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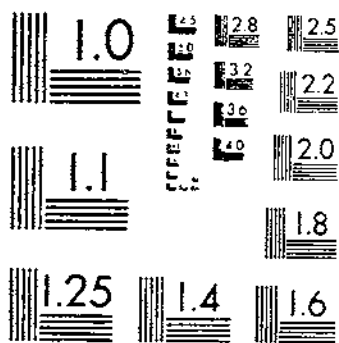
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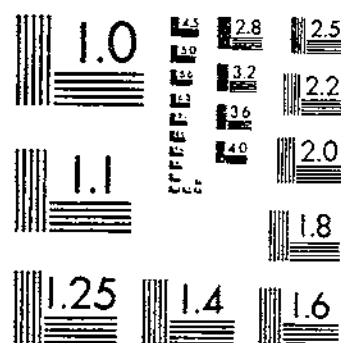
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**UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.**

Input-Output Relationships in Milk Production¹

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CONTENTS

	Page		Page
Introduction	1	Feeding grain at certain rates in proportion to milk produced in comparison with feeding from week to week according to requirements of an accepted feeding standard	40
Input-output relationships in general	2	The influence of levels of feeding	51
Input-output relationships in milk production	3	Influence upon peak production and persistency of production	51
Different views regarding the possibility of increasing production through more intensive feeding	5	Influence upon the percentage of fat in the milk	53
Previous investigations and their limitations	6	The influence on the breeding and calving efficiency and on the health of dairy cows	54
The statistical approach	6	Economic significance of physical input-output relationships	58
The experimental approach	7	Regional differences in intensity of feeding	62
Plan and procedure of present input-output investigations	9	Input-output relationships and organization of the dairy enterprise	67
Two series of experiments	11	Increased grain feeding without expansion of herd	68
Plan of the experiments	11	Intensification of milk production through increased grain feeding and herd expansion with no increase in roughage production	69
Procedure	12	Intensification of dairying through increased roughage production	73
Preparation of experimental data for analysis	14	Interpretation of experimental results	77
Combining parts of two lactation records	15	Extension of input-output curve to low levels of feeding	79
Changes in body weight	15	Summary	86
Results of present input-output experiments	17	Methods	86
Series I experiments	17	Results and applications	87
Series II experiments	28	Literature cited	88
Roughage feeding, including excellent pastures, compared with roughage and a moderate amount of grain at the Virginia agricultural experiment station	33		
Results of Series I experiments and Series II experiments combined	35		
Differences in response between good and poor cows	40		
Experimental levels compared with the Haecker standard	45		

INTRODUCTION

Inputs are the factors used in production. They are also called the factors of production. They may be men with all the different degrees of skill; they may be buildings, machines, raw materials and supplies, land or livestock. Output is the result of the productive processes.

Farm production usually consists in bringing the factors together so that the physical processes of nature can bring about the things

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needed. For example, wheat kernels placed in a properly prepared seedbed in a normal season will develop into a wheat crop; dairy cows properly housed, fed, and cared for will produce milk; beef cattle and hogs will produce beef and pork. These physical processes are the fundamental processes. The people of the world are fed and clothed with things, not with money.

But as modern economic life is organized on a specialized and commercialized basis, there is also a monetary side to all production and it is the deciding force. The material elements used are owned by someone. Before production can begin, the input elements must be bought or their services must be hired.

Most things are produced to be sold for money. To sell they must be marketable. Only producers of marketable commodities or services can stay in business. Success in production depends upon the ability so to organize productive processes that the money return—that is, the difference between the cash outlays for inputs and the receipts for outputs—becomes the largest possible.

INPUT-OUTPUT RELATIONSHIPS IN GENERAL

The production process may be organized in several ways. By using more machinery, requirements for human labor may be reduced. Tractor power may be substituted for horse power, wholly or in part. To a certain extent, grain and roughage may be substituted for each other in feeding livestock. The producer must select from the many different alternatives that organization which pays best. What pays best at any given time depends upon the response in physical output to the changes in the production process, and upon the changing prices of the various inputs and outputs. Therefore, in actual production he is confronted constantly with the problem: How much does it pay to use? How many men or machines? How much fertilizer? How much feed?

Many everyday problems of management can be decided without research. The development of a new method of production often represents not just a small step, but a great stride forward. For example, in harvesting small grain, a grain binder—in itself a result of much input-output engineering research—saves so much human labor that its use has paid exceedingly well, not only in the Americas and in Australia, where the cost of labor is high, but also in northwestern Europe where wages of agricultural laborers are considerably lower. The cost of guarding against certain livestock diseases constitutes so low an insurance premium against serious losses that its profitability is never in doubt. Many technical innovations are of similar nature. Careful observation and experience suffice to show whether the new method will pay.

But numerous vitally important production problems on farms as well as in factories cannot be solved by ordinary observation and experience. Input-output research is required. From the appearance of the stand of a crop of corn or cotton it is not possible to know whether with normal prices it would pay to use not only 200 pounds of superphosphate per acre but even 400 pounds. A farmer may easily use twice as much, or only half as much, as is profitable. He may year after year spend money for fertilizer that does not pay its

way; or, as is more often the case, he may miss the increased returns that could be obtained by heavier applications.

Numerous problems of the same general nature arise repeatedly in the growing of crops and the raising of livestock. To what degree, for example, should practices be changed when prices change and certain factors become scarce and expensive in relation to others? Systematic experimentation is needed to obtain an answer to these problems quickly, accurately, and at small cost.

Both technical and economic analyses are needed, but the technical research must be of a special kind. It must furnish physical data that will show how soon will be encountered and how serious will be the effects of the law of diminishing returns. These effects may show up as a decline in output per man due to excessive overtime; or they may show up in poorer utilization of feed at heavy feeding levels, or in smaller increases in yields from additional units of fertilizer.

With such technical information, together with prices for cost factors and products, the most economical method of production under varying circumstances can be learned and how far it pays to go as conditions change. As a rule, it is fairly easy to obtain large crop yields by the lavish use of fertilizers, but a farmer must ask: Does it pay? Input-output information will enable producers to select the most economic practices under changing price conditions, and thus to increase their net returns.

The object of input-output research in farming then is to furnish more accurate and complete basic knowledge of how yield per acre, production per animal, or quality of product, is affected by changes in methods of production and rates of application of the input elements and to ascertain by economic analysis how the relationships affect organization and adjustment of production.

Experience has shown that the kind of technical information needed can best be provided if controlled experiments are planned from the beginning, by economists and technologists working together.

That was the way the plan for this present study of milk production was worked out. The input-output experiments reported in this bulletin were undertaken jointly by the Bureau of Agricultural Economics and the Bureau of Dairy Industry. They were designed to measure the response of dairy cows to a whole series of rates of feeding. Knowing these responses, it can be ascertained how the economic limit will shift under changing conditions of price.

INPUT-OUTPUT RELATIONSHIPS IN MILK PRODUCTION

In milk production, feed accounts for about 40 to 50 percent of all the costs; labor amounts to about 30 percent; and use of buildings and equipment, purchase of breeding stock, veterinary fees, and other costs make up the rest. It is natural, therefore, that input-output studies in milk production should be concerned first with the relationship between feed inputs and milk output.

How can the most important cost factor, the feed, best be economized? How much does it pay to change the established feeding practices if the relationship between prices of feed and prices of milk should be substantially altered? To answer these questions we must know with sufficient accuracy what basic physical relationships are

involved, that is, how dairy cows react to increases and decreases in the level of feeding.

On this particular problem very few data were available when work on this project began, and these data were restricted mainly to a comparison of production when nothing but roughage was fed with production when roughage was supplemented by grain. The basic data therefore had to be developed.

THE NATURAL PRODUCTION CYCLE

To learn how dairy cows react to increased feeding, a certain period of time must be considered. In milk production, as in other types of biological production, the volume of production and the requirements for input elements go through certain characteristic changes from time to time (fig. 1). Milk production normally proceeds according to a typical curve, the lactation curve, which at first rises sharply, reaches a maximum in a few weeks, and then falls off gradually to zero in about 10 months, when the cow is said to be dry. Preferably, the dry period should not last for more than about 8 weeks. The cow should then freshen again and repeat the pro-

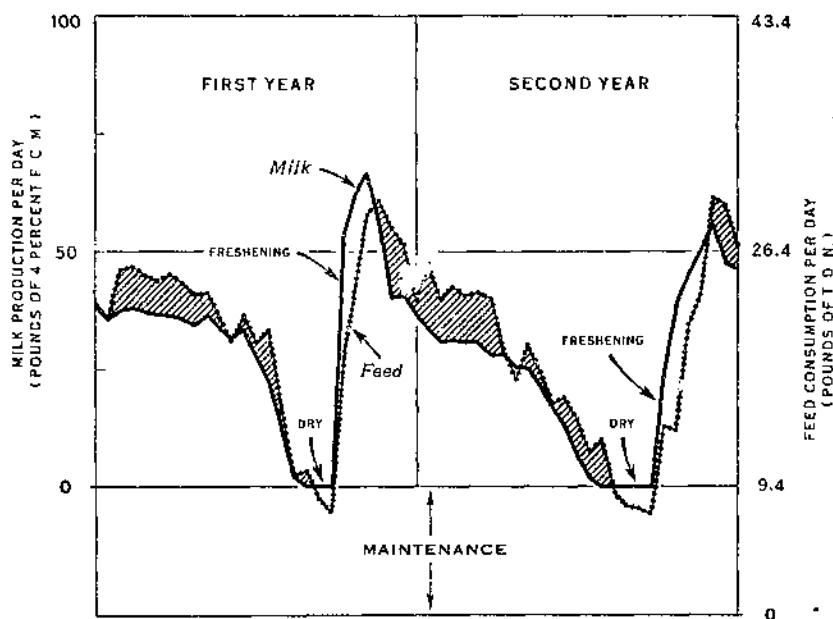


FIGURE 1. TYPICAL CHANGES IN MILK PRODUCTION AND FEED CONSUMPTION THROUGH THE PRODUCTION CYCLE.

The graph shows 2 years' milk production and feed consumption of a Holstein cow on input-output experiment. The feed-consumption scale has been so arranged that the Haecker standard requirements for the milk production are shown on the feed-consumption scale; so whenever the feed-consumption line is above the milk-production line it indicates the cow has eaten more than standard requirements. These areas are shaded. Similarly, when the area between the lines is not shaded it indicates the cow has eaten less than standard requirements.

duction cycle. But the cycle is not repeated on exactly the same level. As a rule, the cow's production in each lactation period increases until the cow is about 7 years old. After that it decreases. Feed consumption rises and falls corresponding to milk production although not in exact proportion.

By cutting off suitable periods of time—say one lactation period or 1 year—and by totaling all the inputs and outputs for the period, the analysis can be greatly simplified. The problem then becomes one of learning whether the whole lactation curve can be changed, whether it can be pressed to higher levels. The aim is to ascertain how much feed it takes to do that and whether additional increases create progressively smaller responses. The input-output experiments were designed to measure these relationships.

DIFFERENT VIEWS REGARDING THE POSSIBILITY OF INCREASING PRODUCTION THROUGH MORE INTENSIVE FEEDING

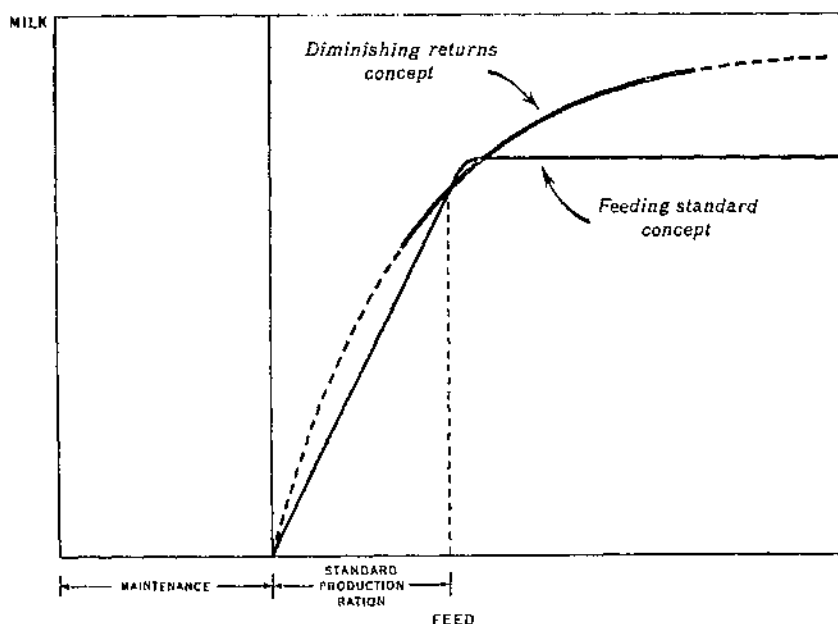
The present input-output investigations have started out with the observation that in actual practice the intensity of feeding of dairy cows varies considerably from one dairy area to another in this country. Among practical dairy farmers it is a well-known fact that heavy feeding of dairy cows will result in greater milk production than light feeding.

Dairy technologists also hold the view that milk production can be increased by raising the level of feeding. But many believe that for most economical production and for maintenance of the health of the herd, cows should not regularly be fed much beyond the standard level. The majority would hold that dairy cows should rarely, if ever, be fed substantially less than the requirements of the accepted feeding standards.

In the absence of experimental evidence, there is naturally some diversity of opinion regarding the effect on production of dropping below the standard and of raising the feeding level substantially above the standard. Some would probably hold that milk production increases in proportion to increased feed until the level set by the feeding standards is reached, and that beyond this point there is only a slight further increase. Other technologists, perhaps, would be inclined to the view that the changes in milk production are not only more gradual but also extend farther beyond the level of the feeding standard. Graphically, these two views are presented in figure 2.

It is of considerable practical importance whether the first or the second point of view is the correct one. If the principle of diminishing returns² does not apply to the range covered in practical dairy feeding, it appears that it would pay to feed always at a rate that would insure maximum production. If prices were such that it was profitable to feed grain, it would pay to feed all the grain they would take because if it were profitable to feed the first unit of grain it would be equally profitable to feed the second, the third, and as many more units as the animals would consume.

² The diminishing returns concept refers to the general principle of diminishing physical outputs, in this case output of milk. The decrease in physical return (output) per added unit of input (intake) gives rise to diminishing economic returns.



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FIGURE 2.—TWO CONCEPTS OF PRODUCTION RESPONSE TO INCREASED FEEDING.

According to this view, maximum production, presumably would be reached by feeding according to an accepted standard. Regardless of changes in prices of milk and feeds, this practice then should be adhered to as long as any profits remained in feeding for milk production. If then a contraction of production were called for, it should be brought about by increased culling of cows, not by feeding at a lower rate per cow; and an expansion of production should be accomplished by raising more dairy heifers, thus increasing the size of the herd—a slow method if in an emergency an increase in milk production were called for.

If, on the other hand, the response of dairy cows in the form of additional milk yield for each extra unit of feed declines as the feeding level is raised step by step, it will be seen that the intensity of feeding should change as prices change. Although an extra unit of feed added to a ration already heavy may bring only a small increase in milk yield, this increase may be more than enough to pay for the feed if the price of milk is very high in relation to the price of feed. But in periods of comparatively low milk prices and in areas where milk prices normally are low, the value of the extra yield would not suffice to pay for the extra feed.

PREVIOUS INVESTIGATIONS AND THEIR LIMITATIONS

THE STATISTICAL APPROACH

Several attempts have been made to establish such economically important relationships as those between feed inputs and milk outputs in order to use them for economic analysis of the dairy enter-

prise. So far the attempts mostly have taken the form of the well-known "statistical" studies. Usually they have tried to establish the relationship by statistical treatment of data obtained from farm-survey records, dairy-herd improvement records, and supervised-accounting records (2, 7, 10, 14).³ In the farm-surveyed and cost-route records only herd averages have been available and the findings must be discounted to some extent because it was not possible to measure differences in basic producing ability of the herds. In all three types of records, data on feed inputs are likely to be inaccurate.

There have been some inconsistencies in the results of different studies of this type. This has not been due to the methods employed but to the difficulties of estimating with sufficient accuracy how great were the average feed inputs and other inputs per cow in the different herds of varying average milk production. In some studies, the differences in feed inputs and milk outputs did not cover a sufficient range to permit accurate measurement of the relationships.

Nevertheless, these investigations have produced valuable information in spite of the shortcomings (1, 6). In some cases, the results have approximated fairly closely the results obtained in the present study but the inconsistencies between the different studies have not been fully explained.

However, had it not been for the interest stimulated and the possibilities indicated by these early studies, the present investigations would hardly have been undertaken. When some of the most important input-output relationships have been established by studies combining experimental and statistical work, valuable additional information to complete such production studies may be obtained by more studies of the statistical type.

In the present investigation the experimental method has been employed in an endeavor to obtain more reliable original data.⁴ The data have been obtained by conducting experiments designed specifically with regard to the problem at hand.

THE EXPERIMENTAL APPROACH

Technical research in milk production has been carried on for more than half a century. Most of the investigations have dealt with such matters as: (1) The extent to which proteins, fats, carbohydrates, and other constituents of feeds, could be utilized by dairy cows for conversion into milk; (2) how well different kinds of feeds were suited for use as dairy feeds measured by their influence on production and quality of the milk and health of the cows; (3) determination of the relative nutritive value of various feeds for milk production; and (4) how much of the different kinds of feed constituents are needed for milk production and for the maintenance of body weight. Experiments of this type have served as a basis for computing feeding standards.

³ Numbers in italics refer to Literature Cited, p. 88. A number of other reports available only as unpublished theses have been made, utilizing the same technique which was indicated in the early bulletin by H. R. Tolley, J. D. Black, and M. J. B. Ezekiel, *Input as Related to Output in Farm Organization and Cost-of-Production Studies*. U. S. D. A. Bul. 1271, 1924.

⁴ In reality, the experimental method is also statistical. The observations obtained from the experiment must be subjected to statistical analyses in order to determine what the data mean and how reliable the results are.

Although profit-and-loss statements have sometimes been included in the reports, only a few investigations have been designed specifically to learn the most economical quantity of feed to use, and these investigations have been concerned mostly with ascertaining the effect on production of feeding grain in addition to roughage as compared with feeding roughage alone in the alfalfa-growing regions of the West (4, 5, 7, 8, 11, 12).

The Bureau of Dairy Industry at its Huntley, Mont., Field Station (8) found that 82 percent as much milk was produced by cows fed roughage alone as by cows fed roughage and a limited amount of grain. In returns over cost of feed at the actual prices prevailing at the time the experiment was conducted the feeding of roughage and a limited amount of grain (1 pound to 6 pounds of 3.5 percent milk) proved a little more profitable than the feeding of roughage alone.

The Oregon Agricultural Experiment Station in work at the Umatilla Field Station (12) found that cows when fed alfalfa hay alone produced 79 percent as much milk as when fed alfalfa hay and grain (4.6 pounds for each 1 pound of butterfat). A table is presented showing the price above which butterfat must sell to make that rate of grain feeding pay at different sets of assigned prices for the hay and grain. Whether it would pay better to feed more or less grain was not determined.

The Nevada Agricultural Experiment Station (5) over a period of 8 years fed cows on alfalfa alone in comparison with alfalfa and grain. The amount of grain averaged 1,745 pounds per cow per year or at the approximate rate of 1 pound for each 5.4 pounds of milk produced. The profitableness of grain feeding depended upon the inherent productivity of the cows as well as upon the prices of feed and product. High-producing cows responded to grain feeding more than low-producing cows.

Cooperative work of the Bureau of Dairy Industry and the Utah Agricultural Experiment Station (4) in which cows were fed alfalfa hay and pasture in comparison with alfalfa hay, pasture, and barley showed that the production on roughage alone was 79 percent of that on roughage and barley; 1,818 pounds of barley fed at the rate of 1 pound to 6.1 pounds of 3.1 percent milk saved 863 pounds of hay and led to the production of 2,048 pounds more milk.

The results of some of these investigations have been summarized in a paper presented at the 1940 meeting of the American Society of Animal Production (15) in which it is stated that "when milk testing up to 4 percent is worth as much as an equal weight or more of grain, it pays to feed grain in at least moderate amounts, say, 1 pound to each 5 or 6 pounds of milk."

Although these investigations, perhaps, provide adequate data on the effect of moderate grain feeding along with liberal feeding of high-quality alfalfa hay, they do not give enough information on either the higher or the lower levels of grain feeding which, under certain price conditions, might be more profitable; nor have they been conducted elsewhere than in the alfalfa-growing regions of the West.

The feeding-standards investigations have been aimed at establishing how much feed, on the average, it is desirable to give to cows

of different sizes, yielding different quantities of milk. It was not ascertained how the average cow would react if the ration were cut down below normal, nor how far production could be forced by feeding far heavier than normal, nor to what extent the law of diminishing returns would be met if the feeding level were increased more and more. These problems have remained unsolved.

There are reasons why, after some rough approximations were made as to the average quantity normally required, these related problems of an economic nature have been neglected. The subject of dairy feeding is very broad, extending into the fields of animal physiology and nutrition, plant physiology, and agronomy. In it are involved considerations of the conservation of crops, the construction of dairy barns, and the organization of the work of feeding and caring for the dairy herds.

The quantity of feed needed to maintain cows has been learned, and the average requirements for milk production have been established by numerous experiments with cows fed such quantities of balanced rations as would keep them at uniform body weight. Thus, when all feed above maintenance was converted into milk, and none into increased body weight, technically the most efficient production was obtained. It has been assumed that this rate of feeding would also be the most economical, as a rule, and feeding standards have been worked out on the basis of these figures. Total milk production has been divided by total feed consumed above maintenance, and thus the average requirements for feed input per unit of milk output has been computed and the basis provided for accepted feeding standards.

The type of experiments that come nearest to providing input-output data of the kind needed are experiments in which many cows of known productivity are fed at different levels of intensity. A good example is a series of experiments in Denmark conducted in the years 1922 to 1928 by the State Research Laboratory of Copenhagen (3). These experiments employed a considerable number of cows in large balanced groups fed at three different levels, but the experiments were of the short-term type, running only for about $2\frac{1}{2}$ to 5 months. In this type of experiment there is not time enough for fluctuations in body weight to become stabilized. Losses in weight, with a corresponding saving in feed, and gains in weights, which mean use of feed for beef production instead of milk production, prove to be a seriously disturbing influence. Some additional long-term experiments were so badly disturbed by losses of animals on experiment that the investigations were stopped. The results of the short-term experiments were used for computing average feed requirements per pound of milk produced and for revising feeding standards, not for determining input-output curves.

PLAN AND PROCEDURE OF PRESENT INPUT-OUTPUT INVESTIGATIONS

TWO SERIES OF EXPERIMENTS

Two series of experiments were conducted. In the so-called series I experiments, cows were fed rations computed in what might be called the scientific way—strictly according to an accepted feeding standard,

either the Haecker standard or the Morrison standard. All animals were fed maintenance rations according to their weight, but production rations varied from 30 percent below to 30 percent above the standard level. The differences in rates of feeding were designed to represent conditions where some herds continuously were fed more than the requirements called for per pound of milk in contrast to other herds that continuously were fed less than requirements. Therefore, if cows on the experiment in the heavy-fed groups responded to the feeding above standard requirements with increased production of milk, the production ration was increased.

For example, if cows in a group fed 20 percent above the Haecker standard responded with an increase in milk production, the production ration was at once increased so as to supply 20 percent over and above standard requirements at the new and higher level of production. In the same way, if cows fed at a rate which supplied only 80 percent of the requirements reduced their milk production the production ration, for the next week, would be reduced sufficiently to supply only 80 percent of standard requirements at the new and lower level. Thus, the total ration was continuously adjusted to milk production in the same way that practical dairymen adjust the grain ration when they feed grain at the rate of 1:2, 1:3, etc.

The differences in rates of feeding were accomplished mainly by varying the allowance of concentrates, but when the cows were dry or nearly so, roughage consumption sometimes had to be restricted also. To obtain complete feeding control, cows were fed in the barns the year round. They were allowed to exercise in the open in small enclosures near the barn, but they did not have any pasture.

In another series, the so-called series II experiments, the feeding as practiced by practical dairymen was approached more closely. Only one check group was fed according to the Haecker standard; the other groups were fed roughage at liberty, but the grain ration was varied in proportion to milk produced, so as to feed different groups 1 to 2, 1 to 3, 1 to 4, and 1 to 6 (1 pound of grain for every 2 pounds of 4-percent milk, etc.). At two stations the cows in one group were fed only roughage. Except for some of the groups fed at standard the allowance of roughage was in no case curtailed, even if this meant that when cows were dry or giving only a small quantity of milk, they received more feed than was called for by the requirements of the feeding standard used. In this series some of the herds were barn-fed throughout the year; others were on pasture during the summer.

Altogether, 157 yearly records were obtained of cows fed according to the series I method, and 210 according to the series II method. Each station, except the one in Virginia, fed groups of cows at not less than five levels. One group at each station was fed according to the Haecker or the Morrison standard.

Toward the end of the second year, it appeared that even the highest levels of feeding were still not high enough to yield a sufficient number of observations on which to base the very uppermost part of the curve of diminishing returns. Yet that range of observations seemed to be what was needed to ascertain the economic limit to intensive feeding under practical conditions where milk prices were very high in relation to grain prices. Therefore, at five experiment stations—Delaware, Indiana, Maryland, Mississippi, and Pennsyl-

vania—the work was continued for a third year during which 87 cows were fed all the grain they would eat for most of the lactation period.

The sum totals of feed intake and milk output for the entire year for each of the cows from the different herds constituted the observations. The few production records that were discarded were of animals that suffered really serious disturbances such as sickness or accident.

PLAN OF THE EXPERIMENTS

It was planned to use the best available experimental technique to obtain close control of feeding and accurate measurement of milk output and of quantities of all feeds consumed. At the same time the cows were to be housed in average dairy barns where they would be tied up in stanchions, milked two or three times daily, and given average care. Thus environmental conditions would correspond to good dairy practice and the results could be applied directly to dairy farming as now practiced.

These requirements could be fulfilled at reasonable expense only at the State agricultural experiment stations. At the cooperating experiment stations, the production of each cow during previous lactation periods was known from the records kept. Assuming that all animals had had an equal chance to demonstrate their ability to produce under similar conditions of good dairy practice, the productivity of each of the cows used in the experiments could be estimated. The basic producing ability during each experimental year was estimated from the previous records by applying Dairy Herd Improvement Association correction factors for age, length of lactation period, and number of times a day milked. On the basis of this information, together with the data on breed, age, and weight of the animals, the cows were selected for experimental work and allocated to different experiment groups in such a way that these groups, so far as possible, were homogeneous with respect to breed, yield, percentage of butterfat in the milk, age, and weight.

The plan then required these balanced groups to be fed at different levels of intensity for a period of time long enough to cover at least two full lactation periods. Liberal feeding may result partly in increased milk yields and partly in increased body weight, and a cow may draw on built-up body reserves at later periods. By continuing the experiments for two full lactation periods it was expected that the full cumulated effects of heavy and scant feeding could be learned.

But the very long period of experimentation also meant vastly greater difficulties on account of loss of animals on experiment. Some cows would have to be taken off the experiment when records were only partly completed; groups would become unbalanced when satisfactory substitutes could not be found. Because of disease, injury, or death of some of the cows, altogether 41 percent of the original cows were eliminated before the experiment had run through two lactation periods: 17 percent were lost during the first year and 24 percent during the second year. These percentages are high but no higher than culling percentages in many commercial herds.

Cows under 3 years of age were not used because a cow had to have at least one lactation record to serve as a base for an estimate of the expected production during the period when being fed experimentally.

Because only cows that had at least one lactation record and were normal in all respects could be used for experimentation, only a limited number of cows (as a rule 10 to 30) could be used from each herd. It became necessary, therefore, to enlist the cooperation of 10 State agricultural experiment stations. At these stations, altogether 454 annual records of milk production and feed consumption were obtained.

PROCEDURE

As a matter of convenience in conducting the work at different stations all the cows were started on the experiment at the same time, regardless of the stage of lactation. For each cow the first year ended and the second year began when she again reached the stage of lactation at which the experiment started. By combining parts of the two experimental years it was also possible to obtain a separate set of data on unbroken lactation periods for most of the cows. The cows varied greatly with respect to the interval between calvings and the length of the lactation periods. The records were therefore standardized as nearly as possible to a common basis by eliminating those parts of the records which were in excess of a dry period of 60 days and a lactation period of 302 days. Records of milk and feed for the 3 days immediately after the calving were disregarded. These omissions cause a reduction in overhead feed costs and this must not be overlooked in certain types of economic computations.

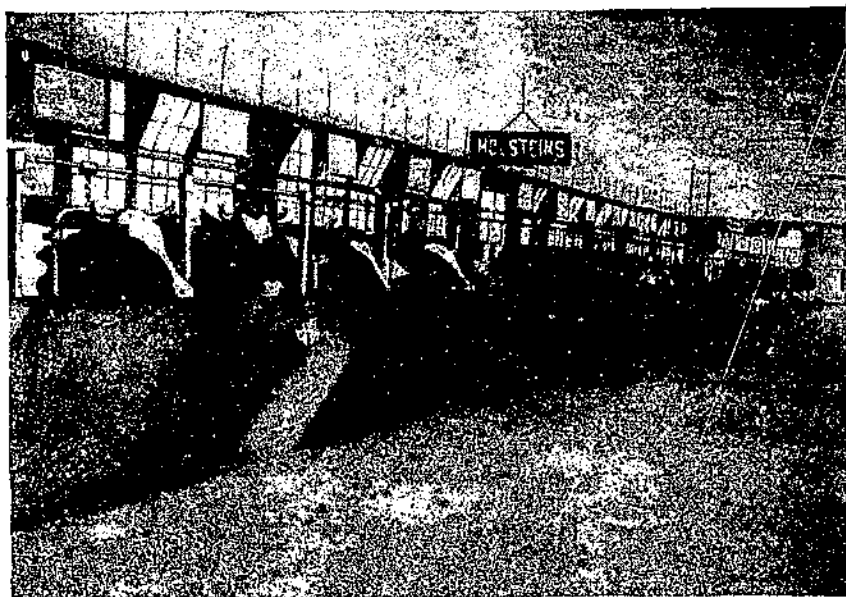
It was intended to limit the investigations to the economic problem of how much to feed under different price conditions. Therefore, all rations were prepared in a way to guard against any deficiency of protein, minerals, or vitamins. At all stations all groups were fed enough protein to meet fully the requirements of the Haacker standard and the rations all contained what would be considered a suitable variety of ingredients. Legume hay and either wheat bran or one of the oilmeals made up part of the rations, and the use of these feeds no doubt prevented any shortage of calcium or phosphorus. The quality of hay and silage was high enough to prevent symptoms of vitamin A deficiency. At one station the grade of the hay averaged midway between U. S. No. 1 and U. S. No. 2 in quality; at two others it averaged U. S. No. 3; and at all other stations it averaged U. S. No. 2. It was believed, therefore, that any differences observed in the response of the cows fed at different levels could be attributed to the quantity of feed eaten and not to shortcomings of the rations in other respects.

The feeds varied somewhat in nutrient content from one station to another so that in averaging results from several stations certain adjustments had to be made. The grain was adjusted to a total digestible nutrient content of 75 percent. The silage at two stations was so much above the average in dry matter that it was adjusted to a total digestible nutrient content of 18.7 percent. The figures for grain and silage in all the tables represent adjusted values.

Only a very small part of the nutrient intake was obtained from pasture. At half the stations the cows on experiment had no pasture. All cows, whether they were fed heavily or lightly, consumed some hay and silage in the barn during the days on pasture, and grain feeding was continued at the usual rates. It was assumed that the cows would consume as many nutrients in pasturage and in the

roughage fed as supplements to pasture as they consumed in roughage during the nonpasture season. The nutrient intake from pasture, then, was estimated from the quantity of barn feed saved in the following way. From the nutrients consumed by the cows in the form of roughage before they went on pasture were deducted the nutrients in hay and silage fed as supplements to pasture. The remainder was considered to represent roughly the nutrients obtained from pasture.

At one station cows received a considerable quantity of nutrients during a day's grazing; at other stations they received very little. In order to express the pasture-nutrient intake in terms of pasture days of equal value, the total quantity of nutrients replaced by pasturage was divided by 15. One cow-day of grazing was considered



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FIGURE 3. SPECIAL MANGER PARTITIONS USED FOR THESE EXPERIMENTS BY THE PENNSYLVANIA EXPERIMENT STATION. THE PARTITIONS WERE PLACED IN FRONT OF EVERY OTHER COW, THUS PREVENTING EACH COW FROM STEALING FEED FROM HER NEIGHBORS.

to be equal to 15 pounds of total digestible nutrients in pasturage. This quantity is about what cows would ordinarily get from first-class pastures.

It is recognized that these estimates are burdened with a sizable error. However, on an average the number of days on pasture was very small and ranged within rather narrow limits for the different groups. Therefore, even sizable errors in the method of evaluating pasturage could have no material effect on the final averages derived from the total number of cow records.

All milk produced and all feed consumed were weighed every day. The feeds were fed to each animal separately (fig. 3). Manger partitions prevented cows from stealing either concentrate feed or

roughage from each other. What was not eaten was weighed back. Samples of all the feeds used except pasture grass were analyzed by the stations. Digestion trials were not run. Instead, the coefficients of digestibility published in Morrison's Feeds and Feeding, 20th edition, were applied to the chemical analyses in estimating the digestible nutrients. Each lot of hay was carefully graded by the Grain and Seed Division of the Agricultural Marketing Service. Samples of milk were tested for butterfat. In general, the experimental work was handled in accordance with the best available technique which it was possible to employ and still have experimental conditions correspond to ordinary good farm practice.

The quantities of the various feeds were adjusted every week according to the plan of the experiment so that any change in production during any one week was reflected in the rations computed for the following week.

Reports on the experimental work were made every week. The data received were checked against the original barn records, apparent inconsistencies were investigated and a so-called deviation report was returned immediately to each station. In this report it was stated to what degree the feeding of each animal had deviated from the plan for the experiments and how much correction in feed would be required the next week to make up the difference. A dairy technologist visited the stations from time to time and talked with the persons who actually fed and cared for the cows on experiment.

PREPARATION OF EXPERIMENTAL DATA FOR ANALYSIS

AVERAGING OF FIRST, SECOND, AND THIRD YEARS' RECORDS

As the weekly records of feed consumption, milk production, weights, health, and chemical analysis of the feeds, etc., were received from the cooperating stations, the data were accumulated into annual records for each cow in the experiment. But before tabulating the results it was necessary to learn whether the first, second, and third years' records could be averaged together and whether all these records or only those obtained in the second and third year were to be used.

In setting up the experiments it was expected that the full effect of the different rations would not become manifest until the second year. But at the end of the second year no consistent pattern was found in the response of the cows the second year as compared with that of the first year, except that the definitely underfed cows produced less the second year. Of the cows that had two consecutive yearly records the percentage that produced more the second year than the first at five different levels of feeding from the lowest to the highest was 44, 69, 65, 40, and 62, respectively; similarly, in the five groups the second year's production in percent of the first year's production was as follows: 92, 106, 106, 99, and 101, respectively. Because production the second year failed to show any definite trend, group by group, compared with that of the first year, it was considered best to work up all the data together rather than separately by years.

COMBINING PARTS OF TWO LACTATION RECORDS

Another problem was whether results would be biased when parts of two lactation records were combined in order to make up one complete lactation instead of measuring results in terms of unbroken lactation records. The cows were started on experiment at various stages of lactation and ended the year at the same stage of lactation at which they started. The question is whether a year's record made in this way is comparable with a record that starts during the dry period or immediately after calving. If only unbroken lactation records could be used, the number of observations would be reduced by 24 percent. A separate analysis was made, therefore, to ascertain whether any significant difference would result from using the one kind of production records instead of the other.

A total of 367 original yearly records made by 256 cows yielded 280 unbroken lactations; 180 cows made records of sufficient length to make it possible to compute production records by both methods. In many cases cows were started on experiment so close to the drying-off date that the periods covered by their broken and unbroken records were practically identical, but in 88 cases there were substantial differences in the dates on which the cows started their broken and unbroken records. That is to say, some of the cows had been fresh for several months before they were put on experiment, at which date their broken record began.

The comparison of the broken and unbroken records made by these 88 cows showed an average difference of only 60 pounds of milk per cow per year. This indicates that very little bias will result from using the method of compositing broken records instead of using unbroken lactation records. It was found that in 42 percent of the cases the deviation of the broken from the unbroken record was less than, plus or minus, 500 pounds, and in 69 percent of the cases it was less than 1,000 pounds.

This indicates a standard error of about 1,000 pounds and this error is no greater than the usual unexplained variation found in analyzing records of cows of the same size, productivity, and feed intake. It was therefore concluded that no significant difference would result from using one method of computation instead of the other. Naturally, therefore, the method of combining parts of two lactation records into one annual production record was selected because one-third more records could be obtained from the available material.

CHANGES IN BODY WEIGHT

As feed can be used for making body substance as well as for making milk, gains or losses in weight should be evaluated in terms of milk or feed provided the animal is to be so fed that she will at some time revert to the same weight as at the beginning of the experiment. In short-time experiments a given gain or loss exerts a greater influence than in long-time experiments because the nutrients associated with gains and losses make up a greater proportion of the total.

After a cow is put in better condition through heavier feeding she will tend to maintain this condition so long as the heavier feeding continues; after she becomes thin through lighter feeding the tendency will be to remain thin until the feeding is more liberal. The

nutrients associated with gains and losses therefore should be taken into account only once for the entire period.

The intent of the input-output investigations was to ascertain the most profitable level of feeding for a period that might extend over several years but in no case would be less than 1 year. Even then, the value of the increased body weight produced by liberal feeding will finally be realized some years later when the cow is culled and sold for beef. But this increased value is probably more than counterbalanced by the cost of the extra feed required year after year to maintain the heavier animal. Therefore, if the gains or losses in body weight are not very great they may well be ignored in the analysis of long-term input-output experiments.

In these experiments a continuous record of body weights was obtained from weekly or biweekly 1-day weighings or from monthly weighings for 3 consecutive days. In addition, a system of grading for condition was adopted and at intervals throughout the experiment the cows were graded by the same men at the various stations. The grades ran from 1 to 4, 1 representing excellent condition, 2 good, 3 fair, and 4 poor.

A comparison of the weights taken at the beginning and at the end of each of the cow's year on experiment for 2 consecutive years showed that the six groups (table 7) from the lowest to the highest level of feeding gained or lost the following number of pounds per cow: First year: -26, +11, -21, +52, +29, +66; second year: -5, +7, -2, -9, +26, +9.

The lowest fed group lost the most, and the highest fed group gained the most. The data for the intermediate groups are not very consistent, especially if considered separately by years, but if the results from the first and second years are added together, then only groups 2 and 3 need to exchange places to make the gains conform to the different levels of feeding, as will be seen from the following 2-year totals: -31, +18, -23, +43, +55, +75. The ratings for condition of flesh varied in the same way as the weights. The average ratings of all cows from low to high levels of feeding were as follows:

Group 1, 2.79; group 2, 2.74; group 3, 2.51; group 4, 2.33; group 5, 2.29; and group 6, 2.03.

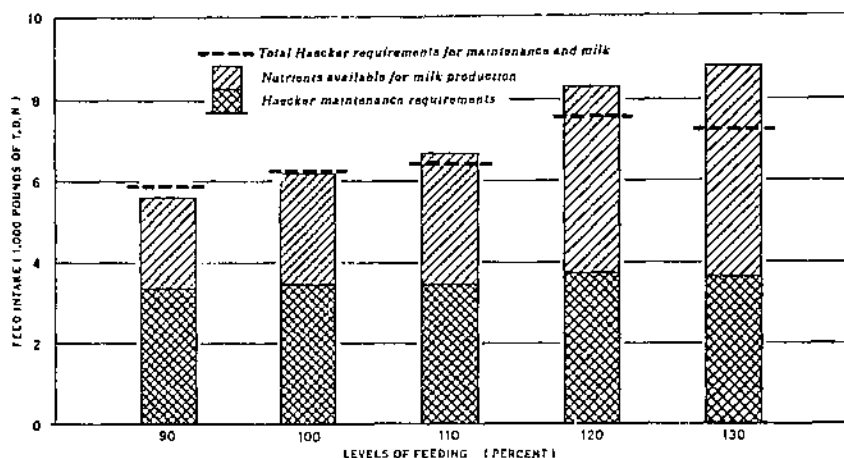
It will be observed that the weights the second year tend to become stabilized, the largest loss the second year being 9 pounds and the largest gain being 26 pounds, as against a 26-pound loss and a 66-pound gain the first year. The authors did not think that these losses and gains, especially after the first year, were large enough to be taken into account when analyzing the results. If the value of output obtained in the form of increased body weight is to be considered, the cost of the extra feed inputs required to maintain the added weight must also be taken into account. If this is done, it is found that the value of the gain is more than counterbalanced by the added cost of maintenance in one and one-half years.⁵ Therefore, in this study no credit can properly be given to gains in weight.

⁵ If 3.53 pounds of digestible nutrients are required to produce a pound of gain, it takes 353 pounds of nutrients to produce a gain of 100 pounds. On the basis of the Morrison standard for the maintenance of dairy cows, it is estimated that to maintain the gain of 100 pounds will require 248 pounds of nutrients a year. Thus, if for the sake of simplicity it is assumed that the value of the added weight corresponds to the value of feed it took to produce it, the cumulative cost of maintaining the added weight will counterbalance the value of the gain in less than 1½ years.

RESULTS OF PRESENT INPUT-OUTPUT EXPERIMENTS

SERIES I EXPERIMENTS

The results of these experiments can be described most briefly by figure 4, which presents an example of how the plan was actually carried out at one station for 1 year and how balanced groups of cows responded to the changes in feeding level at the stations that conducted the series I experiments. At this particular station the group fed at 120 percent of standard had the highest production but on an average for all these experiments production increased consistently with heavier feeding and the heaviest fed group produced the most.



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FIGURE 4.—COMPARISON OF HAECKER STANDARD REQUIREMENTS WITH TOTAL FEED CONSUMPTION OF GROUPS OF COWS FED AT DIFFERENT LEVELS AT STATION A.

The plan required that the cows be fed strictly according to the Haecker standard with some groups fed more than the standard, and other groups below the standard. Figure 4 shows that the purpose was accomplished. The cows on the scantiest rations received less than the standard called for, and those on the high feeding levels received a surplus. The figure also shows that these differences were brought about by changing the grain ration. The roughage part of the ration was practically constant from group to group. Only a limited amount of roughage was fed—1.8 pounds of hay equivalent per 100 pounds of live weight. Therefore, in these experiments increased grain feeding was not accompanied by a reduction in roughage consumption as was the case in the series II experiments where there was no limitation on the amount of roughage fed to the different groups.

That milk yields generally increase with increased feed is brought out more clearly in tables 1 and 2 and figures 5 and 6, which deal only with the relationship between feed inputs and milk outputs, and show what differences in yearly feed consumption over a whole year

TABLE 1.—Milk output and feed inputs, yearly averages of cows fed at specified percentages of the Haecker standard; series No. 1 experiment at station A¹

FIRST-YEAR RECORDS											
Level of feeding (percent of Haecker standard) ²	Yearly records	Basic producing ability, 4-percent fat-corrected milk	Average live weight for year	Milk produced, 4-percent fat-corrected milk	Total digestible nutrients consumed		Grain consumed	Hay consumed	Silage consumed	Total feed consumption (total digestible nutrients) related to Haecker standard	
					Total	Over maintenance ³				Total	Over maintenance
	Number	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Percent	Percent
90	6	8,982	1,173	7,581	5,627	2,632	1,968	3,094	12,217	91	79
100	5	9,332	1,208	8,293	6,215	2,620	2,495	4,096	12,753	97	93
110	5	9,875	1,203	8,887	6,722	3,127	3,302	4,090	12,672	102	104
120	5	9,306	1,303	11,487	8,371	4,776	5,012	4,248	13,664	112	122
130	5	9,285	1,260	10,915	8,378	4,783	5,282	4,178	12,814	115	132
SECOND-YEAR RECORDS											
90	5	9,325	1,193	8,228	5,988	2,393	2,455	3,252	15,604	94	86
100	5	9,510	1,295	9,844	7,052	3,457	3,412	3,446	16,792	102	103
110	4	10,047	1,226	10,778	7,520	3,025	4,358	3,447	15,333	104	107
120	4	9,512	1,312	12,342	8,746	5,151	5,778	3,595	16,020	112	123
130	5	9,214	1,290	10,660	8,317	4,722	5,288	3,356	16,100	115	130
ADDITIONAL RECORDS ⁴											
Unlimited ⁴	8	8,745	1,304	11,224	8,965	5,370	6,072	3,511	12,162	121	141

¹ At this station the cows were all large Holstein cows milked twice a day.² The average maintenance requirements of 57 cows, 3,595 total digestible nutrients was used for all groups.³ These records supplemented the regular plan of the experiment by providing more information at the heaviest levels of feeding. They were made in the third year of the experiment partly by cows on experiment before, but mostly by new cows added to the experiment.⁴ In this group the cows were fed all the grain they would consume in addition to a roughage intake of 1.5 pounds of hay equivalent daily per 100 pounds of live weight.

TABLE 2.—Milk output and feed inputs, yearly averages of cows fed at specified percentages of the Haeccker standard; series No. 1 experiment at station B¹

FIRST-YEAR RECORDS											
Level of feeding (percent of Haeccker standard)	Yearly records	Basic producing ability, 4-percent fat-corrected milk	Average live weight for year	Milk produced, 4-percent fat-corrected milk	Total digestible nutrients consumed		Grain consumed	Hay consumed	Silage consumed	Total feed consumption (total digestible nutrients) related to Haeccker standard	
					Total	Over maintenance ²				Total	Over maintenance
	Number	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Percent	Percent
70	2	9,333	1,250	7,993	5,606	1,836	1,516	3,185	17,538	86	68
80	5	9,177	1,287	9,717	6,452	2,682	2,947	3,214	17,179	91	81
90	5	9,283	1,169	9,933	6,449	2,670	3,194	3,017	16,225	90	79
100	5	9,162	1,380	11,385	7,965	4,195	4,624	3,367	18,285	104	108
110	5	9,388	1,311	11,707	8,086	4,316	5,493	3,272	16,223	104	108
120	2	9,479	1,317	11,831	8,411	4,641	6,241	3,247	15,415	108	115
SECOND-YEAR RECORDS											
80	5	9,339	1,292	7,915	5,928	2,158	1,548	3,276	16,820	92	80
90	4	9,597	1,206	10,653	6,768	2,698	3,041	3,112	15,850	92	83
100	4	9,690	1,419	11,684	8,053	4,283	3,806	3,476	18,685	104	108
110	5	9,514	1,356	10,051	7,576	3,806	4,098	3,369	15,326	105	111
120	2	9,827	1,396	12,508	8,900	5,130	6,260	3,375	13,944	111	121
ADDITIONAL RECORDS											
Unlimited	22	9,846	1,334	12,756	9,116	5,346	7,324	3,645	11,012	112	123

¹ At this station the cows were large Holstein and Brown Swiss cows milked 3 times a day.² The average maintenance of 66 cows, 3,770 total digestible nutrients was used for all groups.

resulted from the feeding of different groups at various feeding levels. The data are from two experiment stations each of which for 3 years conducted one of the series I experiments.

The data obtained through these 3 years of experiments show clearly that it is possible to increase the milk production of dairy cows substantially by feeding more than the feeding standard calls for. At the two stations A and B, for example, the production of the groups

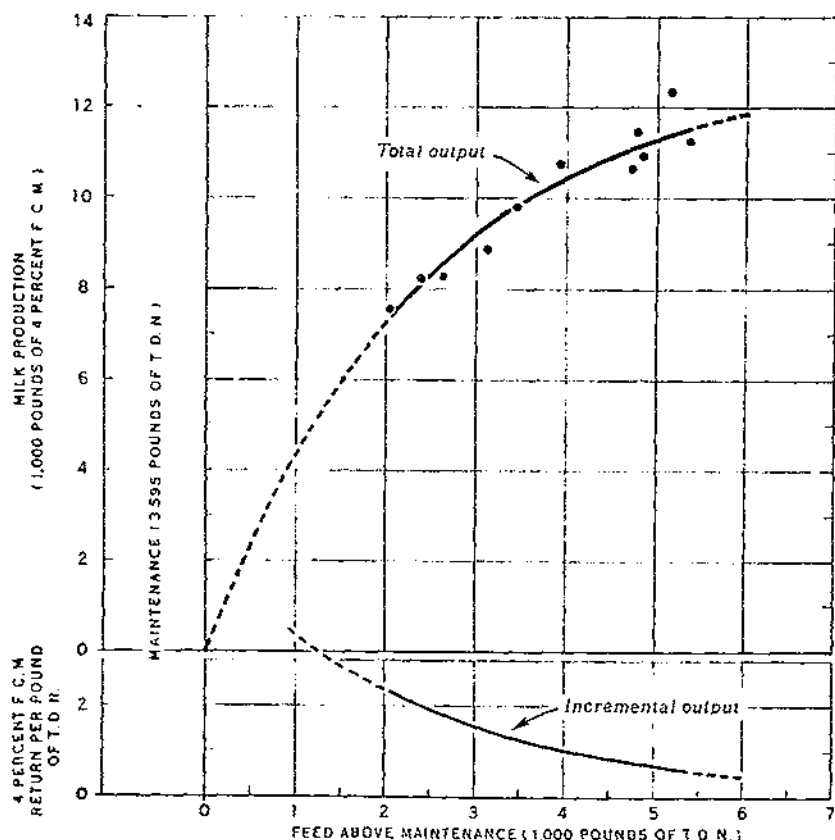


FIGURE 5.—RESPONSE IN MILK PRODUCTION TO INCREASED FEEDING. DIFFERENCES IN PRODUCTION OF BALANCED GROUPS OF COWS FED AT DIFFERENT LEVELS FOR THREE YEARS AT EXPERIMENT STATION A.

that were fed the largest rations averaged as much as 15 to 20 percent above the production of the groups fed at standard, and about 45 percent more than the lowest fed group, which received only 70 to 80 percent of what the standard requirements called for. This is truly a remarkable difference.

DETERMINATION OF PRODUCTION RESPONSE TO MORE INTENSIVE FEEDING

The experiments aimed also to measure these differences with enough accuracy to permit them to serve as the basis for economic analysis.

In other words, the purpose was to learn how much extra milk would be obtained for each additional unit of feed, and how soon and how seriously the principle of diminishing returns would apply. When the feeding level was changed from the standard level to a level 10, 20, and 30 percent above the standard production ration, how much of an increase in milk production would follow from each increase in feed intake? Would increases in milk production be proportionately

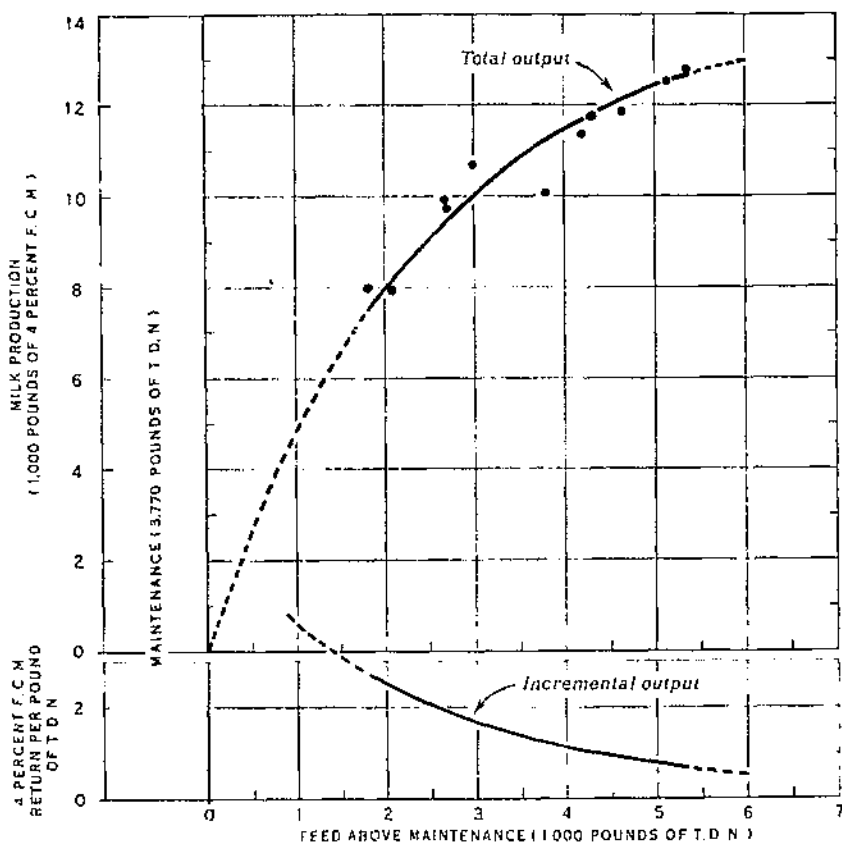


FIGURE 6.—RESPONSE IN MILK PRODUCTION TO INCREASED FEEDING. DIFFERENCES IN PRODUCTION OF BALANCED GROUPS OF COWS FED AT DIFFERENT LEVELS FOR THREE YEARS AT EXPERIMENT STATION B.

large, or would the second and third increase show declines in the return?

The typical picture of the results from the series I experiments is revealed in figures 5, 6, and 7, which show the response of the cows at individual stations, and table 3 and figure 8, which represent the average response at all the series I stations. In figures 5 and 6 the upper curve shows to what degree total milk production has been increased by heavier feeding of two herds at two State experiment stations which for 3 years fed the herds according to the plan of the series I experiments. The lower curves show incremental output—the

increase in milk production obtained for an extra pound of digestible nutrients—at the different levels of feeding. In figure 8 the average output per unit of feed is also shown. The three kinds of curves are merely different ways of expressing the relationship between feed input and milk output at various levels of feeding.

The observations in figures 5 and 6 covered a period of 3 years. Each observation represents one year's production of a balanced group usually consisting of five cows fed individually at a certain level of feeding

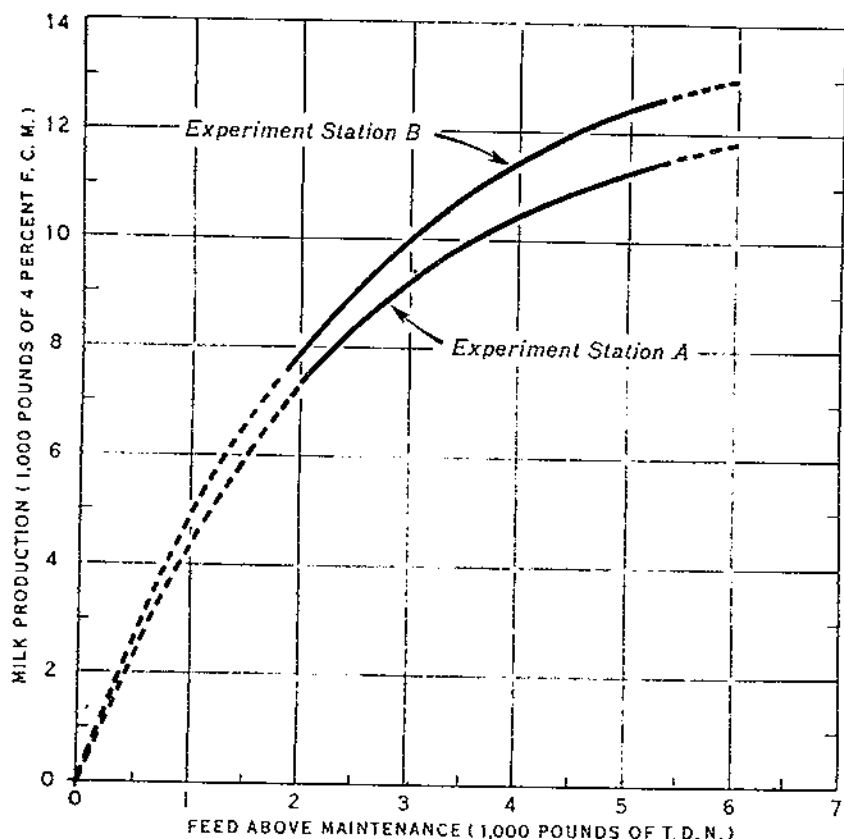


FIGURE 7. COMPARISON OF INPUT-OUTPUT CURVES SHOWING RESPONSE IN PRODUCTION TO INCREASED FEEDING AT TWO STATIONS CONDUCTING SERIES I EXPERIMENTS.

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according to plan. Actually, feed consumption for the whole year did not come out exactly as planned but its average was close to the assigned level.⁶ For example, it might be 83 percent of the feeding-standard requirements instead of 80 percent. With the method of analysis used, small errors in feeding are not carried into the results as errors. All this method requires is a number of careful observations covering a suitable range.

⁶ Because a great amount of data has accumulated from the experiments which ran for more than 3 years, the original data for each animal on experiment will be issued separately, and not included in this bulletin.

The data from these two individual stations are presented separately because the data from only one herd bring out the principle of diminishing physical output more clearly than similar data arrived at by computing averages of larger balanced groups of records obtained from different stations and presented in table 11 and figure 13. At station A, for example, the herd consisted of large Holstein cows all of the same strain, of uniform type and rather uniform productive capacity. The environmental conditions were the same. All the cows

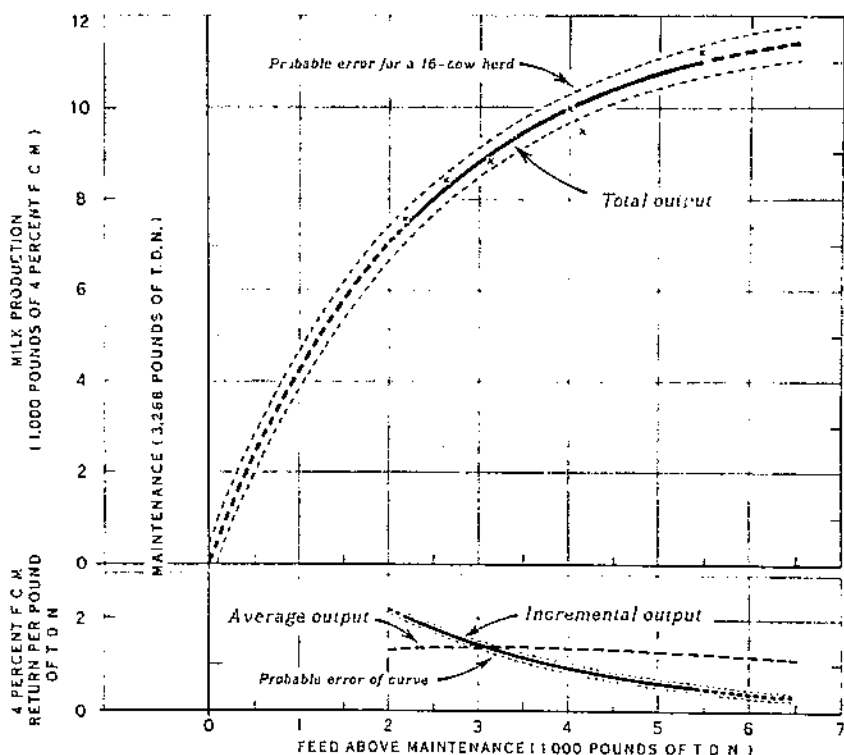


FIGURE 8.—RESPONSE IN MILK PRODUCTION TO INCREASED FEEDING. DIFFERENCES IN PRODUCTION OF SIX BALANCED GROUPS AT ALL OF THE FOUR STATIONS CONDUCTING SERIES I EXPERIMENTS.

were fed for 3 years in the same barn, they were supplied the same feeds and received the same care. The balanced groups of cows which were made up at the beginning of the experiment were carried through to the completion of the investigation and the observations which are plotted on figure 5 and to which the input-output curve has been fitted represent the average production per cow in these balanced groups. There has been no regrouping of records and no adjustments of the original data.

At station B the original balanced groups were likewise maintained. These groups were made up from Holstein and Brown Swiss cows likewise fed for 3 years in the same barn and subject to the same environmental conditions throughout.

It seems important that the input-output relationships exhibited by these two individual herds were practically the same as the relationships arrived at by averaging large balanced groups of production records obtained at nine different experiment stations. Any process of grouping records and arriving at weighted averages for all the groups at the nine different stations may be open to criticism at some points, but in the case of the two individual station herds no such grouping was made. The results from these two herds thus serve as a check on the results from all nine stations. Based upon these two stations alone a briefer report could have been prepared without any material change in the general conclusions.

TABLE 3.—Milk output and feed inputs, average per year per cow, fed at specified rates¹ of Haecker standard, series No. 1 experiments; average of 4 stations

Item	Unit	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Yearly records	Number	31	28	33	23	16	36
Basic producing ability, 4-percent fat-corrected milk	Pounds	8,836	8,592	8,853	8,841	8,833	9,000
Live weight of cows (average)	Pounds	1,127	1,091	1,095	1,130	1,182	1,212
Outputs:							
Milk produced	Pounds	7,783	8,708	9,067	10,107	9,865	11,545
Butterfat	Percent	3.81	3.78	3.84	3.93	3.79	3.80
Do	Pounds	296.3	328.7	348.6	397.0	371.8	438.9
4-percent fat-corrected milk	Pounds	7,558	8,411	8,855	9,909	9,497	11,204
Inputs:							
Grain consumed in year	Pounds	1,876	2,583	3,347	4,469	4,533	6,783
Hay	Pounds	3,494	3,337	3,422	3,485	3,598	3,678
Silage, corn (or sorghum)	Pounds	12,608	12,439	12,010	12,054	12,197	9,960
Silage, alfalfa	Pounds	990	520	569	579	270	203
Mangels	Pounds	243	175	232	241	206	120
Total digestible nutrients consumed	Pounds	5,485	5,894	6,460	7,283	7,435	8,716
Total digestible nutrients consumed over maintenance ²	Pounds	2,197	2,626	3,132	4,015	4,167	5,448
Feed consumption related to Haecker standard:							
Total ³	Percent	94	96	102	109	114	123
Over maintenance ³	Percent	85	92	104	118	120	143

¹ Production records for experimental groups of cows in different stations have been arranged in an ascending order with reference to the Haecker standard and the groups balanced with respect to basic producing ability. The grouping is explained in more detail in pages 35-38 and is shown for Delaware, Mississippi, New York, and Pennsylvania in table 7.

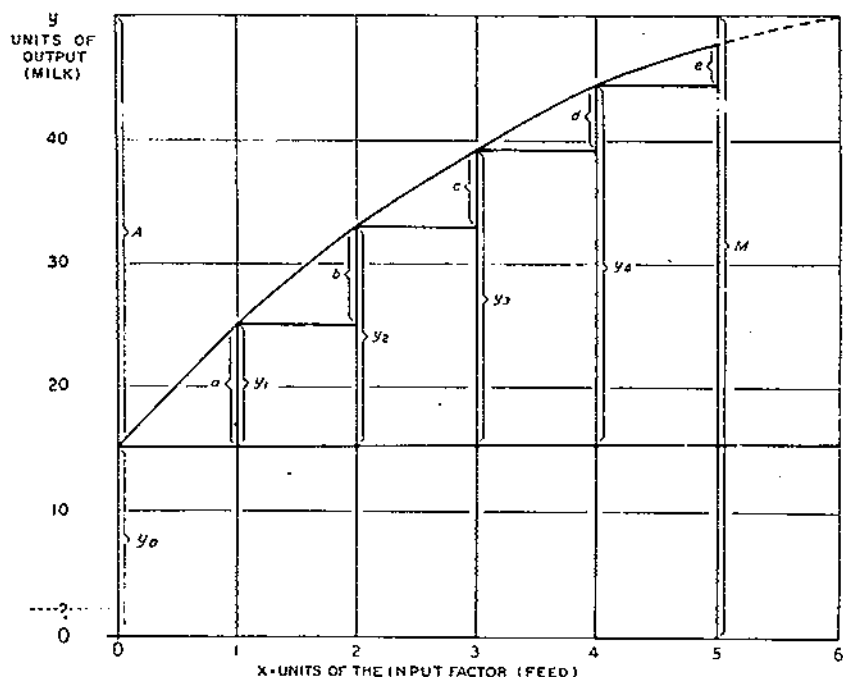
² The average maintenance requirement of 177 cows, 3,208 total digestible nutrients, was used for all groups.

Several mathematical curves have been fitted to the observations. None of these curves gave any appreciably better fit than the curve of diminishing returns—an exponential curve—used by W. J. Spillman (13) in Technical Bulletin No. 348 to describe the law of diminishing returns as it applies to the use of fertilizer on crops. The equation of this curve is $Y = M - AR^x$. It was found that the same curve also fits very closely the data obtained on the relationship between feed input and milk output. It describes satisfactorily how the principle of diminishing returns applies to milk production (fig. 9).

In applying it to the results of the input-output experiment it was even possible to introduce a simplification. It was found that M , the maximum output, apparently was equal to A , the range between maximum and minimum, when feed consumption, x —the independent variable—was expressed in terms of total feed minus Haecker maintenance requirements, in other words when feed consumption is expressed in terms of the production ration. It is assumed then that the cow

produces no milk when fed only the Haecker maintenance ration.⁷ The equation then reduces to $Y = A(1 - R^x)$. This curve passes through the origin and it fits the data about as well as the original equation $Y = M - A/R^x$.

The value of Y , output, increases at a diminishing rate and as x , the feed consumption, becomes very large the Y value of the curve describing total milk production approaches A , A being the maximum



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FIGURE 9.—EXPONENTIAL INPUT-OUTPUT CURVE FOR A SINGLE VARIABLE INPUT FACTOR.

Except for a few changes in labeling, this figure is a reproduction of the graph used by W. J. Spillman in explaining his exponential yield curve. Y_0 is the production when none of the variable factor is applied, y_1 the increase in production due to one unit of the factor, y_2 the increase for two units, and so on. Y is the actual production for x units of the factor. M is the maximum production. Theoretically, this maximum production would only be forthcoming when x is infinitely large. However, in practice, the curve will approach this maximum within the limit of the observations. A is the range between the Y_0 , the minimum production, and M the maximum production. The vertical lines a, b, c, d , etc., are the increments in production due to the first, second, third, fourth, etc. inputs applied. R is the ratio between these increments; that is,

$$R = \frac{b}{a} = \frac{c}{b} = \frac{d}{c} = \frac{e}{d} \text{ etc., or } b = aR; c = bR, \text{ etc.}$$

⁷ Since the groups were all balanced also with respect to weight at the start of the experiment, the average weight per cow of all groups taken together was used in computing the maintenance ration. For economic computations this procedure is preferable because increased milk production through increased feeding can only be obtained along with an increase in weight and therefore in maintenance ration. This increase in maintenance ration must be considered part of the additional feed input necessary to obtain the milk output.

production possible at the very heaviest feeding. It may not, of course, be possible to feed the cow enough to reach this maximum production expressed by A . Nevertheless, the A might be taken as a measure of the productivity of the cow—in these experiments as a measure of the average productivity in the balanced groups.

The R in the equation determines the path of the curve between the origin and A . It measures how much milk would be forthcoming from an additional 1,000 pounds of total digestible nutrients as compared with the production that resulted from the previous 1,000 pounds. If, for example, a particular cow returns 3,500 pounds of 4-percent fat-corrected milk on a production ration of 1,000 pounds of total digestible nutrients and 5,700 pounds of 4-percent fat-corrected milk on a production ration of 2,000 pounds, then the return for the second 1,000 pounds of production ration would be 2,200 pounds of milk, and for this cow the R in the equation fitted to the production

figures would be $\frac{2200}{3500} = 0.63$. The second 1,000 pounds of produc-

tion ration resulted only in 63 percent as much milk as was obtained from the first 1,000 pounds. If a third 1,000 pounds of total digestible nutrients were added to the ration, the additional milk obtained would be $0.63 \times 2,200 = 1,400$ pounds. The total milk production of the cow would then be 7,100 pounds and she would be receiving a production ration of 3,000 pounds of total digestible nutrients.

It will be noticed that as more feed is supplied, more milk is obtained, but the additional production for an additional unit of feed declines.

The curve is a curve of total output that increases with increasing input but at a diminishing rate. It was chosen not only because it fits the data but also because experimental experience was in accord with the logic behind the equation.

The comparison is made, not between individual cows but between balanced groups of cows. In this way the error is avoided of attributing to increased feeding the higher yields that really are due to superior productivity. In balancing the experimental groups, high producers as well as low producers were allocated to each group in a way that tended to average out the differences. As far as can be ascertained from previous production records, all groups were as nearly alike as possible with respect to productivity, breed, size, and age of the animals.

The curves show to what degree increased quantities of feed supplied to these balanced groups of cows have resulted in increased milk yields. They constitute the basic input-output curves. They show how "the average cow" as represented by the group responds to increased feeding. These curves show themselves to be diminishing-output curves.

It is possible to increase milk yields considerably by supplying increased quantities of feed, but the increase in yield is not the same for each added quantity of feed. The increase falls off as the limit of the animal's productive capacity is approached.

It should also be possible to analyze the data by comparing individual cows while taking full account of the differences in productivity, as measured by "expected" yield based on previous

production records. However, in experimental work it is difficult to get cows for which there are enough records on file to reflect truly their inborn productive ability. The group comparisons therefore are probably more reliable than individual comparisons; animals with serious bias in their records of basic producing ability have a chance of being allocated to each of the different groups and thus should be found throughout the range of feeding. Bias is most likely to be found among high producers and, if individual records are used, the bias may be concentrated at the upper end of the curve, thus influencing its entire slope.

MARGINAL RETURNS USUALLY LESS THAN AVERAGE RETURNS

The most important fact expressed in figures 5, 6, and 8 is that although more milk output can be obtained by heavier feeding, on the average only 1.0-1.5 pounds of milk is obtained for an additional pound of total digestible nutrients. This is less than half the average return of 3 pounds of milk which is obtained per pound of total digestible nutrients in the production ration. So far, this has been the central figure in the computation of rations for dairy cows. It is the equivalent of 2.2 pounds of milk per pound of grain. (This applies when the grain ration contains 75 percent total digestible nutrients and the substitution values of other feeds correspond to the accepted average feed values.) It is based on wide experience gained from the feeding experiments on which feeding standards have been based.

The present experiments substantiate this figure, but at the same time they show that at normal feeding levels the marginal or incremental rate of return is not of the same magnitude as the average rate, but much lower.^a If, in an effort to find the most economical level of feeding, present feeding practices are changed step by step, so as gradually to raise the feeding level to about 25 percent above the Haecker standard, or if the feeding level is decreased to 25 percent below the standard level, it is the incremental rate of return that should be considered. Within this important range of feeding levels, most changes made by farmers actually take place. This incremental rate, which measures the increase in milk return for each additional unit of feed, is only about half the average return, or about 1.5 pounds of 4-percent fat-corrected milk for each additional pound of total digestible nutrients.

The so-called requirement for milk production—1 pound of total digestible nutrient per 3 pounds of 4-percent fat-corrected milk—represents average inputs and outputs for the total production ration and does not indicate what additional or incremental returns can be obtained and what losses in output must be expected by moderate increases or decreases in feeding above and below the feeding standard level. The marginal rate of output, also called the additional or incremental rate, answers most directly the problem of how much more milk can be obtained by heavier feeding.

The response seems to be modified by other forces at work. For

^a The terms "additional," "marginal," and "incremental" return are used synonymously. All denote the same thing—the increase in total output resulting from the use of one more unit of input in the production process, or the loss in output sustained by withdrawing one unit of input from the process.

example, it appears to be greater—as much as 2 pounds of milk for an extra pound of total digestible nutrient—if the increase in feeding starts from a low level of feed intake; and the response is smaller—about 0.75—if the animals are already on a liberal feeding level.

Although the principle of diminishing returns does apply to dairy feeding, incremental returns decline slowly within a considerable range above and below the level indicated by the feeding standard.

SERIES II EXPERIMENTS

The series of experiments discussed in this section was designed to disclose the relation between the quantity of grain fed and the quantity of milk produced, when grain was fed at different levels of intensity and an unlimited quantity of roughage was made available to the cows at all times. As in series No. I, the intensity of feeding was increased by adding nutrients in the form of grain. The cows would reduce roughage consumption to some degree as more grain was fed, thus changing still more the composition of the ration toward more grain and less roughage.

The variation in intensity of feeding was brought about not by feeding at various rates in relation to a feeding standard but by feeding grain at various rates in relation to milk production in the same way as most dairy farmers do; that is, grain was fed at the rate of 1:3 or 1:4, etc. (1 pound of grain for each 3 pounds of milk, etc.). For a more detailed description, see the section on Plan and Procedure, page 11. At two stations, Maryland and South Dakota, the range of grain feeding varied all the way from no grain at all up to the rate of 1:2. At three other stations the lowest level of feeding was at the rate of 1:6.

At the stations of Indiana, Michigan, and New Jersey the experimental cows had pasture; at the Maryland and South Dakota stations they did not. Thus, at these last two stations all feeds were weighed and analyzed the year round in the same way as in the series I experiments.

Another characteristic of this series of experiments was that the differences in feeding between groups consisted not only in a difference in quantity of nutrients consumed but also in the distribution of feed through the lactation period.

It is easily seen that the method of feeding may influence milk output because one method may be more effective than another in supplying a greater part of the nutrients at periods during lactation when they can be utilized most effectively. All modern feeding standards are based upon the principle that most economical feeding is obtained when the production ration of milking cows is varied, week by week, in exact proportion to milk production. This does not apply to the very first part of the lactation period, when cows cannot consume the full ration.

Those groups which were fed grain at the rate of only 1 pound of grain to 6 pounds of milk, as well as the group which received only roughage, differed from groups fed more grain in that they could not possibly consume the feed needed to cover the requirements during the early part of the lactation period. At this time they were

seriously underfed. Later in the lactation period when milk production had declined they got enough or more than enough feed to meet requirements, but then the greatest need for liberal feeding had passed.

When cows are left free to consume as much roughage as they want in addition to grain and the roughage is of good quality, they will eat large quantities of feed over and above the requirements of the feeding standard (fig. 10) as the lactation period progresses and the requirements for production fall off. As a result the distribution of feed through the lactation does not follow milk production as closely as when cows are fed according to a feeding standard.

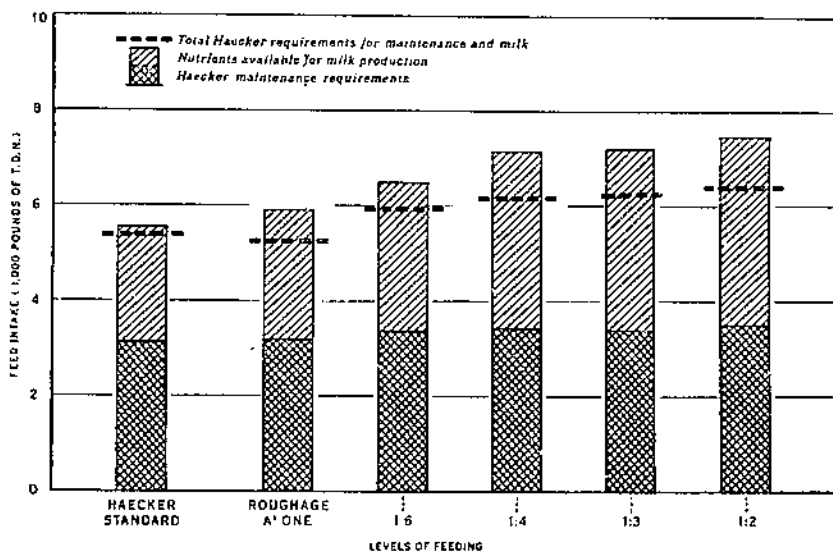


FIGURE 10.—COMPARISON OF HAECKER STANDARD REQUIREMENTS WITH TOTAL FEED CONSUMPTION OF COWS FED AT DIFFERENT LEVELS AT TWO STATIONS THAT CONDUCTED SERIES II EXPERIMENTS—NONPASTURE.

Furthermore, when feed inputs are averaged for the whole year and compared to milk output it was found that the method of feeding good roughage freely in addition to grain caused the cows to consume considerably more than requirements as measured by commonly used feeding standards. That was true for practically all cows, whether they were fed heavily on grain or received only a moderate grain ration, or no grain at all. They so balanced their milk output against feed intake that when the year was over they had consumed feed at the rate of 120 to 125 percent of the Haecker standard for milk production, in addition to their maintenance ration.

The cows fed only roughage were underfed during the early part of the lactation period, but milk production soon declined and during the latter part of the lactation period a sizable surplus of feed was consumed; and even these cows ended the year with the same 20 to 25 percent nutrients consumed above the requirements of the feeding standard for milk. As most of the overfeeding takes place in the latter part of the lactation period when the production is likely to be low,

it is not possible for cows to respond in milk production to any considerable degree during that lactation but the surplus feed will tend to put the cow in condition to produce more milk after the next freshening.

Some aspects common to all the series II experiments have been presented. It remains to mention the results obtained by analyzing separately the pasture stations and the nonpasture stations.

NONPASTURE STATIONS

The practice of barn-feeding cows the year round at the Maryland and South Dakota stations made possible complete feed control. The quality of the roughage—alfalfa hay and corn silage—used in the experiment was above average; the hay graded U. S. No. 1 or No. 2. One station had exceptionally good hay and silage of average quality. The other had unusually high-quality silage and hay of about average quality.

TABLE 4. *Series II experiments without pasture: Milk output and feed inputs and yearly average per cow for 2 stations*

Item	Unit	Roughage only	Grain fed at specified rates in addition to all the roughage the cows would consume			
			1:6	1:4	1:3	1:2.5 or 1:2 ¹
Yearly records	Number	15	16	11	11	15
Basic producing ability, 4-percent fat-corrected milk	Pounds	7,196	7,107	7,179	7,282	7,120
Live weight of cows (average)	Pounds	1,108	1,173	1,189	1,177	1,219
Output:						
Milk produced	Pounds	6,091	7,600	8,128	8,378	8,488
Butterfat	Percent	4.04	3.38	3.90	3.95	4.01
Do	Pounds	246	299	324	331	340
4-percent fat-corrected milk	Pounds	6,128	7,521	8,113	8,310	8,490
Inputs:						
Grain consumed in year	Pounds	0	1,369	2,374	2,936	4,135
Hay	Pounds	6,527	5,788	5,614	5,352	4,543
Corn silage	Pounds	13,319	12,007	12,674	11,697	10,084
Total digestible nutrients consumed	Pounds	5,807	6,475	7,154	7,191	7,473
Total digestible nutrients consumed over maintenance, ²	Pounds	2,531	3,108	3,788	3,825	4,107

¹ At one of the stations the heaviest fed group was fed grain at the rate of 1:2.5. At the other station the corresponding group was fed at the rate of 1:2.

² The average maintenance of 68 cows, 3,360 total digestible nutrients, was used for all groups.

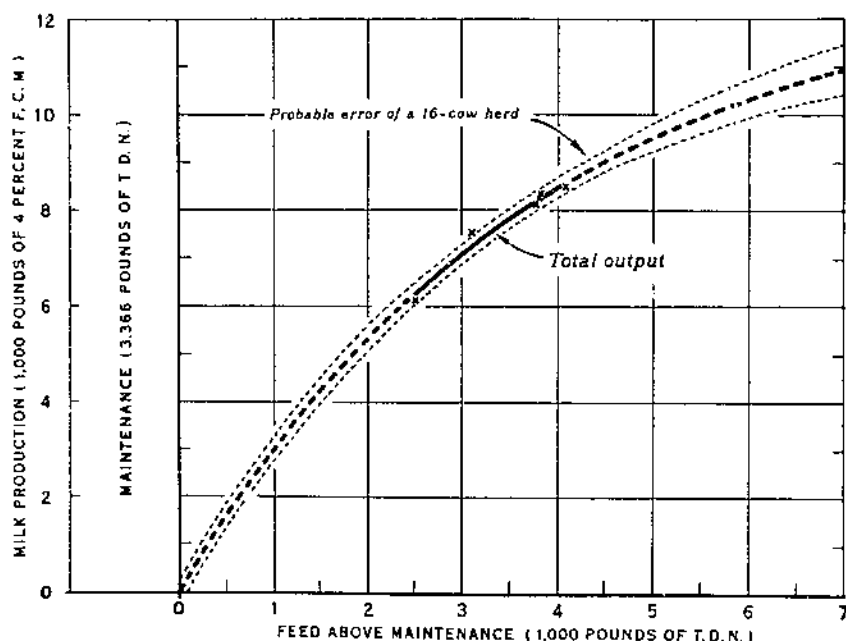
At one station, 41 normal yearly production records were used and at the other 27 records. In computing weighted averages for both stations the results from each station were weighted by these numbers so as to give most weight to the stations with the most records.

The results measured in terms of feeds consumed, and milk produced per cow per year, are shown in table 4 and figure 11. They show how the cows responded to the different rates of feeding grain in addition to roughage at liberty. Roughage consumption is measured in pounds of hay and silage and in terms of hay equivalent and grain in pounds of standard grain.*

* One pound of hay equivalent in this study is considered equal to 0.50 pound of total digestible nutrients in the form of roughage and 1 pound of grain equal to 0.75 pound of total digestible nutrients in the form of concentrates.

The group fed roughage alone produced 74 percent as much milk as the group fed roughage and grain when the grain was fed at the rate of 1 pound for each 3 pounds of milk produced. This agrees fairly well with the results obtained by feeding grain at a similar rate to cows in a Bureau of Dairy Industry herd at Huntley, Mont. (8), where the cows fed roughage alone produced 76.5 percent as much as cows fed roughage and grain. Similar comparisons of roughage alone with grain feeding at the 1:6 rate show 81.5 percent as much production in this work and at other stations 79 to 82 percent as much. (See p. 8.)

A comparison of figure 11 with figure 8 shows that the additional output of milk for increased nutrients consumed in these experiments verify the results obtained from the herds in the series I experiments. The whole level of production is lower in the two herds on series II experiments, nonpasture, but the slope of the input-output curve is practically the same.



BAE 39623

FIGURE 11.—RESPONSE IN MILK PRODUCTION TO INCREASED FEEDING. DIFFERENCES IN PRODUCTION OF BALANCED GROUPS OF COWS FED AT FIVE DIFFERENT LEVELS AT TWO STATIONS THAT CONDUCTED SERIES II EXPERIMENTS—NON-PASTURE.

PASTURE STATIONS

Input-output data obtained from the stations where cows had some pasture showed much the same general trends as the data from the nonpasture stations. Production was consistently higher at all intensities of grain feeding, however, because the cows at the pasture stations were higher in average inherent productivity.

The pasturage obtained by the cows at the three pasture stations amounted only to about the equivalent of 2.5 months grazing on first-

class pasture.¹⁰ However, the cows actually were on pasture almost twice that length of time. In these three experiments there is not much variation in roughage consumption from group to group. On an average, the consumption per cow was about $4\frac{1}{2}$ tons of hay equivalent including pasture. This uniformity is in sharp contrast to what was found at the nonpasture stations. There the average roughage consumption in the group fed roughage alone was about 6 tons of hay equivalent. In the grain-fed groups the consumption declined as more grain was fed, and in the heaviest fed group the consumption was 4.3 tons per cow. The reason for these differences probably lies in the fact that the roughage used at the pasture stations was of only fair quality, except for one of the stations which had relatively few cows and had roughage of unusually high quality.

TABLE 5.—Series II experiments with pasture: Milk output and feed inputs and yearly averages per cow¹ for 3 stations

Item	Unit	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Yearly records	Number	14	17	21	19	21	24
Basic producing ability, 4-percent fat-corrected milk	Pounds	10,514	10,363	10,320	10,456	10,383	10,385
Live weight of cows (average)	Pounds	1,003	1,105	1,116	1,108	1,187	1,283
Output:							
Milk produced	Pounds	8,413	8,800	9,035	9,563	10,090	10,464
Butterfat	Percent	4.09	3.88	4.12	3.92	4.05	3.89
Do	Pounds	343.9	344.8	371.9	375.2	408.8	407.4
4-percent fat-corrected milk	Pounds	8,523	8,722	9,183	9,457	10,168	10,295
Inputs:							
Grain consumed in year	Pounds	1,598	2,268	2,513	3,186	3,872	4,639
Hay	Pounds	3,470	3,480	3,632	3,666	3,628	3,415
Corn silage	Pounds	8,890	8,812	9,242	9,108	8,782	7,868
Alfalfa silage	Pounds	768	756	581	544	491	1,185
Pasture (1 day=15 pounds total digestible nutrients.)	Days	81.5	86.9	68.5	76.2	70.3	75.7
Total digestible nutrients consumed	Pounds	6,102	6,478	6,595	7,128	7,459	7,988
Total digestible nutrients consumed over maintenance. ²	Pounds	2,748	3,121	3,151	3,774	4,105	4,634

¹ Production records for the experimental groups at the different stations were arranged so as to represent increasing levels of grain feeding and then balanced with respect to basic producing ability of the cows. The grouping is explained in more detail in pages 35-38 and is shown for the stations represented here (Indiana, Michigan, and New Jersey) in table 7.

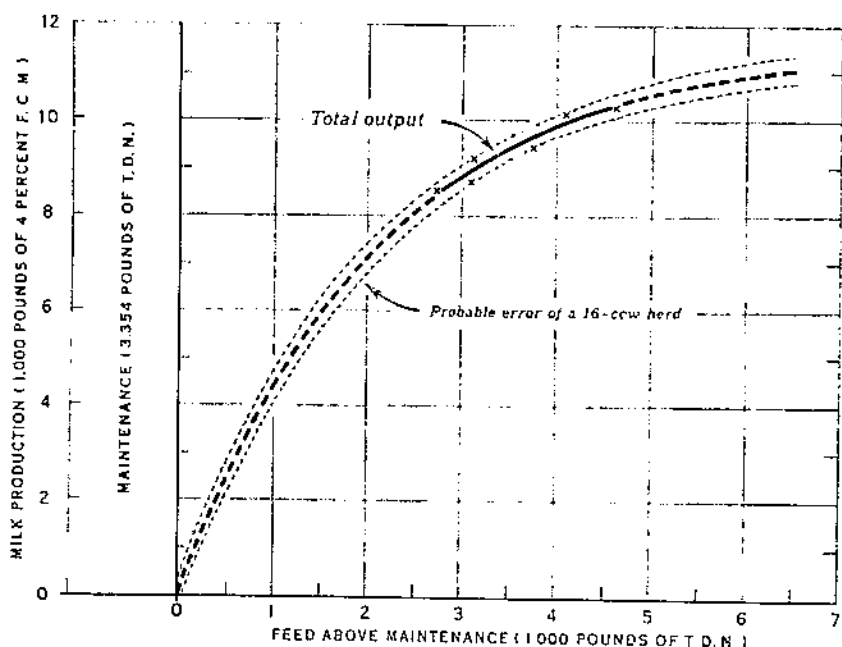
² The average maintenance of 116 cows, 3,354 total digestible nutrients, was used for all groups.

As mentioned above, milk production per cow at the pasture stations averaged higher in all groups than at the nonpasture stations (table 5). In the groups of cows fed at comparable levels the difference amounted to about 1,600 pounds of milk per cow. In the pasture-station herds the cows were of higher inherent productivity. They consumed more feed and produced more milk. In the heaviest fed pasture group the cows ate, on an average, about 500 pounds more grain and produced about 1,800 pounds more milk than in the heaviest fed nonpasture group. However, the fact that the cows had pasture does not seem to be responsible for the difference in milk production, for two stations in the series No. I experiments without pasture gave considerably more milk per cow than those in the series No. II experiment with pasture.

The range in the levels of grain feeding was not so great in series II experiments, pasture, as in series II experiments, nonpasture. The

¹⁰ A standardized pasture day as used here is assumed to yield pasturage equivalent to 15 pounds of total digestible nutrients.

lowest fed group averaged for the year 1 pound of grain to 41½ pounds of milk; the highest fed group consumed for the year 1 pound of grain to 2.3 pounds of milk. This gives six group averages all within the range in which much of the commercial milk of the United States is produced. Thus the input-output curve (Fig. 12) showing the average relationship between digestible nutrients and milk production per cow could only be based on observations fairly close together. The more limited range in total digestible nutrients consumed as well as the uncertainty of pasture estimates makes it more difficult to determine accurately the slope of the curve.



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FIGURE 12. RESPONSE IN MILK PRODUCTION TO INCREASED FEEDING DIFFERENCES IN PRODUCTION OF BALANCED GROUPS OF COWS FED AT SIX DIFFERENT LEVELS AT THREE STATIONS THAT CONDUCTED SERIES II EXPERIMENTS PASTURE

This slope seems to indicate a more rapid decline in incremental output at the very highest feeding levels than was found at the nonpasture stations. It suggests the possibility that the cows that were fed most heavily on grain would graze less intensively and consume less nutrients than were arrived at by the method employed to estimate pasturage intake.

ROUGHAGE FEEDING, INCLUDING EXCELLENT PASTURES, COMPARED WITH ROUGHAGE AND A MODERATE AMOUNT OF GRAIN AT THE VIRGINIA AGRICULTURAL EXPERIMENT STATION

The possibilities in the East of dairy farming without grain are illustrated by results of the experiment at the Virginia station. It was not practicable, however, to combine the results of this experi-

ment with results from the other stations because the cows were fed at only two levels.

One group of cows at the Virginia station had all the pasture, alfalfa hay, and corn silage it could eat, but no grain; the other group had all the pasturage, hay, and silage it could eat, with enough grain when necessary to bring the total nutrients up to the Haecker standard.

The cows were on pasture a full 6 months, and the pastures were good virtually all the time. From the saving in barn feed, it was estimated that an average of nearly 19 pounds of digestible nutrients per cow per day was obtained from the pasturage. This was enough for maintenance, and for the production of about 1 pound of butterfat per day, which is equivalent to around 300 pounds a year.

Although it is not desirable to give too much consideration to the exact results of these comparisons, the indications are that the grain-fed cows consumed 2,100 pounds of grain per year; and they consumed approximately 1,100 pounds less roughage expressed in terms of hay equivalent than the cows fed roughage only (table 6).

TABLE 6.—Basic producing ability, actual production, and feeds consumed by cows fed on roughage and grain compared with similar cows fed roughage only at the Virginia Agricultural Experiment Station

Item	Unit	First comparison ¹		Second comparison ¹	
		Roughage and grain	Roughage only	Roughage and grain	Roughage only
Yearly records	Number	8	6	7	7
Average live weight	Pounds	1,311	1,300	1,315	1,280
Basic producing ability, 4-percent fat-corrected milk	Pounds	9,684	9,679	9,316	9,790
Production of 4-percent fat-corrected milk	Pounds	9,253	7,708	9,353	8,148
Feeds consumed:					
Alfalfa hay	Pounds	3,695	3,964	3,423	3,928
Corn silage (15.7 percent total digestible nutrients)	Pounds	7,184	7,155	7,025	6,808
Actual days on pasture	Days	188	180	175	184
Pasture (total digestible nutrients 15)	Days	197	225	207	231
Grain (75 percent total digestible nutrients)	Pounds	2,082		2,179	
Grain (75 percent total digestible nutrients) during lactation	Pounds	2,076		2,172	
Ratio of grain consumed to milk produced		4.46		4.31	
Total digestible nutrients consumed in year	Pounds	7,894	6,885	7,931	6,895
Total digestible nutrients required according to Haecker standard	Pounds	6,907	6,381	6,955	6,442
Total digestible nutrients, percent of Haecker standard for both maintenance and milk	Percent	114	108	114	107
Total digestible nutrients, percent of Haecker standard for milk only	Percent	131	119	131	116
Roughage in terms of hay equivalent (hay 51.2 percent total digestible nutrients)	Pounds	12,307	13,447	12,269	13,467
Hay equivalent per day per 100 pounds live weight	Pounds	2.61	2.86	2.58	2.91
Percentage of nutrients consumed in a year that was obtained from pasture	Percent	37.5	40.0	39.2	50.3

¹ It was found that the cows of the two groups could be balanced with reference to basic producing ability either by omitting 1 cow from the group fed roughage only, making the numbers 8 and 6, or by omitting 1 cow from the group fed roughage and grain, making the numbers 7 and 7. As there was no reason for preferring one method of balancing over the other, the data from both groupings are presented.

Incidentally, the Virginia experiments illustrate the difficulty of carrying on experiments with dairy cows for a 2-year period. At the beginning, there were four cows in the roughage-fed group and four in the grain-fed group but before the end of the 2 years one of the roughage-fed cows was removed, because of sterility, another died from cancer, and a third cow was killed because tumors and incurable abscesses had developed. In view of the fact that other

experiments have shown that cows can be fed on roughage alone for 2 years or more without any bad effect on their health, it was considered unlikely that the character of the ration was in any way responsible for the death or removal of the roughage-fed cows. Two other cows, as nearly comparable as possible with the three removed from the roughage-fed group, were substituted in the experiments and every effort was made to make the data as comparable as possible, although the small groups and the substitutions obviously increase the chance for error in these comparisons.

The grain-fed cows consumed somewhat less pasturage; and they produced from 1,200 to 1,450 more pounds of milk in a year, on the average, than the cows fed roughage only. The results of this comparison were in general agreement with those obtained in other experiments. (See p. 8.)

It should be noted that only three of the seven records made on roughage in the Virginia experiment were with cows that calved in the late summer or fall, while seven of the eight records made on grain feeding were with cows that calved in the late summer or fall. It is logical that a dairy farmer depending principally on pasture for feed would get a greater production from the cows if they freshened in the spring than if they freshened in the fall. The chief value of the Virginia experiments lies in the fact that they indicate a high rate of production amounting to 1 pound of butterfat a day or more than 300 pounds a year that can be obtained, in the East, from roughage alone when the pastures are of the first class, the cows are good, and most of them calve in the spring. This is borne out by the data showing that when cows on pasture were fed in addition an average of only 2.75 pounds of hay daily, they produced 186 pounds of butterfat in 184 days.

RESULTS OF SERIES I EXPERIMENTS AND SERIES II EXPERIMENTS COMBINED

It was found that in the two series of experiments, the response in production to more intensive feeding was substantially the same. Therefore, it was decided to combine the data obtained in both series, and by computing weighted averages of larger groups obtain greater consistency in the result. In this way, differences in the performance between stations could be eliminated. At some stations the average productivity of the herd was greater than at other stations, the quality of the feed was somewhat better at some stations than at others, and there were also some differences with respect to housing and care. At two stations the cows were milked three times a day, while they were milked only twice a day at the other stations. Although the input-output curves obtained from the different experiments were of the same shape, these differences between stations would yield curves at different levels, as shown in figure 7.

At some stations the loss among the cows on experiment caused several groups to be unbalanced and the group observations were reduced to so small a number that reliable input-output curves could not be fitted to them.¹¹ To utilize the information still left at such

¹¹ Input-output curves were not fitted to observations representing the production of individual cows because it was felt that the measurement of basic producing ability was subject to too much bias and error to obtain reliable results from that procedure.

stations it became necessary to combine the observations from the several stations. The method chosen was to build up new balanced groups from the total number of completed normal records left at all stations. The new groups, balanced with respect to expected yield, were built to represent six different levels of feeding. This procedure was repeated at one station after another so as to work over the entire number of completed normal records obtained at nine experiment stations. At the tenth station only two levels of feeding were tested and the results from this station were treated separately.

At the nine stations the new groups were so arranged as to represent six different levels of feeding, ranging from a low level of grain feeding (1 pound of grain for every 4.4 pounds of milk) to a very high level of grain feeding (1 pound of grain for every 1.9 pounds of milk). Group by group these different levels of feeding would correspond, on the average, to increasing quantities of feed consumed, but there would be some overlapping by groups from individual stations in the same way as there was overlapping by individual cows between balanced groups at any one station. (See table 7.)

In the formation of the six new balanced groups at one station after another there arose the problem of what to do at three of the stations which fed only at five levels. In these three cases interpolation was resorted to not only to provide observations for the missing groups and thus complete the table and facilitate computations but also to approach more closely the true differences between the groups fed at different levels. The whole level of productivity was higher in some experimental herds than in others. If a certain feeding-level group were averaged without any contribution from the herd of highest productivity, a serious bias would be introduced through the method of averaging. This bias is avoided if all stations contribute their share to each feeding-level group. The interpolations should neither add nor subtract from the experimental evidence, and in computing margins of error the true number of observations—without the interpolated groups—must be borne in mind.

Table 7 shows the make-up of the groups in the six levels of feeding, and table 8 shows the number of cows in each group by stations. At two stations the quantity of feed given to the standard group was between the 1:3 and 1:4 levels or the 1:4 and 1:6 levels; at other stations it was below the 1:6 level. At the Mississippi and Pennsylvania stations, which fed at seven different feeding levels, the two levels most nearly similar were combined.

The next question was to decide whether, in computing averages for all stations, the results of individual stations were to be weighted by cows or by stations. Should the results be treated as if all the cows in any one level of feeding were in one herd and each cow contributed equally regardless of the difference in the number of cows at the various stations, or should they be treated as if there were the same number of cows at each station and each station contributed equally?

There are valid arguments for both methods. It would appear that the contribution of 8 or 10 cows from one station to a feeding-level group should be given more weight than 4 or 5 cows at another station. But when this is done the environmental conditions under

TABLE 7.—Classification of the experimental groups into 6 different levels of feeding;¹ combined data from 9 stations

Station	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Delaware	90	Standard	110	120	130	Unlimited.
Indiana	Standard	1:6	1:4	1:3	1:2.5	Do.
Maryland	do	1:6	1:4	1:3	1:2	Do.
Michigan	1:6	Standard ²	1:4	1:3	Average, 1:3 and 1:2.4	1:2.4
Mississippi	85	do	115	130	145	Average, 175 and unlimited.
New Jersey	1:6	1:4	Standard ²	Average, standard and 1:3	1:3	1:2.5
New York	80	90	do	110	120	130
Pennsylvania	Average, 70 and 80.	90	do	110	120	Unlimited.
South Dakota	Standard?	1:6	1:4	Average, 1:3 and 1:4	1:3	1:2.5

¹ The purpose of combining the results of 9 stations is to show the general response to increased feeding for all rows on experiment. The experiment yielded 392 records that could be used for this purpose. The experimental groups are identified either by a figure expressing the percentage of Haecker standard for milk production (over maintenance) the groups were fed or a ratio which expresses the rate at which the groups of cows were fed grain in proportion to milk production (4-percent fat-corrected milk). The word "unlimited" means unlimited grain feeding. At all stations the groups are ranged beginning with the lowest level of feeding. Because the stations differed both in the number and kind of feeding levels employed in the experiments, it was necessary to average milks groups and at some stations interpolate for a missing group. These interpolations are shown in the table.

² At these stations the cows were restricted to the Haecker standard only when the roughage consumption was not sufficient to cover requirements. The cows were fed roughage freely at all times and toward the end of lactation and during the dry period they consumed more than the standard required.

which the different groups were kept cannot be considered to be identical because the conditions as well as the number of cows differed between stations. The data were therefore assembled in both ways and it was found that there was no material difference in the results. The simpler method of weighting by cows was then followed.

THE BALANCING OF EXPECTED YIELDS MEASURING BASIC PRODUCING ABILITY

In making up the balanced groups it was decided that the deviation in average expected yield from group to group should not exceed 100 pounds of 4-percent fat-corrected milk. A separate analy-

TABLE 8. Number of yearly records made by cows in the specified groups by stations; combined data from 9 stations

Station	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
	Number	Number	Number	Number	Number	Number
Delaware	11	10	9	8	10	8
Indiana	4	7	9	7	8	14
Maryland	9	7	8	9	10	20
Michigan	4	4	4	4	14	5
Mississippi	8	7	12	13	4	8
New Jersey	8	9	8	10	8	8
New York	3	2	3	3	2	2
Pennsylvania	10	9	9	10	4	22
South Dakota	8	5	1	13	6	7
Total	85	60	66	55	52	94

¹ An interpolation has been made for this missing group by taking the average of the next lower and next higher feeding level groups before balancing all the groups. The numbers for the missing groups have not been included in the totals.

sis of variance of expected yields had shown that with the number of cows available, larger deviations from group to group are likely to be real deviations not caused by chance variations and error in measurements of expected yields. The expected production of all cows which contributed records for this analysis averaged 8,917 pounds of 4-percent fat-corrected milk, and the groups representing different feeding levels in all nine stations were therefore built up in such a way as to average between 8,817 and 9,017 pounds.

Some records could not be fitted into the groups where they belonged without unbalancing the group. These records were eliminated from the analysis. Such eliminations were made entirely on the basis of expected production without regard to the quantity of milk produced during the time of experiment. After they were made, it was thought that the groups fed at the six different levels could be considered equal in all essential respects.

The basic producing ability of each group, as estimated from previous records after adjusting to the age at which each cow entered the experiment, and adjusting to a 10-month lactation period, is shown in table 9. Dairy-herd improvement factors were used in making these adjustments.

TABLE 9.—Basic producing ability of cows in the 6 feeding-level groups; combined data from 9 stations

Feeding level	Milk		Butterfat		4-per- cent fat- cor- rected milk
	Pounds	Percent	Pounds	Pounds	
1	8,809	4.05	357.3	3,888	
2	8,852	4.00	355.8	3,852	
3	8,968	4.05	361.0	3,908	
4	8,819	4.05	357.0	3,886	
5	8,866	4.11	364.4	3,912	
6	8,829	4.03	356.1	3,809	

The relationship of the different feeding levels to the Haecker standard is shown in table 10. If maintenance is calculated at the Haecker standard and any nutrients above maintenance are compared with the Haecker standard for milk it is found that the lowest fed group consumed about 9 percent less than the standard and the highest fed group 36 percent more than the Haecker standard. If both maintenance and production requirements at the Haecker standard are combined and compared with total nutrient intake, the level of feeding at the lowest fed group is 4 percent below the standard and that of the highest fed group is 18 percent above the standard.

THE RELATION OF MILK OUTPUT TO FEED INPUTS

Table 10 shows the production of the cows and the feed consumption during the course of the experiment. There is a consistent stepping-up of production with every increase in the quantity of feed, ranging from 7,626 pounds of 4-percent milk for the group fed grain during the lactation period at the rate of 1 pound for each 4.4 pounds of milk produced to 9,965 pounds for the group fed grain

at the rate of 1 pound for each 1.9 pounds of milk produced. There was no great variation in the quantity of roughage consumed, but the grain ranged from 1,770 pounds for the lowest fed group to 5,416 pounds for the highest fed group. The hay equivalent per 100 pounds live weight per day ranged from 1.7 pounds for the highest fed group to 2.1 for the lowest fed group. This rate of roughage consumption is about what can be expected when the hay is of medium to good quality.

TABLE 10. *Feed inputs and milk output of cows fed at the 6 levels; combined data from 9 stations*

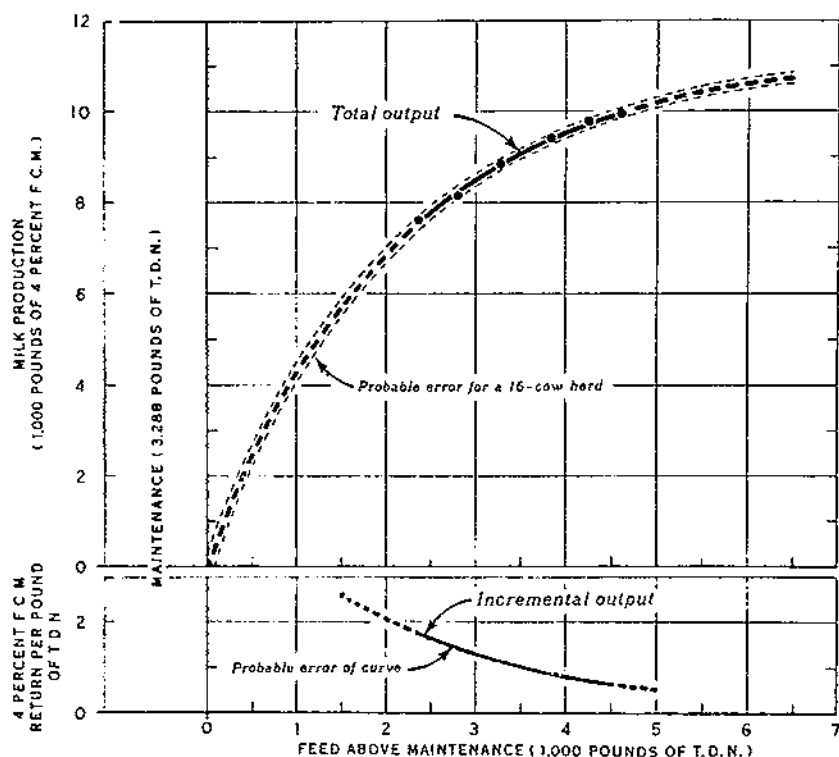
Item	Unit	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Yearly records	Number	65	60	66	55	52	94
Live weight of cows (average)	Pounds	1,100	1,108	1,123	1,144	1,174	1,203
Output:							
Milk produced	Pounds	7,738	8,367	8,896	9,454	9,813	10,154
Butterfat	Percent	3.90	38.86	3.95	3.96	3.98	3.89
Do	Pounds	302.0	322.6	351.0	374.5	390.4	393.6
4-percent fat-corrected milk	Pounds	7,026	8,184	8,824	9,400	9,780	9,965
Inputs:							
Grain consumed during lactation	Pounds	1,722	2,098	2,777	3,666	4,132	5,304
Ratio grain to 4-percent milk during lactation.		1:4.43	1:3.90	1:3.18	1:2.56	1:2.37	1:1.86
Grain consumed in year	Pounds	1,770	2,179	2,870	3,762	4,260	5,416
Hay	Pounds	3,873	3,921	3,853	3,783	3,911	3,718
Silage, corn (or sorghum)	Pounds	10,800	11,104	11,490	11,162	10,441	8,713
Silage, alfalfa	Pounds	407	457	460	439	322	308
Alfalfa	Pounds	116	82	116	119	109	50
Pasture (1 day = 15 pounds total digestible nutrients).	Days	22.5	28.3	21.8	21.8	25.0	19.7
Roughage expressed as hay equivalent per 100 pounds live weight.	Pounds	2.12	2.18	2.13	2.04	1.99	1.72
Total digestible nutrients consumed	Pounds	5,654	6,117	6,575	7,132	7,531	7,899
Total digestible nutrients consumed over maintenance. ¹	Pounds	2,366	2,820	3,287	3,844	4,243	4,611
Feed consumption (total digestible nutrients) related to Haerker standard:							
Total	Percent	96	101	105	110	114	116
Over maintenance	Percent	91	102	110	120	125	138

¹The average maintenance of 392 cows, 3,288 pounds of total digestible nutrients, was used for all groups.

Figure 13 shows the basic relationship between feed inputs and milk output. The response to heavier feeding increases at a progressively slower rate as the level of feeding increases and is properly represented by a curve instead of a straight line. The output for added feed is more than twice as much at the lowest level as at the highest level. At the lowest level 1 pound of added nutrients produced 1.7 pounds of 4-percent milk; at the highest level 1 pound produced 0.6 pound of 4-percent milk. Even these highest and lowest levels are within the levels found in practice.

The average results expressed by this input-output curve obtained from all the records verify the results obtained in the analysis of the data from the stations in the two series of experiments. (See figs. 5, 6, 7, 8, 11, and 12.) The agreement is not perfect throughout the range. At the highest level the response in output to increased feeding is slightly greater at the two individual stations of series L. But this is to be expected because these two stations had the two highest producing herds.¹²

¹²Other minor discrepancies are to be expected at the lower levels. The composition of the ration was somewhat different at the two stations than at all stations averaged together. The average rations for all stations contained more roughage. Because the digestible nutrients system overvalues the roughage, it is not to be expected that the averages for low levels at all stations should show quite so large an output for 1,000 pounds of nutrients as was obtained at the two series I stations.



BAE 39608

FIGURE 13. FEED INPUT AND MILK OUTPUT OF ALL COWS FED AT SIX DIFFERENT LEVELS OF FEEDING AT NINE STATIONS CONDUCTING EXPERIMENTS IN SERIES I AND II.

DIFFERENCES IN RESPONSE BETWEEN GOOD AND POOR COWS

One of the most difficult problems encountered in this investigation was to ascertain how much difference in production response there is between good cows and poor cows at various levels of feeding. In other words, to what extent does the inherent productive capacity of the cow determine what level of feeding is the most economical?

The discussion so far has dealt with cows that would produce on the average about 350 pounds of butterfat in 302 days under the conditions of feeding and management prevailing at the different experiment stations. To learn the difference between the response of good and poor cows, all the records were first divided into two groups on the basis of inherent producing ability—one below average and one above average. But when this was done it was found that most of the low-producing cows were at certain stations and most of the high-producing cows were at other stations. Any comparison, therefore, of low- and high-producing cows would be distorted by the effect of differences in environmental conditions at the various stations.

To overcome this difficulty a further classification was made. Within each group of stations the average expected yield of all cows was calculated and the records were then divided into two groups; one composed of records of more than average expected yield and the other of records below the average of the group. For the purpose of simple identification the subgroups were called "poor" and "good." The cows were poor and good in relation to the general level of productivity of all the cows, but this level was fairly high so that there was hardly a really poor cow among them.

The classification of all the records then resulted in the following grouping:

- (1) "Low" stations, with an expected production below the average of all cows.
 - (a) "Poor"—below average of group 1.
 - (b) "Good"—above average of group 1.
- (2) "High" stations, with an expected production above the average of all cows.
 - (a) "Poor"—below average of group 2.
 - (b) "Good"—above average of group 2.

This division permitted comparison between the good and poor cows within each group of stations with little bias due to the differences in environment between stations. However, any comparisons made between the "high" and "low" stations will be influenced by this bias.

Handling the data in this way was not as satisfactory as when all records were combined since too few records were available at some levels of feeding to average out individual cow differences. As a result the response shown to different rates of feeding was less consistent when the records were classified this way (fig. 14) than when the records of all cows were analyzed together (fig. 13).

It will be noted in table 11, which shows the data of these four groups that the subgroups fed at each of the six levels were balanced closely with reference to basic producing ability. The body weights of the groups making up the six feeding levels were not very well balanced because the numbers of cows were not sufficient to permit elimination of those that were too light or too heavy and still leave enough in each of the groups.

The standard errors of estimate are a measure of the variations of the groups about the curves shown in figure 14. The curves are fitted to the data given in table 11. It is found that these standard errors of estimate are a little larger than those met with in other analyses of results obtained in these experiments. It is believed that this larger variation is caused by a lack of balance in the groups due to the limited number of cows, although in computing the standard errors the number of cows in the groups are taken into account. However, even with these larger errors there is little possibility that the curves shown in figure 14 vary much from the "true" curves and the odds are extremely small that there is in reality only one curve for each of the two groups, "high" stations and "low" stations.

The yield of the poor cows at the low stations increased with increasing quantities of feed up to the next to highest feeding level. At this level the cows were fed an average of 1 pound of grain to 2.3 pounds of milk. This represented on the basis of the Haacker

standard about 15 percent above total requirements. At the heaviest level, 1 pound of grain to 1.8 pounds of milk resulted in a considerable drop in production. The "good" cows at the low stations dropped off slightly in milk at the heaviest level of feeding while both "good" and "poor" cows at the "high" stations increased their milk production at the heaviest level of feeding.¹³

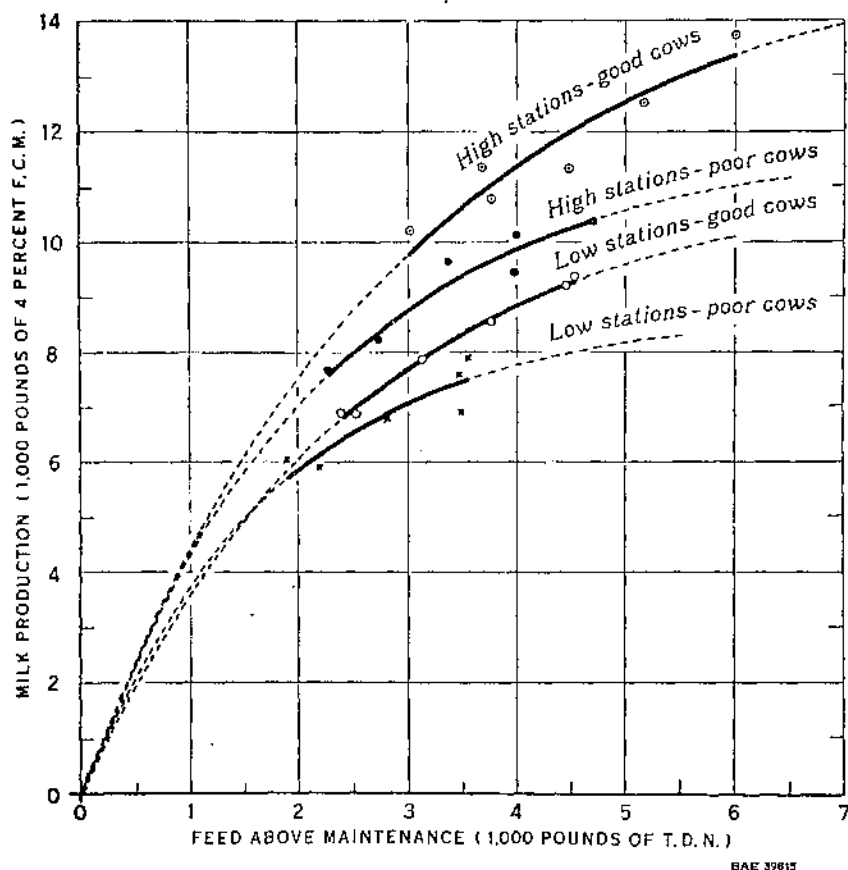


FIGURE 14.—INPUT-OUTPUT CURVES OF COWS OF DIFFERENT INHERENT PRODUCTIVITY AT THE NINE EXPERIMENT STATIONS.

Whether the feed of cows that are naturally low producers can actually be increased to a point at which there is no further increase in milk production or whether the results observed can be ascribed to chance variations or to some conditions peculiar to the "low" sta-

¹³ A similar drop in production was observed by Pettit in England (9). His observations were obtained from a dairy-farm survey of 41 herds over 3-year periods. An increase in feeding levels from 80 percent of the English standard to 115 percent resulted in an increase in production from about 6,200 pounds to about 7,500 pounds of milk per cow per year. But a further increase in feed to more than 140 percent of standard resulted in a drop in production to about 6,800 pounds per cow per year. The cows seemed to be comparable in productive ability to the lowest producing cows in the input-output experiments, but Pettit's report does not tell whether the cows at the different levels were of the same inherent productivity, nor is it clear to what degree the figures are based on actual field data and to what extent on theoretical considerations.

TABLE 11.—Influence of differences in inherent productivity of cows upon response in output to increased feed inputs; yearly averages per cow—combined data from 9 stations

LOW STATIONS, POOR COWS													
Level of feeding	Records	Average live weight	Basic, producing ability, 4-percent fat-corrected milk	4-percent fat-corrected milk produced	Hay	Silage, corn (or sorghum)	Silage, alfalfa	Mangels	Pasture 1 day—15 pounds total digestible nutrients	Grain 75-percent total digestible nutrients	Ratio of grain to 4-percent fat-corrected milk during lactation	Roughage expressed as hay equivalent per day for each 100 pounds live weight	Total digestible nutrients consumed in a year
	Number	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Days	Pounds		Pounds	Pounds
1.	14	936	6,549	6,035	3,570	8,225	43		2.0	1,641	1:3.80	2.02	4,742
2.	23	944	6,524	5,935	4,470	9,554			2.5	1,423	1:4.50	2.27	5,040
3.	19	996	6,562	6,795	3,571	10,652	43		4.7	2,242	1:3.25	2.15	5,656
4.	17	995	6,431	7,602	3,908	10,151			2.2	3,354	1:2.37	2.06	6,309
5.	16	998	6,572	7,893	3,696	9,035	86		8.6	3,662	1:2.30	1.97	6,395
6.	14	1,080	6,444	6,894	4,054	6,154	259		5.2	3,944	1:1.82	1.68	6,326
LOW STATIONS, GOOD COWS													
1.	13	1,099	8,833	6,861	5,035	9,614			3.7	1,775	1:3.94	2.09	5,578
2.	11	1,078	8,831	6,855	5,004	10,406			9.5	1,538	1:4.70	2.29	5,736
3.	14	1,054	8,948	7,887	4,748	10,736	146		5.1	2,562	1:3.19	2.26	6,332
4.	17	1,089	8,966	8,544	4,629	11,848			2.2	3,219	1:2.76	2.26	6,971
5.	9	1,244	8,956	9,354	4,810	10,945			2.1	4,250	1:2.29	1.97	7,739
6.	31	1,134	8,864	9,201	4,106	7,950	31		6.8	5,257	1:1.79	1.77	7,667
HIGH STATIONS, POOR COWS													
1.	17	1,142	8,793	7,618	3,474	11,710	1,488	356	24.5	1,687	1:4.68	2.00	5,697
2.	20	1,147	8,913	8,207	3,087	11,064	943	111	47.5	2,343	1:3.64	2.08	6,182
3.	10	1,207	8,738	9,624	3,270	12,599	818	217	30.2	3,115	1:3.16	2.00	6,817
4.	17	1,239	8,851	10,118	3,470	11,654	751	152	32.6	3,972	1:2.61	1.95	7,448
5.	14	1,180	8,907	9,434	3,424	10,561	674	236	34.9	4,111	1:2.35	1.96	7,865
6.	27	1,267	8,823	10,347	3,188	9,578	747	75	41.6	5,448	1:1.94	1.73	8,142
HIGH STATIONS, GOOD COWS													
1.	17	1,201	11,518	10,195	3,432	13,277	584		60.5	2,207	1:4.71	2.23	6,624
2.	14	1,191	11,482	11,322	3,634	12,576	612	192	32.5	3,407	1:3.37	2.13	7,266
3.	20	1,198	11,445	10,768	3,482	11,630	930	275	50.2	3,418	1:3.21	2.16	7,351
4.	17	1,271	11,554	11,311	3,527	12,273	980	316	44.7	4,320	1:2.66	2.05	8,075
5.	12	1,302	11,489	12,596	3,464	12,472	604	233	48.2	5,225	1:2.46	2.00	8,750
6.	18	1,352	11,389	13,736	3,710	11,140	227	147	32.2	7,068	1:1.99	1.71	9,592

tions is something that cannot be answered from the data at hand. It is evident that something operated to prevent any significant increase either in consumption of nutrients or in milk production of the "poor" cows at the low stations when grain feeding was continued upward beyond the 1:2.4 level of grain feeding. It is not clear whether the seeming inability of the poor cows at the low stations to consume more than an average of 6.326 pounds of total digestible nutrients acted as a brake on production or whether the low production acted as a brake on consumption.

Incremental output was next considered. Inspection of the curves reveals that, if good cows are fed the same amount of nutrients above maintenance as poor cows and all cows then are given a small additional amount of feed, say 100 pounds of grain, the good cows will respond with a larger increase in output than will the poor cows. However, it was found that when we do not compare incremental output of cows fed the same absolute amount of feed above maintenance, but instead compare response when both groups are fed at the same intensity, if, for example, both groups are fed 100 percent of the Haecker standard requirements, then the two groups showed little difference in incremental returns. The good cows fed at Haecker standard produce more milk and receive more feed. Similarly if the input-output curves for both groups are inspected and if on both curves points are selected at which the incremental output for both groups is the same, it is then found that these two points correspond to practically the same percentage of the production standard feeding level for both groups. The figures are shown in table 12.

TABLE 12.—Feeding levels associated with different incremental outputs

Incremental output (additional milk for an additional pound of total digestible nutrient) (pounds)	Feed consumption in percent of Haecker production standard requirements			
	"Low" stations		"High" stations	
	"Good" cows	"Poor" cows	"Good" cows	"Poor" cows
	Percent	Percent	Percent	Percent
2.00	97	91	88	87
1.75	103	97	93	91
1.50	110	103	99	97
1.25	119	110	107	104
1.00	129	120	116	114
0.75	141	134	129	126
0.50	166	153	147	144

At any given incremental output of milk the high stations "good" and "poor" cows were fed at nearly the same percentage of production standard. At the low stations it appears that the "good" cows had to be fed a higher percentage of standard requirements than the "poor" cows, but even here the differences were not very large at the more moderate feeding levels, and if the heaviest fed subgroup of the "poor" cows at the "low" stations is omitted then the figures for the "poor" cows would change and show about the same incremental output as the "good" cows.

A study of the incremental outputs shown and of figure 14 gives some indication of how a whole series of input-output curves for cows of different inherent ability to produce would be arranged in relation to each other. The curves would all start from the origin, rise and fan out as they do in figure 14. It appears that they would be so related to one another that they all would have approximately the same incremental output at the same percentage of Haecker standard.¹⁴ It would seem that one of the criteria for a perfect feeding standard might be that it assigned such amounts of feed to cows of different basic producing ability that the incremental output would be the same for all cows, although they gave different amounts of milk. It appears that the present feeding standards come fairly close to fulfilling such a requirement. As mentioned in another section, that does not mean that the Haecker standard requires enough feed to keep cows in good condition year in and year out or that the standards prescribe the quantities which are most economical to feed.

EXPERIMENTAL LEVELS COMPARED WITH THE HAECKER STANDARD

One of the most notable contributions to the science of feeding dairy cows was made by T. L. Haecker of Minnesota. His standard, promulgated over 30 years ago, has stood the test of time, for in all these years only minor modifications have been made. In the input-output study the Haecker standard was used as the basis of feeding because it appeared to be practically as accurate as any other and because it was not subject to change.¹⁵

In the input-output series I experiments the varying levels at which the cows were fed were based on definite percentage deviations from the Haecker standard. These deviations ranged from 30 percent below standard to 30 percent above. In the series II experiments the cows were fed according to a different system, but a record of the nutrients they received was available for comparison with the requirements of the Haecker standard.

In both series of experiments every station fed one group of cows according to the standard, but at three series II stations the standard was modified to some degree. When the roughage fed, at liberty, at these three stations provided the quantities of nutrients prescribed by the standard, grain was withheld. But at no time was any limitation placed on the quantity of roughage fed. Cows that consistently received all the good roughage they would eat, plus just enough grain to bring the nutrients up to standard, maintained a good state of flesh and produced well. But cows that get all the good roughage they want in the course of a year, consume nutrients in excess of the standard. This is true whether they are fed much or little grain or none at all.

Cows fed roughage only, or very small quantities of grain, not only fail to reach the peak production of more liberally fed cows but the milk flow soon declines to the level at which the feed consumed supplies the quantity of nutrients required. From then on, until the next

¹⁴ Any straight line passing through the origin represents a constant percentage of Haecker standard.

¹⁵ At one station the Morrison standard was used.

lactation, cows will consume more nutrients than specified by the standard. The result is that at the end of the year they will have consumed nutrients in excess of the standard.

The cows that were fed throughout the entire year according to the Haecker standard sometimes became thin in flesh and failed to produce milk in satisfactory quantities. This tendency was particularly striking at four stations. By the second year a casual visitor at any of these stations could pick out at a glance the cows fed according to the Haecker standard. In the most extreme instance, cows fed strictly according to this standard became so thin that the feeding plan was modified before the end of the first year to permit roughage at liberty, at all times, with supplementary grain whenever necessary to bring the intake to standard.

Figures 15 and 16 show the typical appearance of cows fed for more than a year at 100 percent of the Haecker standard as compared with the appearance of cows fed at a level corresponding to 130 percent of the production standard.

Cows fed according to the standard the year round do not have the opportunity to make up for the deficiencies that occur early in the lactation period. The main trouble seems to be that they do not accumulate enough reserve flesh, either during lactation or while dry, to enable them to produce heavily after calving.

When the nutrients are all or mostly in the form of roughage, the Haecker standard assigns amounts of nutrients that are definitely too low for the year-round feeding of dairy cows. No doubt the fact that Haecker fed rations containing a rather high proportion of grain when he was preparing his standard is partly responsible for the moderate quantities of nutrients provided. The fact that the Haecker standard is expressed in terms of digestible nutrients and that a given weight of digestible nutrients in the roughages commonly used probably is not worth so much nutritionally as the same weight in the form of concentrates has considerable to do with the excess of calculated nutrients consumed by cows fed largely on roughage.

But even if there is some limitation on the quantity of roughage fed, the standard specifies sufficient nutrients for most economical production only when the value of milk is low in relation to the price of feed, and light feeding is called for. The Haecker feeding-standard level must be classed, therefore, as a low rather than as an average level of feeding.

It appears that the prevalent ideas about feeding need to be revised. For many years it has been assumed that the standard rate of feeding is near the most profitable rate and the aim has been to feed cows at standard unless they were being run on a test of some kind, in which the economy of production was a matter of secondary consideration—then they were fed more heavily. It is now evident that the most profitable level of feeding, exclusive of maintenance, may range from standard to as much as 30 percent above standard and that the relation between price of feed and price of product is the major consideration in deciding how heavily it pays to feed cows.



BAE 4178-A
FIGURE 15.—COWS FED AT 100 PERCENT OF STANDARD AT MISSISSIPPI EXPERIMENT STATION CONDUCTING SERIES I EXPERIMENTS.



FIGURE 16. —COWS FED AT 130 PERCENT OF STANDARD AT MISSISSIPPI EXPERIMENT STATION CONDUCTING
SERIES I EXPERIMENTS.

BAE 4172-B

FEEDING GRAIN AT CERTAIN RATES IN PROPORTION TO MILK PRODUCED IN COMPARISON WITH FEEDING FROM WEEK TO WEEK ACCORDING TO REQUIREMENTS OF AN ACCEPTED FEEDING STANDARD

One reason for feeding cows according to different grain-milk ratios at some stations and according to a given percentage of standard at other stations, was to disclose whether there is any advantage of one method over the other in economy of production. This was also the reason for including a check group fed at the standard rate at all stations. A true comparison cannot be made between feeding with reference to a standard at some stations and feeding at varying grain-milk ratios at other stations because the environmental conditions and quality of feed were not the same at all stations. It was necessary, therefore, to make the comparisons within, rather than between, stations. Three different comparisons were made between groups of cows fed according to a standard and groups of cows fed at a definite grain-milk ratio.

The first was a comparison between standard-fed cows and cows fed at the nearest comparable rate. Data from five stations were used in this comparison. At three of the five stations, the 1:6 ratio between grain fed and milk produced was closest to the Haecker standard. At the other two stations, the 1:4 ratio was closest to standard.

Data from the same five stations were used in the second comparison but in this instance feeding at the Haecker standard was compared with feeding at the 1:6 ratio in all stations. In both the first and the second comparison results were computed by averaging together the data from all five stations. Thus in each instance the cows were divided into only two groups.

A similar comparison was made by selecting two of the five stations, dividing the cows into one group fed according to a standard and another group fed at the 1:6 level and comparing the average data for the two groups.¹⁶

Table 13 summarizes the results of these three comparisons, indicating in averages the live weight, expected yield, actual yield, and the feed and nutrients consumed by the cows in each group.

In each of the three comparisons, the cows fed according to the Haecker standard produced a smaller total quantity of milk, but more milk per unit of nutrients consumed than the cows fed at the grain-milk ratios used in these comparisons. The standard-fed cows ate more grain and less forage, consuming less total digestible nutrients than the averages for the cows in the other groups.

Feeding according to a standard tends to permit the conversion of feed into milk directly instead of first into body substance and then into milk as when cows are overfed and underfed at different periods of lactation. Theoretically it would appear that feeding

¹⁶ Even though data from these two stations were included in the average data for the entire group of five, they were selected for a separate comparison. This was done because the method of standard feeding at these two stations differed from the method followed at the other stations. At these two stations, the cows had no pasture, and roughage was limited in the latter part of the lactation in order to keep the nutrients more nearly at the standard level during that period.

according to a standard would be more economical because it is a well-established fact that the conversion of nutrients to milk is more efficient than the conversion first into body tissue and then into milk. The above computations bear out the theory. But the advantage in feeding cows from week to week according to their estimated requirements over the common method of underfeeding during the flush of lactation and overfeeding during the latter part of lactation and while they are dry is not sufficiently pronounced to be of any great practical importance.

TABLE 13. - Comparison of efficiency of production of cows fed weekly according to requirements with that of cows fed at approximately the same intensity for the whole year but according to a method which results in temporarily feeding more and less than requirements

Item	Unit	First comparison (5 series II stations)		Second comparison (5 series II stations)		Third comparison (2 series II nonpasture stations)	
		Standard	1:3 or 1:4 ¹	Standard	1:6	Standard	1:6
Measurement of intensity of feeding: Feed consumption (total digestible nutrients) related to Haecker standard requirements, total.	Percent	103	107	103	106	103	109
Measurement of efficiency: Milk produced (4-percent fat-corrected) for each pound of feed consumed (total digestible nutrients).	Pounds	1.283	1.261	1.282	1.276	1.200	1.163
Input-output data.							
Yearly records	Number	37	38	36	41	10	15
Average live weight	Pounds	1,102	1,114	1,112	1,417	1,124	1,170
Basic producing ability, 4-percent fat-corrected milk.	Pounds	8,660	8,601	8,749	8,820	7,531	7,550
Feed consumption (grain (75 percent total digestible nutrients).	Pounds	1,984	1,783	2,030	1,433	1,658	1,366
Hay	Pounds	4,320	4,381	4,354	4,082	4,902	6,130
Silage	Pounds	8,936	11,302	8,951	11,529	9,990	11,200
Pasture	Days	34.0	42.6	33.2	10.6	0	0
Total feed consumption (total digestible nutrients).	Pounds	5,901	6,368	5,338	6,264	5,720	6,433
Milk production, 4-percent fat-corrected milk.	Pounds	7,570	8,031	7,613	7,992	6,863	7,483
Total digestible nutrient requirements for both maintenance and milk	Pounds	5,736	5,927	5,778	5,922	5,558	5,927

¹ At 3 of these stations the cows were restricted to the Haecker standard only when the roughage consumption was not sufficient to cover requirements. The cows were fed roughage freely at all times and toward the end of the lactation and during the dry period they consumed more than the standard required.

² Rate of feeding that appeared most comparable to the standard rate.

Many investigators hold that roughages are overevaluated by the total digestible nutrients method. If so, the small advantage of standard feeding with reference to milk produced per pound of total digestible nutrients consumed would be lessened. This study indicates (table 13, measurement of efficiency) that from a given quantity of total digestible nutrients, cows like those used in this experiment, will produce not over 300 pounds more 4-percent milk in a year if they are fed at a given percentage of standard from week to week during the lactation period instead of at the rate of 1:6 or 1:4; and if no limitation is put upon the roughage consumption the increase will be much less than 300 pounds. In spite of the more efficient use of nutrients when the cows were fed at standard they

actually produced less milk per year. This is more important than efficiency of conversion. Furthermore, the cows fed at standard failed to carry as much flesh as those fed at the rate of 1:6 or 1:4.

That the forages as a rule are cheaper sources of nutrients than the concentrates must not be overlooked. Therefore, the most economical feeding practice usually is to make the fullest possible use of forages. Apparently, in most dairy areas and under normal price conditions there should be no limitation in the quantity of forage cows are allowed to eat. And if cows are allowed to eat all the hay, silage, and pasturage of good quality that they want, they will be overfed when the milk production has declined to a low level and when they are dry, according to any accepted feeding standard.

But this extra feed is not wasted because liberal feeding before calving results in more milk for about 3 or 4 months after calving (15). The greater use of cheap feed before calving may largely counterbalance any less efficient conversion of feed to milk because of the nutrients first being converted to body substance instead of directly into milk. Apparently the chief reason the standard-fed cows produced less than the other groups was that they were in thinner condition at calving time in spite of the fact that during the dry period they had received 100 pounds of total digestible nutrients in addition to maintenance as the plan called for.

The farmers' rule of feeding grain with reference to the milk produced as 1 pound of grain to 3, 4, 6, etc., pounds of milk appears practically as efficient as feeding continuously with reference to a standard and is much simpler to put into practice.

THE INFLUENCE OF LEVELS OF FEEDING

INFLUENCE UPON PEAK PRODUCTION AND PERSISTENCY OF PRODUCTION

All the records beginning when the cows were fresh and running uninterruptedly through 44 weeks were assembled in six groups with reference to the level of feeding. The levels of feeding and the groupings are shown in table 14. Figure 17 gives similar information by weeks—the six levels have been combined so as to make three curves instead of six. This was done by averaging together the data from the lowest two levels, the intermediate two levels, and the highest two levels, and smoothing the data by using an adjusted 5-week moving average. This process eliminated numerous very minor deviations. It was planned to show also the unsmoothed data but the width of the smoothed line practically obscured the deviations.

The lowest fed groups reached peak production in the fourth week, the next lowest in the fifth week, and all the rest of the sixth week. The peak production varied uniformly with the level of feeding—the cows fed the heaviest reached the highest peak and those fed the least had the lowest peak production. The range was from 39.2 pounds of 4-percent milk a day to 45.6 pounds a day.

TABLE 14.—*Persistency of production: Average production of all cows that had unbroken lactation records and were fed at 6 levels similar to those presented in table 7*

Weeks of lactation	Level 1 (63 cows)			Level 2 (55 cows)			Level 3 (56 cows)			Level 4 (62 cows)			Level 5 (46 cows)			Level 6 (89 cows)		
	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period	Production of 4-per-cent fat-corrected milk ¹		Change in production from previous period
	Pounds	Pounds		Pounds	Pounds		Pounds	Pounds		Pounds	Pounds		Pounds	Pounds		Pounds	Pounds	
1-4	921.0			898.4			964.3			959.2			1030.0			1024.5		
5-8	1052.5	+131.5	+14.28	1087.4	+189.0	+21.04	1185.8	+221.5	+22.97	1226.0	+266.8	+27.81	1252.5	+222.5	+21.60	1264.8	+240.3	+23.46
9-12	940.7	-111.8	-10.62	1012.6	-74.8	-6.88	1093.0	-92.8	-7.83	1144.4	-81.6	-6.66	1175.7	-76.8	-6.13	1203.4	-61.4	-4.85
13-16	819.4	-121.3	-12.80	908.8	-103.8	-10.25	987.7	-105.3	-9.63	1044.1	-100.3	-8.76	1089.0	-86.7	-7.37	1119.4	-84.0	-6.98
17-20	726.8	-92.6	-11.30	802.9	-105.9	-11.65	892.4	-105.3	-10.66	960.5	-83.6	-8.01	1020.2	-68.8	-6.32	1027.1	-92.3	-8.25
21-24	666.8	-60.0	-8.26	721.5	-81.4	-10.14	808.5	-73.9	-8.37	880.2	-80.3	-8.36	911.7	-108.5	-10.64	956.7	-70.4	-6.85
25-28	595.1	-71.7	-10.75	666.6	-54.9	-7.61	725.7	-82.8	-10.24	800.1	-80.1	-9.10	850.4	-61.3	-6.72	889.5	-67.2	-7.02
29-32	543.3	-51.8	-8.70	582.3	-84.3	-12.65	659.2	-66.5	-9.16	726.9	-73.2	-9.15	760.5	-89.9	-10.57	821.2	-68.3	-7.68
33-36	481.0	-62.3	-11.47	494.6	-87.7	-15.06	559.6	-99.6	-15.11	618.4	-108.5	-14.93	647.2	-113.3	-14.90	728.4	-92.8	-11.30
37-40	384.3	-96.7	-20.10	394.3	-100.3	-20.28	459.2	-100.4	-17.94	483.1	-135.3	-21.88	508.5	-138.7	-21.43	603.2	-125.2	-17.19
41-44	291.3	-93.0	-24.20	281.2	-113.1	-28.68	353.9	-105.3	-22.93	355.8	-127.3	-26.35	384.6	-123.9	-24.37	460.6	-142.6	-23.64
Total	7422.2			7850.6			8679.3			9198.7			9630.3			10,098.8		
Measure of persistency ²			10.69			10.25			9.87			8.96			8.57			7.37

¹ Average production per cow for the 4-week period.² Average percentage decline from fifth to thirty-sixth week computed by dividing total of declines from 9-12 period through 33-36 period by total production in 5-8 period through 29-32 period. The smaller the figure is, the greater the persistency.

The trend downward from the peak was much the same and very uniform for all groups (fig. 17). A common method of expressing declines is the percentage decrease per month. For example, if a cow gives 1,200 pounds one month and 1,100 the next month, the decline is 100 pounds or 8.33 percent of 1,200 pounds. The yields of milk by 4-week periods and the declines are given in table 14. After the thirty-sixth week the declines were accelerated because of pregnancy. Perhaps from this time on, pregnancy rather than feed is the dominant factor in controlling milk production. To see how the six levels of feeding influenced the monthly decline, an average

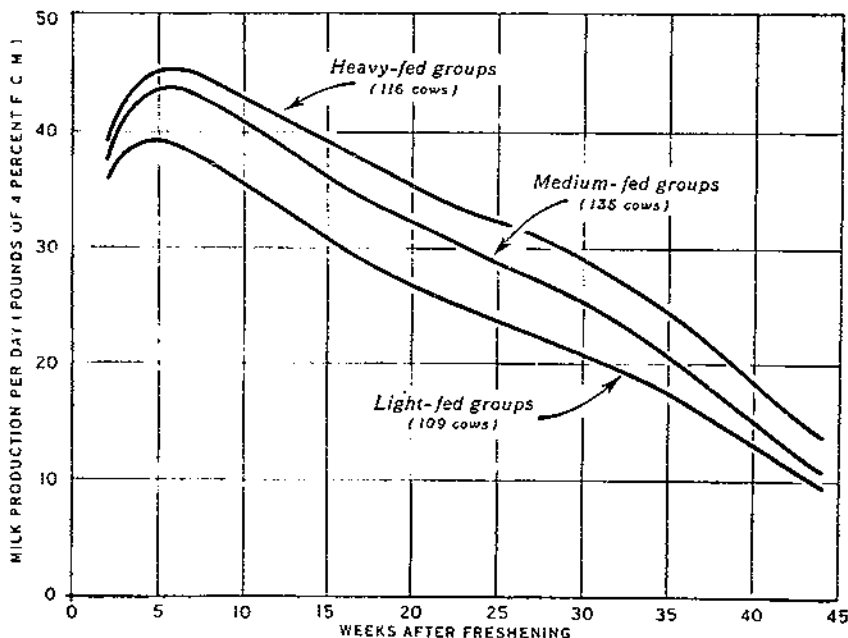


FIGURE 17.—AVERAGE LACTATION CURVES SHOWING PEAK OF PRODUCTION AND PERSISTENCY FOR COWS DIVIDED INTO THREE GROUPS ACCORDING TO LEVEL OF FEEDING 360 UNBROKEN LACTATION RECORDS AT NINE STATIONS CONDUCTING SERIES I AND II EXPERIMENTS.

was taken of the declines for seven 4-week periods from the peak production through the thirty-sixth week.

The percentage declines decreased as the level of feeding increased, and these gradations downward are sufficiently regular to be conclusive. Increases in feed lead to the production of more milk, first by increasing the peak production and, second, by lessening the subsequent declines. In other words, the whole lactation curve has been pushed to a higher level.

INFLUENCE UPON THE PERCENTAGE OF FAT IN THE MILK

The percentage of fat in the milk of the cows fed at the different levels during the experiment was compared with the percentage of fat in the milk produced before the cows were put on experiment.

Table 15 shows the changes in fat at the different feeding levels. The averages at the bottom of the table show that the milk at each of the six feeding levels declined in percentage of fat, ranging from 0.04 percent to 0.18 percent, and there was no consistency of change with reference to the level of feeding. Some slight significance might be attached to the fact that the lowest fed group declined the most, but the general conclusion is that the percentage of fat is not changed by heavy or light feeding. The general decline observed in all groups may have been the result mainly of advancing age, as it is not likely that such consistent declines would occur purely by chance. Another of the possible contributing factors is that the length of the lactation period used to determine the basic producing ability may have been longer than the 302 days allowed in this investigation. The difference in the declines found at the various stations can best be explained by the variation in the factors mentioned above.

TABLE 15.—Change in butterfat test of milk produced during the experiment compared with that of the milk produced previously: combined data from 9 stations

Station	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
	Percent	Percent	Percent	Percent	Percent	Percent
Delaware	-0.14	-0.20	-0.10	-0.05	-0.11	-0.13
Indiana	-0.35	-0.28	-0.01	-0.20	-0.29	-0.37
Maryland	-0.03	-0.22	+0.13	-0.01	+0.02	-0.06
Michigan	-0.02	+0.10	+0.12	-0.02	-0.02	-0.02
Mississippi	-0.31	-0.28	-0.23	-0.02	+0.16	+0.01
New Jersey	-0.10	+0.01	-0.07	-0.10	-0.13	-0.17
New York	-0.49	-0.15	-0.31	-0.18	-0.17	-0.23
Pennsylvania	-0.16	-0.17	+0.05	0	-0.24	-0.08
South Dakota	-0.25	-0.42	-0.25	-0.33	-0.41	-0.45
Total	-1.64	-1.21	-0.37	-0.06	-0.66	-1.00
Simple average	-0.18	-0.15	-0.04	-0.11	-0.07	-0.12

¹ Interpolated; the interpolation was made in the same way as described in tables 7 and 8.

THE INFLUENCE ON THE BREEDING AND CALVING EFFICIENCY AND ON THE HEALTH OF DAIRY COWS

There is a somewhat general feeling among dairy farmers that the heavy feeding of grain is harmful in a number of ways. Some speak of cows being "burnt out" by excessive grain feeding; most of them think that it causes digestive disorders, usually called "off feed"; others have a feeling that it induces mastitis, impairs breeding efficiency, and shortens the useful life of dairy cows.

This investigation gave an opportunity to observe the effects of feeding different quantities of grain upon the health of dairy cows for 2 years. This was probably long enough for the full effect of the rations to become manifest in some respects but not long enough to permit a determination of the relation of heavy grain feeding to the useful life span.

Along with and somewhat incidental to the accumulation of data relative to feed inputs and milk output, detailed information was obtained on the health, breeding records, deaths, and removals from the experiment of cows after the effects of different levels of feeding had a chance to exert themselves. Pregnancy and breedings were not included unless the calving occurred more than 10 months after the cow started on the experiment; likewise, any cow that died or

was removed within 6 months after starting on the experiment was not included.

Information was obtained on 298 cows for the first year of feeding and on 188 for the second year. The cows were divided into six groups, from low to high, according to the level of grain feeding. Most of the cows fed at the highest level were on experiment for only 1 year and this year was the third instead of the first, as might be inferred from table 16 which shows the number of cows under observation at each level of feeding and at each station. The data for Virginia are not included because the cows there were fed at only two levels. Table 17 shows the number of cows removed from the experiment because of disease, death, or other reason. There were far more removals the second year than the first but there was no definite relationship between the level of feeding and the number removed. Although more were removed from the lowest fed groups than from any of the other groups, 3 of the removals were because of poor condition rather than because of disease. These cows might have been retained.

Table 18 gives detailed information regarding breeding, removals from the experiment, and deaths. The causes for the removal of cows from the experiment are of interest. Exclusive of 18 percent removed because of Bang's disease, 16 percent died. The causes of the deaths are listed as follows: Foreign bodies, 40 percent; mastitis, 20 percent; abscesses and infections, 20 percent; and parturition and nephritis, each 10 percent. Of those removed for causes other than death, sterility accounted for 42 percent; mastitis, 24 percent; abortion (noncontagious), 24 percent; poor condition and unprofitable, 8 percent, and old age, 2 percent.

TABLE 16.—Number of cows from various stations used to determine effects of feeding level upon health and breeding efficiency

Year and station	Data for feeding levels indicated—						Total
	1	2	3	4	5	6	
FIRST YEAR	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Number</i>
Delaware	6	5	5	5	5	5	34
Indiana	5	5	5	4	8	15	40
Maryland	5	6	4	5	5	21	46
Michigan	3	3	3	4		3	16
Mississippi	5	19	9	10	4	8	46
New Jersey	5	5	5		7	6	28
New York	4	2	3	3	3	3	18
Pennsylvania	7	5	5	5	2	23	47
South Dakota	5	4	4		5	5	23
Total	45	45	43	36	37	92	298
SECOND YEAR							
Delaware	6	5	5	5	5		26
Indiana	4	5	5	4	5		23
Maryland	5	5	4	5	5		24
Michigan	3	2	2	3			13
Mississippi	4	4	5	6			19
New Jersey	5	4	4		6	6	25
New York	3	2	3	3	3	3	17
Pennsylvania	7	4	4	5	2		22
South Dakota	4	4	4		3	4	19
Total	41	35	36	31	29	16	188
Total, 2 years	86	80	79	67	66	108	486

TABLE 17.—*Number of cows from each group by stations that died or were removed from the experiment*

Year and station	Data for feeding levels indicated—						
	1	2	3	4	5	6	Total
FIRST YEAR	Number	Number	Number	Number	Number	Number	Number
Delaware.....							
Indiana.....	1				1	1	3
Maryland.....		1				1	2
Michigan.....		1		1			2
Mississippi.....		1	1				2
New Jersey.....							
New York.....	1						1
Pennsylvania.....						1	1
South Dakota.....					2		2
Total.....	2	3	1	1	3	1	13
SECOND YEAR							
Delaware.....	1		1	1			3
Indiana.....	2	3	1	1	2		9
Maryland.....	1						1
Michigan.....	1	1	1	2		1	6
Mississippi.....	1	1	1	3			6
New Jersey.....	2				3	4	9
New York.....	2				1	1	4
Pennsylvania.....	2						2
South Dakota.....	1	2	4			1	8
Total.....	13	7	8	7	6	7	48
Total, 2 years.....	15	10	9	8	9	10	61

It cannot be said that either light or heavy feeding was superior in its effect upon the staying power of the dairy cows during the 2 years that they were on this experiment continuously.

There was a definite trend upward in the number of cases of "off feed" as the level of feeding increased. This finding is in accordance with the general belief. Few of the cases of "off feed" were serious. Cows that were fed all the grain they would eat sometimes went off feed once or twice and, thereafter, avoided overeating. Probably some of the cases were merely symptomatic of other ailments and in no way attributable to the kind or quantity of the feed consumed. Udder troubles were more prevalent in the highest fed group, but between the five other groups there was no significant difference. The total number of cases of udder troubles was not excessive, being only 11 percent of the cow-years. Thus 100 cows kept for one year would have 11 cases of udder trouble.

The breeding data are more voluminous and, therefore, provide a basis for more definite conclusions. It will be seen that the services required for conception are not dependent in any way upon the level of feeding. One of the two medium-fed groups had the best record so far as pregnancies were concerned, while the other medium-fed group had the worst record.

From the study of these data covering 2 years it appears that the only ailment or trouble that can be definitely attributed to the level of feeding is the frequency with which cows go "off feed." However, the number of cases of udder troubles observed among the cows fed at the highest level would lead one to suspect some relationship between the quantity of grain fed and the incidence of udder trouble. The study was not continued long enough to ascertain the long-time effect upon the health and staying power of dairy herds of continuous feeding at different levels.

TABLE 18.— *Breeding and health data of cows fed at 6 different levels*¹

Feeding level from lowest to highest	Cow years	Breeding data				Health data										Cause of death				
		Times bred	Preg-nancies	Services for concep-tion	Abor-tions	Ailments of digestion and mammary systems		Cause of removal from experiment other than death					Cause of death							
						Times off feed	Udder troubles	Sterility	Masti-tis	Abor-tion	Poor condition and un-profitable	Old age	Masti-tis	Foreign body	Abscesses and infection	Calving	Nephri-tis			
Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number		
1	86	167	75	2.2	4	5	4	3	2	3	3				1	1	1	1		
2	80	157	71	2.2	5	8	9	4	2	3										
3	79	133	75	1.8	4	9	6	2	4	3										
4	67	119	53	2.2	3	18	6	5		3					1					
5	66	123	57	2.2	1	16	6	5	2						1					
6	108	191	100	1.9	2	20	23	2	2		1	1	2	1	1	1				
1 ²	100	194	87	2.2	4.7	5.8	4.7	3.5	2.3	3.5	3.5				1.2	1.2	1.2	1.2		
2 ²	100	196	89	2.2	6.3	10.0	11.3	5.0	2.5	3.8										
3 ²	100	168	95	1.8	5.1	11.4	7.6	2.5	5.1	3.8										
4 ²	100	178	79	2.2	4.5	26.9	9.0	7.5		4.5					1.5					
5 ²	100	186	86	2.2	1.5	24.2	9.1	7.6	3.0						1.5					
6 ²	100	177	93	1.9	1.9	18.5	21.3	1.9	1.9		.9	.9	1.9	.9	.9	.9				

¹ The classifications under health data are not mutually exclusive. The same cow may have been off feed, have had mastitis and died from a foreign body.² Calculated on the basis of 100 cow-years.

ECONOMIC SIGNIFICANCE OF PHYSICAL INPUT-OUTPUT RELATIONSHIPS

Agriculture in this country long ago passed the stage where pasture and roughage crops for dairy cows were produced mostly on lands that could not very well be used for other purposes. A large part of the best lands in the country are now used for production of feed crops. In the dairy regions most of the cultivated area is devoted to the growing of feed crops which are used directly—or indirectly through feeding to young stock and workstock—to provide for the dairy herds. Thus, at present the greater part of the dairy feed crops—grain crops and roughage crops—is produced through an expensive combination of hard work, good land, and valuable machinery. These crops must be used economically.

That purchased feeds, usually representing a heavy cash outlay, must be economized is self-evident. To gain this economy, many dairymen weigh the daily grain ration to each individual cow.

If both grain and roughages are to be used most effectively they must be fed in such quantities that their conversion into milk will result in the largest net cash return to the dairy farmer. He must feed at the most economical level.

The input-output curves supply in condensed form some data which so far have been lacking for ascertaining definitely the most economical feeding level. With these data it becomes possible to learn how much in the quantity of feed should be varied upward or downward in accordance with changes in the relationship between the prices of feeds and of milk.

The feeding standards indicate the physical needs of dairy cows. They tell how much feed must be given to cows of different size and different inherent productivity in order to keep them producing without losing or gaining in body weight. In many localities the feeding level arrived at by supplying the quantity of grain and roughage needed to bring nutrients up to the Haecker standard will not be far from the most economic level of feeding but only by chance does the rate of feeding indicated by the feeding standard coincide with the most economical rate of feeding. In areas where the price of 100 pounds of milk is much lower than the price of 100 pounds of grain, good cows will be fed much less than the feeding standards call for during the early part of the lactation period. As a rule they are unable to consume roughage enough to produce as much as they would if they were also fed some grain, but it does not pay to supplement the roughage by feeding grain.

In the very beginning of the lactation period such cows may produce at a high rate. For a while they may maintain this rate fairly well by milking off their flesh. But when the nutrients intake is entirely insufficient for the output of milk the time is soon reached when nature protects herself by a continuous decline in milk production, a decline that comes earlier than normal and continues until a level is reached which can be sustained on the quantity of nutrients received. Still later, in the lactation period when the natural decline in milk production has further reduced the milk yield, the intake of nutrients will be far in excess of the quantities required for maintenance and production. Thus, for the year as a whole the cow will balance ac-

counts in such a way as to come out with a feed consumption well in excess of the requirements corresponding to the reduced milk production.

The health of the cow does not seem to suffer because she is fed in this way. Cows go through such a period of deficiency regularly year after year in those areas where grain is so expensive in relation to milk that it cost considerably more per pound than milk does. The reason why dairy farming continues in such areas is that there is no better way of using available roughage supplies.

On the other hand, if milk prices are very favorable in relation to grain prices it pays to go considerably beyond the feeding standard level and to feed practically as much grain as the cows will eat. Such practices may mean that the production ration is increased to more than 30 percent above the production ration prescribed by the standard.

In other words, the quantities that are economical to supply depend upon prices of feed and milk.¹⁷ This price relationship determines to what extent it is economical to utilize the cow's ability to produce, whether this ability is to be utilized only partly, and production restricted to the quantity which can be produced by feeding only roughage, or whether the inherent productivity is to be used to its very limit, a limit which, in the case of good cows, may be reached when the cow refuses to eat more. At this point the production response might still be sufficient to pay for still more grain if the cows would eat it.

When the input-output relationship is learned, the economic limit can be located under varying conditions of prices by relating the input-output data to the prices which prevail in different areas and at different periods of time. The data obtained from the input-output experiments in series No. 1 tell how much milk can be expected from extra inputs of grain in addition to a constant intake of roughage and to what extent the rate of output falls off if grain feeding is forced to higher levels. Because the rate diminishes, a point is reached where extra milk output will not pay for additional feed. How far it pays to go then depends upon prices; that is, upon the cost of the extra grain and the value of the increase in milk yield.

The economic limit may be located by several different kinds of computations. A simple way is to consider the balance between the added cost of another increment of feed and the increase in receipts due to the corresponding increase in milk yield. As long as each step results in an addition to receipts greater than the increase in feed

¹⁷ Within certain limits additional feed may be supplied in the form of roughage or in the form of grain. The capacity of the cows to consume roughage limits the choice between these two types of feed. Beyond a certain point, depending upon the size of the cow and the quality of the roughage, it is not possible to provide more feed except in the concentrated form; that is, except in the form of grain. Until this limit is reached, the farmer has a choice and will attempt to supply the feed in the cheapest form. That may be in the form of home-grown roughage, home-grown grain, or in the form of purchased grain. Whether it pays best for farmers to spend money on fertilizers and seeds for fertilization and reseeding of pastures and hay lands and for increased production of silage crops, or if it is more profitable to purchase some additional concentrate feeds depends upon the acreages of good and poor land available, what other crops can be grown on these lands, and to what extent the yields of the roughage crops can be increased by fertilizers and improved cultural practices. It also depends upon how heavily the farms are stocked, how profitably home-grown grain can be used for other types of livestock and at what prices concentrates are available, etc. These and other factors which determine the relative profitability of feeding roughages as compared to feeding grain will vary from area to area and even from farm to farm and it is outside the scope of this study to discuss these problems in detail. To simplify the discussion, it has therefore been restricted so as to deal mainly with grain prices and milk prices.

cost due to another increment of feed—other receipts and expenses remaining the same—it pays to take that step.

As outputs grow smaller, a point is finally reached where the incremental milk output is no more than sufficient to cover in value the cost of the corresponding increment of feed. Here the economic limit has been reached. How soon the limit is reached depends upon the price of milk as related to the price of grain. How small an incremental milk output will suffice to pay for another pound of grain can be found immediately by computing the grain milk price ratio.¹⁸

In other words, the number of pounds of milk it takes to pay for an extra pound of grain is found by dividing the milk price into the price of grain. If milk costs \$3 per hundredweight and grain \$1.50 per hundredweight, the grain-milk price ratio is 0.5. An added output of only 50 pounds of milk will still pay for an increase in ration of 100 pounds of grain. Column 4 in table 20 thus shows how many pounds of milk in added output will be sufficient to pay for an extra pound of grain at prices prevailing in different areas. Evidently, in the areas with the highest milk prices in relation to grain prices it will pay to increase grain feeding to a level where only an increase in output of about 70 pounds of milk is obtained for each extra 100 pounds of grain fed.

The input-output experiments show that so low an incremental output is reached only at the heaviest levels of feeding. This means that for fairly high-producing cows within the areas with a favorable price relationship there is no practical limit to grain feeding, except perhaps, the limits dictated by concern for the health of the cows. Most cows which produce 9,000 pounds or more of 4-percent milk, if fed grain in addition to a constant roughage intake as in series I experiments, are unable to consume feed enough to bring the production ration above 130 percent of the Haecker standard feeding level, and at this level the incremental output is still 70 to 80 pounds per 100 pounds of grain added to the ration.

TABLE 19. *Response of dairy cows to increased feeding*

[Total feed consumption, total milk output, and incremental output at different levels of feeding in relation to Haecker standard—experiment station 2]

Production ration in percent of Haecker requirements	Total feed consumption, pounds of grain equivalent	Total milk output, pounds of 4-percent fat-corrected milk	Incremental output, ¹ pounds of 4-percent fat-corrected milk for an additional pound of grain or grain equivalent
90	8,260	8,500	1.4
100	9,110	9,530	1.0
110	9,910	10,270	.8
120	10,690	10,840	.6
130	11,430	11,270	.5

¹ To find the incremental output, a regression equation was fitted to the original data by the method of least squares. The first derivative of this equation gives the incremental output. Thus, the values given in column 4 represent the slopes of the curve at the 90-, 100-, 110-, 120-, and 130-percent points. In other words, the figures indicating incremental output apply exactly to the feeding level for which they are listed and not to the intervals between these levels. For example, the incremental output of 1.4 pounds of milk for an extra pound of grain applies to the feeding level of 90 percent of standard; it is not an average which applies to the whole interval between 90 and 100 percent of standard.

¹⁸ The relationship between prices of milk and grain is usually expressed as the milk-grain price ratio. But if instead the grain price is divided by the milk price the result gives directly the pounds, or part of a pound, of additional milk needed to pay for 1 pound more grain.

These facts may now be related to the input-output curves to determine more accurately how far it pays to increase feeding in different localities with varying prices. When it is known how small an additional output is needed to pay for an extra pound of grain, the feeding levels which correspond to a certain additional (incremental) output can be located on the input-output curve or in a table of the type presented as table 19 which is derived from the input-output curves. The feeding levels are expressed in percent of the standard feeding level.

The determination is simplified if the roughage consumption remains constant at the different levels of grain feeding as it will if roughage of not too poor quality is fed sparingly. The value of the roughage then becomes a kind of overhead cost and has no influence in determining where the economic limit is reached. It depends entirely upon the relationship between grain prices and milk prices. The local price of grain divided by the price of milk at the barn door gives us the ratio which indicates how many pounds of milk we must obtain for an extra pound of grain at the economic limit; that is, when feeding at the most profitable level.

In the input-output experiment series I, roughage consumption was limited to some degree and did remain practically constant at all feeding levels. The results from these experiments may serve as a basis for making recommendations for practice in dairy areas where cows are fed approximately the same way as in this series of experiments. In actual practice, we find that on many eastern dairy farms the roughage ration is limited and increased grain feeding does not lead to any decrease in roughage consumption.

Table 19 was derived from input-output curves obtained in the series I experiments. It presents the results obtained with good Holstein cows weighing 1,200 pounds and producing 8,000 to 9,000 pounds of 4-percent fat-corrected milk when fed at the Haecker standard level. But it has much wider application. As was shown in the section discussing the response of good and poor cows the incremental output for cows fed the same percentage of standard requirements would be approximately the same for cows of different basic producing ability. But cows weighing more or less than these cows will require a different maintenance ration and to that extent total feed consumption will be changed.

This discussion has been in terms of adjustments made by the individual dairy farmer and how the input-output relationships apply to such adjustments. However, when the same problems are viewed on the national scale and it is realized that the same problems are met with on a million farms the knowledge of these relationships takes on added importance.

Such knowledge will make it possible to plan national programs of adjustments on a more secure basis than before. For example, a program for regulating milk production by controlling the number of dairy cows is not likely to succeed if the road is left open to take advantage of the great possibilities of increasing production per cow by more heavy feeding. If suddenly a great expansion of milk production is needed, it is important to know that the average requirement of feed per pound of milk is not applicable when it comes to obtaining more milk from the number of cows now on hand. The feed requirements for such an increase in production from the same

number of cows are twice as large as the average feed requirement. If about 11 billion pounds additional milk is needed, it does not take about 100 million bushels of grain, but about 200 million bushels.

REGIONAL DIFFERENCES IN INTENSITY OF FEEDING

Dairy farming is practiced in all the 48 States, but the areas with a substantial amount of commercial dairy production make up only a small proportion of the land in the South, and a still smaller proportion of the agricultural area in the Great Plains and in the Mountain States (fig. 18).¹⁹

The principal dairy regions are found in the North Atlantic, North Central, and Pacific Coast States. Between the different parts of this vast area, rather pronounced differences are found in the prevailing practices with respect to management and feeding of dairy herds. The determination of input-output curves throw some light on the extent to which these differences are economically justified.

It has been shown that the quantities which may be fed economically in different areas depend mainly upon the relationship between grain prices and milk prices. This relationship also varies to a great extent between different parts of the dairy region, but it was found that the variations of this ratio between areas were considerably smaller than the variations of either milk or grain prices.

Throughout this discussion the term "grain" means that concentrate ration which is most commonly fed in the various regions. Farmers and feed dealers constantly attempt to make up this ration from such proportions of the commonly used feeds (such as corn, small grains, wheat bran, and oilseed meals) as will furnish a sufficient quantity of nutrients and proteins most cheaply. Generally speaking, this grain mixture can be provided at lowest cost in the great surplus grain-producing region of the North Central States from which grain is exported to other regions. Although these other regions produce both grains and oilseeds they ship in more feed than they ship out. Therefore, the farther away a dairy area is located from the surplus grain-producing region, the higher is the price of grain. The South and the Pacific coast have higher prices than the Middle West, and the very highest prices are found along the Atlantic seaboard.

But these price differences, which in turn tend to give rise to

¹⁹The 1939 grain milk price ratios on which the map (p. 63) is based were computed by dividing the price of grain by the composite price of 100 pounds of milk. The small scale of the map necessitated some smoothing of these ratios.

The grain prices used were based on the price of 100 pounds of concentrates of the type usually fed to milk cows in each area. In the East, the grain price was virtually a commercial mixed feed price. In parts of the Midwest, the grain price was based mostly on the value of home-grown concentrates.

The prices of milk used in these computations were a composite of the whole milk price and the price of 100 pounds of 1-percent fat-corrected milk marketed in the form of cream. It was assumed that the cream marketed would continue to test 25 percent butterfat, and that skim milk was worth 30 cents a hundred pounds. Individual prices of the items entering into the composite price were weighted by the amounts sold during 1939. The prices of milk sold at retail and of farm butter sold, have been ignored. It was assumed that prices of retail milk less distribution costs would approximate prices for whole milk and that farm butter prices less distribution costs would approximate butterfat prices.

Prices collected monthly by the Agricultural Marketing Service, and A. M. S. data showing the types of concentrates fed to milk cows in each area, were used as the basis for all estimates.

A distinction was made, on a county basis (1940 census data), between areas where whole milk sales were important, areas where sales of farm butter and of cream sold as butterfat were important, and areas where neither of these was important.

Areas where milk sales did not reach a minimum of 6,500 pounds of milk equivalent per square mile, were left blank.

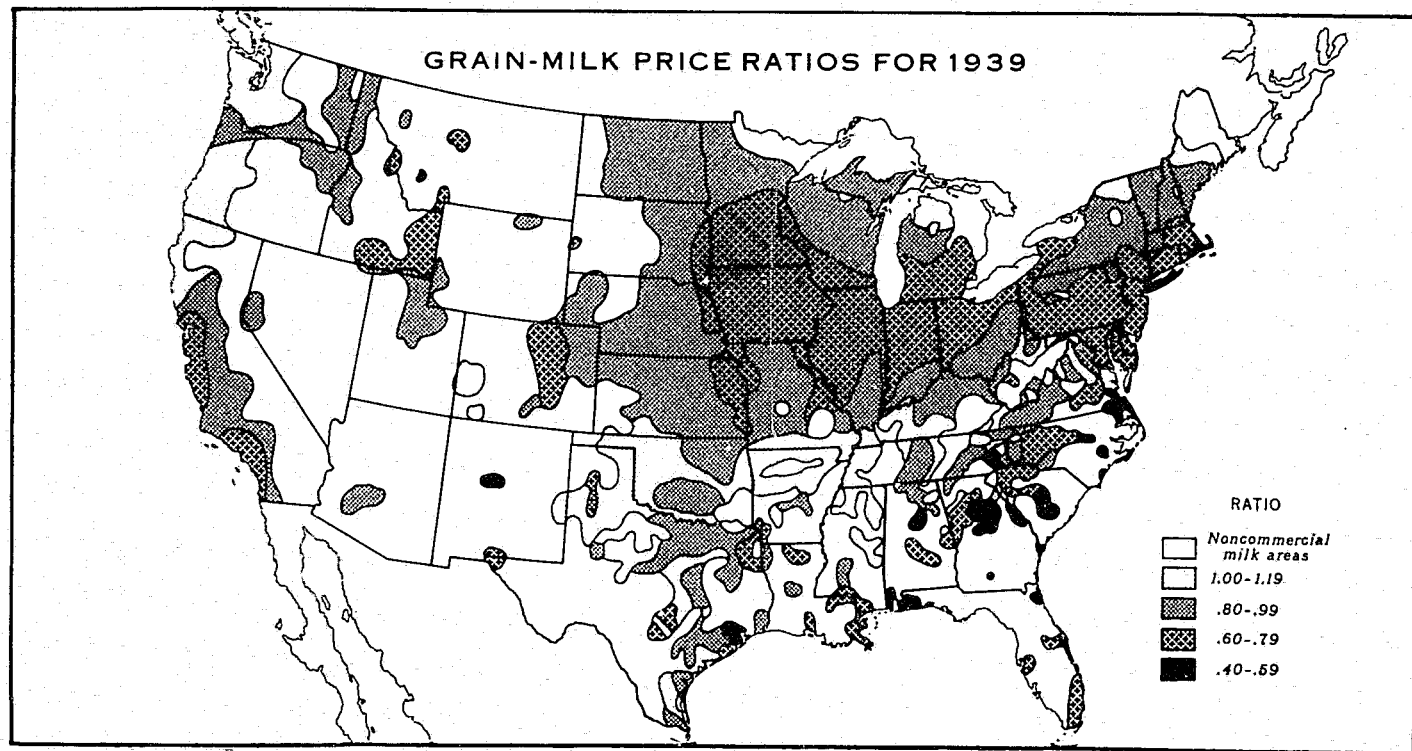


FIGURE 18.—MAP OF GRAIN-MILK PRICE RATIOS, 1939.

The farm price of 100 pounds of the concentrates most commonly fed in an area, divided by the wholesale price of either 100 pounds of milk containing 4-percent butterfat, or its milk equivalent in terms of butterfat and skim milk, whichever was more common, was used for computing the ratios.

differences in the grain-milk price ratio are counteracted, to some degree, by corresponding differences in milk prices. In general, milk prices follow the grain prices, being lowest in the central part of the country, increasing with distance both to the west and to the east, and reaching the highest point along the Atlantic seaboard.

Although the general pattern of regional prices is the same for both grain and milk, the relative differences between the prices within the different regions are not the same. Therefore, the grain-milk price ratio varies from one dairy area to another and that ratio determines to a large extent how intensively it pays to feed.

Figure 18 shows what areas have a uniform price ratio and how great are the differences between the ratios found in various areas. The most favorable price relationship prevails in some small areas along the Atlantic seaboard and the Gulf coast, for example, in eastern Massachusetts, on Long Island, around the cities of the Southeast, and along the Gulf coast.

A favorable relationship, although not quite so favorable as the one mentioned, is found in a vast area taking in not only the densely populated industrialized parts of the Eastern States, but most of the Corn Belt, and stretching to the eastern edge of Kansas, Nebraska, and South Dakota. It is rather surprising that the price ratio throughout the greater part of the Middle West is as favorable as in Connecticut, the lower part of New York State, New Jersey, Maryland, and Pennsylvania. Some areas in the Great Plains, the Rocky Mountain States, and in southern California, have the same favorable ratio.

A less favorable ratio is found in a broad belt to the north, as well as to the south and west, nearly surrounding the area just outlined. This zone also takes in good-sized areas in the Rocky Mountain States and the Pacific Coast States.

The least favorable price relationships are found in a few northern areas near the Canadian border, in a belt extending roughly from central Tennessee through the Texas Panhandle, and in the northern part of the Pacific Coast States.

Before considering more closely the influence of these price relationships it is well to recall that the most economical level of feeding is determined in the main by the relationship between feed prices and milk prices.

This reasoning applies to the level of feeding as determined by nutrients intake in relation to production. How much milk is obtained for an extra 100 pounds of grain or its equivalent in other feeds depends upon how far we have gone along the curve of diminishing returns and this in turn depends upon the inherent productivity of the cow—which, so to speak, determines the level and shape of the curve—and the quantity of total nutrients consumed.

The total ration is made up of roughages and grain. Therefore, heavy grain feeding is not necessarily the same as intensive feeding. The grain ration may be large because the roughage ration is small, and heavy grain feeding may be a sign indicating that roughage is scarce or not of the best quality. That is the case to some extent in the Eastern States and in the South.

In the Middle West, roughage supplies are usually plentiful and of fairly good quality, although unfavorable weather during the hay-curing period may still play havoc with the quality of the hay.

In the irrigated valleys of the West the pasture yields can be kept at a high level all through the summer and hay can be harvested under ideal conditions. Therefore the roughage is of high quality and great quantities of roughage are consumed. The low rate of grain feeding practiced in these areas may still coincide with a high level of total nutrients fed. Similar conditions are found in the interior parts of the Pacific Coast States.

Therefore, although price relationships constitute a major influence in determining feeding intensity, these price relationships give rise to proportional differences in grain feeding only if the quality and quantity of the roughage supply is approximately the same between regions.

To simplify discussion of the influence of the grain-milk price ratio upon the intensity of feeding, it is convenient to consider first only the midpoint value of the incremental outputs. It has been found that variations in incremental outputs center around 1 extra pound of milk per pound of grain added to the ration. Later the decrease in this rate as higher levels of feeding are reached must also be taken into account.

This simplified input-output relationship "1 for 1" can be related to prices as they are found in different parts of the country in the way presented in table 20.

TABLE 20. *Relationship between prices of grain rations and milk in different areas*

States	Price of grain per 100 pounds	Price of milk per 100 pounds	Difference between the price of 100 pounds of milk and 100 pounds of grain ¹	Ratio of grain prices to milk prices ²
	(1)	(2)	(3)	(4)
	Dollars	Dollars	Dollars	
Vermont	1.75	1.85	0.10	0.93
Connecticut	1.90	2.02	.12	.73
Northern New Jersey	1.75	2.02	.27	.67
Central Pennsylvania	1.50	1.90	.40	.79
Western Minnesota	.98	1.21	.23	.81
Iowa	.95	1.25	.30	.76
Wisconsin	1.12	1.38	.26	.81
Northern Idaho	1.05	1.25	.20	.84
Northern Arkansas	1.25	1.08	— .17	1.10
Western Washington	1.45	1.38	— .07	1.05
Western Kentucky	1.20	1.05	— .15	1.14
Western Texas	1.15	1.10	— .05	1.05

¹ Average of prices reported to the Agricultural Marketing Service for 1939.

² Column (2) minus column (1).

Column (3) divided by column (2).

Table 20, columns 1 and 2, shows how the average price of the dairy ration (grain) and the prevailing farm price of milk vary from one dairy area to another. Bearing in mind that a return of 100 pounds of milk may reasonably be expected for each 100 pounds of grain added to the ration at a rather low level of feeding, the table shows the changes in monetary returns that will result from the use of an extra 100 pounds of grain ration fed to dairy cows.

These figures (column 3) show the wide difference in the gains to be made by feeding grain to dairy cows in one region compared with another. In some areas no gain is shown. The added receipts for

milk barely cover the outlay for the extra feed. Indeed, if grain feeding were not necessary in some of these areas, to provide more protein for an unbalanced ration, or to supplement an insufficient roughage ration, grain feeding might not pay at all. As will be seen, however (figs. 5 and 6), when feeding is scarce the incremental output—the output for an additional 100 pounds of grain—increases to 150 pounds of milk, and may even approach 200 pounds. This explains why a moderate quantity of grain may prove profitable even under these price conditions.

However, in the areas where the price ratio is 1 or even more—and thus less favorable—grain will have to be used very cautiously. Here it is easy to go beyond the economic limit, especially if the roughage is of high quality.

An entirely different picture is presented under the conditions that prevail near the metropolitan centers of the North Atlantic coast. The prices here are the highest found in any of the large milk markets in the world. Yet grain prices, although higher than in the Middle West, are not nearly so high relative to milk prices. Near the big cities they are no higher than in northern New England where farmers are more than 200 miles away from their market and milk prices are low.

As the ratio of the price of grain to the price of milk drops below 1—and thus becomes more favorable—it pays to feed more heavily. If a dairy farmer were to move from western Washington to northern New Jersey and adjust his practices to the new price relationship, table 20 shows that he might reasonably expect to gain from 75 cents to close to a dollar on every 100 pounds of grain added to the ration of his cows as compared to the way he fed his herd before.

Thus, in the eastern area, the dairy farmer, by feeding a ton more grain to each of his cows per year than do his fellow farmers in butter-producing regions far away from the metropolitan milk markets, gain close to \$15 to \$20 per cow. For a herd of 20 cows, this amounts to approximately \$300 to \$400 per year. The basic input-output relationships, together with prevailing prices, largely explain why heavy feeding even of purchased grain prevails in these Atlantic seaboard areas.

In certain northern areas on the Pacific coast and in parts of the South, prices of grain are fairly high while the prices of milk and cream sold for manufacturing purposes are rather low. In some areas where cream is sold for butter production the relationship between the value of milk and of grain is such that there is no margin at all to encourage liberal feeding of grain.

In southern California, where milk prices are influenced by the market for milk in the great urban centers, price relationships are about the same as in the Middle West.

In the Middle West milk prices are fairly low but grain prices are sufficiently lower to allow for a margin in favor of grain feeding. As a matter of fact, the grain-milk price ratio is just as favorable throughout most of the dairy areas of the Middle West as in the larger part of the eastern dairy areas. Dairy farmers in the Middle West may carry grain feeding as far as farmers in the East within the same price ratio zone (fig. 18).

When in actual practice it is found that a majority of middle western

dairy farmers do not feed as heavily as in the East, the explanation probably lies partly in the fact that more and, perhaps, somewhat better roughage is available and partly in the smaller absolute margin that prevails in the Corn Belt, Lake States, and the wheat-producing areas.

Although the relationship between a grain price of \$1 and a milk price of \$1.50 per hundred pounds in the Middle West is the same as between a grain price of \$2 and a milk price of \$3 per 100 pounds in the East, the reward for converting another 100 pounds of grain into milk is 50 cents in the first case and \$1 in the second.

The small additional cost of milking and cooling and providing cans for an additional 100 pounds of milk should also be taken into consideration. However, in many cases, the fertilizer value of additional amounts of nitrogen, phosphorus, and potassium obtained in the form of the additional purchased grain may lower the net cost of the extra grain as much as the small additional costs lower the net value of the additional milk. Therefore, for the sake of simplicity, all of these additional items have been left out of consideration. If that is done, the gain in the example just given comes to 50 cents in the Middle West as compared to \$1 in the East.

In addition, there is also the factor of risk to consider. The practical dairy farmer has no means of knowing exactly the degree of intensity at which he is feeding. To play safe he will prefer to stop before the limit is reached rather than go too far. When the reward in the western areas in dollars and cents is so much lower for each of the units of feed supplied before the limit is reached, it is prudent to stop at a slightly lower rate than in the eastern areas.

This is especially the case if profitable returns can be obtained by putting the feed to other uses, such as feeding the roughage to beef cattle or sheep and the grain to beef cattle, lambs, hogs, and poultry.

INPUT-OUTPUT RELATIONSHIPS AND ORGANIZATION OF THE DAIRY ENTERPRISE

It has been shown in what way the fundamental input-output relationships govern feeding practices on dairy farms and compel dairy farmers to follow different practices in different areas depending mainly on prevailing prices of grain and milk, if farmers are to realize full returns from their dairy herds.

When only 100 pounds of milk can be obtained for an extra 100 pounds of grain—and at liberal feeding levels even less of an increase in output is obtained—dairy farmers must consider milk prices and grain prices closely and adjust the quantities fed if the relationship between the prices is altered.

It is now to be considered how this adjustment process works out on individual farms under different circumstances which correspond to conditions found on farms in various areas of the dairy regions.

It is not a question of feeding intensity alone. It is a problem of changing the quantities of feeds supplied at the same time other changes are made. Of these other changes the most important ones are concerned with the size of the herd and the cropping system followed on the farm in order to produce more and better roughage.

INCREASED GRAIN FEEDING WITHOUT EXPANSION OF HERD

On a farm where the quality of the roughage and the productivity of the cows²⁰ correspond to conditions at the series II nonpasture stations, the advantage of heavier grain feeding is reduced if the number of cows cannot be increased. In the series II experiments cows were fed all the good-quality roughage they would eat.

Under these circumstances the heavier grain feeding was not fully reflected in an increase in total feed consumed and in production because the herd if fed more grain consumes less roughage. Whether this saving in roughage can be counted at full value depends upon what other use can be made of it.

If the increase in milk production is measured against the increased quantity of grain fed and not against the smaller increase in total feed consumed, the incremental output—that is, the increase in milk obtained for an extra pound of grain—at different feeding levels will be shown in the following tabulation.

TABLE 21. *Changes in incremental output with increased grain feeding when the amount of roughage decreases*

Grain per cow per year (pounds)	Incremental output of milk (fat-corrected milk) for an extra pound of grain (pounds)
0	1.50
500	1.13
1,000	.85
1,500	.61
2,000	.40
2,500	.37

When a small quantity of grain is added to a ration consisting only of roughage, the response is 1.5 pounds of additional milk per 1 pound of additional grain. When 500 pounds of grain is fed the response is 1.13 pounds of additional milk per 1 pound of additional grain, etc. This tabulation brings out clearly the rapid decline in incremental output with increased grain feeding, if this heavier feeding is accompanied by a reduction in roughage consumption. These incremental returns indicate that, if there are no alternative uses on the farm for the roughage saved—and this might well be the case if only a fairly short period of time is considered within the same crop year—it would not pay to go much beyond 1,000 pounds of grain per cow. This applies to farms that produce high-grade roughage and operate under the price conditions which prevailed in recent years.²¹

However, the increased grain feeding may yet pay better than it appears to, judging from the incremental output shown in the tabulation, provided profitable use can be made of the roughage saved, for example, by adding more cows to the herd.

²⁰ That is, U. S. No. 1 and No. 2 hay and silage of average quality or better; and cows with an inherent productivity of 7,200 pounds of 4 percent fat corrected milk per year.

²¹ So long as the value of the additional milk is appreciably greater than the value of the additional grain, it pays to feed the extra grain. Thus, with milk at \$1.75 and grain at \$1.35 per 100 pounds, the value of 85 pounds of milk—the incremental output when 1,000 pounds of grain is fed—is worth \$1.49 and the cost of 100 pounds of grain is \$1.35—a difference of only 14 cents. The increment when 1,500 pounds of grain is fed is only 64 pounds of milk for an extra 100 pounds of grain which is worth \$1.12. This is 23 cents less than the value of 100 pounds of additional grain it took to produce it.

Prices of \$2.50 for milk and \$1.70 for grain per 100 pounds would encourage feeding beyond 1,000 pounds but not up to the 1,500 level. At 1,500 pounds of grain per cow, the value of the additional milk would be \$2.50 × 0.64 = \$1.60, which is 10 cents less than \$1.70, the value of the additional grain.

INTENSIFICATION OF MILK PRODUCTION THROUGH INCREASED GRAIN FEEDING AND HERD EXPANSION WITH NO INCREASE IN ROUGHAGE PRODUCTION

The discussion in the preceding section was limited to the possibilities of increasing milk production economically by feeding more grain per cow, without expanding the size of the herd. But in actual farm practice, there are a number of other possibilities for increasing the total milk production. For example, by purchasing additional grain it may be possible to feed more cows economically even on farms where it is impossible to increase the quantity of roughage grown.

Dairy farmers throughout the country can supplement their own feed supplies with comparative ease, by purchasing grain. But with roughages it is a different matter. As a rule, these feeds are bulky and it is not profitable to transport them very far from the place they are grown. Roughages are regularly bought only in a few areas of exceptionally high prices for milk. Thus, on many farms, the quantity of roughage that can be produced is one factor that limits the size of the dairy herd.

As pointed out later, it may be possible to increase the production of roughage on some farms with no increase in the total crop acreage by changes in the farm organization. However, these changes may take some time; and on some farms the limit of roughage production may already have been reached. But on these farms if grain feeding is stepped up, the cows will reduce their consumption of roughage to a certain extent and it then becomes possible to keep more cows with the same limited roughage supply.

The extent to which herd expansion is practical will partly depend on the barn space available, the amount of labor required to take care of the extra cows, and whether additional cows can be raised in time or bought at a satisfactory price. For the most part, these considerations are outside the scope of this study.

Changes from light to heavy grain feeding usually come about over a period of years as the price of milk increases in a given locality. As a result of regional differences in the price of milk and grain, together with a scarcity of high-quality roughage, farmers in the market-milk areas near the cities of the Northeastern United States are feeding more grain per cow than farmers in any other part of the country. In these market-milk areas of the Northeast, the number of cows and other roughage-consuming animals is comparatively high in relation to the acreage of forage crops. Milk production per cow is also high in these areas, exceeded only in certain parts of the West where a high quality of alfalfa hay and excellent pastures are available.

Table 22 shows to what extent the practice of heavy grain feeding reduces roughage consumption and makes possible an increase in the size of the herd. The rate of feeding in this table varies from no grain to 4,000 pounds of grain per cow. The cows are given as much roughage as they will consume.²² Just how many more can be kept

²² The roughage fed per cow might be arbitrarily cut down below the amounts actually consumed in this experiment by the cows that were fed most heavily on grain. But under most circumstances it would not pay to go much lower because the heavily fed cows in the experiments were approaching a roughage intake so low that it provided no more than was needed to insure against mineral and vitamin deficiencies.

may be estimated on the basis of data obtained in the two non-pasture experiments in series II. To begin with, it is assumed that a certain farm produces enough good-quality alfalfa hay to feed 20 cows if they consume roughage alone.²³ This same quantity of roughage will be enough to feed 26 cows, if they are given a heavy grain ration at the rate of 1:2.

TABLE 22.—*Application of the results of series II experiments (nonpasture) to a dairy farm with a limited supply of roughage¹ and on which increases in production may be obtained through feeding grain*

VARYING INPUTS AND OUTPUT FOR THE WHOLE HERD

Item	Unit	When amounts of grain fed per cow are 2—				
		No grain	1,000 pounds	2,000 pounds	3,000 pounds	4,000 pounds
Hay equivalent eaten per cow (total digestible nutrients X 2).	Pounds...	11,726	11,324	10,724	9,028	8,934
Number of cows required to eat all the hay.	Number...	20	21	22	24	26
Milk (4-percent fat-corrected milk) produced per cow.	Pounds	6,123	7,271	7,924	8,294	8,504
Total milk produced.....	Pounds	122,460	152,091	174,328	199,056	221,104

RETURNS

A. When prices approximate those of Wisconsin, 1941:						
Value of milk at \$1.75.....	Dollars.....	2,143	2,072	3,051	3,483	3,869
Value of grain fed at \$1.35.....	Dollars.....	0	284	594	872	1,404
Difference.....	Dollars.....	2,143	2,388	2,457	2,511	2,465
B. When prices approximate those of Massachusetts, 1941:						
Value of milk at \$3.....	Dollars.....	3,674	4,581	5,230	5,972	6,033
Value of grain at \$2.....	Dollars.....	0	420	880	1,440	2,080
Difference.....	Dollars.....	3,674	4,161	4,350	4,532	4,553
C. When prices approximate those of Wisconsin, 1939:						
Value of milk at \$1.25.....	Dollars.....	1,531	1,909	2,179	2,486	2,764
Value of grain at \$1.10.....	Dollars.....	0	231	484	792	1,144
Difference.....	Dollars.....	1,531	1,678	1,695	1,696	1,620
D. When prices approximate those of Massachusetts, 1939:						
Value of milk at \$2.50.....	Dollars.....	3,062	3,817	4,358	4,976	5,528
Value of grain at \$1.75.....	Dollars.....	0	357	748	1,224	1,768
Difference.....	Dollars.....	3,062	3,460	3,610	3,752	3,760

¹ Of the total roughage supply on the farm it is assumed that an amount equal to 117 tons of hay equivalent is available for the dairy cows.

² In addition to the specified quantities of grain the cows are fed all the good roughage they will eat.

Table 22 shows that as the quantity of grain fed is increased the total quantity of digestible nutrients in the ration also is increased but not in the same proportion because there is a decrease in roughage eaten.²⁴ The increased grain feeding results in a fairly rapid increase in milk production, an increase that is very pronounced at

²³ In these computations, the cows were assumed to have an average basic producing ability of 7,200 pounds of 4-percent fat-corrected milk and the alfalfa was assumed to be U. S. No. 1 and U. S. No. 2 in quality.

²⁴ The extent of the decrease has been estimated by Headley (5) as 0.5 pound hay for each 1 pound of grain added to a ration of roughage only. Computations from data taken at other places (4, 7, 8, 11, 12) confirm Headley's observations. In these experiments it was found that the decrease on the average varied from 0.5 to 0.7 pound.

first and less marked as larger quantities of grain are eaten. In figure 19 the digestible nutrients in grain, roughage, and total feed, as well as the milk produced shown in table 4, are plotted with reference to the vertical axis, against actual pounds of grain fed per cow plotted along the horizontal axis. This gives a straight-line increase for total digestible nutrients fed in grain. The decrease from group to group in nutrients consumed in the form of roughage is better represented by a curve.²⁵ The curve representing the best fit for the total digestible nutrients is the sum of the digestible nutrients in the grain and roughage. The actual increase in milk production from group to group closely approximates the diminishing returns curve which was fitted to the milk production data.²⁶

The next step is to determine the feeding level at which the maximum cash return or difference between the value of milk and the value of grain can be obtained from the entire herd at specified prices for milk and grain.²⁷

Table 22, section A, shows that with supplies of silage and hay corresponding to approximately 235,000 pounds (117 tons) of hay equivalent, with milk at \$1.75 and grain at \$1.35 per 100 pounds, the maximum cash return is reached when 24 cows share the roughage and consume 3,000 pounds of grain per head. However, the return of \$2,511 in this case is only \$54 more than when 22 cows consume the available roughage and receive 2,000 pounds of grain per head; and it is only \$123 higher than the return when 21 cows share the roughage and consume grain at the 1,000-pound level. In turn, feeding 21 cows at the 1,000-pound level would bring a return of \$245 above feeding 20 cows on roughage alone. Under these price conditions, it is probable that few farmers would feed much above 2,000 pounds of grain per cow. The additional return of \$54 above the cost of the grain would not induce many farmers to keep two more cows.

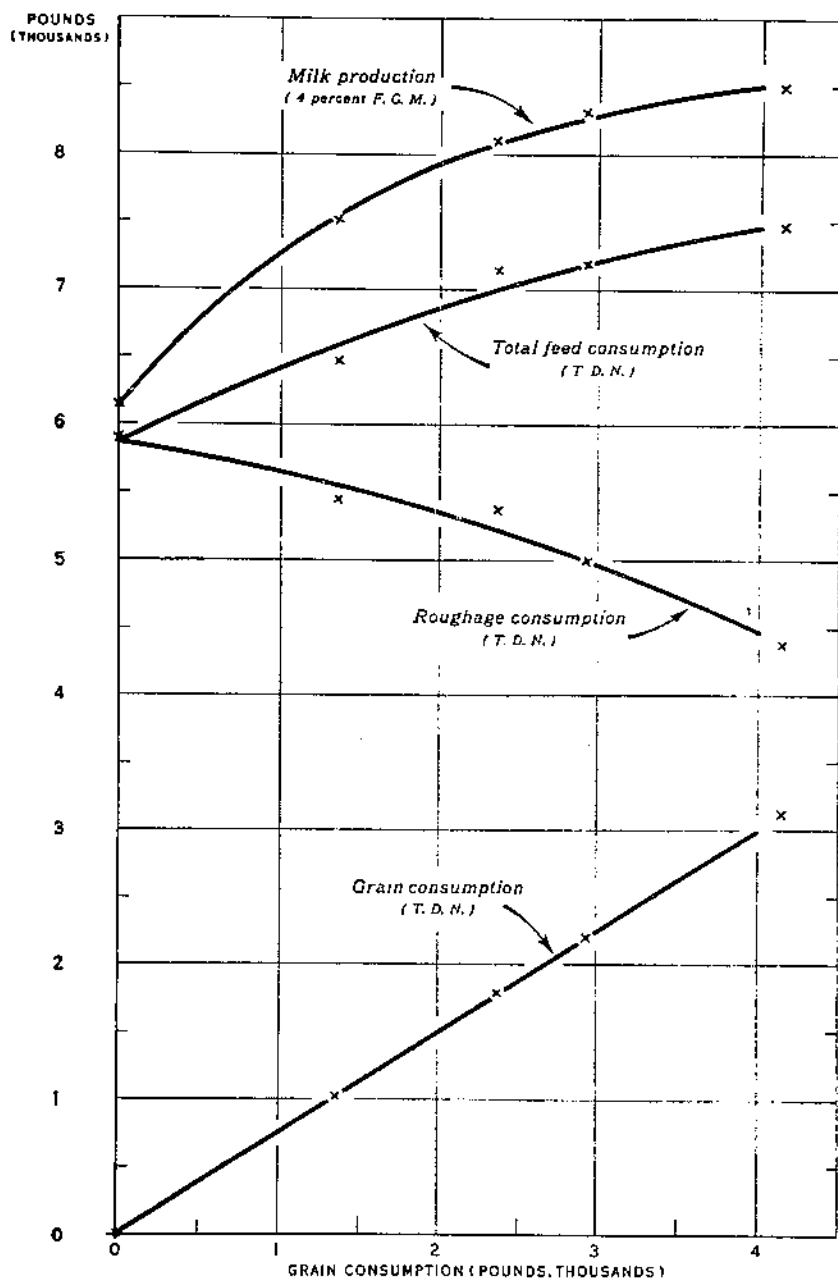
In contrast, there is much more to be gained by feeding up to 2,000 pounds of grain per cow when milk is worth \$3 a hundred and grain is worth \$2 a hundred (the price situation in much of Massachusetts in 1941). This is illustrated in table 22, section B. When 3,000 pounds of grain is fed per cow, the herd is increased to 24 cows, to consume the roughage on hand. At this level of feeding, the milk produced is worth \$4,532 more than the grain fed. This return is \$182 more than when grain is fed at the 2,000-pound level, and \$371 more than the return from grain feeding at the 1,000-pound level.

Lower prices for milk and grain, such as those which prevailed in Wisconsin in 1939, decrease the advantage of heavy grain feeding. Table 22, section C, indicates that in this situation little advantage

²⁵ The curve shown is based on the equation $Y = 5863 - 0.152g - 0.000492g^2$ in which Y is the pounds of total digestible nutrients in roughage, and g the actual pounds of grain.

²⁶ The curve is based on the equation $Y = 8781 - 2658(0.56794)^{\frac{g}{1000}}$ in which Y represents the pounds of 4-percent fat-corrected milk produced per cow and g represents the pounds of grain eaten per cow.

²⁷ Cash return as used here is not to be confused with net income. It is merely that "difference" which at various levels of feeding is available for paying other costs of producing and marketing milk. Any attempt to itemize those costs in detail is outside the scope of this study, since they would vary from farm to farm and from region to region. On the other side of the ledger, however, more intensive feeding means that more manure will be available for maintaining the fertility of the land. This added value is sufficient to be considered in any attempt to estimate all factors bearing on the economy of more intensive feeding.



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FIGURE 19.—RESPONSE IN MILK PRODUCTION AND ROUGHAGE CONSUMPTION TO INCREASED GRAIN FEEDING WHEN COWS ARE FED ROUGHAGE, FREELY AND GRAIN IN PROPORTION TO MILK PRODUCTION. AVERAGES FOR TWO STATIONS CONDUCTING SERIES II EXPERIMENTS—NONPASTURE.

is to be gained from feeding above the 1,000-pound level. At the 1,000-pound grain level, the return from 21 cows is \$1.678. To feed 22 cows at the 2,000-pound level would add only \$17 to this return, and to feed 24 cows at the 3,000-pound level would add but \$1 more, not considering the cost of providing replacements for the extra cows.

In the search for the most profitable feeding level it has been realized that in actual practice this problem is closely connected with the problem of the size of the herd and, incidentally, much light has been thrown on the problem of what is the most profitable size of herd. It has been indicated that the feeding level, the size of the herd, and the roughage supply must be adjusted together in order to reach maximum returns from the dairy enterprise.

It is an interesting fact that in dairy areas where the margin between the value of 100 pounds of milk and 100 pounds of grain is small, the penalty for not keeping the right size of herd is not very great. The farmer and his family may, year after year, needlessly house, milk, feed, and care for 24 cows instead of 20 without being paid for it. But, although much labor has been wasted, there is no additional penalty in dollars and cents.

INTENSIFICATION OF DAIRYING THROUGH INCREASED ROUGHAGE PRODUCTION

Earlier pages of this bulletin have shown to what extent milk production per cow can be increased by heavier grain feeding. They have also indicated to what degree an expansion in the size of the herd is made possible by the reduction in the consumption of roughage which occurs simultaneously with increased grain feeding.

On most farms, however, it is possible to make an even greater expansion in size of herd and in production of milk by increasing the production of home-grown roughage in addition to feeding grain more heavily. This increase in roughage production can be accomplished, in time, without increasing the total crop acreage. In this fashion, some dairy farmers have doubled and trebled the number of cows in their herds, and have increased milk production even more, without increasing the size of their farms.

This trend may be illustrated best by comparing various representative types of dairy-farm organization. For example, table 23 shows a type of farm organization that was fairly common in the Great Lakes States 30 years ago and that still exists, though it is less common today. Hereafter, it will be called farm A to distinguish it from other types of organization discussed later.

Similar changes have occurred in other areas with different prices. Examples could be multiplied, but this illustration will serve to show the application of the experimental results to dairy farming.

To simplify the work of estimating how much milk could be produced from this much feed, the grain was reduced to pounds; and the roughage was reduced to hay equivalent, also expressed in pounds, figuring 3 pounds of silage equal to 1 pound of hay. In these terms, the total feed-crop production of the farm in table 23 amounted to 36,000 pounds of grain and 113,333 pounds of hay equivalent.

TABLE 23.—*Less intensive type of organization on a 120-acre dairy farm in Wisconsin (farm A)*

Item	Unit	Production
Crops:	<i>Acres</i>	
Corn grain	10	300 bushels.
Corn silage	10	80 tons.
Small grains	20	600 bushels.
Clover hay	20	30 tons.
Total cropland	60	
Pasture	60	
Livestock:	<i>Head</i>	
Cows	13	
Heifers	4	
Calves	3	
Horses	3	

After deducting the grain and hay required for the horses and young stock, 27,600 pounds of grain and 83,000 pounds of hay equivalent were left for the cows or for other disposition.

The next step was to find how much of this feed could be used profitably in milk production, assuming 1939 prices in the Great Lakes States. Inspection of the experimental data, discussed earlier, indicated that the most profitable level of feeding probably would be close to 1,000 pounds of grain per year for each cow.

Assuming that the cows were kept on pasture for 5 months of the year, which was common practice for this type of farm, the 83,000 pounds of hay equivalent would be approximately the quantity consumed by 13 cows during 7 months of barn feeding.²⁸

At this level of feeding, the 13 cows on farm A would consume 13,000 pounds of grain, leaving the remaining 14,600 pounds for sale or for other uses. If sold, this surplus grain would be worth around \$160 at a price of \$1.10 per 100 pounds.

Average milk production at the 1,000-pound level of grain feeding is close to 7,300 pounds per cow. At 1939 prices in this area, amounting to \$1.25 per 100 pounds of milk, the total production from 13 cows would be worth approximately \$1,185. Added together, the gross value of the surplus grain and the milk from this farm would be worth close to \$1,345.

The ratio of grain feeding to milk production followed in this plan was approximately 1:7, but with high-quality roughage the incremental output at the 1,000-pound level of feeding is only 1 to 0.85. (See p. 68.) At the prices assumed above, the value of 85 pounds of milk is \$1.06 and the value of 100 pounds of grain is \$1.10. This indicates that the 1,000-pound level of grain feeding has already gone slightly beyond the most profitable point at these prices.

Obviously, then, it would be unprofitable to attempt to increase milk production by heavier grain feeding so long as that particular price relationship exists and so long as hay and corn silage of high quality are available. It also would be obviously unprofitable to add

²⁸ Experiments already cited indicate that cows barn-fed all year and receiving 1,000 pounds of grain will consume approximately 11,300 pounds of hay equivalent, or an average of 944 pounds per month. At that rate, cows on pasture 5 months would consume 6,660 pounds of hay equivalent in 7 months of barn feeding; and 13 cows would consume, in round numbers, approximately 85,900 pounds of hay equivalent. It is assumed the total quantity of grain fed would remain about the same whether the cows were on pasture part of the time, or barn-fed all year.

another cow to the herd unless more roughage or a better quality of roughage could be obtained, since a decrease in the quantity of roughage fed per cow would necessitate heavier grain feeding.

What possibilities are there, then, for increasing the net return by changing the type of farm organization without altering the size of the farm? Some dairy farmers in the Great Lakes States have increased their production of roughage by changing their crop rotations, by utilizing a large share of the crops as roughage instead of as grain, and by increasing their crop yields through the use of manure supplemented in some cases by purchased fertilizers.

These changes to a more intensive system of dairy farming are illustrated in the 120-acre farm in table 24. For convenience, this farm will be referred to hereafter as farm B. During the last 10 to 30 years many farms have changed so that they are now like farm B.

TABLE 24.—*More intensive type of organization on a 120-acre dairy farm in Wisconsin (farm B)*

Item	Unit	Production
Crops:		
	<i>Acres</i>	
Corn silage	20	200 tons.
Small grain	10	500 bushels.
Alfalfa	30	75 tons.
Total cropland	60	
Pasture	60	
Livestock:		
	<i>Head</i>	
Cows	24	
Heifers	8	
Calves	6	
Horses	3	

Feed production on this farm amounts to 16,000 pounds of grain and 283,400 pounds of hay equivalent. Of this, 10,800 pounds of grain and 51,400 pounds of hay equivalent were allotted to the horses and young stock. This left 5,200 pounds of grain and 232,000 pounds of hay equivalent for the cows or for other uses.

It was assumed that the 60 acres of pasture on farm B was about equal in quality to the pasture on farm A. Preliminary calculations then indicated that if the number of cows were increased enough to use all the roughage available, the pasture would provide feed for only 2 months. Barn feeding with roughage would be required the remaining 10 months. It was also assumed that the rate of grain feeding remained at 1,000 pounds per cow. On this basis, the 232,000 pounds of roughage left after other stock had been cared for would be sufficient to take care of 24 cows.²⁹

The 24 cows on farm B would then require 24,000 pounds of grain. As only 5,200 pounds of grain was left after deducting the needs of other livestock from the total produced, it would be necessary to buy 18,800 pounds of grain.

At the 1939 Wisconsin prices of \$1.10 per 100 pounds, this purchased grain would cost \$207. And at \$1.25 per 100 pounds for milk, and an average of 7,300 pounds per cow, the milk produced in a year by 24

²⁹ Estimated, as in the case of farm A, on the basis of 944 pounds of hay equivalent per cow for each month of barn feeding or 9,440 pounds for 10 months.

cows would be worth \$2,190. Subtracting the value of the purchased grain from the value of the milk leaves about \$1,980.

To recapitulate, the value of the milk from 24 cows on farm B would be around \$1,980 after deducting the cost of grain purchased; and the value of the milk from 13 cows on farm A would be around \$1,345 after adding the value of the surplus grain sold. This indicates that a change in the type of farm organization increased the gross return by approximately \$635. It is to be assumed that additional sales of about two cows and five calves from farm B would add another \$125, raising the total difference in gross return to about \$760.

The net increase in cash returns resulting from the change in farm organization would be less than \$760, however, for there would be some increase in expenses other than the grain which already has been considered.

The increase in general expenses resulting from more intensive dairy farming varies greatly on different farms. For example, surplus family labor is available on some farms and can be more fully utilized as crop production becomes more intensive and more livestock is kept. Labor-saving machinery and equipment is widely used now, and with improved barns and haymows enable a person to accomplish more work in a given time than can be done without them. Allowing for these and other differences, table 25 contains a liberal estimate of additional expenses involved in the increased production of feed and increased number of cows on farm B as compared with farm A.

It has already been estimated that the change from a less intensive type of dairy farming, as represented by farm A, to a more intensive type as represented by farm B, increased the gross returns by around \$760. Subtracting the \$313 added expenses, shown in table 25, leaves \$447 added net income from the more intensive type of farming with no change in the total acreage of crops.

TABLE 25.—Additional expenses due to more intensive farming—farm B

Labor—extra for haying and silo filling, 2 months.....	\$70
Silo filling, machine and power hire.....	15
Grain (already deducted).....	—
Buildings upkeep.....	50
Milking-machine upkeep.....	20
Silo-delivery rake, hay loader, power fork, lime-sprender upkeep.....	30
Alfalfa seed for 10 acres—100 pounds.....	21
Limestone—10 tons.....	20
Fertilizer—3,000 pounds of 0-20-20.....	60
Veterinarian and medicine—\$0.65 per cow for 11 cows.....	7
Taxes and insurance.....	20
Total.....	313

In ascertaining whether the less intensive or the more intensive type of dairy farming is most desirable, an important consideration is the frequency or infrequency of drought. In areas where unfavorable years for crop production are fairly common, the intensive dairy farm runs the risk that the hay and silage crops may not furnish enough roughage for the larger number of livestock. The only chance for adding to the roughage on such a farm would be to cut the oats for hay. Another alternative would be to feed more grain in place of part of the roughage, since nutrients usually can be bought more cheaply in the form of grain than in the form of hay. This is particularly true in a year when the hay crop is short.

The less intensive dairy farm, with fewer cows and with 20 acres of corn, 20 acres of small grain, and 20 acres of clover, is much less likely ever to be short of roughage. Corn from half the corn acreage normally goes into the silo, and in case of a poor yield all of the corn crop may be used as roughage.

Pasture improvement gives an opportunity for even more intensive dairy farming. For example, the 232,000 pounds of hay equivalent available for milk cows on farm B would carry 35 cows for 7 months, provided the 60 acres of pasture could be improved sufficiently to carry them the other 5 months. This, of course, would necessitate the purchase of still more grain.

So far in this discussion, the 1939 prices of grain and milk in Wisconsin have been assumed. But if the price ratio became enough more favorable to justify feeding grain at a 3,000-pound level instead of a 1,000-pound level, the process of intensification could be carried still farther. Feeding 3,000 pounds of grain per cow reduces the required hay equivalent to 825 pounds per month. This would make it possible to carry 40 cows instead of 35 for 7 months barn feeding, by using all available roughage and buying approximately 115,000 pounds of grain.²⁰

Many dairy farmers who are near cities where prices of fluid milk and feed are high buy all their cows. This would release the roughage consumed by young stock, making it possible to increase further the size of the herds on those particular farms. Obviously, this can be done only so long as other farms produce a surplus of young dairy stock for sale. Dairy areas in which milk and feed prices are low usually produce a surplus of young dairy stock for sale.

The use of tractors and trucks for farm work instead of horses would also release additional roughage, increasing the total quantity of feed available for milk cows, both on individual farms and throughout the country as a whole.

Assuming 7 months of barn feeding at the 3,000-pound grain level, it would take 40 cows to consume all the roughage produced on farm B (283,400 pounds of hay equivalent). This extremely intensive type of dairy farming is not unusual near the large eastern fluid-milk markets. A fair proportion of these intensive farms are highly profitable although they must draw on other farms for grain and replacements.

INTERPRETATION OF EXPERIMENTAL RESULTS

Different ways of analyzing the records obtained from the input-output experiments have been presented, together with the information extracted from these data. The purpose of the study was to ascertain some of the most important of the input-output relationships in milk production and to use this knowledge for making recommendations for use which would enable dairy farmers to approach more closely those feeding practices which are the most profitable under varying price conditions.

In order to utilize the combined experience obtained from the experiment and interpret it in a way that can be applied directly to practical dairy feeding, it is necessary to make certain generalizations

²⁰ That is, 827 pounds of hay equivalent times 7 months equals 5,789 pounds per cow. Divided into the 231,933 pounds of hay equivalent available, it indicates enough roughage is available for 40 cows.

and to smooth the data so they may be used as a basis for feeding recommendations.

In making recommendations for practical feeding, feed inputs may be expressed in terms of many different units. They may be stated in pounds of silage, hay, and grain; in hay equivalent and grain, or in pounds of nutrients, net energy, starch values, feed units, or some other unit that measures feeding value. Some such feed units are used in all feeding standards. To most dairy farmers, however, recommendations regarding the most economical feeding level will be most useful if the recommendations indicate a certain rate of feeding grain in addition to roughage. By itself, the rate of grain feeding has no meaning. The intensity of feeding depends upon the nutrient intake in the form of both roughage and grain. Therefore, changes in the rates of grain feeding will result in corresponding changes in the rates of total feed consumption only if the roughage is held constant or if roughage consumption changes in a regular way together with changes in grain feeding.

On many dairy farms in the Eastern States roughage is fed sparingly, and roughage consumption will remain constant with increased grain feeding because even at high levels of grain feeding the cows will consume all the roughage offered to them. However, on most dairy farms roughage is fed freely, and with increased grain feeding roughage consumption will decline. But if the roughage is of lower quality than that used in the experiments the decline in roughage consumption may be smaller than in the experiments. On a given farm the roughage consumption usually varies within a limited range, e.g., from 2.0-2.5 pounds per 100 pounds of body weight.

In the experiments it was found that there was a very definite tendency for the cows to reduce roughage consumption as grain feeding was pressed to higher levels. When no grain was fed, the cows consumed roughage at the rate of 2.9 pounds of hay equivalent for each 100 pounds of live weight; but at the heaviest level of grain feeding this rate of roughage consumption dropped to 1.7 pounds of hay equivalent per 100 pounds of live weight.

The same tendency was found in the intermediate groups but not with perfect consistency. This was not surprising because at some of the stations which contributed to the six different feeding-level groups (table 11) the cows were not given a chance to eat as much roughage as they wanted.

At other stations the cows were fed roughage freely, but the total number of observations from these stations was not sufficient to provide perfectly regular and consistent changes from one level to another. It was thought, however, that the irregularities found in the observed data were caused by disturbing factors, the influence of which did not average out in the groups with the restricted number of observations obtained. If more and larger groups could have been fed under identical conditions at the different levels, the group averages would probably have shown much smaller variations from the trend which showed up so clearly. Therefore, by the fitting of trends to the observations and smoothing of averages the true average relationship should be approached more closely than if the actual unadjusted observations had been used.

For these reasons, it was decided that on the basis of the averages obtained from all records a generalized feeding chart should be

constructed. This chart should express the experimental results in the form of smoothed averages which related the typical changes in roughage and grain consumption and in milk output to ratios of feeding grain in addition to roughage, as it was done in experiment II. These changes should cover the full range of grain feeding from the level at which no grain at all was fed to a rate of grain feeding of 1:1.8, which resulted in a consumption of 5,400 pounds of grain per cow per year.

EXTENSION OF INPUT-OUTPUT CURVE TO LOW LEVELS OF FEEDING

The six levels of feeding showing average input-output relationships for all cows at nine stations ranged from 1 pound of grain for each 4.4 pounds of milk produced, to 1 pound of grain for each 1.8 pounds of milk. But in practice, under certain circumstances, it may pay to feed below this range. Therefore in order to cover also these lowest parts of the range the next consideration was how much is production reduced if cows are fed at low levels of feeding.

These low levels were represented in the input-output experiments by the groups fed no grain at all and the groups fed only 1 pound of grain to 6 pounds of milk. Of the nine stations that contributed to the general input-output analysis only two, Maryland and South Dakota, had groups that were fed roughage as the sole ration. In comparing the roughage-alone level with the 1 to 6 levels of these two stations, the problem of differences in environment between stations was met again. It was believed that, to avoid attributing to feeding some influences on production actually caused by these differences in environment, comparisons should be made only between groups of cows at the same station.

At each station a group of cows fed roughage only was balanced with respect to body weight and basic producing ability against a group fed 1:6, and the data from the two stations were combined. The combined roughage group produced 5,942 pounds of 4-percent fat-corrected milk and the 1:6 group 7,684 pounds. The roughage group ate more hay (517 pounds) and more silage (852 pounds) but received no grain at all; while the group fed 1:6 consumed 1,369 pounds of grain per cow. The hay fed to both groups averaged U. S. No. 1, and the silage was made from well-cared corn. The quantity of digestible nutrients consumed by each group was 10 percent above the Haeccker standard for maintenance and milk combined. Results of this part of the study are shown in table 26.

TABLE 26. *Roughage versus grain feeding at the rate of 1 pound for each 6 pounds of 4-percent milk at the Maryland and South Dakota stations¹*

Item	14 cows fed roughage alone	15 cows fed grain at the rate of 1 pound for each 6 pounds of milk
	Pounds	Pounds
Average live weight	1,077	1,189
Basic producing ability, 4-percent, fat-corrected milk	7,184	7,202
Production, 4-percent fat-corrected milk	6,089	7,582
Grain (75-percent total digestible nutrients)		1,369
Alfalfa hay—U. S. grade, high No. 2	6,381	5,864
Corn silage	12,915	12,063
Total hay equivalent consumed	11,296	10,701
Yearly intake (total digestible nutrients)	5,737	6,506
Hay equivalent per day for each 100 pounds live weight	2.87	2.40

¹ Average per cow per year.

The roughage group produced 80.4 percent as much milk as did the group fed 1:6. This result is in reasonably close agreement with other work by the Bureau of Dairy Industry at Huntley, Mont. (8), where the roughage ration produced 82 percent as much milk as the 1:6 rate of grain feeding. It also checks well with results obtained by Sherwood and Dean (12), but not so well with those of Headley (5). The cows in Hendley's experiment performed relatively better on a ration of alfalfa hay alone.

In order to cover the full range of grain feeding it was then necessary to combine the input-output information obtained from the comparison of the two lowest levels of feeding, the roughage-only level and the 1:6 level with the general input-output relationship ascertained from the six different levels of feeding at nine stations.

The averages showing feed inputs at intermediate levels were biased to some degree because the stations conducting series I experiments did not feed as much roughage as the cows would consume. It was thought that this bias could best be eliminated by assuming a straight-line trend in the change in rate of roughage consumption from the lowest to the highest level of feeding. For some of the intermediate groups the average consumption arrived at by the application of this trend corresponds closely with the consumption actually found in the experiments. Column 3 in table 27 shows the figures for roughage consumption arrived at by the outlined method, and by taking into account the fact that the body weight of the cows increased from the lowest to the highest fed groups and that large cows consumed more roughage than small cows.

TABLE 27.—Smoothed data from 6 feeding levels at 9 stations and 2 feeding levels at 2 stations, prepared for the purpose of estimating the most profitable rate at which to feed grain

Level of feeding from lowest to highest	Live weight	Roughage expressed as hay equivalent per 100 pounds live weight	Total hay equivalent fed in a year	Grain fed in a year	Grain fed during lactation period	Adjusted total digestible nutrients	Estimated quantities of milk these feeds would produce	Milk produced per pound of grain fed during lactation
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
1	1,080	2.9	11,338	0	0	5,102	6,438	
2	1,090	2.8	11,018	450	420	5,476	7,020	16.7
3	1,100	2.7	10,751	900	840	5,842	7,517	8.9
4	1,110	2.6	10,447	1,350	1,260	6,201	7,947	6.3
5	1,120	2.5	10,136	1,800	1,680	6,551	8,317	5.0
6	1,130	2.4	9,847	2,250	2,100	6,400	8,639	4.1
7	1,140	2.3	9,592	2,700	2,520	6,638	8,915	3.5
8	1,150	2.2	9,356	3,150	2,940	6,868	9,156	3.1
9	1,160	2.1	9,118	3,600	3,360	7,091	9,406	2.8
10	1,170	2.0	8,871	4,050	3,780	7,307	9,550	2.5
11	1,180	1.9	8,646	4,500	4,200	7,511	9,708	2.3
12	1,190	1.8	8,411	4,950	4,620	7,713	9,847	2.1
13	1,200	1.7	8,185	5,400	5,040	7,905	9,971	2.0

Grain feeding increased from no grain at all at the lowest level to 5,400 pounds per cow per year at the highest level. A straight-line trend was also applied to find the grain consumption for the intermediate groups, thereby smoothing the averages showing grain consumption from group to group.

Changes in total feed consumption from the lowest to the highest level were arrived at by adding roughage consumption and grain consumption.

The resulting figures for total feed consumption were then checked against the average input-output relationship arrived at by the analysis of all records classified into six different levels of feeding (table 27, fig. 20). This check against the experimental data showed that at the highest levels of feeding there was a considerable degree of conformity. But at intermediate, and especially at lower levels, smoothed averages indicated larger feed inputs than were actually found in the experiments. It was thought that this discrepancy probably arose because the rations arrived at by assuming perfectly regular changes from one feeding level to another contained somewhat more roughage and less grain than the average ration eaten by some of the groups in the experiments. It is a well-recognized principle that if roughage consumption is increased greatly, the productive value of the nutrients in roughage is reduced to some extent, although there is hardly any experimental data which would indicate how great this reduction should be.

If it be assumed that the reduction would cause the productive value of the hay equivalent to decrease from 52 percent when only 17 pounds per cow per day is eaten at the highest level of feeding to 45 percent when 29 pounds of hay are consumed per cow per day at the lowest level of feeding (table 27), and the nutrients of the computed rations are reduced so as to reflect this change, then the computed averages correspond closely to the feed inputs actually found in the input-output experiments. Therefore, the smoothed averages showing feed inputs were adjusted so as to bring them in line with the results of the input-output experiments.

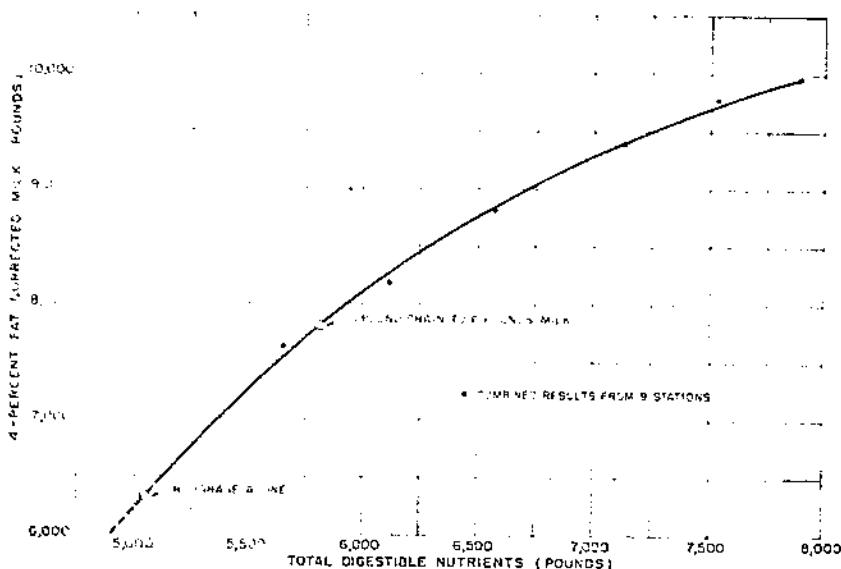


FIGURE 20. CHART, BASED ON THE SMOOTHED DATA OF EXPERIMENT SERIES I AND II COMBINED, AND ROUGHAGE ALONE OF SERIES II, NONPASTURE STATIONS (TABLE 27), AFTER ADJUSTMENT OF SERIES II DATA FOR DIFFERENCE IN BASIC PRODUCING ABILITY OF THE COWS.

DAE 31199

APPLICATION OF RESULTS TO PRACTICAL DAIRY FEEDING

The smoothed averages arrived at in the way described for feed inputs in terms of grain and hay equivalent and milk output in terms of 4-percent fat-corrected milk, were used as the basis for making a general feeding chart which would show the most profitable level of feeding under conditions of varying prices for roughage, grain, and milk.

Along the horizontal axis are plotted widening ratios of the price of roughage (hay equivalent) to the price of milk and along the vertical axis are widening ratios of grain prices to milk prices. When these two ratios are computed from local prices the most profitable rate of feeding grain can be located on the chart. The intersection of a vertical line through the prevailing roughage-milk price ratio and a horizontal line through the grain-milk price ratio will locate a point on the chart. The curve passing through or nearest to this point will indicate the most profitable level of grain feeding.

The returns over cost of feed were calculated for various grain-milk and hay-milk price ratios at each level of feeding shown in table 27. Then the ratio of grain to milk that showed the greatest returns over cost of feed was plotted in figure 21.

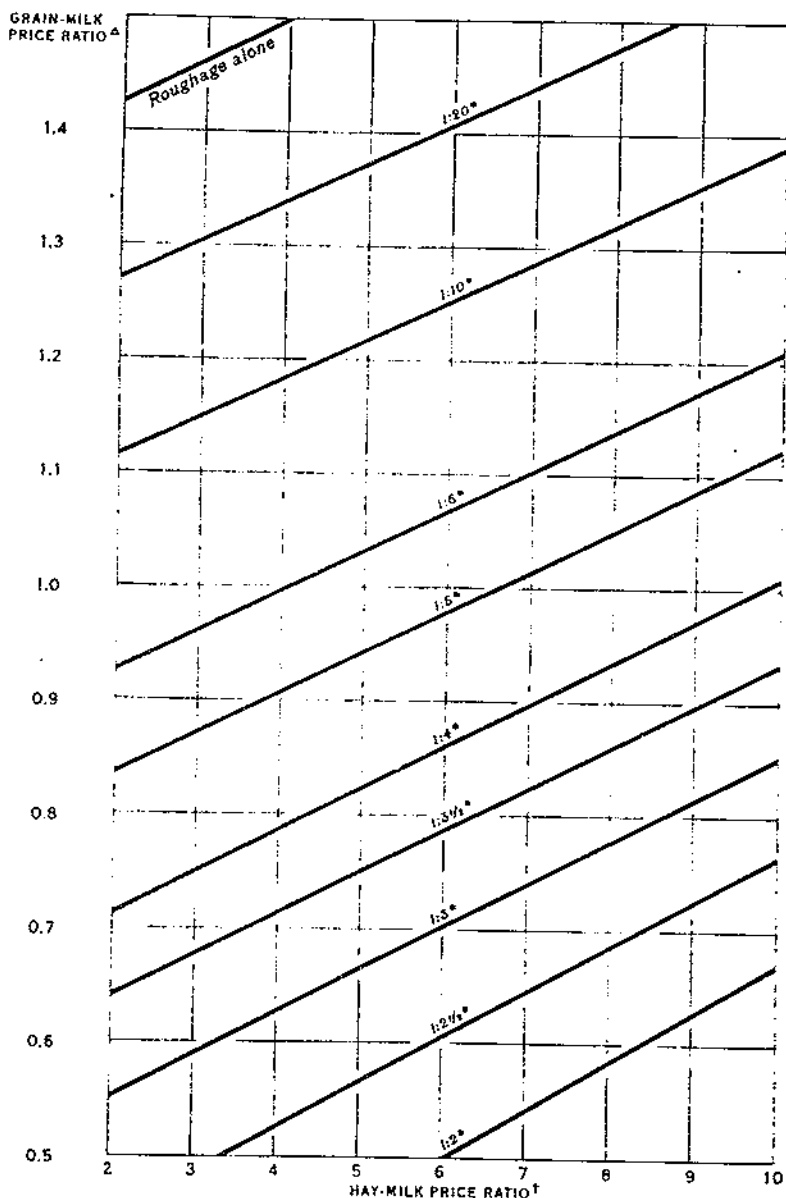
In using this table it should be borne in mind that the table has been based upon the experimental evidence obtained from herds that were fed roughage freely and, in addition, received grain at certain rates in proportion to milk production. It is true that four of the herds were actually fed according to the feeding standard and that this method of feeding required some restriction of roughage feeding during certain parts of the lactation period. But records obtained in this way were adjusted when the combined input-output curve shown in figure 20 was prepared to serve as a basis for the chart presented in figure 21, so as to bring all records to a uniform basis which would correspond to the feeding method used in series II experiments where roughage was fed freely.

The roughage used in the experiments was of good quality but it was not any better than the quality found on many dairy farms. Most of the hay used was alfalfa hay which graded U. S. No. 2. The silage, mostly corn silage, was of average quality or slightly better.

Productivity of the cows at most of the stations corresponds to that of cows found in the herds of farmers who belong to dairy-herd-improvement associations. A few stations had cows of even higher productivity.

Thus, in general, the experimental conditions correspond to conditions on farms where there are good cows, where the roughage is of average quality or slightly better and is fed freely, and where grain is fed at certain rates in proportion to milk production, for example, 1:3 or 1:4, etc. It must be added that the table assumes that the same rate of grain feeding is maintained throughout the lactation period, that is, that the cows are not fed 1:2 during the early part and 1:3 during the late part of the lactation period but at one rate or the other throughout the whole lactation period.

In order to use the table to find out what the most profitable level of feeding will be for a particular herd, it is necessary to know the local prices of milk, grain, and roughage. The local farm price for grain divided by the milk price obtained gives the grain-milk



* COWS FED 1 POUND OF GRAIN TO EVERY 3 POUNDS OF MILK DURING THE LACTATION PERIOD ARE SAID TO BE FED AT THE LEVEL OF 1:3; ETC.

^A PRICE OF 100 POUNDS OF GRAIN DIVIDED BY PRICE OF 100 POUNDS OF 4-PERCENT FAT-CORRECTED MILK.

[†] PRICE OF 1 TON OF HAY OR HAY EQUIVALENT DIVIDED BY PRICE OF 100 POUNDS OF 4-PERCENT FAT-CORRECTED MILK.

FIGURE 21. CHART SHOWING THE MOST PROFITABLE LEVEL OF GRAIN FEEDING, WHEN COWS HAVE FREE ACCESS TO GOOD ROUGHAGE.

BAE 39517

price ratio. A good approximation to the ratio between the price of roughage and the price of milk may be obtained by dividing the local price per ton of hay by the local milk price.

All the prices used in these computations should be prices at the farm. The price of purchased grain should be the price for grain delivered at the farm. If the farm uses mostly home-grown grain, the price should not be the price obtained at the local elevator, but the slightly lower price at the farm, taking into consideration the fact that feed grain used on the farm often is of a slightly lower quality than grain prepared for sale and that it costs something to transport the grain from the farm to a local market.

It may be a difficult thing to estimate accurately the true value of the supplies of roughage. It may be assumed that nutrients in silage cost the same as nutrients in hay but in many areas even hay is bought and sold so rarely that it is difficult to estimate what is really the true value of a ton of hay on the farm. However, in reality it makes very little difference whether the price of hay is estimated accurately. Even if very large errors are made in estimating the price of hay, the feeding level indicated by the table will not be changed very much.

With respect to the price of grain, it is a different matter. Any change in the grain price is reflected fully in the feeding level indicated by the table.

The price of milk to be used also is the farm price, or what might perhaps better be called the barn-door price. In other words, not only the cost of transporting the milk from the farm to a local dairy plant, but also the cost of cooling the milk, providing cans for transport of the milk, and, if cream is sold, of separating must be deducted from the milk price to obtain the barn-door price. On the other hand, if butterfat is sold the value of the skim milk for use on the farm should be added to the value of the butterfat sold.

When the actual farm prices have been determined as accurately as possible, it only remains to compute the grain-milk price ratio by dividing the grain price by the milk price and the hay-milk price ratio by dividing the hay price by the milk price and locate on the chart the nearest heavy line that indicates the most profitable feeding level under the prevailing price conditions.

If the chart were to be used in the most accurate manner the percentage of fat of the milk should also be taken into account.⁴¹ Actually, the error involved in omitting these computations is so small that it may be disregarded. The chart may, therefore, be used as if it applied not only to the production of 4-percent fat-corrected milk but to milk of other fat percentages as well.

An important limitation in the use of figure 21 to find the most profitable level of grain feeding should be pointed out. This figure

⁴¹ The price of 100 pounds of 4-percent fat-corrected milk should be computed by multiplying the price of the fat percentage actually produced by a factor, converting it to the corresponding price for 4-percent fat-corrected milk. This price per 100 pounds of 4-percent fat-corrected milk should then be used in computing the grain-milk price ratio and the hay-milk price ratio. The feeding chart then indicates what rate of feeding is the most economical when 4-percent fat-corrected milk is produced. In order to find out what rate of feeding is most economical for a certain herd which perhaps produces milk with only 3.5 percent fat, the ratio which indicates the rate of feeding should again be corrected by applying the same conversion factor as before. In this way another and different rate of feeding is determined which, under prevailing price conditions, applies to the herds which produce milk of 3.5 percent fat.

was prepared on the basis of results obtained by liberal feeding of good roughage, in such quantities as the cows would eat. A large proportion of the cows in the United States are not fed roughage of as good quality nor as liberally as were the cows in this investigation. In some areas the quantity of roughage fed is limited because of the high cost of roughage in relation to grain but shortcomings with respect to quality of the roughage is the main reason for the low consumption of roughage by most cows. It is a well-known fact that the palatability of poor roughage is less than that of good roughage. Consequently, cows will eat smaller quantities of the poor roughage.

Table 28 has been prepared to show the most profitable level of grain feeding when a limited amount of good roughage is fed.

This table is based on series I experiments which are summarized in table 3 (p. 24) and figure 8 (p. 23). The cows were fed approximately 1.85 pounds of hay or its equivalent daily for each 100 pounds of live weight except at the highest level of feeding. In these calculations the hay equivalent was held constant at 1.85 pounds per 100 pounds of live weight and the digestible nutrients fed above these amounts were converted to a grain-equivalent basis by dividing by 0.75. Thus, in using table 28, the ratio between the price of grain and the price of milk shows approximately how many pounds of milk it takes to pay for 100 pounds of grain under the conditions specified.

TABLE 28.—Data for determining the most profitable level of feeding when a limited amount of good-quality roughage is fed¹

Ratio of grain or grain equivalent ² fed to milk produced	In terms of 11-necker standard (exclusive of main- tenance)	Incremental output (addi- tional milk produced when an additional 100 pounds of grain or grain equivalent ² is fed)
	Percent	Pounds
1:4	82	170
1:3½	88	147
1:3	96	110
1:2½	108	87
1:2	128	55

¹ The hay was alfalfa and graded about U. S. No. 2.

² Digestible nutrients divided by 0.75 after allowing for the feeding of 1.85 pounds of hay or its equivalent for each 100 pounds of live weight.

Next, in table 28, in the column called "Incremental Output," that figure which is nearest to the grain-milk price ratio is located. For example, if the grain-milk price ratio is 0.90, which means that 90 pounds of milk is sufficient to pay for 100 pounds of grain, then the incremental value in table 28 which is nearest to this figure is 87. The table shows that this rate of incremental output is reached when grain is fed at the rate of 1:2½. This rate then is the limit to which grain feeding can be carried without loss when prices are such that 87 pounds of milk will pay for 100 pounds of grain.

SUMMARY

METHODS

A total of 346 individual cows were used over a period of 3 years to obtain 469 yearly records of production and feed.

Daily records were kept of feed and production; bimonthly records of body weight; also records on quality of feeds, on breeding, and on calving and health.

At each station, groups were balanced as nearly as possible with reference to age, body weight, breed as well as the quantity of production that might be expected during the experiment (basic producing ability).

Expected production was arrived at from past performance and by the application of Dairy Herd Improvement Association factors for age, length of lactation period, and times a day milked. The expected production for all cows averaged about 350 pounds of butterfat.

At four of the stations, the level of feeding was based on the Haecker standard; at the other six, on the ratio of grain to milk during lactation.

At seven stations, these groups of cows were fed at six or more levels; at two stations, five levels; and at one station, two levels. The results from this last station were analyzed separately.

RESULTS AND APPLICATIONS

On the basis of input-output experiments, it was determined to what degree milk output can be raised by more intensive feeding. It was found that in the herds used for experiments, 15 to 20 percent more milk was obtained from the cows at high levels of feeding than from cows fed at standard, and 45 percent more than from cows fed at 70-80 percent of standard.

The law of diminishing physical output applies to milk production. There was a consistent stepping up of production with every increase in grain allowance, but the additional milk produced for each additional unit of feed decreased. The average response is represented by a curve instead of a straight line. (See fig. 1.)

The response to increased feed was less at the high levels than at the low levels—0.6 pound of 4-percent fat-corrected milk for each additional pound of digestible nutrients at the highest level and 1.7 pounds at the lowest level.

At normal feeding levels the additional output for an additional unit of feed was much smaller than the average output per unit of feed consumed above maintenance. On an average, cows returned about 3 pounds of milk per pound of digestible nutrients consumed above maintenance; but for each additional pound of total digestible nutrient added to a normal ration, an increase of only about 1.0-1.5 pounds of 4-percent milk was obtained. At low feeding levels this additional return was greater. At higher feeding levels it was even smaller.

At two stations a group of cows fed roughage alone produced 80 percent as much as a comparable group fed grain at the rate of 1 pound for each 6 pounds of milk in addition to all the roughage they would eat.

If cows are fed all the good roughage they will eat, the average decrease in hay consumption for each 100 pounds increase in grain appears to lie somewhere between 50 and 70 pounds.

Cows fed at the Haecker standard for the whole year in some cases became thin in flesh and failed to produce satisfactorily. It was especially evident that the cows were too thin at calving time.

If cows at all times had all the good roughage they wanted so that they were in a good state of flesh at calving time, they produced well if fed grain enough during the lactation period to bring the intake of nutrients up to the Haecker standard.

It is not possible by increased feeding to stimulate the milk production of cows of low inherent productivity as much as the production of cows of high inherent productivity. But it was found that at the same percentages of the standard production requirements, the low and high producing cows gave about the same additional amounts of milk for 1 additional pound of feed.

With an increase in feeding level, cows reached a higher peak of production and maintained consistently higher production during the lactation period. The entire lactation curve was raised to a higher level.

There was a fairly consistent increase in body weight as the feeding level increased. The difference in weight between cows fed at the lowest and highest levels was over 100 pounds. Careful grading for condition at somewhat regular intervals also showed a consistent improvement with increasing amounts of feed.

Feeding at different levels had no influence on the fat percentage of the milk.

There was no significant difference between heavy and light fed cows with respect to services required for conception, number of abortions, and susceptibility to ailments or diseases that necessitated their removal from the experiment except that the incidence of "off-feed" was greater at the higher levels.

The input-output relationships determined, if applied on a national scale, show that large additional quantities of feed grains can be converted into milk with only a small loss in efficiency.

When the input-output relationships are known, it can be determined how much extra feed it will take to bring about a certain expansion in milk output from the same number of cows by more intensive feeding. By applying local prices to feed inputs and milk output, it can be determined to what extent it pays—or does not pay—to expand production under prevailing price conditions. Likewise, it can be learned what price relationships must prevail to permit farmers to bring about the adjustment in production which is wanted.

The most profitable level of feeding is not fixed. It ranges all the way from no grain at all to more than 5,000 pounds of concentrates per year for cows capable of high production, depending upon prices of feed and milk. This means that the feeding standards may be profitably exceeded when the relationship between prices of feed and milk is favorable.

A chart and a table are presented which will facilitate the determination of the most profitable level of feeding when prices of grain, hay, and milk are known.

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