.26
Barrows and gilts	cwt.		17.01	
Old sow	cwt.		15.57	
Breeding gilt	head		45.00	
Yearling feeder steers	cwt.		19.88	
Feeder calves	cwt.		21.95	
Choice fat cattle	cwt.		23.04	
Veal calf	cwt.		17.44	
Cows (commercial)	cwt.		12.55	
Cows (utility)	cwt.		11.07	
Beef breeding cow	head		145.00	
Dairy cow	head		170.00	
Eggs	doz.		.32	
Milk (grade B)	cwt.		2.75	
Chickens (fryers)	lb.		.18	
Baby chicks	100 head		24.00	
Old hens	lb.		.13	
Poultry supplement	cwt.		4.50	
Protein supplement	cwt.		5.00	
Phosphoric acid	cwt.		10.00	
Nitrogen	cwt.		13.50	
Muriate of potash	cwt.		8.00	
Seed corn	bu.		12.00	
Seed oats	bu.		1.10	
Soybean seed	bu.		2.75	
Alfalfa seed	cwt.		45.00	
Ladino	cwt.		80.00	
Brome grass	cwt.		25.00	

[a]From (40, 46).

Table 31. 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 32. Functions used in estimating crop losses due to 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 and 3rd time	"		0.25 bu.[c]
Corn harvesting	Oct. 31	Oct. 19	0.6 percent[d]
Oats planting	Apr. 11	Apr. 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]

[a]Loss estimates given apply to Carrington-Clyde area. These losses were adjusted percentage wise 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]Source, Link (30, p. 136).

[e]K. J. Frey, Ames, Iowa. Data on trials on late planting oats at Independence, Iowa. Private communication. 1959.

[f]Source, Link (30, p. 134).

[g]Source, Weber (49).

Table 32. (Continued)

Field operation	Date when losses begin: Carrington-Clyde area	Ida-Monona area	Losses per day late
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

[h]Based on results obtained by Dawson (8).

Table 33. Number of hours available per day for field work by weeks[a]

Week	Soil area: Carrington-Clyde	Soil area: Ida-Monona
March 15-21	0.41	0.41
March 22-28	1.50	1.50
March 29-April 4	3.54	3.54
April 5-11	5.11	5.11
April 12-18	5.90	5.90
April 19-25	6.62	6.62
April 26-May 2	5.79	5.79
May 3-9	5.57	5.57
May 10-16	6.50	6.50
May 17-23	6.47	6.47
May 24-30	7.10	7.10
May 31-June 6	6.36	6.36
June 7-13	6.62	6.62
June 14-20	6.62	6.62
June 21-27	6.89	6.89
June 28-July 4	7.45	7.45
July 5-11	7.93	7.93
July 12-18	7.63	7.63
July 19-25	7.75	7.75
July 26-Aug. 1	7.45	7.45
Aug. 2-8	7.06	7.06
Aug. 9-15	7.52	7.52
Aug. 16-22	7.90	7.90
Aug. 23-29	7.49	7.49
Aug. 30-Sept. 5	7.46	7.46
Sept. 6-12	7.86	7.86
Sept. 13-19	8.05	8.05
Sept. 20-26	7.59	7.59
Sept. 27-Oct. 3	7.59	7.59

[a]Basic estimates obtained from McKee (34) and adjusted on the basis of meteorological data (42).

Table 33. (Continued)

Week	Soil area Carrington-Clyde	Ida-Monona
Oct. 4-10	7.46	7.46
Oct. 11-17	7.82	7.82
Oct. 18-24	7.77	7.77
Oct. 25-31	8.13	8.13
Nov. 1-7	8.13	8.13
Nov. 8-14	6.39	7.10
Nov. 15-21	6.39	7.10
Nov. 22-28	5.63	6.26
Nov. 29-Dec. 5	2.69	.99

Table 34. Sequence of field operations used in budgeting[a]

First year corn	Second year corn	Oats	Soybeans
spring plow	tandem disk	tandem disk	tandem disk
tandem disk	fall plow	tandem disk	plow
harrow	tandem disk	harrow	tandem disk
plant	tandem disk	apply fertilizer	tandem disk
harrow	harrow	seed	harrow
cultivate	plant	harrow	plant
cultivate	harrow	combine	harrow
cultivate	cultivate	bale straw	cultivate
pick	cultivate		cultivate
	cultivate		cultivate
	pick		combine

[a]Same sequence of field operations is assumed for both soil areas.

Table 35. Machines included in the two-plow, two-row machinery combination

Machine	Average retail price[a] ($)
Tractor, 2-plow	2,810
Plow, 2-14"	394
Tandem disk, 8'	399
Harrow, 20'	177
Row planter, 2-row	400
Cultivator, 2-row	388
Endaget seeder	99
Power mower, 7'	371
Side delivery rake	440
Corn picker, one-row pull type	1,355
Grain and bale elevator, 40'	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	8,481
Average value (55% of purchase cost)	4,665

[a]Prices of all machines are averages of retail prices quoted by four machinery manufacturers, and include freight costs.

Table 36. Machines included in the three-plow, four-row machinery combination

Machine	Average retail price ($)
Tractor, 3-plow	3,444
Plow, 3-14"	563
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 4-row	759
Cultivator, 4-row	724
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 7'	2,656
Grain and bale elevator, 40'	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	15,747
Average value	8,661

Table 37. Machines included in the four-plow, four-row machinery combination

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Plow, 4-14"	737
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 4-row	759
Cultivator, 4-row	724
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 7'	2,656
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	16,694
Average value	9,182

Table 38. Machines included in the three- and three-plow, four-row machinery combination

Machine	Average retail price ($)
Tractor, 3-plow	3,444
Tractor, 3-plow	3,444
Plow, 3-14"	563
Plow, 3-14"	563
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 4-row	759
Cultivator, 4-row	724
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 7'	2,656
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	19,754
Average value	10,865

Table 39. Machines included in the three- and four-plow, four-row machinery combination

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Tractor, 3-plow	3,444
Plow, 4-14"	737
Plow, 3-14"	563
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 4-row	759
Cultivator, 4-row	724
Rotary hoe, 4-row	433
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 12' pull type	4,657
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	23,135
Average value	12,724

Table 40. Machines included in the three- and four-plow, six-row machinery combination

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Tractor, 3-plow	3,444
Plow, 4-14"	737
Plow, 3-14"	563
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 6-row	1,213
Cultivator, 6-row	1,166
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 12' pull type	4,657
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	23,598
Average value	12,979

Table 41. Machines included in the three- and four-plow, combine-picker machinery combination

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Tractor, 3-plow	3,444
Plow, 4-14"	737
Plow, 3-14"	563
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 4-row	759
Cultivator, 4-row	724
Rotary hoe, 4-row	433
Endgate seeder	99
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Combine, 12' S.P. with corn picker head	7,399[a]
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	24,324
Average value	12,829

[a]For the three- and four-plow, picker-sheller combination, this machine is replaced by a 12' pull type combine and a two-row mounted picker with sheller attachment. With the picker-sheller combination, total purchase cost is $23,814, and average value is $13,098.

Table 42. Machines included in one-man operation on continuous corn

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Plow, 4-14"	737
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 6-row	1,213
Cultivator, 6-row	1,166
Corn picker, 2-row mounted with sheller attachment	3,231
Grain elevator	600
Two 4-wheel trailers with grain boxes	814
Total purchase cost	12,650
Average value	6,958

Table 43. Machines included in two-man operations on continuous corn

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Tractor, 3-plow	3,444
Plow, 4-14"	737
Tandem disk, 10'	455
Harrow, 24'	217
Row planter, 6-row	1,213
Cultivator, 6-row	1,166
Cultivator, 4-row	724
Corn picker, 2-row mounted	2,552[a]
Grain elevator	600
Two 4-wheel trailers with grain boxes	814
Total purchase cost	16,139
Average value	8,876

[a]$3,231 with sheller attachment. Total purchase cost for the two-man operation with sheller is $16,818 with an average value of $9,250.

Table 44. Machines included in one-man machinery combination on Ida-Monona soils

Machine	Average retail price ($)
Tractor, 3-plow	3,444
Plow, 3-14" two-way	958
Tandem disk, 10'	455
Harrow, 20'	177
Lister planter, 2-row	340
Cultivator, 2-row	388
Rotary hoe, 2-row	220
Endgate seeder	99
Fertilizer spreader	310
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552
Combine, 7'	2,656
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	15,877
Average value	8,732

Table 45. Machines included in two-man machinery combinations on Ida-Monona soils

Machine	Average retail price ($)
Tractor, 4-plow	4,217
Tractor, 3-plow	3,444
Plow, 3-14" two-way	958
Tandem disk, 10'	455
Harrow, 20'	177
Lister planter, 4-row	600
Cultivator, 4-row	724
Cultivator, 2-row	388
Rotary hoe, 4-row	433
Endgate seeder	99
Fertilizer spreader	310
Power mower, 7'	371
Side delivery rake	440
Baler, P.T.O.	1,819
Corn picker, 2-row mounted	2,552[a]
Combine, 7'	2,656
Grain and bale elevator	684
Two 4-wheel trailers with flair boxes and hay racks	964
Total purchase cost	21,287
Average value	11,708

[a]$3,231 with sheller attachment. Total purchase cost for the two-man operation with sheller is $21,970 with an average value of $12,081.