Economy of Innovations in Dairy Farming And Adjustments To Increase Resource Returns

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CONTENTS

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BY RANDOLPH BARKER AND EARL O. HEADY

Technological innovations have allowed a gradual change to take place in dairy farm organization and management practices. Improved breeding and feeding have resulted in a steady rise in production per cow, and labor-saving devices have allowed herd size to expand. With new techniques in housing, feeding and milking, the possibility exists for one laborer to handle a larger number of cows. The result can be an increase in labor productivity.

In recent years, however, the cost of labor and capital has risen more rapidly than the price of dairy products. A cost-price squeeze has occured in dairying, as it has in most other types of Midwest farming. For the majority of dairy farmers in Iowa and throughout the nation, over-all change in organization and in the scale of enterprise has been too slow to keep pace with rising costs. Consequently, returns to resources in dairying—particularly to labor—are lower than in many other types of farming.

Hence, there is need for analysis to examine the possibility of reducing unit costs by adjustments in dairy farming. To what extent can herd expansion and over-all organizational changes in the dairy farm increase labor returns? To what extent can cost per unit be reduced through the expansion of herd size under the various dairy technologies? What size of herd is necessary to allow attainment of most of the cost economies under various new techniques? What are the effects of alternative techniques and herd size on over-all farm organization and profit?

OBJECTIVES

This study was undertaken to assist Iowa farmers in answering the previous questions. The intent is to show what farmers are capable of doing, not what the majority are now doing. Costs and returns were computed for a wide range of herd sizes and dairying methods. The specific objectives of the study are:

1. To determine the effect of herd size, new dairy technologies and farm organization on labor productivity.

2. To determine the structure of costs and the nature of cost curves for the dairy enterprise and for the farm as a whole under several dairy techniques.

3. To determine the minimum herd size for attaining most of the cost savings associated with greater output.

4. To analyze the effect of alternative dairy techniques and herd size on farm organization and profits.

5. To compute from selected alternatives, considering the organization of the entire farm, the least-cost method of meeting dairy feed requirements.

DAIRY TECHNIQUES

Recent dairy innovations can be divided into two broad categories—those concerned with the harvesting and storage of crops and those related to the care and feeding of animals. The former category includes such equipment as field choppers, hay crimpers, barn dryers, high-speed forage unloading wagons and hay pelleting machines. This study, however, is concerned primarily with new methods for handling animals. In this category, loose housing promises to become the most significant and revolutionary development in dairy farm organization. Loose housing has brought with it a number of other new techniques and has encouraged some radically different concepts in herd management.

Loose housing is not new. It has always been prominent in the South. A number of factors, however, have contributed to its growing popularity in northern dairy areas. Rising building costs have increased the advantage of the less expensive loose housing structures over conventional stanchion barns. The Wisconsin Controlled Barn Project (1940-51) provided convincing evidence and corroborated earlier findings that cows do as well outside as in the stanchions, regardless of the weather.[2] Then too, loose housing is a more flexible arrangement. The dairy enterprise can be expanded with little additional building cost; or,

[1] Project 1277, Iowa Agricultural and Home Economics Experiment Station.

[2] Witzel, S. A. and Heizer, E. E. Loose housing or stanchion type barns? Wisc. Agr. Exp. Sta. Bul. 503. 1953.

alternatively, contracted and the loafing sheds converted to other uses. Finally, and most important, loose housing offers an opportunity both to save labor and to increase its productivity.

Labor is saved principally in the feeding and milking operations. Roughage normally is fed outside when cows are housed in loafing sheds. Forage stored at the ground level needs to be moved only a short distance, and the self-feeding of hay and silage is not uncommon. More than 50 percent of the farmer's chore time, however, is required for milking. It is here that the greatest opportunity for labor saving is offered. Although milking speed has not been increased greatly in the majority of milking parlors, loose housing systems are promising in this respect. The six-stall parlor allows the operator to milk better than 35 cows per hour. The New Zealand "herringbone," recently introduced into this country, has raised the rate to almost 60 cows per hour.

The bulk tank and pipeline are closely associated with the introduction of loose housing. While less important than housing methods in improving labor efficiency, they can contribute greatly to improved sanitation and to the ease of milking.

Other techniques make it possible to increase greatly the volume of production per man. Careful culling and selection of cows, not only for high milk production but also for rapid milking, presents another possibility in labor saving. There is evidence that the rapid let-down of milk is an inherited characteristic, and cows may yet be bred for rapid milking.[3] Artificial insemination, improved grain rations, higher quality roughage and disease control are important factors in both production per cow and production per man-hour.

EMPIRICAL METHODS

A number of the techniques associated with loose housing which were mentioned in the previous section are analyzed and compared in this study. The empirical procedure, the source of data and the method of presentation are described in this section.

Empirical Procedure

New techniques traditionally have been analyzed by budgeting cost curves for the dairy enterprise to indicate the unit cost of production over a range of outputs and herd sizes. Budgeting was used in this study to develop a number of these average cost curves, each curve representing a separate technology. A comparison of cost curves not only indicates how the curves decline with an increase in herd size, but also indicates the size of herd necessary before any one milking technique becomes feasible.

For the more complex situations, budgetary analysis has been supplemented by linear programming. The latter was used to analyze the effect of technological innovation on the organization and profits of the entire farm. Linear programming is particularly well suited to an over-all farm analysis because it simultaneously considers both the opportunities open to the farmer and the limited resources which he possesses. Computations for these complex situations are less difficult, and the results are more accurate than when the budgeting technique is used.

Source of Data

The first step in budgeting and programming is to specify available resources and relevant enterprises or activities for the situation under analysis. The next step is to obtain the data on costs and returns and resource requirements for each of the enterprises under consideration. The basic data on costs and resource requirements then are transformed into production coefficients to indicate the amount of a given resource either used or supplied by one unit of each enterprise. Hence, the production coefficients provide the link in selecting the enterprises and indicating the size of enterprise that can be established with given resources.

Coefficients of production for the farm and production situations studied were obtained from a farm survey and several secondary sources. The 1957 farm survey, which provided information on labor requirements and related data for loose housing, included 25 central Iowa farms. Herd sizes ranged from 15 to 45 cows on these farms. Records were kept of chore time and labor requirements in April, May and June. Where possible, regression analysis was used to indicate the per-cow marginal or added labor requirements for various chore-time tasks. Most tasks (feeding roughage, for instance) could not be analyzed in this manner because equipment and methods varied widely among farms. Information relating to this equipment, however, provided a basis for developing labor coefficients under the different feeding methods.

Crop yields and fertilizer requirements for alternate rotations were obtained from the Department of Agronomy, Iowa State University. Staff members from the Department of Dairy Husbandry supplied information on feed requirements for various levels of production, and the Department of Agricultural Engineering furnished data on building costs. These sources were supplemented by information gathered from a number of publications.[4]

Production coefficients were developed in most instances for better-than-average Iowa conditions, although all coefficients represented levels of achievement well within the range of good farm managers. The selection of coefficients thus was in keeping with the normative emphasis of this study, showing what farmers can do with respect to dairy farm reorganization, not what the majority are doing.

Method of Presentation

In the analysis of new dairy techniques, major emphasis was placed upon the development of cost curves to show the cost per unit of production over the

[3] Petersen, W. E. Tomorrow's answer to today's producer problems. Univ. of Minn., St. Paul. (Original publication source unknown).

[4] For an excellent discussion and review of a wide number of publications on the subject of loose housing, see: Angus, R. C. and Burr, W. L. An appraisal of research literature dealing with loose housing and conventional dairy cattle housing. Jour. Dairy Sci. 38:391-406. 1955.

relevant output range. The first set of curves showed the investment per cow in buildings and equipment for loose housing and stanchion arrangements. Then, annual capital and labor costs were combined to demonstrate the effect on costs of substituting capital for labor. Next, cost curves were developed for the dairy enterprise showing cost per hundredweight of milk produced under each of the farm systems. Finally, cost curves were determined for the whole farm, with each one of these curves also representing a different dairy system. The latter curves then were used to develop a long-run average cost or planning curve to indicate the optimum route of expansion in volume of production and cow numbers.

The cost curve analysis was supplemented by computing average and marginal returns to labor for selected discrete levels of output. Finally, optimum farm plans were determined for two-man farms to indicate profit opportunities in complete farm reorganization.

SITUATIONS AND TECHNIQUES ANALYZED

This study is conducted for grade A dairy farms on the Clarion-Webster soil association. While major emphasis is on the technology associated with loose housing, standard stanchion barn practices are used as a basis of comparison with newer methods.

Cows of only one production level are included in the analysis—an annual milk output per cow of 12,000 pounds with 3.5 percent butterfat. For the linear programming analysis the labor supply is limited to a maximum of two full-time men and one summer hand per farm. It is supposed that an investment in new techniques will not be made unless the return is at least 5 percent. Land is not considered to be a limiting resource. Choice is allowed between two grain and four roughage rations; grain rations emphasizing either corn or oats, and roughage rations emphasizing either hay, grass silage, corn silage or oat silage. In analyzing milking systems, the same feed coefficients are used, but capital and labor requirements vary with the methods.

Milking Methods

Four parlor milking systems are studied and compared with the conventional stanchion barn. Certain equipment and handling practices are considered to be standard for the milking parlors. The parlors themselves are equipped with pipelines and bulk tanks. Cows are housed in loafing sheds. Feed is stored at ground level and fed outside; hay is fed from a hay keeper, and silage from a trench silo.

THE STANCHION PARLOR

In the stanchion parlor four or more stanchions are set in a single row. A pipeline runs the length of the stanchions to the milk room, and milking units are attached between each pair of cows. Cows are driven in and backed out of the stanchions. Although this system shows a slight decrease in labor efficiency compared with the three- and four-stall elevated parlors, it requires the least amount of capital. In the initial stages of converting to loose housing, many farmers prefer to retain a portion of the stanchions. When conversion cannot be accomplished in a single step, a new milking parlor usually is added last, because it is the least flexible of the structures employed in conversion to loose housing.[5]

THE THREE- AND FOUR-STALL PARLORS

The three- and four-stall parlors are considered in a single group because they are similar in terms of cost and labor efficiency. There are two types of parlors in this group—the walk-through and the side-entry.

The walk-through parlor has two stalls on either side of a central pit. Cows enter the stalls, one behind the other. Once the animals are in place, the stalls are closed by sliding panels to which feed troughs are attached. When cows on one side have been milked, the two milking units are switched across the center aisle. Slow milking cows create a "bottleneck" since cows are received and released in pairs. The side-entry stall, on the other hand, permits separate entry and exit. There is usually one milking unit per stall. Stalls may be strung out in a single line, laid out in "U" shape or set parallel, as in the case of the walk-through parlor.

The three-stall side-entry parlor is probably the most popular of the parlors in this group. This parlor is used in the analysis which follows.

THE SIX-STALL PARLOR

The third system analyzed in this study is the six-stall parlor. It is arranged with three stalls on either side of the central pit. A pipeline runs to the milk room over the operator's head. As in the case of the walk-through parlor, there are normally half as many milking units as stalls, and units are switched back and forth across the center aisle or pit. Milking units, therefore, are never left idle, and the stalls in which cows are not being milked serve as preparation stalls.

The six-stall parlor is the largest of the elevated stall parlors in which milking can be carried on by a single operator. Although this parlor is more expensive, is has a "time and motion" advantage over the smaller systems. As many as 35 cows can be milked in an hour, an increase of 10 cows over the three-stall parlor.

THE HERRINGBONE PARLOR

The final loose housing milking system analyzed in this study is the "herringbone" parlor. This design was introduced into the Midwest from New Zealand

[5] An important modification of this system common in New Zealand is found in this country, principally in California. This is the walk-through stanchion (not to be confused with the walk-through parlor). By releasing a lever the operator can guide the cow directly ahead through the stanchion. The next cow is not hindered in entering from the rear. Studies show that this method is slightly more efficient in the use of labor than the three- and four-stall elevated stanchions. For further information on this system, see Beyers, George B. Effect of work methods and building design on building costs and labor efficiency for dairy chores. Ky. Agr. Exp. Sta. Bul. 589. 1952.

in 1956.[6] The term "herringbone" is descriptive of the manner in which cows stand on the elevated platforms. The milking room consists of a central passageway or pit with cement platforms raised 30 inches on either side. There are no stalls or partitions between cows, which stand side by side with heads away from the operator at an angle of 30 degrees to the outside wall. The majority of parlors in this country are built to handle six cows on a side and have six milking units, although smaller parlors with five and four cows on a side are gaining in popularity.

The twelve-cow herringbone parlor concentrates three times the number of cows and milking units in an area slightly smaller than that occupied by a four-stall parlor. The cow is placed at exactly the right height and position for fastest milking. In a parlor of this size from 50 to 60 cows can be milked per man-hour.

CAPITAL AND LABOR REQUIREMENTS FOR MILKING PARLORS

Table 1 compares the capital requirements and milking time for each of the milking parlors described. The capital investment in particular kind and size of parlor and the actual milking time per cow do not vary with herd size. As capital requirements increase between types of parlors, however, the labor requirements decrease.

In table 1, movement from the stanchion parlor toward the herringbone parlor represents a substitution of capital for labor. Thus, as later analysis will demonstrate, the selection of the appropriate parlor depends not only upon the size of herd, but also upon the relative scarcity or opportunity cost of capital and labor on a given farm.

THE STANCHION BARN

For the stanchion system used as a basis of comparison, all cows are stanchioned in the barn and are milked by machine with two operators and four machines. Hay is stored overhead, and silage is fed from an upright silo without a silage unloader. A gutter cleaner is used to remove manure.

Cropping Methods

Four crop rotations are considered in the analysis of the over-all farm organization—CCOM, CCOMM, COMM and COMMM. This range of rotations is included to allow sufficient forage for the plans using intensive dairy activities, should they prove profitable. Yields are based upon a medium level of fertilizer application. Associated with these rotations are transfer activities permitting the conversion of corn to corn silage, oats to oat silage and pasture to hay or grass silage.[7] Thus, feed can be provided by the rotations for any one of the dairy rations previously described.

TABLE 1. COMPARISON OF CAPITAL INVESTMENT IN THE MILKING PARLOR AND LABOR REQUIREMENTS FOR THE MILKING OPERATION IN FOUR PARLOR SYSTEMS.[a]

Type of parlor	Capital: Building	Capital: Equipment[b]	Capital: Total	Labor, man-minutes/cow[c]
Four-abreast	$2,273	$1,436	$3,709	3.16
Three-stall	3,576	2,275	5,851	2.61
Six-stall	5,972	3,422	9,394	1.71
Twelve-cow Herringbone	5,445	5,122	10,567	1.09

[a] Adapted from: Information obtained from the Department of Agricultural Engineering at Iowa State University, from dairy equipment dealers and from a field survey conducted in central Iowa, 1957.

[b] Does not include bulk tank.

[c] Does not include preparation and clean-up time.

RESOURCE AND COST CURVES FOR THE DAIRY ENTERPRISE

This section includes a graphical presentation of resource requirements and per-unit cost of various housing techniques. Relationships have been derived for the dairy enterprise only.

Investment per Cow

Investment per cow in buildings and equipment declines as herd size increases for all housing and milking techniques (see fig. 1). The sharpest decline occurs with herds up to 50 cows. The investments include all buildings needed for the storage of feed and milking and housing of cows, but do not include field machinery. Investment per cow decreases as herd size increases: first, because fixed costs are spread over a larger herd and, secondly, because the investment in many items is not proportional to the

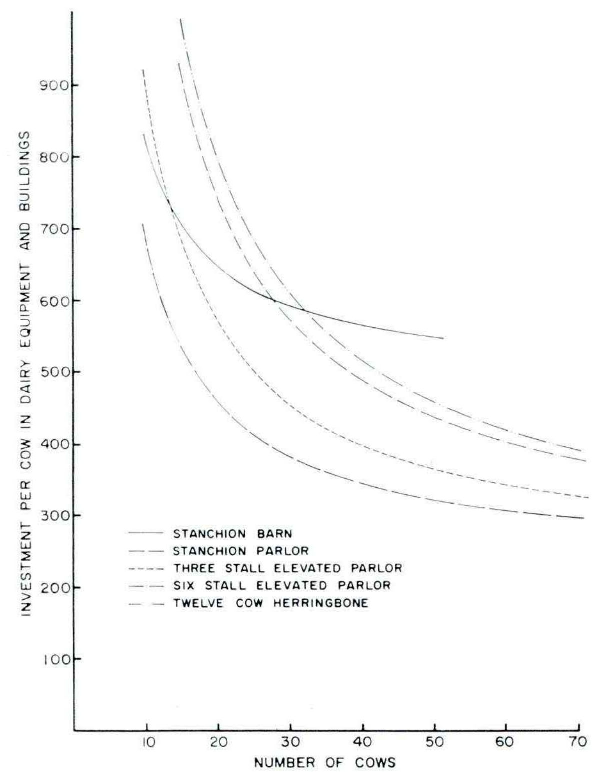

Fig. 1. Curves showing investment per cow in dairy buildings and equipment for five milking systems.

[6] For a description of the New Zealand herringbone parlor see: Green, S. L. The modern herringbone shed. New Zealand Dairy Exporter. 31:11. 1955.

[7] See Heady, Earl O. and Candler, Wilfred. Linear programming methods. Iowa State University Press, Ames, Iowa. 1958. Ch. 4 and 6.

herd size. For example, regardless of the length of a stanchion dairy barn only two gable ends are needed. Silage storage space is cheaper per cubic foot in a large silo than in a small silo of the same kind. This also holds true for the storage of milk in bulk tanks.

The actual investment per cow for a given herd size will depend upon the equipment, type of building and milking arrangement. Estimates of these costs for typical equipment and buildings are presented in fig. 1, table 1 and table A-3 of Appendix A.

In contrast to the stanchion barn, the investment curves for all of the loose housing systems decline more rapidly as cow numbers increase. This is because investment in the parlor and milking equipment (except for the bulk tank) does not change with herd size; it is the same for 10 as for 50 cows. Therefore, investment per cow declines sharply as this fixed parlor investment is spread over a larger herd size.

If the milking parlor were expanded as the herd size increased, parlor milking curves would slope more gradually. The milking parlor, however, has been designed principally for a single operator. Usually, therefore, expansion of the parlor does not involve a mere doubling of the number of stalls, but requires technological changes which will allow the operator to reduce the milking time per cow. Technological differences between the analyzed parlor systems have been described in the previous section. Part of the task in the following sections will be to determine over what range of herd size the various loose housing systems are least-cost.

Investment per cow is lowest for the four-abreast stanchion parlor for herds above 10 cows: first, because the cost of parlor and equipment is less than for any other loose housing system and, secondly, because the cost for feed storage and cow housing is less for loose housing than for the stanchion barn. A barn must be of sturdy construction to avoid drafts. Loafing sheds, on the other hand, are usually built with one side open. Loose housing is also less expensive because it utilizes such feed storage facilities as hay keepers and bunker silos, which can be constructed at lower cost.

The three-stall and stanchion parlors involve considerably less investment than the larger six-stall and herringbone systems which require more building space and more equipment. As herd size increases, however, the difference in investment per cow among loose housing systems decreases.

With less than 28 cows, investment per cow is greater for the two larger milking parlors than for the stanchion barn. The high cost of equipment in the larger parlors causes the investment curves to rise well above the curve for the stanchion barn system as size of herd decreases. Beyond 35 cows, however, the stanchion barn has the highest per-cow investment. The building cost is lower for the herringbone than for the six-stall parlor, but the cost of equipment is higher. This is mainly because of the more complex feeding system and the additional milking units required.

Any milking parlor arrangement can accommodate a wide range in herd size. Larger parlors require less milking time per cow but have a higher initial investment. In the section that follows, annual costs for capital and labor are presented. From these data it will be possible to determine the range over which each parlor milking arrangement is least-cost.

Cost Curves for the Dairy Enterprise Developed by Budgeting

Figures 2 and 3 show the annual capital and labor cost per cow when milking herds are of different sizes. The two sets of relationships are based upon different opportunity costs for capital. Capital is charged at 7 percent in fig. 2 and at 12 percent in fig. 3. Labor is charged at $1 per hour. The two levels of capital were chosen to demonstrate the effect on the cost curves of a difference in opportunity cost. The capital cost includes depreciation, repairs, taxes, insurance and interest on dairy buildings and equipment. The labor cost includes all labor required in the dairy, but does not include that required for field work and crop production.

All curves fall with an increase in herd size. This is largely the result of the distribution of fixed costs over a larger herd size. As previously mentioned, however, economies in per-cow capital cost are associated with larger constructions. In addition, a distinction has been made between "fixed" and "variable" labor.[8] In a portion of the tasks associated with dairying (for example, preparation and clean-up of equipment) labor requirements do not vary appreciably with herd size. This "fixed" labor intensifies the initial downward slope of the cost curves as cow numbers are increased.

In fig. 2 labor is charged at $1 and capital at 7 percent. Changes in the per-cow cost of capital and labor caused by an increase in herd size result in the intersection of cost curves. For very small herds, the order of curves reflects differences in capital investment. The herringbone parlor is the most costly system with herds below 13 cows. The stanchion parlor is least-cost for herds up to 23 cows. As the dairy enterprise expands, however, fixed costs are spread rapidly, and labor efficiency becomes increasingly more important. With herds above 23 cows the labor-saving herringbone system is the least-cost. The cost pattern for loose housing parlors with herds larger than 35 cows is completely the reverse of that with 13 cows or less. That is, with very small herds the least-cost system is the stanchion parlor, followed by the three-stall, the six-stall and the herringbone. With large herds the least-cost system is the herringbone, followed by the six-stall, the three-stall and the stanchion parlor.

Capital requirements do not decline as rapidly with an increase in herd size for the stanchion barn as with loose housing arrangements (as fig. 1 indicates). Labor requirements are also higher since labor economies are achieved in loose housing in both feeding and milking operations. Combined capital and labor costs for the stanchion barn are higher than for any other system with herds larger than 18 cows.

In fig. 3 annual costs per cow for capital and labor

[8] This useful distinction has been substantiated by empirical investigation. See: Day, L. M., Aune, H. J. and Pond, G. A. Effect of herd size on dairy chore labor. Minn. Agr. Exp. Sta. Bul. 449. See also table A-1 in Appendix A of this bulletin.

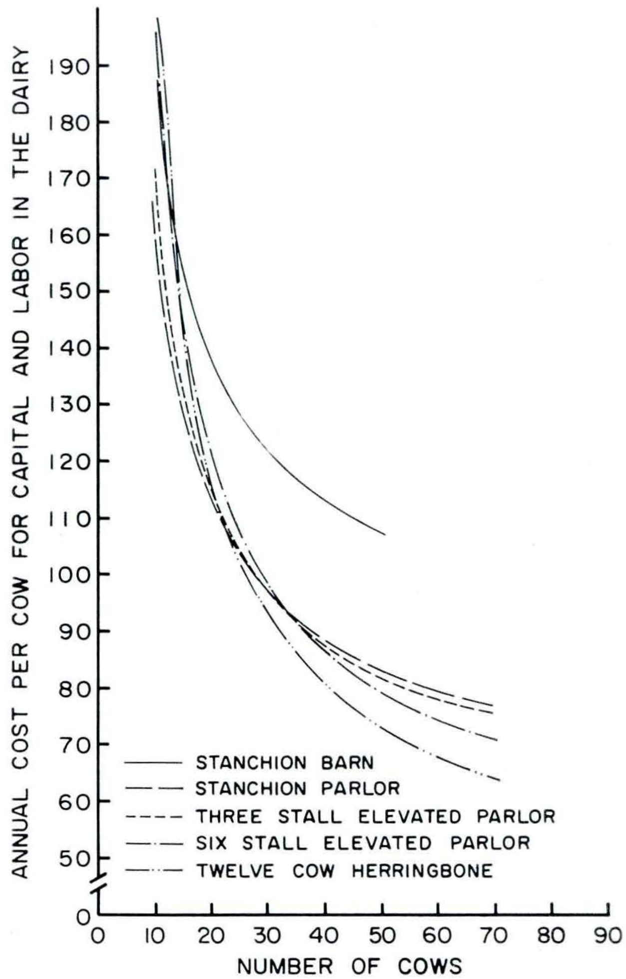

Fig. 2. Curves showing annual cost per cow for capital and labor for for five parlor milking systems with capital at 12 percent and labor at $1 per hour.

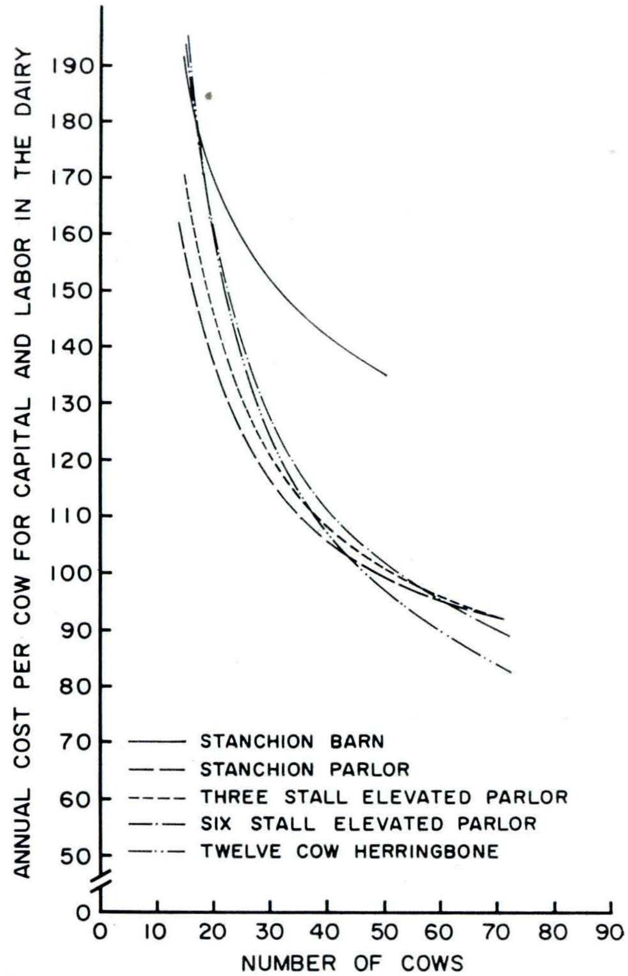

Fig. 3. Curves showing annual cost per cow for capital and labor for five milking systems with capital at 12 percent and labor at $1 per hour.

are higher because the assumed opportunity cost for capital is higher (12 percent). The pattern of change in cost curves is similar. As before, capital and labor costs are highest for the stanchion barn with herds larger than 18 cows. Nevertheless, the higher charge for capital extends the advantage of the parlors with smaller investment over a wider range of output. For example, the stanchion parlor is now least-cost up to 43 cows. Lower costs occur for the herringbone only beyond this point. As in fig. 2 the order of cost curves for loose housing completely reverses between very small and very large herds. The process is more gradual, however, and is completed only at a herd size of 70 cows. Again, this is a result of a higher charge for capital.

Figures 2 and 3 demonstrate that a change in the cost of capital with respect to the cost of labor affects considerably the relationship between the parlors. As the price of capital decreases with respect to the price of labor, costs for the labor-efficient systems—such as the six-stall and herringbone—decline more rapidly. Hence, these systems become feasible with a smaller herd size.

At the same time, the relationship between the various loose housing systems and the stanchion barn changes very little with a change in the cost relationship between the two resources. Compared with loose housing, the stanchion barn has an increasingly higher cost for both capital and labor as herd size is expanded beyond 18 cows.

The budgetary analysis indicates a considerable cost advantage for loose housing as herd size is increased.[9] No consideration has been given to the problem of conversion to loose housing, however. Many farmers have a considerable investment in stanchion barns. The cost of abandoning these facilities should be included when applicable.[10]

Cost Curves for the Dairy Enterprise Developed By Linear Programming

A different type of enterprise cost curve is presented in fig. 4. Those of the previous section were computed by budgeting and algebraic analysis as continuous curves. Those which follow represent discrete points

[9] When farmers have accurate information regarding opportunity costs for resources, curves derived by this procedure of partial budgeting may prove useful. On-farm opportunity costs for resources, however, often are difficult to determine without an analysis of the entire farm operation. Opportunity cost has relevance only when resources are limited.

[10] The conventional procedure is to take the value of the undepreciated portion of the old system, less the salvage value, and add this to the fixed investment for the new system.

on a cost function as determined by linear programming methods for the farm as a whole.

The basic method was that of "variable resource programming."[11] Through this procedure a resource is allowed to vary continuously throughout the relevant range. The plans designated are those representing "corner points" in resource use. A corner point indicates a plan limited by the scarcity of some specific resource. Corner points, or optimum plans for the particular level of resources, are connected by line segments. This establishes a functional relationship between returns and the quantity of resources used.

For purposes of this study, however, the quantity of milk, rather than the quantity of some resource, was allowed to vary. At each iteration in programming a new plan was developed which represents the optimum organization of resources for the particular level of milk output. The procedure was continued until the maximum level of milk production was attained.

The cost analysis for the dairy enterprise under linear programming differs from the budgetary analysis in the following respects: First, programming was initially carried out for the entire farm, and dairy costs were segregated to determine the cost per hundredweight of milk.[12] Cash grain for sale was the only alternative enterprise included in the analysis of the whole farm. The farm labor was limited to two full-time men and one summer hand. The minimum return to capital was 5 percent.

Costs for the dairy included other items besides labor and investment capital; namely commercial concentrates, home grown feeds, bedding, veterinary expenses, breeding expenses, electricity and taxes and insurance on buildings and equipment. In contrast to the previous section, capital and labor costs are not on an "opportunity" basis but are at market rates. Costs are 5 percent for fixed capital, 7 percent for operating capital and $2,500 per man-year for labor. The per-unit cost thus includes a charge for all items with the exception of management.

Finally, an opportunity cost for resource use also is incorporated into the programming analysis. The expansion of the dairy enterprise results in a gradual transfer of resources away from the production of cash grain for sale. This results eventually in a decline in farm profits. The decrease in farm profits is charged as an opportunity cost to the dairy enterprise. As a consequence, cost per hundredweight of milk does not continue to fall indefinitely as herd size is increased. Most Corn Belt farmers do, in fact, combine a sizeable cash grain enterprise or other livestock enterprise with the dairy. Therefore, incorporation of this opportunity cost is believed to be a realistic procedure.

Cost per hundredweight of milk was determined for each minimum cost plan under a given milking system. As shown in fig. 4, these points of minimum cost are connected by line segments. Curved lines could have been used to conform to the orthodox presentation of costs. This has not been done, however, because optimum farm programs for the particular resource limitations do not fall in between points,

[11] See Heady, Earl O. and Candler, Wilfred. Op. cit. Ch. 7.

[12] The task of separating enterprise costs is difficult, always representing some arbitrary decisions that are open to question. For example, overhead charges, such as taxes, are not imputed to different enterprises.

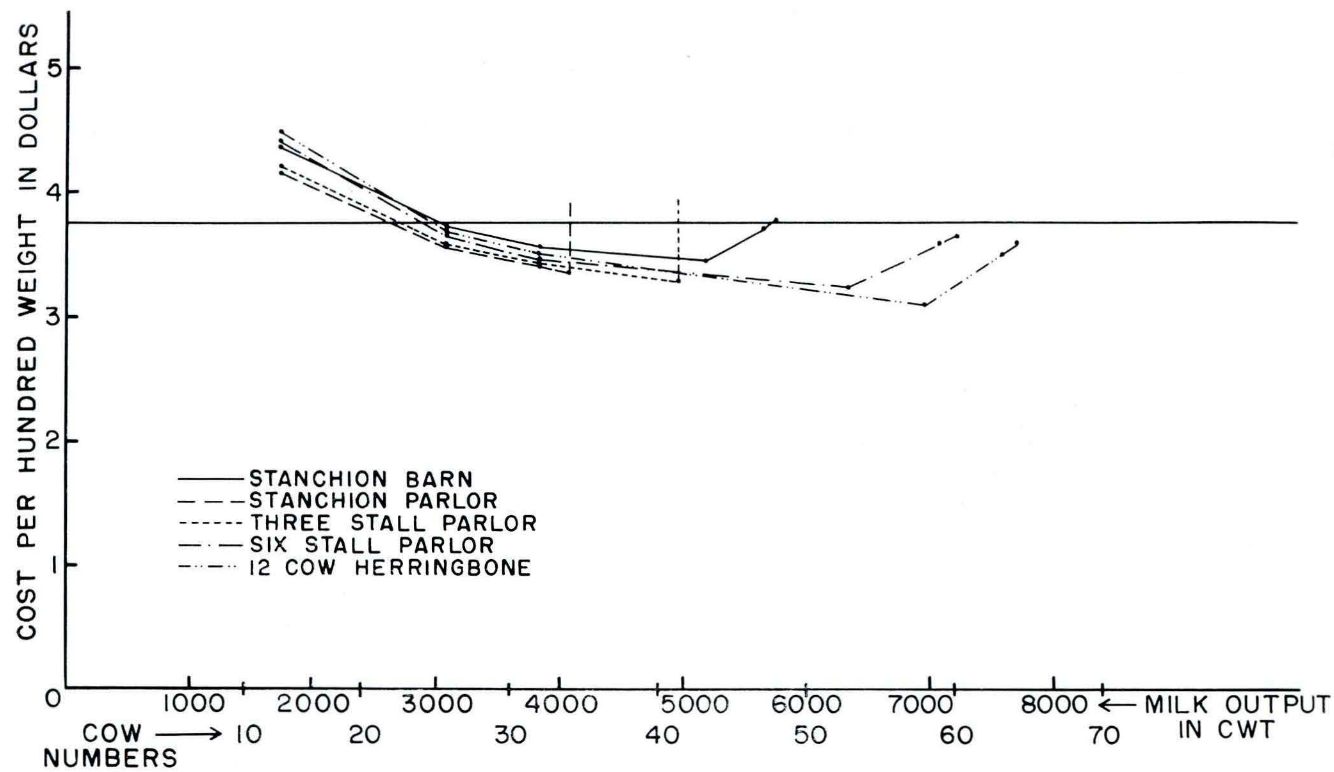

Fig. 4. Short-run average cost curves showing cost per hundredweight of milk for five dairy enterprises on central Iowa farms.

but rather at exactly the points indicated (i.e., at the corner points).

Five average cost "curves," one for each of the dairy systems analyzed, are presented in fig. 4. The market price for milk, $3.75, is represented by a horizontal line. Intersection of a cost curve with the price line indicates the break-even volume of production. At this point the price per unit is just equal to the cost per unit with resource prices at rates designated previously.

As the volume of production or herd size is increased, these cost curves behave in a similar manner, declining rapidly at first, then more gradually, and finally swinging upward. The decline in the curves results from the spreading of "fixed" capital and labor over a larger number of cows. The curves for the three-stall and stanchion parlors rise vertically from the minimum cost point under the assumption that operators would not milk in excess of an annual average of 4 hours per day.[13] For the other three milking systems, a point is reached at which greater output can be achieved only by a considerable sacrifice in the output of cash grain. As previously mentioned, the loss in revenue from cash grain was considered to be an opportunity cost to the dairy enterprise. This cost was added to the other cost for the dairy, thus causing the cost curves to rise. There is a point beyond which it is impossible to expand milk production through a reorganization of the farm. This capacity or production level is determined by the limited labor supply and by the technology employed.

The stanchion parlor. The cost curves differ for each system because of differences in labor and capital requirements. The average cost of producing milk is least for the stanchion parlor up to a herd size of 34 cows. At this point milk is produced at $3.36 per hundredweight. The break-even point, at which cost just matches price per hundredweight, is attained at 22 cows. This is the lowest breakeven point of all the systems considered; it is caused by the low capital requirements of the stanchion parlor.

The three-stall parlor. Average cost is lowest for the three-stall parlor with herds of from 34 to 41 cows. Efficient use of labor permits the curve to be extended downward to the right beyond the limits of the stanchion parlor. Throughout this range the three-stall parlor maintains its advantage over the two larger parlor systems because of lower capital costs. Cost economies are realized up to 4,959 hundredweight. The cost per hundredweight at this output is $3.27.

The six-stall parlor. To expand herd size beyond 50 cows, it is necessary to adopt either the six-stall or the herringbone parlor. The six-stall is never the least-cost system. Up to a herd size of 53 cows, however, the difference in per-unit cost between the two larger systems is very slight. The minimum cost for the six-stall parlor is $3.22 per hundredweight, while the cost per hundredweight for the herringbone parlor at this minimum point is approximately 4 cents less.

The herringbone parlor. The herringbone has the highest cost for small herds of less than 22 cows. As volume of production is increased, capital costs decline rapidly, and labor efficiency results in lower costs. Lowest per-unit cost occurs under the herringbone parlor with herds larger than 41 cows. Cost economies are realized up to 6,946 hundredweight, or 58 cows. At this point cost per hundredweight is $3.10, the lowest for all systems. Herd size can be increased to a maximum of 64 cows.

The stanchion barn. In comparing the cost curves for the parlor milking systems with those for the stanchion barn, it should be remembered that these parlors are designed for one operator, whereas it is assumed that there are two workers with the stanchion barn system. High capital and labor requirements combine to make the stanchion barn the most costly system with herds larger than 22 cows. With fewer than 15 cows, the cost per hundredweight with the stanchion barn is less than for the two largest parlors. But as herd size increases beyond 22 cows, the cost spread between the stanchion barn and the milking parlors increases. The minimum cost of $3.41 per hundredweight is reached at 5,160 hundredweight, or 43 cows. This is approximately 12 cents per hundredweight above the cost for the six-stall parlor at this point. The capacity of the stanchion barn exceeds that of the two smallest milking parlors because, under our assumption that two men will do the milking, more total hours can be devoted to the dairy.

The break-even point at which costs just match returns occurs for all systems in the range of 22 to 26 cows. An operator with a small volume of production at a cost per hundredweight greater than $3.75 would not necessarily be forced out of business. He would continue farming, at least in the short run, if he met his operating expenses, since he would not have to pay himself a wage or pay for capital depreciation.

Farmers, however, must increase production beyond the break-even point to take full advantage of cost economies. Most of the cost savings are realized for the two smallest parlors at about 32 cows. At this point the cost for the three-stall and stanchion parlors is 35 to 36 cents below the $3.75 return per hundredweight. Cost per hundredweight continues to decline for the six-stall and herringbone parlors. The minimum cost per hundredweight, $3.10 under the herringbone system, is 65 cents below the selling price of milk.

RETURNS TO LABOR AND MANAGEMENT FOR THE DAIRY ENTERPRISE

The family of curves presented in fig. 5 indicates the level of hourly returns to labor and management over the output range included in the cost curve analysis. Wage rates were determined for the optimum plans represented by the "corner points" for the cost curves in the previous section. These wage rates were calculated in the following manner: A 5-percent

[13] Herd size could be expanded either by the operator working longer hours in the dairy or by using two men instead of one to do the milking. Many farmers choose the latter alternative, but this defeats the purpose of the milking parlor. The smaller parlors in particular are designed to be one man operations. Two men can be employed more efficiently in a stanchion barn than in a small three- or four-stall parlor. While the operator and the hired man can alternate between milkings in the parlor system, few grade A dairymen prefer to leave the task of milking to unsupervised hired help.

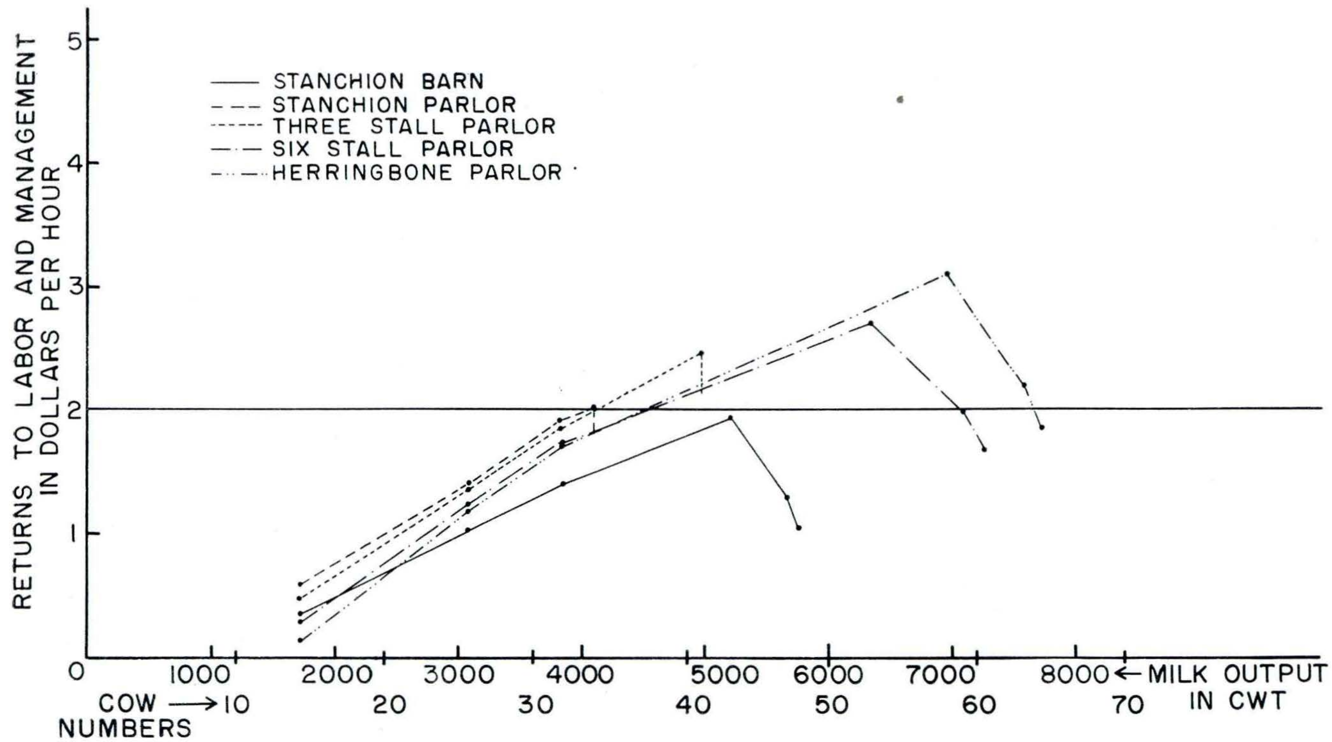

Fig. 5. Curves showing returns to labor and management for different levels of milk output on central Iowa dairy enterprises with fixed capital charged at 5 percent and operating capital at 7 percent.

return was assigned to fixed capital and a 7-percent return to operating capital for the dairy enterprise. This capital charge was added to the annual operating expenses for the dairy, and the total subtracted from the gross income of the dairy enterprise. The resulting net return to labor and management then was divided by the total number of hours of operator labor devoted annually to the dairy enterprise.

The common nonfarm wage rate was $2 per hour in Iowa at the time of this analysis. A wage rate of this level is represented by the horizontal line in fig. 5. Except for the stanchion barn, all milking systems achieve this $2 urban wage for some level of output. Maximum hourly return for the stanchion barn is $1.92 at 5,195 hundredweight. Returns to labor are lower because of high capital costs and less efficient use of labor. The highest hourly return for the stanchion parlor is $2.01 at 4,095 hundredweight. Although the other systems require a larger volume of output to reach this $2 level, they allow returns to labor to go higher. This is made possible by the declining per-unit cost of fixed equipment and by the substitution of capital for labor. Through this substitution, output is increased without expanding the labor force. This results in increased labor productivity.

The highest return for all systems is $3.08 attained by the herringbone system at 6,946 hundredweight of milk. At a smaller volume of production, the three-stall and stanchion parlors provide higher hourly returns than either of the two larger systems. The six-stall and herringbone parlors require less labor per cow, however, permitting herd size to be expanded. The given supply of labor is used to produce a larger volume of milk. With the given labor restrictions, the herringbone can handle a maximum of 64 cows. An increasing return to labor is provided up to 58 cows.

Labor curves turn down because of the limited supply of labor. For example, expansion beyond 58 cows under the herringbone system can be achieved only at an opportunity cost. Land and labor are removed from the production of cash grain. The reduction in returns to cash grain more than offsets the increase in returns to the dairy.

These labor curves demonstrate that grade A dairy farmers are capable of earning a return to labor in the dairy enterprise comparable to an urban wage rate. This is true for the four loose housing methods shown in fig. 5 but not for the ordinary stanchion barn which uses labor less efficiently. The computations are, of course, for techniques which suppose a fairly efficient level of management for all farm enterprises. But as was pointed out earlier, in terms of abilities required, these management practices are within the reach of a majority of farmers. They would require more capital than is now used by the typical dairy farm enterprise in central Iowa.

COST CURVES FOR THE WHOLE FARM DEVELOPED BY LINEAR PROGRAMMING

Cost curves developed by linear programming for the dairy farm as a unit are presented in fig. 6. In this analysis, cash grain for sale represents a second opportunity for the use of farm resources. Therefore, a resource such as labor will not be shifted from cash

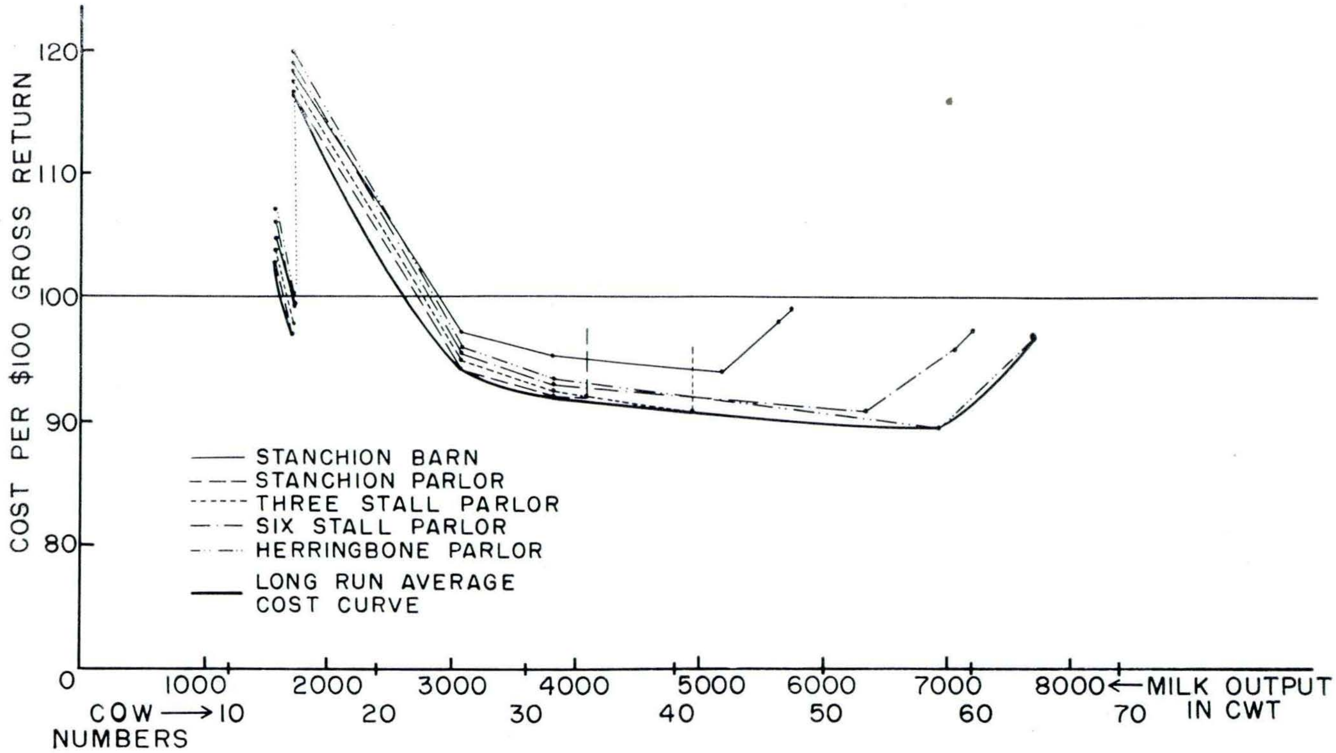

Fig. 6. Short-run average cost curves showing cost per $100 return for five dairy-cash grain farms in central Iowa with a long-run average cost curve for dairy farming.

grain to dairying unless it will bring a higher return in the latter alternative.

Since products sold include grain as well as milk, it was necessary to change the measure of cost. The vertical axis of fig. 6 indicates cost per $100 gross return from both enterprises. Changing the scale of the vertical axis in this manner alters the slope of the cost curves. For example, cost per $100 gross return might have been used instead of cost per hundredweight of milk as a measure of cost efficiency for the dairy enterprise in fig. 4. (Gross return for the dairy is the hundredweight of milk multiplied by the return per hundredweight, $3.75.) Altering the vertical scale in this manner without a corresponding change in the horizontal axis would tend to increase the slope of the cost curves. In the case of a single product, the horizontal axis could be adjusted accurately to compensate for the change in scale in the vertical axis. This is not possible with two products, however, unless size is measured in terms of gross returns.

Size is measured on the vertical axis by production of milk. Number of cows is also indicated. Although other measures of size are frequently used, this study deals with dairy technology; it concerns only those farmers with a major portion of their resources committed to dairying. Therefore, volume of milk output was considered to be an appropriate measure of size.

Again, charges for resources include 5 percent for fixed capital, 7 percent for operating capital and $2,500 for 12 months of labor. In contrast to the analysis of the dairy enterprise, labor is considered to be hired in whole units rather than by the hour. The analysis assumes that a full-time worker can be hired at $2,500 annually, or for the 3 summer months at $600.

The "curves" of per-unit cost in fig. 6 are composed of linear segments because, as in fig. 4, they are derived from optimum plans computed under variable programming methods. The enterprise and whole-farm curves differ in several respects, however, as the discussion that follows indicates.

The cost curves for the entire farm are discontinuous at 1,737 hundredweight of milk.[14] This discontinuity or "jump" in the cost curves is explained by the "lumpiness" of the labor input. To expand dairy and cash grain operations, the operator must hire an additional man. The cost of this added labor causes the cost per $100 return to jump vertically for all systems by approximately $20. At this point, costs for all farm systems are higher than gross returns. Farmers who hire full-time help must expand if they are to keep per-unit cost of production low. Additional help is needed to take full advantage of the cost economies realized by spreading fixed costs over a larger volume of production.

The combination of cash grain with the dairy enterprise causes the cost curves to slope more gradually than those for the dairy enterprise alone.[15] This is explained as follows: The cash grain enterprise has a smaller investment in fixed equipment. Over the relevant milk output range all farms exceed 150 acres. Hence, most of the cost economies for field machinery

[14] For a discussion of discontinuous cost curves, see: Boulding, Kenneth E. Economic analysis. Harper and Brothers, New York. 1955. pp. 615-616.

[15] This is not indicated by a comparison of figs. 4 and 6 because of the different measures of cost efficiency on the vertical axis and because labor is handled as a discontinuous input in the latter diagram.

have been realized.[16] In contrast to dairying, the cost per $100 gross return for cash grain is more constant over the milk output range of this analysis. As the number of cows increases, however, the quantity of grain produced for sale decreases. Cash grain accounts for 48 percent of gross returns at a herd size of 13 cows and 28 percent of gross returns at 58 cows. The combination of a comparatively large cash grain operation with a small dairy herd tends to lessen the effect of high fixed dairy costs, and cost curves decline more gradually.

Also, for the whole farm analysis, cost curves lie more closely together at a given level of milk output.[17] The addition of cash grain to the various dairy systems reduces the difference in cost arising from the difference in technology. For example, assume that cost per $100 return is represented by five different fractions (total cost divided by gross return) at some specified level of milk output. Increase each of the numerators (costs) by a constant and each of the denominators (gross return) by another constant. This will reduce the difference between the five fractions and, consequently, will reduce the difference in cost per $100 gross return. For a given milk production grain enterprises are not all of the same size, but the differences are comparatively small.

The cost curve analysis for the whole farm indicates that a two-man dairy-cash grain operation can achieve a break-even point, where costs just match receipts, at a herd size of 23 to 24 cows under better than average management conditions. This figure is currently above the average Iowa herd size. Farmers with herds of less than 23 cows could probably receive higher profits from the employment of their resources elsewhere. To take full advantage of cost economies, however, farmers should expand production beyond this break-even point.

The major cost economies have been realized for herds of 32 cows. Reduction in cost continues until the cost curves are forced upward by the limited supply of labor. The efficient utilization of labor in the herringbone parlor allows herd size to be expanded with declining per-unit cost up to 58 cows. The maximum herd size possible with assumed labor restrictions is 64 cows. To increase from 58 to 64 cows, however, it is necessary to shift more labor and land into forage production. Rotations with 3 years of meadow enter the plan. The sacrifice in cash grain returns exceeds the increase in milk profits. Hence, expansion beyond 58 cows under the herringbone system can be achieved only at an "opportunity cost."

The stanchion barn never has the lowest per-unit cost over the output range. For small herds, however, the difference in cost between stanchion barns and loose housing systems is considerably less. In fact, the cost per $100 return is less than for the herringbone system with fewer than 20 cows and less than for the six-stall parlor with fewer than 16 cows.

[16] See Heady, Earl O., McKee, Dean E. and Haver, C. B. Farm size adjustments in Iowa and cost economies in crop production for farms of different sizes. Iowa Agr. and Home Econ. Exp. Sta. Res. Bul. 428. 1955.

[17] See footnote 15.

The Long-Run Average Cost Curve

The long-run average cost curve indicates the optimum route of expansion in volume of production and herd size. The long-run curve in fig. 6 has been fitted by hand to the short-run average cost curves for the various dairy systems.

Only three of the short-run curves—the stanchion parlor, the three-stall parlor and the herringbone—have points lying on the long-run curve. This is because the stanchion barn and six-stall systems do not have the lowest per-unit cost for any point in the output range of the analysis.

Costs per $100 return decline rapidly between 1,600 and 3,100 hundredweight of milk for the jump caused by the discontinuity. Beyond 3,100 hundreweight, or 26 cows, the long-run curve continues to fall more gradually. The lowest point on the curve is at 6,946 hundredweight, the minimum point for the short-run herringbone curve. The decline is caused by differences in both the techniques employed and the proportion of resources used. At larger outputs labor is combined with a larger amount of capital to lower per-unit cost.

The slope of the curve cannot be determined accurately beyond 6,946 hundredweight. In the traditional concept of the "long-run" it is generally assumed that all resources are variable. This would mean that the labor supply, as well as land and capital, could be increased. Under these circumstances the long-run average cost curve might continue to fall. It is generally hypothesized, however, that at some point the economies associated with proportionality and the spreading of fixed costs are completely exhausted.[18] Beyond this point long-run average costs would be constant until management becomes restricting. Although land, labor and capital could be combined in very large units, the coordinating ability of management is limited and cannot be increased indefinitely along with other resources. Once the capacity of the operator for efficient farm management is exhausted, cost curves will turn upward.

In this analysis it has been assumed that the farm labor supply is limited. This assumption appears to be realistic for the immediate future. If this labor limitation holds in the long run, the long-run cost curve will rise as in fig. 6, touching the cornerpoints on the short-run average cost curve for the herringbone parlor. This means that labor, instead of management, would be the long-run limiting factor.

Since the long-run average cost curve indicates the optimum route of expansion, it can be thought of as a planning curve. In the long run, dairy farmers will want to adopt new techniques as they expand herd size. The rising cost of labor and building materials has increased the cost of production for the stanchion barn. Therefore, the least-cost path of expansion is represented by loose housing technology. Farmers with limited capital can realize most of the cost economies under the stanchion parlor system. Herds can be expanded slightly by adopting a three-stall elevated parlor. For expansion beyond 41 cows, how-

[18] See: Heady, Earl O. Economics of agricultural production and resource use. Prentice Hall, Inc., New York. 1952. pp. 364-369.

ever, the herringbone parlor provides the lowest per-unit cost.

RETURNS TO LABOR AND MANAGEMENT FOR THE WHOLE FARM

The family of curves presented in fig. 7 indicates the hourly returns to labor and management for the output range included in the cost curve analysis. Returns to labor and management were computed in the same manner as those in fig. 5. The capital charge (5 percent for fixed and 7 percent for operating capital) was added to the annual operating expenses and the sum subtracted from the gross return. The remainder was divided by the number of hours the operator worked in all enterprises to give an hourly wage rate.

The labor curves in fig. 7 follow much the same pattern as those for the dairy enterprise. They rise rapidly at first, then more gradually, and finally decline. The addition of the cash grain enterprise has a noticeable effect on these curves. First, the labor curves for the whole farm lie more closely together at a given volume of milk output. The combination of cash grain with dairy tends to lessen the difference in cost curves caused by the various techniques. Secondly, hourly wage rates for the whole farm, as compared with the dairy enterprise, are higher for a small volume of milk output and slightly lower for a very large volume of milk output. This is explained as follows: Because of the high fixed costs associated with the dairy farming, the returns to labor for the dairy enterprise with small herds are extremely low. The addition of a cash grain enterprise, accounting for as high as 48 percent of the gross return at 1,566 hundredweight raises the hourly labor returns. As fixed costs are spread, however, the hourly return to labor for the dairy enterprise increases rapidly compared with cash grain returns.

With the addition of cash grain, the $2 per hour urban wage is attained by all systems at a smaller volume of output. The stanchion parlor achieves the $2 level at 3,250 hundredweight of milk, or 27 cows, and reaches a maximum return, $2.27 per hour, at 4,095 hundredweight, or 34 cows. Other systems need a slightly higher volume of production to attain the urban wage level, but capital can be substituted for labor to expand dairy production and achieve higher hourly returns. The maximum hourly wage is $2.98 at 6,946 hundredweight, or 58 cows, for the herringbone system.

Curves turn down, as previously explained, because of the limited supply of labor. If milk production is increased, the reorganization of the farm results in the lowering of income for the whole farm. With this loss in income considered as a cost, the per-unit cost of production increases, and hourly wage returns decline.

Hourly wage returns for the whole farm again indicate that dairy farmers are capable of earning a return to labor comparable with the urban wage rate. The $2 return is achieved at herds of from 27 to 32 cows for loose housing and at 40 cows for the stanchion barn. The larger dairy parlor systems receive the highest returns because they are able to substitute capital for labor to increase their volume of production. Again, it should be emphasized that these com-

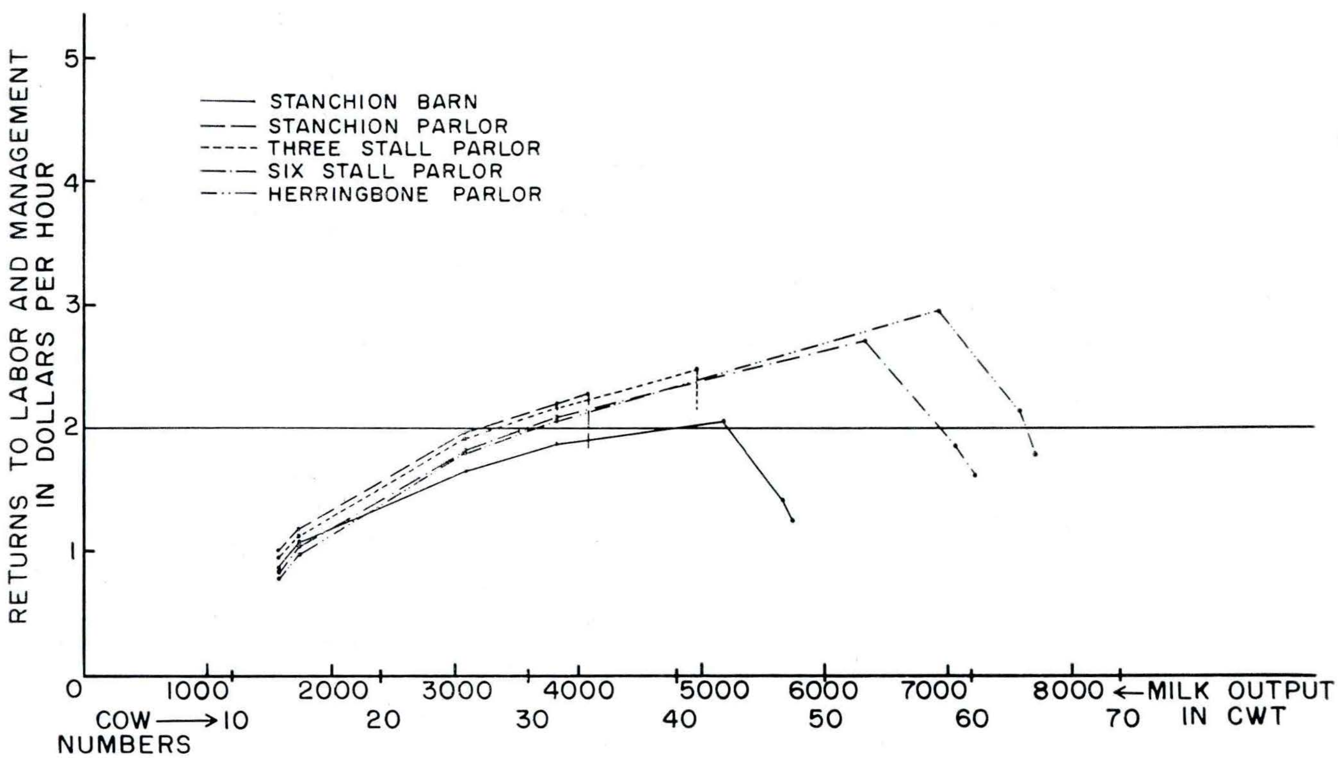

Fig. 7. Curves showing returns to labor and management for different levels of milk output on central Iowa dairy-cash grain farms with fixed capital charged at 5 percent and operating capital at 7 percent.

TABLE 2. MARGINAL RETURNS TO LABOR IN DOLLARS PER HOUR FOR SPECIFIED LEVELS OF OUTPUT ON THE LONG-RUN AVERAGE COST CURVE FOR THE DAIRY-CASH GRAIN FARM BY SPECIFIED MONTH.

Month	Levels of output (hundredweight of milk)								
	1,566	1,737	3,088	3,812	4,095	4,959	6,946	7,565	7,705
May	20.57	11.03	19.35	8.89	12.27	11.75	9.66	0	0
June	0	27.00	3.47	10.43	4.71	5.30	8.27	10.19	11.34
Sept.	0	0	0	0	0	0	7.93	9.55	11.27

putations assume an efficient but readily attainable level of management for all farm enterprises and indicate a higher capital investment than is now common on central Iowa farms.

Marginal Returns to Labor

Average returns to labor for the whole farm were discussed in the previous section. This section deals with the marginal return to labor. The marginal return to labor is the return that can be obtained from the addition of one unit of labor.

The demand for and the supply of labor vary throughout the year. For example, there is often an excess of labor during the winter months. In this case, purchase of an additional unit of labor would not increase farm returns. In contrast, there is usually a shortage of labor in the summer. An additional unit of labor available during planting or harvesting might increase farm returns by a substantial amount. Hence, in critical periods, when the shortage of labor limits expansion, the marginal productivity of labor is high. During these periods, farmers may be well rewarded for investment in additional labor or labor-saving techniques. Many farmers, however, adjust to the heavy demand for labor by working more hours.

The year was divided into spans of a specified number of months for linear programming purposes. The months from May through Septemeber were handled as separate periods of a single month duration. May, June and September proved to be the critical months in the dairy-cash grain operation for the following reasons. Corn is planted in May. In June large amounts of labor are used for harvesting hay and grass silage and for cultivating corn. Labor requirements are high in September because the harvesting of corn silage and the last cutting of hay occur then.

Table 2 shows the marginal return to labor in each of the 3 months (May, June and September) for specified levels of milk production. These specified levels of production are represented by the "corner points" touching the long-run average cost curve. The marginal return in each instance is for the system with the minimum per-unit cost for the particular level of milk output as indicated in fig. 6. For example, marginal figures up to 4,095 hundredweight of milk are for the stanchion parlor. At 4,959 hundredweight they are for the three-stall parlor, etc.

At 4,095 hundredweight of milk, an additional hour of May labor will return $12.27, and an additional hour of June labor will return $4.21. Conversely, these figures can be thought of as costs. Used in this sense, one *less* hour of May labor would cost $12.27; one *less* hour of June labor would cost $4.71. September labor at this output has a zero marginal productivity because the supply exceeds requirements.

As output is increased, the marginal return to labor in each of the 3 months fluctuates over a wide range. In the majority of cases May labor return is highest. Although the demand for June labor is probably as high or higher, the marginal return is lower because farmers have the alternative of hiring an extra man for the summer. With intensification of dairy production there is a shift toward the use of more corn silage. An acre of corn silage supplies more TDN than any other form of roughage. Hence, the use of corn silages increases the carrying capacity of the land. This increase in production of corn silage, together with the added demand for hay with larger herds, raises the marginal productivity of September labor.

The figures in table 2 show that the marginal return to labor is highest in the heavy cropping months. This emphasizes the need to compare labor-saving cropping innovations with those considered for adoption in the dairy. An innovation can increase profits by reducing costs or by freeing labor for other profitable enterprises. For a given situation, the introduction of new labor-saving field machinery may prove to be more profitable than the

TABLE 3. OPTIMUM FARM PLANS FOR FIVE MILKING SYSTEMS ON CENTRAL IOWA FARMS.

Item	Stanchion barn		Stanchion parlor		Three-stall parlor		Six-stall parlor		Herringbone parlor	
	(units)	(dollars)	(units)	(dollars)	(units)	(dollars)	(units)	(dollars)	(units)	(dollars)
Sales										
Milk (cwt.)	5,160	19,350	4,095	15,358	4,959	18,596	6,360	23,850	6,946	26,048
Corn (bu.)	6,495	8,573	9,264	12,228	8,542	11,157	7,365	9,721	7,169	9,463
Oats (bu.)	1,172	750	1,894	1,212	1,657	1,060	1,277	817	1,187	760
Gross returns	....	28,673	....	28,798	....	30,813	....	34,388	....	36,271
Costs										
CCOM rotation (acres)	225	3,769	319	5,343	300	5,025	270	4,523	255	4,268
COMM rotation (acres)	155	2,054	78	1,033	115	1,524	176	2,332	212	2,809
Roughage & straw		650		567		624		743		783
Cows (head)	43	5,240	34	4,380	41	5,142	53	6,701	58	7,333
Hired man	1	2,500	1	2,500	1	2,500	1	2,500	1	2,500
Summer help	1	600	1	600	1	600	1	600	1	600
Total costs	....	14,813	....	14,423	....	15,415	....	17,399	....	18,293
NET RETURNS	....	13,860	....	14,375	....	15,398	....	16,989	....	17,978
Fixed capital										
Land	....	104,500	....	109,175	....	114,125	....	122,650	....	128,425
Bldgs. & equip.[a]	....	38,500	....	26,200	....	30,500	....	38,875	....	43,650
Dairy cattle	....	15,050	....	11,900	....	14,350	....	18,550	....	20,300
Total	....	158,050	....	147,275	....	158,975	....	180,075	....	192,375

[a] Value of dairy buildings and equipment when new; value of machinery when 50 percent depreciated.

adoption of new dairy technology. This possibility should not be overlooked although cropping innovations are not analyzed in this study.

OPTIMUM FARM PLANS

Optimum farm plans are presented for each of the five dairy systems in table 3. These plans provide a more complete analysis of over-all farm operation and organization of resources and enterprises necessary to maximize profits. Because labor is the most limiting resource, each of these plans combines the same quantity of labor (two full-time men plus one summer hand) with different amounts of land and capital.

Net returns are computed in each case by subtracting operating expenses from gross returns. Operating expenses include such items as hired labor, feed purchased, breeding fees and taxes on equipment and cattle, as well as property taxes. Hence, fixed costs are included in the list of expenses. For example, in table 3 property taxes are associated with the rotations along with taxes on field machinery. Taxes on buildings and cattle are included under the heading "cows." No charge is made for the use of capital (i.e., no interest on captial), however, or for the operator's labor. In addition, net return figures assume full equity. If a portion of the capital were borrowed at interest, returns would be less.

Acreage and capital requirements for all systems are much higher than is common for central Iowa farms at present. Nevertheless, the long-run trend is toward farms with more capital and more land. While farm size is increasing with respect to these two resources, the per-farm labor supply has remained fairly constant. Hired farm labor is becoming scarce.

Net returns are lowest for the stanchion barn. This is because annual capital costs are higher, and more labor is required to milk and feed cows. As a consequence, the cost of producing milk is higher. In addition, because less labor is available for field work, gross returns for the cash grain enterprise are the smallest of any system.

In moving from the stanchion parlor to the herringbone system, net returns gradually increase. This rise in profits is accompanied by an increase in land and capital requirements, an increase in herd size and milk production and a decrease in the size of the cash grain enterprise. The net return for the stanchion parlor is $14,375. The labor supply on this 34-cow farm is combined with 397 acres of land and $147,275 capital (including the cost of land at $275 per acre). The highest net return is $17,978 under the herringbone parlor with 58 cows, 467 acres of land and $192,375 capital.

The addition of more cows with the consequent increase in net returns is made possible by the substitution of capital for labor in the larger parlor milking systems. Attributing all profits to capital (i.e., dividing net return by the total capital requirements), however, it can be seen that the percent return to capital declines with expansion in herd size and adoption of new parlor techniques. The return to capital is approximately 9 percent for the stanchion parlor and 8.5 percent for the herringbone.

Dairy Feed Rations

Feed rations shown in table 4 indicate the least-cost method of producing 12,000 pounds of milk per cow annually. A ration is presented for each of the optimum farm plans. The programming matrix was arranged to allow for a choice between rations of straight hay or hay combined with some form of silage. The possibilities included corn silage, grass silage and oat silage. The optimum combination of corn and oat grain was also decided by programming. Restrictions were placed on the possible combinations to insure a balanced ration. For example, cows were fed at least 10 pounds of hay per day, but they could consume a maximum of 32 pounds dry matter equivalent in the form of roughage.

As previously indicated, four crop rotations were considered in the analysis: CCOM, CCOMM, COMM and COMMM. Thus, a minimum of 25 percent of the land was in hay silage or pasture.

The feed rations in all cases include some combination of hay, corn silage and grass silage. The ratio of land to the number of cows is a primary factor in determining the roughage combination selected. With a small concentration of cows on the land, one cow for 16 acres, sufficient roughage is supplied by the minimum 25 percent of the land in forage. As the concentration increases, however, it is necessary to withdraw cropland from production of corn to provide adequate forage and pasture. At this stage corn silage begins to substitute for grass silage, since it yields more TDN per acre. There are 12 acres of cropland per cow for the stanchion parlor plan. Roughage consists of 3.2 tons of corn, 4.5 tons of grass silage and the minimum 1.3 tons of hay. As dairy technology is changed, cow numbers increase more rapidly than acres of land. There are only 8 acres of cropland per cow under the optimum herringbone plan. Corn silage is increased to 6.5 tons and grass silage decreased to 1.2 tons.

Neither a straight-hay forage ration nor a ration that includes oats silage is economical. In fact, computations show that the marginal cost of introducing one cow on an all-hay ration is approximately $35 per year; the marginal cost of introducing one cow on an oats silage and hay ration is about $140 per year. All land in oats was harvested for grain. The majority of this was fed to the cows and the remainder sold for cash grain.

Straight grain rotations are not considered in the analysis, although these rotations are receiving increasing attention. If continuous corn were profitable, it would eliminate the necessity of placing a minimum 25 percent of the land in forage. The opportunity cost for all land would be based upon its use in pro-

TABLE 4. ANNUAL FEED REQUIREMENTS PER COW FOR THE OPTIMUM DAIRY FARMS.

Feed	Milking system				
	Stanchion barn	Stanchion parlor	Three-stall parlor	Six-stall parlor	Herringbone parlor
Corn, bu.	20.1	22.0	20.9	19.7	19.2
Oats, bu.	46.8	47.6	47.2	46.6	46.4
Soybean meal, lbs.	555	462	517	574	604
Corn silage, tons	5.5	3.2	4.5	4.9	6.5
Grass silage, tons	2.2	4.5	3.2	1.8	1.2
Hay, tons	1.3	1.3	1.3	1.3	1.3
Pasture, acres	1.0	1.0	1.0	1.0	1.0

ducing corn. Since corn silage yields the most TDN per acre, all rations would emphasize corn silage and exclude other forms of silage.

INTERPRETATIONS AND IMPLICATIONS OF RESULTS

In the preceding sections cost curves have been presented and analyzed for the dairy enterprise and for the entire farm. This analysis has been accompanied by information on returns to labor and by plans showing the optimum farm organization under several milking systems. This section summarizes these findings and discusses their implications for Iowa dairy farmers.

New Technology vs. the Conventional Stanchion Barn

The introduction of loose housing with herds larger than 25 cows permits a considerable saving over conventional stanchion methods in both labor and capital. The efficient use of labor allows one worker to handle up to one-third more cows. Loose housing requires a smaller investment per cow for both housing and feed storage facilities. Thus it is possible to shift the average cost curve downward and to the right; i.e., a larger volume of production is achieved at a lower unit cost. The result is a higher productivity of labor. Average hourly returns to labor under the most efficient loose housing system are more than $1 above the maximum for the stanchion barn.

With a herd of less than 25 cows, however, little is to be gained by adopting loose housing techniques. In fact, for very small herds the cost per hundredweight of milk is higher for certain loose housing systems than for the stanchion barn. This is a result of the high fixed capital requirement for the milking parlor and equipment. Although there is comparatively little difference in cost between methods at low levels of output, returns to all dairy systems are extremely low. Hourly returns to labor for the various dairy enterprises are less than $1 with herds of fewer than 20 cows.

The Effect of New Techniques

A number of different parlor milking arrangements can be combined with loose housing. No one of these systems is least-cost over the entire output range, because parlors differ as to amount of capital and labor required. Movement out along the long-run average cost curve involves the substitution of capital for labor.

Farmers with limited capital can adopt the stanchion parlor, which combines the stanchion barn technique of milking with the labor-saving feeding methods of loose housing. Because of its low capital requirements the stanchion parlor is particularly well suited to the small dairy farms prevalent in Iowa. Alternatively, it may serve as a "stepping stone" in the process of conversion and expansion of the dairy enterprise.

The popularity of three- and four-stall elevated parlors, the most common parlors in Iowa, may not be fully justified. They have no cost advantage over the stanchion parlors with herds of less than 34 cows. Their labor efficiency gives them a slightly greater capacity; however, this falls short of the capacity of the larger parlors.

Farms with herds above 50 cows are rare in Iowa but may become more common. For these farms, the six-stall or the herringbone parlor is the lowest cost method. Although these two parlors require a large outlay in fixed capital, they save a considerable amount of labor. The most efficient of these parlors is the herringbone.[19] Under this system as many as 60 cows can be milked in an hour, thus permitting returns to labor for the dairy enterprise to exceed $3 per hour with a herd size of 58 cows.

These new dairy techniques have the effect of lowering costs and, consequently, of increasing returns to labor. By expanding herds beyond 35 cows under loose housing it is possible for efficient farm managers to obtain returns to labor well above the $2 urban wage level. These results are based on $3.75 per hundredweight for grade A milk.

Implications for Iowa Dairy Farmers

The analysis of loose housing indicates that it is an output-increasing and cost-decreasing innovation. Adoption of this technology could shift the supply curve to the right. At the same time, the demand for dairy products is relatively inelastic. The demand elasticity of fluid milk is estimated at —0.30 to —0.40.[20] Consequently, acceptance of loose housing can result in a decrease in gross returns to dairy farmers as a group. If the reduction in gross returns is less than the decrease in total cost, net revenue for the dairy industry will increase. Conversely, if the reduction in total revenue is greater than the decrease in total costs, net revenue will decrease. This means that, although new technology makes it possible to produce milk at a lower cost, this may not increase returns to dairy farmers in the long run.[21]

Nevertheless, those few farmers who first adopt a cost-reducing technique receive the greatest benefit. This is because they continue to receive higher net returns until the number of people using the new technique is sufficient to increase production significantly and force down the price of the product. The benefits of innovation then are transfered to the consumer through a lower price for dairy products. Failure to adopt an innovation such as loose housing once it has been widely accepted may result in an even greater loss for Iowa dairy farmers if they continue to produce milk at a high cost.

Iowa dairy farmers will need to combine larger quantities of land and capital with their labor to benefit from the cost economies offered by loose housing.

[19] There are a number of disadvantages in handling cows in the herringbone system. Farmers object particularly to the fact that it is difficult to give individual attention to cows. Farmers concerned with increasing labor productivity, however, should consider new technology in terms of its effect on production per man as well as production per cow. It is interesting to note in this regard that New Zealand farmers think primarily in terms of production per man or production per acre, as these are scarce resources.

[20] See: Rojko, Anthony S. The demand and price structure for dairy products. U. S. Dept. of Agr. Tech. Bul. 1168. 1957. p. 109.

[21] For further discussion of the impact of technological innovation on farm income see: Heady, op. cit., chap. 27.

Dairy herds must be increased to at least 30 cows to take advantage of the major cost economies. Herds can be expanded beyond 50 cows on the two-man dairy farm with a lowering of costs and a consequent increase in returns. With high quality cows this can represent a production of more than 600,000 pounds annually and a return to labor above the urban wage rate.

NEED FOR FURTHER RESEARCH

This study has dealt with labor-saving innovations in the dairy. The chief technique analyzed was loose housing. Little attention was given to the problem of conversion from the stanchion barn to loose housing. Moreover, new techniques in crop production have not been analyzed. This section suggests areas for further research.

The growing pace of technological innovation in dairy farming heightens the adjustment problem. Equipment often becomes obsolete before it wears out. Farmers need to know when they can profitably abandon one technique and adopt another. For example, when is it feasible to abandon the dairy barn in favor of loose housing? More work has been done on the problem of obsolescence in this country than in any other, but perhaps too little of this research has been in the field of agriculture. Knowledge in this area would be of great value to dairy farmers whose operations are already highly mechanized.

The marginal returns to labor in the summer cropping months are high. This indicates that labor-saving field innovations may also serve to lower costs and increase labor productivity. Although new techniques in crop production have not been analyzed in the study, innovations that *warrant further investigation* are mentioned briefly here.

Four-row equipment may prove as valuable to the dairy farmer as to the cash grain farmer. For example, a four-row cultivator would release labor for harvesting hay and silage in June.

The most modern forage chopping and hauling equipment would be justified in some instances. Although more labor may be needed to feed out chopped hay, more is available during the winter feeding months.

The use of hay crushers and barn dryers is still open to question. Much of this equipment has been improved in recent years. Depending on weather, improved hay-curing methods could be profitable. In the past, Iowa farmers have given comparatively little attention to improving forage yields.

Farmers with limited land or limited labor may find it advantageous either to purchase a portion of their forage or purchase replacement heifers. Either step—each representing a substitution of capital for land and labor—could allow operators to increase output to take advantage of cost economies in the dairy enterprise.

Dairy farmers, particularly on the Clarion-Webster soils, may find it to their advantage to purchase some of their forage in the future. Improved fertilizer techniques will enable farmers on these more productive soils to raise continuous corn. Hay pelleting machines could make it feasible to ship hay longer distances, however, the possibility of substituting pelleted hay for regular forage in the dairy ration is still under investigation.

Further research is needed to determine whether or not these suggested cropping innovations will prove economical. In making decisions regarding the adoption of either new techniques in the dairy or new cropping methods, farmers should consider their complete bundle of resources. It may be more profitable to invest in better cows or more fertilizer than to purchase new equipment.

SUMMARY

This study examines the possibility of reducing costs and increasing labor productivity through adjustments in dairy farming. The primary objective is to determine the effect of herd size and new dairy technology on cost per unit of output and on returns to labor. Four loose housing methods are compared with a conventional stanchion barn system. Costs and returns are analyzed by budgeting and linear programming over a wide range of herd sizes.

An increase in herd size can result in a considerable reduction in cost per unit under both loose housing and conventional stanchion methods. Costs decline rapidly at first as fixed costs are spread over a large herd. For example, as cow numbers are increased from 15 to 35, cost per hundredweight of milk is reduced by 75 cents under conventional stanchion methods and by slightly more under loose housing. Beyond 35 cows, costs decline more gradually. A limited supply of labor eventually causes all cost curves to rise.

The decline in costs as herd size is expanded is accompanied by a sharp rise in returns to labor. Hourly wage rates for the dairy enterprise rise by more than $1 as dairy herds are increased from 15 to 35 cows.

With small herds, the cost of producing milk is higher than the return per hundredweight. Under the prices and costs assumed for this study, the break-even point at which price per unit just equals cost per unit varies from 22 to 26 cows, depending upon the system. Farmers with herds of less than 22 cows probably would receive higher returns by employing their resources in some enterprise other than dairying.

The comparison of costs and returns to labor shows an advantage for loose housing over the conventional stanchion barn system which grows with an increase in herd size. With herds of less than 25 cows the cost advantage of loose housing is not large. In fact, with very small herds costs are less under conventional stanchion barn methods than for the six-stall and herringbone parlor. This is because of the high fixed cost in the milking parlor and equipment. The added re-

quirements per cow, however, for both capital and labor are greater for the stanchion barn. Capital is saved under loose housing because of the lower cost buildings for housing cows and storing feed. Labor is saved in both the milking and feeding operations. The efficient use of labor permits the handling of up to one third more cows. The minimum cost per hundredweight of milk is $3.45 with 43 cows for the stanchion barn system and $3.10 with 58 cows for loose housing. The maximum hourly returns to labor and management (at the point of minimum cost) are $1.92 and $3.08, respectively.

The analysis indicates that grade A dairy farmers who adopt loose housing and expand herd size are capable of earning a return to labor comparable with an urban wage rate (approximately $2 per hour in Iowa at the time of this study). The computations are for techniques which assume fairly efficient management. These management practices represent levels of achievement well within the reach of the majority of farmers, however.

The four parlor milking systems which were compared differed in both labor and capital requirements. No one of the systems proved to be least-cost over the entire output range. The four-abreast parlor system, which combines stanchion milking with loose housing, has the lowest unit cost up to 34 cows. With its low fixed capital requirement it is well adaped to the small dairy enterprises found throughout Iowa. Although the other parlors require a larger investment, they permit the substitution of capital for labor which makes an increase in herd size possible. For herd sizes of 34 to 41 cows, the lowest cost per hundredweight can be attained with a three-stall parlor. For herds larger than this, the six-stall and herringbone parlors are economical.

Optimum farm plans were computed for each of the five milking systems with the supply of labor limited to two full-time men and one summer hand. Net returns were lowest for the stanchion barn ($13,860) and highest for the herringbone parlor ($17,978). For these optimum plans, acreage and capital requirements are much higher than is common for central Iowa farms at present. Nevertheless, the long-run trend is toward farms with more capital and more land.

Two major conclusions can be drawn from this study. First, Iowa dairy farmers must increase herd size to take advantage of cost economies. If land cannot be readily increased as suggested by the optimum farm plans, other ways must be found to expand the volume of production. For example, purchasing forage represents one possibility of substituting capital for land.

Secondly, it can be concluded that loose housing has a definite cost advantage over the conventional stanchion barn. The majority of farmers in Iowa and throughout the nation, however, currently use the stanchion barn. The shift toward loose housing will occur gradually as old facilities become obsolete and are replaced by new buildings and equipment. During this transition period additional research should be conducted to determine more accurately when a stanchion barn can be considered obsolete.

APPENDIX A—BASIC DATA

TABLE A-1. ANNUAL LABOR REQUIREMENTS FOR DAIRY COWS BY TYPE OF MILKING SYSTEM.[a]

Task performed	Number of days	Hours per year for milking systems: Stanchion barn[b] (Fixed)	Stanchion barn[b] (Variable)[c]	Stanchion parlor (Fixed)	Stanchion parlor (Variable)	Three-stall parlor (Fixed)	Three-stall parlor (Variable)	Six-stall parlor (Fixed)	Six-stall parlor (Variable)	Herringbone (Fixed)	Herringbone (Variable)
Milking	305	....	33.35	....	32.13	....	26.53	....	17.39	....	11.08
Preparation and clean-up[d]	365	450.00	2.00	365.00	...	365.00		426.00	...	426.00	..
Bedding	215	18.00	2.63	8.00	2.38	8.00	2.38	8.00	2.38	8.00	2.38
Grain	365	20.00	2.00	20.00	2.00	20.00	0.25	20.00	0.25	20.00	0.25
Hay	215	25.00	3.14	25.00	2.22	25.00	2.22	25.00	2.22	25.00	2.22
Silage	215	54.00	8.12	24.00	5.42	24.00	5.42	24.00	5.42	24.00	5.42
Gathering cows	215	25.00	1.15	25.00	1.25	25.00	1.25	25.00	1.25	25.00	1.25
Cows from pasture	150	34.00	1.35	34.00	1.35	34.00	1.35	34.00	1.35	34.00	1.35
Miscellaneous	365	25.00	3.10	25.00	3.10	25.00	3.10	25.00	3.10	25.00	3.10
Total		651.00	56.84	526.00	49.85	526.00	42.50	587.00	33.36	587.00	27.05

[a] Adapted from: Field survey conducted by Randolph Barker in central Iowa, 1957.
Cleaver, Thayer. A comparison of milking practices, East, West, and Midwest. U. S. Dep. Agr. (Unpublished mimeo).
Fenzan, C. J. and Van Arsdall, R. N. Economics in farm dairy buildings and equipment. U. S. Dept. Agr. Inf. Bul. 153. 1957.

[b] In terms of the effect of dairy herd size on annual chore labor, these statistics compare favorably with the recent study of Day and Aune on labor used in stanchion barns in Minnesota. See Day, L. M., Aune, H. J. and Pond, G. A. Effect of herd size on dairy chore labor. Minn. Agr. Exp. Sta. Bul. 449. Table 1, p. 5.

[c] The variable hours should be multiplied by the number of cows and the fixed hours added to this total.. This sum divided by the number of cows gives the man-hours per cow required annually. For a 20-cow herd under the stanchion barn, 20 X 56.84 = 1,136.80. Add 651 and divide by 20. The annual requirement in man-hours per cow is 89.39. Results are not reliable with herds smaller than 10 cows.

[d] Includes cleaning of barn but not loafing sheds.

TABLE A-2. LABOR COEFFICIENTS FOR THE PRODUCTION O F FIELD CROPS.[a]

Crop	Hours per acre required for the month of—												Total
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Corn[b]	...	...	...	0.96	1.76	1.04	0.88	...	0.11	0.96	1.01	0.28	7
Oats[c]	...	...	0.28	0.72	...	...	1.52	1.48	...	...	...	...	4
Hay—baled	...	...	...	...	...	3.51	2.97	...	2.52	...	...	...	9
Corn silage[d]	...	...	...	0.96	1.76	1.04	...	2.06	4.12	1.91	0.15	...	12
Grass or oats silage	...	...	...	...	...	6.20	...	...	...	...	...	...	6.2
Straw	...	...	...	...	...	...	...	3.00	...	...	...	...	3

[a] Adapted from: Bauman, R. V. (Unpublished data) Iowa State University, Ames, Iowa.
Hecht, Reuben W. and Vice, Keith R. Labor used for field crops. U. S. Dept. Agr. Stat. Bul. 144. 1954.
Hendrix, A. T. Equipment and labor requirements of different methods of storing and feeding silage. Univ. of Georgia. Athens, Ga. (Unpublished mimeo).

[b] Corn harvested with mechanical picker.

[c] Oats combined from windrow.

[d] All silage harvested with field forage harvester.

TABLE A-3. CAPITAL REQUIREMENT FOR THE DAIRY AND CASH GRAIN ENTERPRISE FOR FIVE MILKING SYSTEMS.[a]

Item[b]	Stanchion barn		Stanchion parlor		Three-stall parlor		Six-stall parlor		Herringbone	
	(Fixed)	(Variable)[c]	(Fixed)	(Variable)	(Fixed)	(Variable)	(Fixed)	(Variable)	(Fixed)	(Variable)
Stanchion barn[d]	$ 3,600	$480	....	....	....	...	....	...	....	...
Parlor	....	...	$ 2,273	....	$ 3,576	...	$ 5,972	...	$ 5,445	...
Dairy equipment	810	...	1,436	....	2,275	...	3,422	...	5,122	...
Bulk tank	500	70	500	$ 70	500	$ 70	500	$ 70	500	$ 70
Dairy Buildings	....	...	....	228	...	228	....	228	....	228
Cow—young stock	....	350	....	350	...	350	....	350	....	350
Field machinery	8,204	...	8,204	...	8,204	...	8,204	...	8,204	...
Total	13,114	900	12,413	648	14,555	648	18,098	648	19,271	648

[a] Adapted from: Information obtained from the Department of Agricultural Engineering, Iowa State University, and from dairy equipment dealers.
Van Arsdall, R. N., Ibach, D. B. and Cleaver, Thayer. Economic and functional characteristics of farm dairy buildings. Ill. Agr. Exp. Sta. Bul. 570. 1953.

[b] Value of dairy buildings and equipment when new; value of machinery 50 percent depreciated.

[c] Variable numbers should be treated here in the same manner as in Table A-1. Using a 20-cow herd, the total capital investment would be $13,114 plus $18,000 under the stanchion barn system. This total, $31,114, divided by 20 gives $1,555.70, the investment per cow.

[d] Includes silo.

APPENDIX B—SUPPLEMENTARY TABLE OF RESULTS

TABLE B-1. FARM PLANS FOR DISCRETE OUTPUT LEVELS ON THE LONG-RUN AVERAGE COST CURVE.

Farm plan	Milk (cwt.)	Cows (no.)	Type of parlor	Rotation CCOM (acre)	Rotation COMM (acre)	Rotation COMMM (acre)	Labor (men)	Capital[a] (dollars)	Gross returns Milk (dollars)	Gross returns Cash grain (dollars)	Net return (dollars)
1.	1,566	13	Four-abreast Stanchion	152	...	...	1	62,550	5,872	5,315	5,579
2.	1,737	14	Four-abreast Stanchion	156	...	...	1	77,000	6,513	6,293	6,688
3.	3,088	26	Four-abreast Stanchion	358	...	...	2¼	130,500	11,580	14,030	12,318
4.	3,811	32	Four-abreast Stanchion	325	65	...	2¼	143,550	14,290	13,842	13,983
5.	4,095	34	Four-abreast Stanchion	319	78	...	2¼	147,275	15,358	13,440	14,375
6.	4,959	41	Three-stall	300	115	...	2¼	158,975	18,596	12,217	15,398
7.	6,946	58	Herringbone	255	212	...	2¼	192,375	26,048	10,273	17,978
8.	7,565	63	Herringbone	...	364		2¼	165,850	28,369	2,435	12,948
9.	7,705	64	Herringbone	...	96	235	2¼	156,525	28,894	..	11,887

[a] Includes capital in land, livestock, buildings and equipment.