The plane of nutrition in relation to milk production
by Joseph C Shaw

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Animal Husbandry
Montana State University

Abstract:
A pertinent problem in dairy cattle nutrition in the Western states is the selection or formulating of a practical method of feeding dairy cows whereby they may be fed more closely to theoretical requirements. The nutrients required can be estimated with a fair degree of accuracy by referring to the feeding standards which have been prepared by various investigators. These standards agree rather closely, and for all practical purposes they may be relied upon.

The usual method of apportioning grain is to feed each cow 1 pound of grain to each 3 or 4 pounds of milk produced, depending upon the richness, regardless of the quantity or quality of roughage consumed. This method of feeding is at fault, especially under Western conditions, because cows will get enough nutrients from good roughage alone to provide for the maintenance of their bodies as well as for the production of a certain amount of milk, and because 1 pound of grain does not provide enough nutrients for as much as 3 pounds of milk.

Western dairy husbandmen have attempted to work out a method of feeding that would be more satisfactory under their conditions. Since alfalfa hay Is usually the cheapest dairy cattle feed that can be produced in large quantities in many Western states, the methods suggested have been based upon the assumption that the majority of dairymen feed alfalfa hay In large quantities as the sole roughage. In making up these feeding rules an attempt Is made to determine the amount of nutrients In the faom of alfalfa hay that dairy cows will consume, In excess of their maintenance requirements. Acting upon the accepted principle that the nutrients consumed by dairy cows in excess of their maintenance requirements are converted Into milk, providing the cow does not make more than a slight gain In body weight, the number of pounds of milk that can be produced on this excess of nutrients Is determined. Concentrates are then fed in sufficient amounts to provide the nutrients required, according to a certain feeding standard, for each pound of milk produced above this amount.

The object of this thesis, "The Plane of nutrition in Relation to Milk Production", is to give a summary of the present available information which may be of value, In working out a more satisfactory method of apportioning concentrates to dairy cows in Montana, or in the revisal of the present method. A brief review is given of certain phases of dairy nutrition which deals more or less indirectly with the subject.

A more detailed review Ie given of the literature more directly applied to the subject, together with a discussion of an experiment conducted bythe author under the direction of tha Animal Husbandry Department of the Montana Experiment Station.

For the convenience of the reader, this thesis Is divided Into five parts; Part I gives In condensed form a review of the Important daily cattle feeding stuff* in Montana.

Part II presents a review of the literature in regard to feeding methods, and experimental work dealing with the important problems involved in the feeding of alfalfa hay to dairy cows as the sole roughage.

Part III reviews very briefly the more important findings regarding the protein, energy, and vitamin requirements of dairy cows.

Part IT presents in detail the methods of procedure and the results of an experiment which the author conducted under the direction of the Staff of the Animal Husbandry Department of the Montana Experiment Station.

Part T presents the general conclusions of the review of the literature and the results of the experiment.

THE PLANE OF NUTRITION IN RELATION TO MILK PRODUCTION

by

JOSEPH C. SHAW

A THESIS

Submitted to the Graduate Committee in partial fulfillment
of the requirements for the Degree of Master
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at Montana State College

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Bozeman, Montana
June, 1933

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Introduction

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PART I

FEEDS AVAILABLE FOR DAIRY CATTLE FEEDING IN MONTANA

Roughages

Roughages are the coarser feeding stuffs, which are high in fiber and supply a low percentage of digestible matter. They may be divided into two classes depending upon the amount of protein they contain. Nitrogenous roughages are high in protein and include hay and forage from the legumes. The carbonaceous roughages are low in nitrogen and include the non-legume hays, grain hays, and straws from cereal grains. Roughages may be further divided into dry roughages and green roughages.

In dairy cattle feeding the roughages usually furnish from half to all of the nutrients. Throughout the West, dairy cattle are fed much larger quantities of roughages than is the case farther East. While under Western conditions it is a common practice to feed alfalfa hay as the exclusive ration, this practice is practically unheard of in the middle Western and Eastern states where grain feeding is universally practiced.

Dried Legume Roughages. Properly cured alfalfa hay easily ranks first among hays for dairy cattle. It is very palatable, laxative in character, and is high in protein, containing three times as much as timothy, and is the highest of all common feeds in calcium. Dairy cattle in the Western states are able to consume large quantities of alfalfa due to their ruggedness and also due to the fact that most of them are fed large quantities of it from the time they are a few weeks old until they are mature.

A legume hay having advantages similar to alfalfa is red clover, but it is not quite as palatable, nor so abundant in protein and minerals. Sweet clover properly cured has a feeding value about the same as that of red clover, although it is not quite as palatable. A considerable proportion of the stems is usually refused by the cow. It has been found that sweet clover hay may cause death in cattle due to the failure of the blood to clot normally. A slight cut may allow the animal to bleed to death. For this reason sweet clover cannot be considered as being entirely safe.

While not grown so abundantly for hay as is alfalfa and the clovers, oat and pea hay when cut at an early stage is palatable and nutritious. The protein content is about three-fourths that of alfalfa, while the total digestible nutrients are about equal.

Dried Non-Legume Roughages. Although timothy hay in the Rocky Mountain States is a little higher in protein than the timothy hay in other states, it is not a very satisfactory feed for dairy cows. It is not only low in protein, but is the lowest in minerals of all common feeds. When it is used as the roughage, it is necessary to add considerable amounts of high protein feeds to the ration. Blue joint ranks above timothy as a hay for dairy cattle, being more palatable and higher in minerals, protein and total digestible nutrients.

One of the best non-legume hays is oat hay, cut for hay when in the milk stage. It is quite palatable and has about the same feeding value for dairy cows as blue joint. Another cereal hay sometimes used for dairy cattle feeding is rye hay. However, this hay is low in protein and less palatable than timothy. Oat straw is also sometimes fed to dairy cattle, but is very unsatisfactory feed, being low in protein and total digestible nutrients and lacking palatability. Wheat, rye, and barley straw can not(3) be counted on as feeds, but make good bedding material.

Corn fodder is used to some extent for dairy cattle feeding in Montana. As is commonly known, corn fodder is the stock with the ear attached. Its chief value is in the ear corn. Aside from the grain included, it is about equal to timothy hay in total digestible nutrients, but is less palatable. Silage made from the corn plant cut while still in the green stage is one of the best dairy cattle roughages, being very palatable and succulent. However, there is very little corn put up in the form of silage in Montana.

Concentrates. Concentrates are feeding stuffs in condensed nature, which are low in fiber and hence furnish a large amount of digestible matter. While concentrates do not supply a very large portion of the total digestible nutrients fed to dairy cows in Montana, they are nevertheless very valuable in supplementing the roughages. It is generally considered that half of the concentrate ration should be made up of relatively bulky feeds such as ground oats, bran and wheat screenings.

Corn forms a part of the grain ration on some Montana dairy farms, in those sections where this grain is grown. It is nutritious and palatable and a splendid feed for the cow in milk. However, it should not make up over half of the ration. Corn and cob meal was reported by McCandlish (37) of the Iowa Station to be valuable for dairy cows in just the proportion of corn grain it contained. One hundred pounds of cracked corn was equal to 125 pounds of corn and cob meal. Barley and wheat compare very favorably with corn as a dairy cattle feed and are much more common in Montana than is corn. The barley should be ground or crushed because of the tough outer covering. Wheat has more protein than corn and is slightly superior as a source of minerals. It may safely make up half of the ration (43). Rye has a composition not greatly different from corn but ranks below it, being rather unpalatable. If mixed with other feeds it may be fed in amounts up to three pounds per day. When fed in large quantities it tends to produce butter with a hard body.

Of the more bulky concentrates bran is one of the most valuable for dairy cattle feeding because it is palatable and bulky, has a desirable laxative effect, and is one of the best sources of phosphorus. Oats, however, are fully as valuable as bran and may be substituted for bran in the ration pound for pound. Screenings from wheat are available in large quantities in this state. This product consists mainly of broken and shrunken wheat kernels and a variety of weed seeds. High grade screenings have a feeding value of about ten per cent below that of oats according to Eckles (8). Screenings have a rather bitter taste and are for this reason somewhat unpalatable. Cattle take them readily, however, when mixed with other ground feed.

Most of the beet pulp fed in the state is fed as wet pulp, especially in the vicinity of the factories. It is highly valued by dairymen both in the wet and dry state. The dried pulp compares favorably with corn as a concentrate. It is especially favored for test cow feeding. The disadvantage of wet pulp is that it spoils rapidly on exposure to the air. It is necessary to store it in large tank-like silos, straw silos or well drained trench silos. The pulp is low in minerals and protein and must be fed with feeds high in these two constituents.

Beet molasses is a valuable carbonaceous feed that is fed to some extent in Montana. It has about the same feeding value as corn when not fed in too large amounts. Compared to black strap molasses it is somewhat bitter. Dairy cows should not receive more than three pounds per day because of its laxative effect. Molasses is useful as an appetizer for cows receiving a heavy ration and is used extensively in test cow feeding.

Nitrogenous Concentrates. The most common mistake in feeding dairy cows is the failure to give enough feed to make use of the milk-producing ability of the animal. Next to the failure to feed liberally enough is the failure to give enough protein. If a cow, having enough other material to produce 30 pounds of milk, gives only 20 on account of a shortage of protein, it is useless to increase the ration further. The addition of a small amount of concentrate, high in protein, would allow the cow to make full use of all the ration.

Where liberal quantities of good quality alfalfa hay is fed, as is often the case in Montana, the addition of high protein concentrates should not be necessary. When the roughage consists of a non-legume hay or a legume hay of poor quality, it is usually necessary to add a high protein concentrate to the ration. The two most important purchased protein supplements used in Montana are cottonseed meal and linseed meal.

Bran is somewhat higher in protein content than are the cereal grains, but it must not be looked upon as a source of protein to balance home grown rations. Linseed meal is one of the best protein feeds for dairy cattle, being palatable and laxative and has a wonderful effect upon all kinds of animals to which it is fed. While cottonseed meal contains the highest amount of protein of any feed ordinarily fed to cattle, it is not quite as popular among dairymen as is linseed meal. When fed in too large amounts it has a constipating effect and when making a large portion of a ration lacking variety it may have a toxic effect. Results of Experiments by Woodward, Shepherd and Graves (61) show that large quantities of cottonseed meal may be fed to dairy cows without any apparent ill effects, if good roughage, such as pasture grass, green forage, or nicely cured hay is fed with it.

PART II

METHODS OF FEEDING - DAIRY CATTLE EXPERIMENTS WITH ALFALFA HAY

Methods of Feeding by Prominent Dairymen

Roughages usually form the major portion of dairy cattle rations. The dairy cow is very well adapted to the conversion of large quantities of roughage into edible food for man. With a few possible exceptions the cheapest and most economical feed for dairy cows is good quality roughage and it may well make up from half to all of the nutrients required. Concentrates then constitute the balance of the ration.

Although it is usually considered that the most economical production of milk can be secured by feeding large amounts of roughages and comparatively small smounts of concentrates, there are times when the digestible nutrients supplied by means of roughages are higher in price than the same amount of nutrients supplied by means of concentrates. In this case it would be more economical to feed large quantities of grain and a minimum amount of roughages. Feeding rules or methods are usually based on the fact that it is usually more economical to feed large quantities of roughage and make up the additional requirements by means of concentrates.

The object of feeding rules is to furnish a practical method of feeding dairy cows so as to enable the feeder to supply the proper amounts of the several nutrients necessary for maintenance, growth, development of the fetus and production of milk, as shown by an accepted feeding standard. It is generally considered that for the most economical production of milk, dairy cows should be fed individually and as close as possible to their requirements as shown by one of these accepted standards.

A method of feeding recently published in bulletin form by Headley (31) of the Nevada Station is to feed dairy cows all the alfalfa hay they will eat; and to Holsteins, grain in the proportion of 1 pound to every 2½ pounds of milk they produce in excess of 30 pounds; and to Jerseys, 1 pound of grain to every 2 pounds of milk they produce in excess of 25 pounds.

Another method, somewhat similar to this, is to feed dairy cows all the alfalfa hay they will eat, and grain to low testing cows in the proportion of 1 pound to every 2 1/2 pounds of milk produced in excess of 16 to 20 pounds, and to high testing cows, 1 pound of grain to every 2 pounds of milk they give in excess of 10 to 14 pounds. Tretsven (52) of the Montana Station is the author of this method. When connected with the California Station, Woll (58) proposed a feeding rule for Western dairymen in which dairy cows, receiving all the alfalfa hay they would eat, were to receive 1 pound of grain to every 4 or 5 pounds of milk produced, when the cows production of butterfat exceeded 1 pound per day.

The following is a method suggested by Eckles (8): "Feed all the roughage a cow will eat. This should include a succulent feed and a legume hay. In addition, feed a Jersey or Guernsey 1 pound of grain to each 2 1/2 to 3 pounds of milk, and a Holstein, Brown Swiss, or Shorthorn, 1 pound of grain for each 3 to 3 1/2 pounds of milk. When silage is not available, feed the same grain mixture but in somewhat larger amounts".

A method differing very little from that suggested by Eckles was advocated by Weaver (57) of the Iowa Station. Weaver's method was to: "Feed all the legume hay a cow will eat. If legume hay is the only roughage fed, the cow will eat nearly 2 pounds of it daily for each 100 pounds of live weight. If used along with silage, she will eat about 1 pound per 100 pounds of live weight and 3 pounds of silage per 100 pounds of live weight. With legume hay and silage, feed Jerseys and Guernseys 1 pound of grain for every 3 pounds of milk and a Holstein, Aryshire or Brown Swiss 1 pound for every 3 1/2 pounds of milk produced".

A method which has given very satisfactory results under experimental conditions at the Government Station at Beltsville, Maryland, is the following as stated by Woodward (61): "When cows are given 3 pounds of silage a day for each 100 pounds of live weight and all the No. 2 or No. 3 alfalfa they will eat, give grain to Jersey cows at the rate of 0.6 pound for each pound of milk produced above 10 pounds, and to Holsteins give 0.4 pound of grain for each pound of milk above 16 pounds."

From the review of methods of feeding offered by prominent dairymen it is evident that two methods of feeding are commonly advocated: (1) The method suggested by Eckles and Weaver, based on a practice of feeding a certain amount of grain for every pound of milk produced; (2) The method which is advocated by Woodward, Tretsven and Headley based on a practice of feeding a certain amount of grain for every pound of milk produced in excess of that provided for by the roughage. The amount of grain fed for each pound of milk is just enough to produce that pound of milk. It is assumed that the roughage in addition to providing for maintenance will also provide nutrients for a certain amount of milk. Woll proposed a method that attempts to include both methods outlined, with the result that it is probably not as accurate as either one. The method worked out by Woodward is the only one that takes into consideration the quality of the hay.

The second method can be varied so as to include both Eastern and Western conditions. The plan suggested by Woodward applies only to Eastern and Mid-Western conditions, and the plan suggested by Tretsven and Headley applies only to Western conditions. Both are based on the same principle, however. It is interesting to note that although their feeding rules are based upon the same principle, Headley and Tretsven disagree as to the point where grain feeding should begin.

Woodward (61) states that the ordinary method of apportioning grain is to give each cow 1 pound of grain to each 3 or 4 pounds of milk produced, depending upon the richness of the milk. This method is inaccurate for two reasons: (1) Because cows will get enough nutrients from good roughage alone to provide for the maintenance of their bodies, as well as for the production of a certain amount of milk, and (2) because 1 pound of grain does not contain sufficient nutrients for as much as 3 pounds of milk.

In the review of experimental work in which one or the other of the two systems of feeding were used, the first method will be referred to as "the usual method", and the second will be referred to as "Woodward's Method".

Woodward's Method Versus the Usual Method. In all the literature reviewed there was no work reported in which an experiment was conducted to compare the efficiency of the different methods of feeding. However, in most of the dairy feeding trials reported, a definite rule for feeding was followed. It should be possible, then, by making a review of this work to glean some information that may be of value in comparing the method worked out by Woodward and the one suggested by Weaver and others. The work which should be more applicable to Montana conditions is that in which alfalfa hay is fed as a part or all of the roughage.

In three feeding trials of from five to six weeks each, Woll (59) and associates of the California Station found that the method of feeding grain to dairy cows at the ratio of 1 pound for every 5 pounds of milk yielded within 5 per cent as good results, on the average, as a ratio of 1 pound of grain to every 3 pounds of milk. The roughage fed consisted of equal parts of corn silage and alfalfa. The "full grain" group averaged 22.8 pounds of milk per day containing .894 pound of butterfat and the same group on the "limited grain" ration averaged 21.8 pounds of milk and .859 pound of butterfat per day. It is therefore quite evident that these experiments were conducted with cows of very average production. Since grain alone in the proportion of either 1 to 3 or 1 to 5 does not provide enough nutrients to produce 1 pound of milk, it is evident that the roughage furnishes part of the nutrients for milk production as well as maintenance.

In all, during a period of 214 cow days, the heavy grain group consumed an average daily ration of 22 pounds of silage, 22 pounds of alfalfa hay, 5 pounds of beets, 1.8 pounds of beet pulp, and 7.5 pounds of grain.

The limited grain group in a period of 214 cow days consumed an average daily ration of 22 pounds of silage, 21.8 pounds of alfalfa hay, 5.5 pounds of beets, 1.9 pounds of beet pulp and 4.2 pounds of grain. Table I gives the average production of milk and a comparison of the nutrients consumed with the nutrients required.

Table I - Heavy Versus Light Grain Feeding

Group	Milk	Test	Average Wt.	Total Digestible Nutrients			Increase In
				Required	Consumed	Difference	Production
Heavy grain	22.8	3.9	1157	16.47	22.84	+6.37	5%
Light grain	21.8	3.9	1158	16.22	20.00	+3.78	

Two conclusions may be arrived at from the data in this table: (1) Both groups were fed in excess of requirements, when fed in the proportion of 1 to 3 and 1 to 5, and (2) there was an increase in production when an already liberal ration was made more liberal.

At the Huntley Field Station, Moseley, Stuart, and Graves (45) fed a group of 10 Holstein cows on a ration of alfalfa, beet silage, and beet pulp; the next year the group was fed the same roughages and grain in the proportion of 1 pound to each 6 pounds of milk; the third year the group received the same roughages and in addition, 1 pound of grain to each 3 pounds of milk. Ten cows in all completed a 365-day test on each of the three rations. Since they were on pasture in the summer the comparisons were made of the three groups during the winter feeding period of 201 days.

The group fed grain at the rate of 1 pound to 6 pounds of milk consumed very close to their theoretical requirements, according to the Meigs and Converse standard (39), their average consumption of total digestible nutrients being 2.4 per cent in excess of their requirements. They also produced 18.2 per cent more butterfat than the group fed roughages exclusively, and gained an average of 87 pounds in live weight.

The group fed roughages exclusively failed by 4.6 per cent to consume enough nutrients according to the Meigs and Converse tables, and lost an average of 23 pounds of live weight during the 201 days.

The third group, or the group receiving 1 pound of grain for each pound of milk, produced only 5.7 per cent more butterfat than the group fed at the rate of 1 pound of grain to each 6 pounds of milk. This group consumed 29.2 per cent more nutrients than were required and gained an average of 106 pounds in live weight during the winter feeding period.

All of the cows in this experiment were high producers and there was but very little variation in their production during the year. During the year they received grain at the rate of 1 pound to 6 pounds of milk, these 10 cows produced an average of 576.45 pounds of butterfat, varying in production from 471.88 to 627.08 pounds of butterfat in their 365-day period.

Since all of these cows produced at about the same level, it is very probably that in this case the proportion of 1 pound of grain to 6 pounds of milk was about the correct proportion for cows producing that quantity of milk and butterfat. Three different rates of feeding were tried on the same group and one proved to be about right for that group. However, would this experiment have proved so satisfactory if the cows had varied widely in production as is more often the case? Due to the fact that the roughages furnished such a large proportion of the nutrients and the cows were such high producers, the data may be interpreted as indicating that low producers would receive a sufficient amount of nutrients from the roughage alone. The fact that these high producers, when fed nothing but roughage, consumed almost enough nutrients to supply their requirements also indicates that such is the case. The consumption of such large amounts of nutrients in the form of roughage was probably due to the great variety of roughages fed.

Dairy cattle feeding trials were conducted by Foster and Latta (16) of the New Mexico Station, in which strictly alfalfa hay feeding was compared with alfalfa hay and grain feeding, by use of the reversal method. The alfalfa was fed ad libitum to both groups and the grain was fed in the proportion of 1 pound of grain to each 3 pounds of milk produced. The grain fed group produced 10 per cent more butterfat than the strictly alfalfa group.

The cows used in these experiments were mostly grade Jerseys with a few pure bred Jerseys, Guernseys and Holsteins. The grain fed consisted of equal parts of corn and bran, containing 73.3 per cent total digestible nutrients according to the Henry and Morrison's tables. The cows fed alfalfa and grain over a period of four months averaged 14.7 pounds of 4.8 per cent milk on 25.6 pounds of alfalfa and 6.66 pounds of grain, and gained 25 pounds in live weight per month. Since their average weight was about 1,100 pounds, their requirements for total digestible nutrients according to the Meigs and Converse tables was 14.23 pounds per day; whereas they received 18.08 pounds of total digestible nutrients per day.

The cows fed alfalfa alone averaged 13.1 pounds of 4.8 per cent milk on 31.25 pounds of good alfalfa hay, and gained 2 pounds per month in live weight. Considering the weight again at 1,100 pounds, the requirements of total digestible nutrients would be 13.6 pounds per day;

whereas they apparently received 16.1 pounds per day.

This experiment furnished a good example of one of the common faults of feeding a certain amount of grain for every pound of milk produced. The alfalfa alone provided sufficient nutrients for these low producing cows. The fact that they gained 2 pounds per month on alfalfa alone indicates that they were receiving about the proper amount of nutrients. The groups receiving grain consumed about the proper amount of nutrients. The groups receiving grain consumed considerable more total digestible nutrients than was required and gained 29 pounds per month in live weight. The increase in production by the grain fed group may have been due to a combination of factors, namely: the supernormal plane of nutrition, and the increased variety and palatability of the ration.

The feeding of alfalfa hay as the exclusive ration for dairy cows was compared with the feeding of barley and alfalfa hay by True, Woll and Voorhies (53) during two successive winter feeding periods. Fourteen cows were fed in the first trial and 18 were fed in the second trial. In both trials the reversal method was used. The ration consisted of alfalfa hay, green alfalfa and barley, in the case of the cows on the grain ration. The group on roughage exclusively received green alfalfa and alfalfa hay. In both trials the addition of barley to the ration increased the production of milk 13 per cent.

The cows in this experiment would be considered as low producers since their average daily production of butterfat was only 0.6 pounds. Barley was fed at the rate of 1 pound to each 5 pounds of milk produced.

Since the information was available on the average live weight of the cow, production of milk, per cent of butterfat, and average daily feed consumption, it was possible to compare the amount of total digestible nutrients eaten by the barley fed groups with the theoretical requirements of these cows according to the Meigs and Converse standard.

The results show that in the first trials the cows received enough nutrients to produce 35 pounds of milk and gain slightly in weight. However, this group averaged only 25 pounds per day. In the second trials the cows received enough nutrients to provide for 35 pounds of milk but produced only 19.2 pounds.

Here, again, low producers were fed in excess of their requirements when allowed a certain amount of grain for every pound of milk produced.

Woll (60) fed one group of heifers exclusively on alfalfa and another group alfalfa, silage and concentrates. The feeding began one year before freshening and continued through two lactation periods. The exclusive alfalfa ration consisted of two-fifths green alfalfa and three-fifths alfalfa hay. The mixed rations were made up of alfalfa hay, green alfalfa, silage and concentrates. The concentrate ration consisted of bran, barley, dried beet pulp and coconut meal. The method of feeding the grain was not given.

The results show that the group on the mixed ration gained 20 per cent more in weight and showed a tendency towards a slightly greater body development, as shown by the measurements of the height of shoulders and hips, width between hips, length from hip bone to pin bone, length from shoulder to pin bones and heart girth.

During the first lactation period the group on the mixed rations produced 40 per cent more butterfat than the alfalfa fed group, and in the second lactation period produced 23 per cent more. Except for some trouble in the second year with one cow in the mixed ration group, which cut her production in half, this group would have shown about the same increase in production over the alfalfa fed group as it did the previous year.

Here again all the figures are available to compare the two groups on the basis of nutrients required and nutrients received by the use of the Meigs and Converse standard. The alfalfa fed group received enough total digestible nutrients above maintenance for the production of 21.5 pounds of milk; whereas their average production was 17 pounds of milk. The mixed ration group received enough nutrients above maintenance to provide for 34 pounds of milk, whereas their production was only 24.5 pounds of milk.

Apparently the mixed ration had a tendency to increase the production. However, since the group on mixed rations were fed considerably in excess of their requirements, some of this increase may have been due to the super-normal plane of nutrition.

Vernon (55) of the New Mexico Station fed one group of cows all the alfalfa they would eat and eight pounds of bran and another group alfalfa exclusively, using the reversal method, during two periods of six weeks each.

The groups on alfalfa and bran produced 16.5 per cent more milk, but at a lower efficiency of 8 per cent due to an excess of nutrients above requirements. The cows in this group consumed 33.3 pounds of alfalfa per day, or 22 pounds of total digestible nutrients and produced 16.5 pounds of milk per day.

The groups on alfalfa exclusively consumed an average of 33.8 pounds of alfalfa per day or 17.44 pounds of total digestible nutrients and produced 13.7 pounds of milk per day.

Since the cows used were mostly grade Jerseys, it is evident that the production and maintenance was well provided for by the 33 pounds of alfalfa consumed. The eight pounds of bran fed was apparently in excess of requirements. In summarizing this work then it is apparent that the increase in production following the addition of bran may have been due not only to the increased variety and palatibility, but also to an excess of nutrients.

After conducting continuous feeding trials covering four years, Headley (28) of the Nevada Station concluded that when a pound of total digestible nutrients in the form of alfalfa hay is cheaper than a pound of total digestible nutrients in the form of grain, the amount of grain fed should correspond to the milk and fat produced, and its use should be discontinued when production declines to the point where roughage alone will supply the nutrients. The increase in butterfat from feeding grain amounted to .2 pound daily for 250 days for four cows consuming an average of 8 pounds of grain per day.

The results of an experiment with 71 Holsteins and Jerseys over a period of three winters were reported by Woodward, Shepherd and Graves (61), during which time the cows were fed according to Woodward's method which was previously explained in the text of this thesis.

From experiments in which cows had been given all the roughage they would eat, they determined the amount of alfalfa hay large cows and small cows would eat when it was fed in addition to a definite quantity of silage. They found as expected, that the large cows consumed more roughage than the small cows and that Jerseys and Holsteins of the same size ate about the same quantity of roughage. When cows were fed 3 pounds of silage a day per 100 pounds of live weight and all the good alfalfa hay they would eat, the small cows ate about 8 pounds of alfalfa per day above the amount required for maintenance, and the large cows ate about 10 pounds of alfalfa per day above maintenance requirements, or enough to produce 10 and 16 pounds of Jersey and Holstein milk respectively. Jerseys producing over 10 pounds of milk per day were fed .6 pound of grain for each pound of milk over that amount and Holsteins were fed .4 pound of grain for each pound of milk over sixteen pounds.

They state that: "For comparison of this new method of feeding grain to dairy cows with the usual method of feeding 1 pound of grain for each 3 or 4 pounds of milk produced, it would have been desirable to have had similar data on the production, decline in milk yield, and gain or loss in body weight of cows fed by the Usual Method. However, if the nutrients provided by each of these two methods of feeding are compared with those provided by the Haecker and Savage standards, it will be found that, as a rule, this new method more nearly supplies the nutrients in the amounts prescribed by the standards than the one in common use. Furthermore, the results of experimental feeding here reported show that the nutrients were actually supplied in very nearly the correct amounts".

"This method does not apply with accuracy to the irrigated sections of the West where hay of excellent quality is grown, nor will it apply to those sections where a poor roughage is used, as straw, corn stover, cottonseed hulls, or coarse or weather damaged hay. In the former case the excellent roughage alone will support a production much in excess of 10 pounds for Jerseys and 16 for Holsteins; in the latter case the poor roughage will not provide for the nutrients for 10 to 16 pounds respectively."

Experimental work conducted at the Havre Station, under the direction of Vinke (56) shows that 40 pregnant but dry milking shorthorn cows made an average daily gain of .37 pound, on 18.3 pounds of alfalfa hay, during a period of 111 days. Since they averaged 1,082 pounds in body weight they apparently consumed only 1.1 pounds of total digestible nutrients in excess of maintenance requirements, according to the Meigs and Converse standard. Most of these cows calved shortly after the completion of the experiment so it is evident that, although they made an actual gain of .37 pound per day in body weight, this would represent a loss in fleshing of approximately .5 pound per day, due to the fact that the .37 pound per day would not account for the total increasing weight of the fetus. From this work, it is apparent that alfalfa hay fed not to exceed requirements, according to the Meigs and Converse standard, would very nearly provide for the maintenance of a cow.

Conclusions. 1. In all the experiments reviewed, except the Huntley work, the cows were comparatively low producers. The majority of them were fed by the usual method and the ratio of pounds of grain to pounds of milk was 1 to 3, 1 to 4, or 1 to 5. According to the Meigs and Converse tables, the low producing cows in all cases received an excess of nutrients ranging from a few pounds to almost double their requirement.

2. The high producing cows at Huntley received sufficient nutrients from a great variety of roughages, and grain fed at the rate of 1 pound to 6 pounds of milk. We must conclude, therefore, that the roughage provided the nutrients for the major portion of the milk and that low producers fed that same variety of roughages would not need grain.

3. In all experimental work reported in which alfalfa was fed ad libitum to dairy cows as the only roughage, both low and high testing cows consumed enough alfalfa to take care of maintenance and at least 20 pounds of milk per day.

4. When sufficient nutrients were being provided according to the Meigs and Converse tables, the addition of concentrates to the ration increased the production from 10 to 43 per cent.

5. Production was increased by a supernormal plane of nutrition, but not in proportion to the nutrients supplied.

6. Feeding trials at Beltsville, Maryland, showed that the method of feeding suggested by Woodward more nearly supplies the nutrients in the amounts prescribed by the accepted feeding standards than the one in common use.

Amount of Alfalfa Hay that Dairy Cows will Consume. The method of feeding suggested by Woodward, Shepherd and Graves (61) requires that the average consumption of roughage by the various breeds of dairy cattle must be known. They determined what the average consumption of alfalfa hay of good quality would be when the cows were fed silage in the proportion of 3 pounds per day for each 100 pounds of live weight. In order to formulate a method for Western conditions by using this same plan, it is desirable to determine how much alfalfa the cows of the various breeds will consume when concentrates are included in the ration.

From the results of several experiments with alfalfa hay feeding, Headley (28) concludes that the capacity of the average cow for hay is limited to about 30 pounds per day for a 1,000 pound cow or 36 pounds for a 1,300 pound cow.

Table II gives the average consumption of alfalfa hay by dairy cows at the Nevada Station during 1931 in an experiment conducted by Headley (29). These cows did not receive any other feed than alfalfa hay from the time they dropped their first calf. Numbers 1 and 2 dropped their first calves in 1925 and did not receive any other feed than alfalfa until 1932.

Table II Daily Consumption of Alfalfa

Cow Number	Hay Eaten Per Day: Highest for any one month Lbs.	Hay Eaten Per Day: Average for Year 1931 Lbs.	Average milk production per day for year 1931 Lbs.	Average Weight of Cow
1	44.2	38.9	20.6	1430
2	41.8	35.0	18.6	1335
3	43.2	38.9	24.0	1160
4	33.1	30.6	17.6	955
5	35.9	31.0	16.7	1035

Headley (30) stated that he had observed that cows eat the most alfalfa hay during periods of high production and least when they were dry. He also stated that the amount of hay varies with the amount of milk produced as well as with the weight of the cow.

In feeding trials conducted at the New Mexico Station by Foster and Meeks (17) where dairy cows were fed alfalfa ad libitum, 16 cows averaging 1,057 pounds in weight, ate 35 pounds of alfalfa hay and 5.8 pounds of grain per day during a period of 50 days. Grain was fed in the proportion of 1 pound to every 5 pounds of milk produced.

Cows at the Huntley Station (work not yet published) have consumed as much as 50 pounds of alfalfa per day when alfalfa hay constituted the only feed.

If legume hay is the only roughage fed, the cow will eat nearly 2 pounds of it for each 100 pounds of live weight according to Weaver (57).

In an experiment conducted by Foster and Latta (16), two groups of grade Jerseys and a few pure bred Jerseys, Guernseys and Holsteins were fed on exclusive alfalfa hay ration versus an alfalfa hay and concentrate ration, during a period of four months. The body weights were not given. The group on the all hay ration ate 33 pounds of good quality alfalfa hay per day. The group on the hay and grain ration ate 25.6 pounds of good quality alfalfa hay and 6.66 pounds of concentrates per day. Each pound of grain decreased the consumption of alfalfa 0.9 pound.

The report of Vernon's experiment (55) shows that the group on the alfalfa hay ration ate 33.8 pounds of alfalfa hay per day, while the same group on alfalfa hay and bran ate 33.3 pounds of alfalfa per day and 8 pounds of bran. One pound of bran lowered the consumption of alfalfa hay .15 pound.

Headley (28) reports that during a two year feeding period each pound of grain in the ration decreased the consumption of alfalfa hay one-half pound per day. However, the effect was not consistent. The first year the saving was only one-tenth pound of hay for each pound of grain fed. The second year the saving was one pound of hay per pound of grain fed.

Data from the experiment by True, Woll, and Voorhies (53) show that when the two groups were receiving 30 pounds of green alfalfa and alfalfa hay at will, each pound of barley fed decreased the consumption of hay 0.3 pound. The cows were eating about 20 pounds of alfalfa hay.

An experiment conducted by Woodward, Shepherd and Graves (61) totalling seven months, Table III, shows that the better grades of alfalfa hay are eaten in larger quantities than are the poorer grades. Also the better grades of alfalfa were the most effective in maintaining the milk flow.

Table III Effect of the quality of alfalfa hay upon the amounts of hay eaten and decline in milk yield. (Average for 10 cows).

Kind of hay fed	Average quantity of hay eaten daily per cow	Average decline in Milk yield
Alfalfa	Pounds	Per cent
No. 1	14.4	No decline
No. 1	14.8	2.6
No. 2	13.0	5.0
No. 3	12.8	3.5

Silage was fed at the rate of 3 pounds daily per 100 pounds of live weight. In the case of Holsteins, grain was fed at an average rate of 0.4 pound of grain for each pound of milk produced above 16 pounds; and in the case of Jerseys, 0.6 pound of grain for each pound of milk produced above 10 pounds, adjustment being made the first of each month.

Conclusions. 1. Dairy cows will consume between 25 and 35 pounds of good quality alfalfa hay per day when it is fed ad libitum with grain.

2. Other factors being constant the amount of alfalfa hay eaten varies according to the weight of the cow.

3. Good quality alfalfa hay is eaten in larger quantities than is poor quality alfalfa hay.

4. Good quality alfalfa hay is more effective in maintaining the milk flow than is poor quality alfalfa hay.

5. Concentrates added to the ration of a cow in milk will not decrease the consumption of alfalfa more than one pound for each pound of concentrates added.

Effect of Grain in Ration on Efficiency of Production. The effect of grain in the ration upon the efficiency of production was determined by means of the Meigs and Converse standard from the data in a long time experiment reported in the 1929 report of the Huntley Experiment Station.(45). The cows on the roughage ration required 15.2 pounds of total digestible nutrients per pound of butterfat produced. The roughage group was fed 4.6 per cent under requirements while the limited grain group was fed 2.4 per cent over the requirements. Thus the addition of grain apparently made no difference in the efficiency of production when the cows were fed so as not to materially exceed requirements. However, the third group was fed 29.2 per cent in excess of requirements, and consumed 19.3 pounds of total digestible nutrients per pound of butterfat produced.

Results of an experiment conducted by Headley (28) shows that the average requirement of grain fed cows was 19.5 pounds of total digestible nutrients per pound of butterfat produced and that the average requirements for the cows fed exclusively on alfalfa was 18.7 pounds of total digestible nutrients per pound of butterfat produced. Headley concludes that, "Each pound of digestible nutrients fed to cows either in the form of grain or of alfalfa hay returns equal amounts of butterfat to the dairyman providing (1) the ration contains sufficient protein, (2) the ration is palatable, (3) the cows receive all the hay they will clean up, and (4) grain is not fed in excess of theoretical nutrient requirements".

Working with cow testing association records from 18 herds in western Montana, Johnson, Sherman, Tretsven, Ezekiel and Wells (34) reported a rather definite relationship between the per cent of grain in the ration and the efficiency of production. Their results show an increase in efficiency of 2.8 per cent when 10 per cent of the total digestible nutrients are in the form of grain, 8.4 per cent when 20 per cent of the total digestible nutrients are furnished by grain and 14 per cent when 30 per cent of the total digestible nutrients are furnished by grain.

Conclusions. 1. The only controlled experiment found in the literature, on the effect on the efficiency of butterfat production by the addition of grain to an alfalfa ration, was that reported by Headley (28). His conclusions are that grain in the ration does not affect the efficiency of production when the grain is palatable and the cows receive all the hay they will clean up.

2. Due to the lack of conclusive data, no definite conclusions can be made at this time regarding the possibility of increasing the efficiency of production of butterfat by the addition of grain to the dairy cattle ration.

PART III

NUTRITIVE REQUIREMENTS OF DAIRY COWS--PROTEIN--NUTRITIVE ENERGY--VITAMINS AND MINERALS

A dairy cow uses feed for maintaining the body, to supply material for milk, for development of the fetus, for growth in case the animal is immature and at times to produce gain in weight. The general classes of food material for these purposes are protein, carbohydrates and fat, and mineral matter and vitamins.

Protein Requirements. Of all the food nutrients, protein is the most complex. Its distinctive feature is that it contains nitrogen along with many other chemical elements. Proteins have some very important functions to perform. They furnish the essential cellular material for building muscular and other body tissue. They are consequently necessary for growing animals. Proteins are also required by mature animals for the rebuilding of worn out tissues that are being constantly torn down. Pregnant animals demand protein for the proper development of the fetus. The curd of the milk is largely protein. Protein is also used for the elaboration of the fat and sugar of milk.

It is generally understood that as long as alfalfa hay constitutes fifty per cent of the roughage fed, the protein requirements will be fully met without the addition of high protein feeds (31) and when alfalfa constitutes the only roughage, protein is supplied considerably in excess of requirements. Recent work has shown that there is good reason to believe that the protein requirements of existing feeding standards are too high. If this is the case, the Western dairyman must be considered as being even more favorably circumstanced as concerns the problem of supplying sufficient protein. It would be well then to review, in brief, the developments in experimental research on protein requirements of dairy cows.

Jordan (35) was of the opinion that an excess of protein has a stimulating effect on the mammary gland.

Haecker (21) fed cows on less protein than was prescribed by earlier investigators. His protein requirement for milk production in its final form was obtained by observing the consumption of feed protein by the cows in the herd at the University of Minnesota. After deducting a liberal maintenance requirement, the remaining feed protein was found to be approximately 1.38 times the observed protein content of the milk. Believing that his cows were handled under more favorable conditions than the average, Haecker arbitrarily increased the observed factor 1.38 to 1.75 as the proper relation between feed protein and milk protein, in estimating the amount of feed protein necessary to produce milk of different grades under average conditions.

After a series of experiments with rations of different protein content, Lindsey (36) noted that while an excess of protein seemed to increase the production of milk, there was little benefit derived in feeding more than fifty per cent in excess of that required for maintenance and protein in milk.

The standard derived by Savage (49) in a similar manner, from practical observations covering only the winter feeding period in the Cornell University herd, calls for approximately 35 per cent more protein than the Haecker standard or slightly more than double the protein content of milk.

Armsby (1) was of the opinion that 1.60 times the protein in the milk plus maintenance was sufficient.

In addition to maintenance, Morrison's (32) standard for milk production sets Haecker's figures as the lower limit and Savage's figures as the upper limit of digestible crude protein.

Very extensive experiments on protein requirements of dairy cows were conducted by Hills (33) and associates of the Vermont Station. They fed very low, low, medium, and high protein rations to 105 different cows during 450 years of cow life, extending over a period of 10 years. Judging by the results of this extensive work there is every indication to believe that the present standards are too high in their protein requirements, both for maintenance and for milk production. The protein requirements for milk production were only very slightly above that which is in the milk.

The work of Buschmann (5) and associates, as reviewed by Perkins (47) have shown in their short time experiments that feed protein equal in amount to the milk protein produced is adequate to meet the production requirement. In Buschmann's standard, an allowance of twenty-five per cent above this amount is included.

Perkins (47) of the Ohio Station conducted extensive experiments, in which the amount of digestible crude protein fed in the rations varied very much the same as in the rations fed by Hills (33). The results of this work agrees very well with the results of Hills' work. Perkins states that, "These results support the contention of Buschmann and associates that the older standards call for unnecessarily high amounts of protein, that the actual maintenance requirement is less than prescribed in these standards, and that above this maintenance requirement an amount of digestible protein only slightly greater than the protein content of milk appears to be adequate." In this work, the production seemed to follow total digestible nutrients rather than digestible crude protein content. The cows in this experiment received a good variety of feeds and Perkins attributes a good deal of the results to this. This work suggests that much of the difference in productiveness of rations, which in the past has been attributed to variation in digestible crude protein content, may be attributed to total food consumed due to palatability.

Experimental work to determine the minimum protein requirements of dairy cows was conducted by Savage (50) of Cornell, who supervised experiments with three groups of dairy cows of twelve cows each, over a period of three years. The three planes of digestible crude protein intake was 12.69 per cent, 16.34 per cent, and 19.50 per cent. The amount of total digestible nutrients fed was the same for all three groups. The low protein ration was just as effective as the high protein rations in producing milk. When 7 pounds of digestible crude protein per 1,000 pounds of live weight was subtracted for maintenance, the per cent of digestible crude protein consumed to the protein produced in the milk the first two years was 127.8 for the low protein ration.

A tentative feeding standard was worked out by Forbes and Kriss (13) in which two different planes of protein intake are suggested. The lower standard is for moderate production under the best conditions and the digestible crude protein suggested is equal to 1.25 times the protein in the milk. The higher standard is for maximum production under average conditions and requires digestible crude protein equivalent to 1.75 times the milk protein. They suggest .600 pound digestible crude protein for the maintenance of a 1,000 pound cow and state that it is a liberal estimate likely to be diminshed. Forbes states that, "The protein requirement for milk production in addition to the requirement for maintenance, is the protein content of milk plus the loss of absorbed protein in utilization. This must vary with the makeup and the biological value of the protein of the ration."

The fact that nitrogen balances have been secured, when feeding cows on rations having a lower protein content than ordinary feeding standards call for, is significant in that it shows the possibility of lowering the protein requirements.

Positive nitrogen balances were obtained with cows on a protein intake of 24.5 per cent less than that which the Morrison standard calls for by Fries and associates (18). The ration consisted of alfalfa, cornmeal, linseed oil meal, peanut meal, oat straw and corn starch. These workers conclude that 1.25 times the protein in the milk is sufficient to feed above maintenance to establish a nitrogen balance.

Forty-five nitrogen balances were run on dairy cows by Forbes and

Swift (12), thirty-two of which showed positive on rations containing a lower protein than the Morrison standard called for.

Haag et al (19) reported that in some cases cows were found to be in negative nitrogen balance while on a ration of alfalfa hay.

The Supplementary Relations Among the Proteins of Feeds. The importance of the supplementary relations among proteins has been aptly pointed out by Mitchell (42). When two feeds are fed together, it will frequently be found that the biological value of the mixture of proteins is greater than the mean biological value of the constituent proteins, and occasionally it will prove to be much greater. If the amino acid limiting the utilization of the proteins of one feed is not the limiting factor for the proteins of another feed, it is evident that when mixed the biological value of the mixture will be greater than the mean biological value. No supplementary relation will exist when the limiting amino acid is absent or low in both feeds. Also the biological value may be only slightly enchanced, because the utilization of the mixture may be seriously limited by the relative deficiency in each feed of some common indispensable amino acid.

The most extensive early investigations were conducted by Hart and Humphrey (23, 24, 25, 26) of the Wisconsin station. They found that when corn stover and corn silage were used as a roughage, the efficiency of high protein supplements added to the basal ration varied considerably; whereas, when clover or alfalfa hay and corn silage were fed as the roughage there was very little variation in the relative efficiency of the same supplements. They found that it was possible, when feeding equal but limited amounts of protein, to maintain nitrogen equilibrium and high milk production in dairy cows, with a ration composed of either barley or corn supplemented with corn silage and alfalfa hay, but not with the whole oat grain so supplemented. They concluded that biological values of proteins are more qualitative than quantitative measures. These experiments also show that where the feeding of a ration resulted in a negative balance there was a rapid decrease in milk yield until a positive balance was secured.

The work of Cary and Meigs (7) shows that the milk yield can be affected markedly by changes in either the quantity or quality of proteins fed.

The results of combining in all possible ways the proteins of corn, cottonseed meal and alfalfa was reported by Nevens (46). For only one combination, that of cottonseed meal and alfalfa, was any supplementary effect indicated and this effect was slight. Nevens obtained a biological value of 62 for alfalfa proteins when fed to rats at a 9 per cent level of intake.

Mitchell (42) made the following statement in 1924, "While many instances of supplementary relations between animal and vegetable proteins have been indicated or demonstrated by feeding experiments or metabolism studies, few instances of any appreciable supplementary effect of the proteins of one vegetable product upon those of another have been reported".

A biological value of 56 for alfalfa proteins was reported by Satola (48) of the Washington Station when alfalfa hay was fed to lambs at a level of intake equivalent to approximately 14 per cent of the dry matter consumed. He found that a combination of one part alfalfa hay and three parts corn silage had a biological value of 81, while the mathematical value calculated on the basis of the nitrogen each contributed was 64, a difference of 17, due to the supplementary value of the proteins.

Crystine was added to an exclusive alfalfa ration by Haag (20), who conducted experiments with rats at the Oregon Station. These experiments demonstrated a deficiency of cystine in the mixed crude proteins of alfalfa.

Conclusions. 1. Practical feeding experiments indicate that the present feeding standards for dairy cattle are too high in protein requirements for both maintenance and milk production.

2. Above the Armsby maintenance requirements an amount of digestible crude protein only slightly greater than the protein content of milk, appears to be adequate.

3. Nitrogen balance experiments support the contention that the present protein requirements in all accepted feeding standards are too high.

4. Determinations of biological values of proteins show that protein requirements are qualitative as well as quantitative.

5. Alfalfa hay appears to be deficient in cystine.

Energy Requirements of Dairy Cows. Carbohydrates and fats are less complex in composition than are the proteins and are more abundant and cheaper in the usual feeds. Carbohydrates and fats are the main sources of heat and energy needed by the animal. If they are fed in amounts greater than are required to meet the energy need of an animal, the carbohydrates and fats will be stored up as body fat. Carbohydrates and fats are also involved in milk secretion in the elaboration of milk sugar and milk fat. Their functions, while important, are not so inseparably linked with the well-being of the animal as are those of the proteins. If by some chance the amount of carbohydrates and fats in the ration is reduced to a very low level, proteins can furnish the necessary energy. This is an extravagance, however, for the proteins are too costly to be used for this purpose. Under no conditions can carbohydrates serve the especial function of growth, tissue repair, and milk secretion that are ascribed to the proteins.

The experimental work on which existing feeding standards are based is of three types. Haecker (21) and Eckles (9) determined the quantities of food necessary to keep milking cows at uniform body weight. Armsby (40) bases his standard on an experiment of Kellner, in which the complete energy balance was determined for a milk cow. Savage (49) raises the question as to what will happen if cows are fed more than is necessary, according to Haecker's results, to keep them at uniform body weight. Following this article by Savage, several experiments were conducted to answer this question, some of which are reviewed in later paragraphs in this thesis.

Using records which had been kept at the Beltsville farm for four years, Meigs and Converse (38) compared the nutrients required in these experiments with existing feeding standards. They found that their results were in close agreement with the extensive investigations of Haecker in regard to the quantities of total digestible nutrients required to keep milking cows at uniform body weight. When the results obtained by Eckles (9) in the same field were calculated in terms of total digestible nutrients, they were also found to be in close agreement with the results obtained by Meigs and Converse.

Both the Armsby and the Eckles standards are stated in terms of net energy. The Armsby standard is from 11 to 23 per cent higher in requirements, however. Meigs and Converse, therefore, came to the conclusion that the requirements as stated by Armsby were too low.

Meigs (40) reviewed the work of Armsby, Eckles, Haecker, and the work at Beltsville and came to the conclusion that total digestible nutrients were more satisfactory for formulating feeding standards than net energy, because the muscular activity in net energy determinations could not be controlled and this in turn causes a large variation in the heat output of the animal.

In the study of the Armsby standard, Meigs (40) stated that it was not based on any experiments carried out under conditions approaching those obtained in practice, but on an experiment of Kellner in which the complete energy balance was obtained in one milking cow for a period of two weeks. Although two other cows were considered, both were somewhat less economical, and were not used in the calculations.

In the Armsby, Eckles, and Savage feeding standards, the maintenance requirements are given for 1,000 pound cows. In calculating the requirements for cows that weighed more or less than a thousand pounds, Meigs and Converse used corrections based on the assumption that maintenance requirements are proportional to body surface, their requirements being calculated from the formula: $X = \left\{\frac{W}{1000}\right\}^{2/3}$ where X is the maintenance requirement to be determined, M, the maintenance requirement of a 1,000 pound cow, and W the body weight of the cow whose requirement is to be determined.

In formulating their feeding standard, Meigs and Converse also took into consideration the effect of feeding at a plane of nutrition higher than that called for by the existing standards. This feeding standard is a little more liberal in both protein and total digestible nutrients than the Morrison standard.

The effect of the plane of nutrition on milk yield was studied by Eckles and Palmer (10), in well regulated experiments. Both underfeeding and overfeeding were studied. The first influence of underfeeding was to cause a decrease in weight. The milk flow was not materially affected during the first sixty days. The influence of underfeeding became greater with the advance in the lactation period. They also concluded that the increase in the plane of nutrition above normal did not raise the milk flow to any appreciable extent. In the latter part of the lactation period the milk flow did not decrease so rapidly and they concluded that here overfeeding does help slightly in holding milk production to a higher level.

In a reply to Meigs, Forbes (14) stated that the Armsby standard was based not only on Kellners work, but also upon the work of numerous other workers, including Haecker, Eckles, Evvard, Jordan, Woll, and Hart and Humphrey.

Converse (6) reported that the results of rather extensive experiments indicate that feeding cows according to the Savage or Haecker standard, that is, so that they will just maintain uniform body weight, does not keep them at their maximum milk yield. The three experiments reported were in close agreement in showing that an above standard ration very materially increases production. Two short time experiments with cows well along in lactation gave a 16 per cent increase in milk yield, as the result of feeding 12 per cent more than requirements; while the third experiment in which whole lactation period comparisons were used, showed from 14 per cent to 16 per cent increase in production as the result of feeding 17 per cent more than the requirements.

In a review of the work of Eckles and Palmer (6) Converse interpreted the data from this work as really showing that in four of the five experiments reported by them, there was not only an arresting of the normal decline for those cows in advanced lactation, but an actual increase in production due to overfeeding.

The results of investigations by Cary and Meigs (7) show that cows, even in the first months of lactation are quite susceptible to an inadequate energy supply.

Forbes and Kriss (13, 15) proposed a tentative feeding standard in which the total digestible nutrients required are lower than the Morrison standard for both maintenance and milk production. The calorimetric determinations of the maintenance requirements of dry cows in terms of total digestible nutrients, averaged 5.551 pounds; while the determinations of the maintenance requirements of lactating cows compiled from an experiment representing approximately conditions of practice averaged 5,972 pounds. They arbitrarily accepted the higher figure as their standard for the requirement for a 1,000 pound cow.

Conclusions. 1. Due to the limited number of net energy determinations, total digestible nutrients are more satisfactory for formulating feeding standards at the present time.

2. The Meigs and Converse feeding standard is one of the latest standards and is based upon actual results at Beltsville, as well as upon other important experimental work which has been conducted previously by other nutrition experts.

3. Feeding above the Haecker and Savage requirements tends to increase production and to retard the decline in the milk flow.

4. Experiments by Forbes and Kriss indicate that the energy requirements of existing feeding standards may be too high, according to their determinations.

5. While the net-energy conception is theoretically more nearly correct, experimental work does not warrant its use as yet.

Mineral and Vitamin Requirements. Probably no phases of dairy cattle feeding have received more attention during the past few years than the use of mineral supplements and the importance of vitamins. Since mineral and vitamin requirements are only indirectly of importance in connection with the subject of this thesis, the present status of the knowledge of these two phases of nutrition in their relation to dairy cattle feeding, will be reviewed very briefly. Also due to the fact that several volumes could be written on these two phases of nutrition without fully covering the subject, the author will review only the work that pertains to the feeding of alfalfa hay to dairy cows, in which alfalfa hay constitutes the entire ration or makes up a large portion of the ration and is supplemented with concentrates. The review of this field will further be limited to only those minerals and vitamins that are of major importance under these conditions.

The elements on which much information is available include sodium, potassium, calcium, phosphorus, magnesium, sulphur, iron, copper, chlorine, iodine, fluorine, zinc, and manganese, according to Becker (2) in his revies of experimental research on minerals. That many other elements are present in living things was also shown in this review. However, little is known of their functions in nutrition. Among the latter, Becker cites literature showing that there are present in living things: aluminum, arsenic, boron, lithium, rubidium, silicon, strontium, titanium and vanadium.

The mineral elements generally considered of major importance in dairy cattle nutrition are calcium, phosphorus, sodium and chlorine. The need of sodium and chlorine in the form of common salt, as a mineral supplement, is more widely recognized than that of any other mineral. In a review of literature on mineral supplements, other than salts of calcium and phosphorus, Hamilton (22) reported that there was no experimental evidence indicating the general necessity or desirability of supplementing ordinary farm rations with any of these with the exception of sodium and chlorine, the elements of ordinary salt.

At the Wisconsin Station, Hart and associates (27) fed a high lime-high phosphorus ration to one group of dairy cows and a low lime--low phosphorus ration to another group over a period of five years. The high lime-high phosphorus ration consisted of alfalfa hay, corn silage, and a grain mixture made up of 35 parts of yellow corn, 30 of oats, 30 of wheat bran, and 5 of oil meal. To 100 pounds of the grain mixture, 5 pounds of bone meal were also added. Pasture for this group of animals consisted of either alfalfa or sweet clover. The low lime-low phosphorus ration consisted of timothy hay grown on acid soil, corn silage, and a grain mixture made up of 40 parts of oats, 40 of yellow corn and 20 of gluten meal. Timothy-June grass pasture was available a number of months during the year.

Seven cows from each group were slaughtered at the close of the experiment and the two humeri and the twelfth pair of ribs were removed and analyzed for ash. Their figures do not indicate that the timothy hay ration used in this experiment failed to develop as large a skeleton in proportion to live weight as in the case of alfalfa-fed animals. In conclusion they state, "We believe that these data are important in contributing to the problem of the lime and phosphorus metabolism of the milking cow and point to the fact that unless rations with a much lower lime content than our low lime ration are fed, there would seem to be no need of supplementing the ration of dairy cows with extra lime and

and inorganic phosphates. This conclusion, of course, assumes that there is a rest period of 4 to 6 weeks with liberal feeding during which storage can again take place."

A report of six complete calcium and phosphorus balance trials for full lactation and gestation periods by Ellenberger, Newlander and Jones (11) of the Vermont Experiment Station showed that all cows in this experiment ended their trials with positive balances. Negative balances appeared to be normal during the early part of lactation periods and to be compensated by rapid storage as the lactation and gestation periods progress. When mineral supplements were fed the negative periods were noticeably shortened. From these trials they concluded that the necessity of feeding calcium and phosphorus supplements with good grain rations fed in liberal quantities may be seriously questioned.

Research work by Bohstedt (4) both in actual experimental work and in a review of other experimental work coincides with the recent work of other workers, as regards the necessity of adding a calcium or phosphorus supplement to the dairy cattle ration. He concludes, "It is plain that the vast majority of mineral feeding experiments using practical rations as control rations have not shown a need for additional calcium and phosphorus. Dairy cows and other cattle are much more frequently in need of additional phosphorus than calcium, and it is well appreciated that phosphorus may be easily supplied through wheat bran, cottonseed meal, linseed meal or other high protein concentrates, which phosphorus feeds, from the mineral standpoint balance the lime of the mixed legume and grass hay, or legume hay, which most dairymen strive to feed."

Meigs and Turner and collaborators (41) conducted calcium and phosphorus trial balances with dairy cows, in which rations containing alfalfa hay, green feed, timothy hay, and bonemeal were compared. They concluded that (1) calcium from well-cured or fairly well cured hays, both timothy and alfalfa, is much better assimilated than is that from bonemeal; (2) calcium is decidedly better assimilated from fresh green material than from the same material after it has been dried; (3) the manner in which hay is cured makes a great difference in the rate at which calcium is assimilated from it; (4) phosphorus assimilation may be interfered with by an excess of calcium in the ration. "Two parts or more by weight of calcium to one of phosphorus constitute an excess."

That three conditions are important for insuring a positive balance in dairy cows in respect to calcium and phosphorus was reported by Turner and associates (54) of the Bureau of Dairy Industry. After conducting a series of metabolism experiments they came to the conclusion that the conditions necessary were, (1) that a sufficient quantity of calcium and phosphorus must be supplied in the ration; (2) the calcium and phosphorus should be supplied in about equal quantities. The amount of calcium probably should not exceed the amount of phosphorus by more than 50 per cent, and (3) the calcium should be supplied as a constituent of natural feeds in a ration including a good quality of legume hay, preferably alfalfa, and a good grain mixture.

Numerous experiments have shown that the assimilation of calcium and phosphorus is dependent upon the anti-rachitic vitamin D. In his recent review of the literature pertaining to calcium and phosphorus supplements, Bohstedt (4) of the University of Wisconsin came to the following conclusions: "Small animal work leads us to assume that only in the presence of a generous amount of vitamin D may the calcium-phosphorus ration be drastically different from what is considered the normal, and still permit proper growth on the part of the animals. Practical rations of ruminants due to the large amount of sun-cured hay consumed are so well supplied with vitamin D that the two elements-calcium and phosphorus, may safely be present in much lower percentages and may vary more with reference to each other, than they may in rations of the smaller animals that subsist almost entirely on concentrates."

The most extensive and accurate review of the literature found in relation to calcium and phosphorus assimilation as affected by vitamin D is the report by Bethke (3) of the Ohio Station. Bethke cited a number of experiments showing that vitamin D or ultra-violet light are associated with calcium and phosphorus utilization in the rat and the chick and the pig; and that calcium and phosphorus must be present in the diet and in correct relationship to each other before the rat, and probably the chick and the pig can retain them in proper amounts for normal bone deposition, regardless of vitamin D. The relation of vitamin D, or its equivalent, to calcium and phosphorus metabolism in lactating animals was stated to still be an open question. Bethke stated that although the literature does not definitely show that vitamin D increases the calcium and phosphorus utilization in the heavy milking cow, no one has definitely demonstrated that the addition of an anti-rachitic factor to a vitamin-D-free ration would not favorably influence calcium and phosphorus utilization.

With the exception of vitamin D, dairy cattle rations are not apt to be lacking in vitamins, according to a brief review of the work on vitamins by Morrison (44). Apparently neither vitamin C or vitamin G are important in livestock feeding.

Conclusions: 1. Sodium and chlorine in the form of common salt are the two mineral elements most apt to be lacking in dairy cattle rations.

2. Recent work indicates that calcium and phosphorus are furnished in sufficient amounts in normal dairy cattle rations where mineral deficiencies are not a problem.

3. Vitamin D is the vitamin most apt to be lacking in dairy cattle rations.

4. In irrigated sections of Montana where considerable alfalfa hay is fed to dairy cows, minerals and vitamins should be present in the ration in sufficiently large amounts except in mineral deficient areas.

PART IV

RESULTS OF EXPERIMENT AT THE MONTANA EXPERIMENT STATION

A Comparison of Two Methods of Apportioning Grain to Milking Cows

The feeding standards as they now exist have been worked out after years of research work at no small expense. Every effort has been made to obtain data that would be of value in determining the requirements of dairy cows. As a result of this work it is possible to calculate with reasonable accuracy the requirements of individual dairy cows and by making use of the information available regarding the digestible nutrients of the feed, to prepare a ration that will supply what is needed.

It would be impractical to calculate the requirements of each individual animal in the herd by means of a feeding standard, because of the time involved and also because most dairymen are not sufficiently versed in the methods of working out a ration by means of a feeding standard. For these reasons feeding rules based on a certain feeding standard have been adopted.

In view of the enormous amount of work involved in obtaining the data for these standards, it seems that too little emphasis has been placed on the necessity of actual experimental work in the selection of feeding methods whereby the full value of these standards may be realized under practical conditions.

The two methods of feeding dairy cows most commonly advocated were compared by means of an experiment conducted by the author at the Montana Experiment Station under the direction of Louis Vinke. Both methods are based upon two facts which are considered fundamental in the economical feeding of dairy cows: (1) Cows should be fed all or nearly all the good roughage they will eat; (2) Cows should at all times, except for a few weeks after calving, receive enough feed to provide the nutrients required for the production of milk and the maintenance of body weight without any loss of weight but with no more than a small gain. The Meigs and Converse standard was used in estimating the amounts of nutrients required.

The usual method of apportioning concentrates is to give each cow 1 pound of grain to each 3 or 4 pounds of milk produced, depending upon the richness of the milk. This method is unsatisfactory under Western conditions for two reasons: (1) Because cows will get enough nutrients from alfalfa hay alone to provide for the maintenance of their bodies as well as for the production of a certain amount of milk; and (2) because 1 pound of concentrates does not contain sufficient nutrients for as much as 3 pounds of milk.

A method advocated more recently by Western dairy husbandmen is to feed dairy cows all the alfalfa hay they will eat, and in addition enough grain to provide the nutrients for every pound of milk produced in excess of the amount that will be provided for by the nutrients consumed above maintenance requirements, in the form of alfalfa hay. Low testing cows are fed 1 pound of grain for every 2 1/2 pounds of milk they produce daily in excess of a certain amount, and high-testing cows are fed 1 pound of grain for every 2 pounds of milk they produce daily in excess of a certain amount. One pound of grain furnishes just enough nutrients for the production of 2 and 2 1/2 pounds of milk of a high and low butterfat content respectively. This method will be referred to as Woodward's Method.

According to the methods proposed for the feeding of dairy cows in milk, some workers, notably Woll and Headley, are of the opinion that low-testing cows will consume enough alfalfa hay to provide the nutrients for maintenance and about 30 pounds of milk per day. Tretsven states that low-testing cows will not consume sufficient alfalfa hay to provide enough nutrients, above maintenance requirements, for the production of more than 16 to 20 pounds of milk per day. The same variation exists in regard to high-testing cows.

Due to this lack of sufficient data on the consumption of alfalfa hay by dairy cows, it was necessary to apportion the grain at the beginning of each week, in the case of the second method described, according to the average daily consumption of alfalfa hay during the previous week. Although this experiment would probably have been a little more practical if the daily consumption of alfalfa hay could have been estimated previous to the experiment, it is hoped that the information contained herein will be of considerable value in the working out of a more satisfactory method of feeding dairy cows or in the revisal of some of the present methods.

Objects of the Experiment. 1. To compare a relatively new method of apportioning grain to dairy cows, when the roughage consists of alfalfa hay fed ad libitum to the usual method of feeding a certain amount of grain for every pound of milk produced; the comparison to be made on the basis of gain or loss in milk production, gain or loss in body weight, and the amount of nutrients consumed above or below requirements as shown by the Meigs and Converse standard.

2. To determine the amount of alfalfa hay of a known quality that dairy cows will consume when grain is included in the ration and is fed as close to requirements as possible according to the Meigs and Converse standard.

3. To determine what factors must be given major consideration in working out a more satisfactory method of apportioning grain to dairy cows under Western conditions.

Methods of Experimentation.

Duration of Experiment: The first period of the experiment started the evening of December 14, 1932, and continued until the evening of January 25, 1933. The second period of the experiment began the evening of February 1, 1933, and continued until the evening of March 15, 1933. The reversal method was used during the two periods of 42 days each.

Cows Used: Six purebred Holstein cows and six purebred Jersey cows were selected from the College dairy herd for this experiment. All of the cows had had access to all the alfalfa hay they would eat from the time they were heifer calves up until the beginning of the experiment. Grain was also fed liberally during this period.

Allotment Consideration: The twelve cows were divided as uniformly as possible into two groups of 6 head each. Each group consisted of three Holsteins and three Jerseys, and were divided as evenly as possible with respect to length of time in milk, age, weight, milk production, per cent of butterfat in milk, and period of gestation. The history and production of the experimental cows is given in Table IV.

Table IV History and Production of Experimental Cows at Beginning of Experiment

Name and Breed	Weight	Age	Due to Calve	Time since last calving	Milk Production on Dec. 8-14, 1932.
	Lbs.	Yrs.	Months	Months	Ave. Lbs. per day
Group I					
Beauty, Jersey	1127	$8\frac{1}{2}$	(12)*	1	34.0
Stephanna, Jersey	991	4	5	7	16.9
Latona, Jersey	850	4	8	$4\frac{1}{2}$	21.1
Amy, Holstein	1525	$4\frac{1}{4}$	5	7	27.4
Amelia, Holstein	1314	$6\frac{1}{4}$	5	$8\frac{1}{2}$	44.1
Forbes, Holstein	1421	6	$7\frac{1}{2}$	$5\frac{1}{2}$	55.8
Average	1205	$5\frac{1}{2}$	7	$5\frac{1}{2}$	33.2
Group II					
Queen, Jersey	970	6	(11)*	$1\frac{1}{2}$	27.4
Idowell, Jersey	1061	$4\frac{1}{2}$	$4\frac{1}{2}$	7	16.0
Ona, Jersey	973	$5\frac{1}{4}$	8	5	23.6
Alberta, Holstein	1476	$4\frac{1}{2}$	$4\frac{1}{2}$	7	19.2
Adeline, Holstein	1553	5	$4\frac{1}{2}$	7	30.4
Idabelle, Holstein	1271	5 3/4	(11)*	3	53.8
Average	1217	5	7	5	28.4

*Not bred at beginning of experiment.

Weight of Cows: Each cow was weighed on the three consecutive days preceeding both periods. At the close of each period, individual weights were taken on each of the last three days. The average of the three weights was taken as the average weight of the cow at the beginning and at the end of both periods. It was necessary to get the average weight of each cow before the day the experimental period began in order to determine the nutritive requirements of each cow.

Milk and Butterfat Records: The cows were milked three times each day, the periods of milking being at 1 A. M., 8:30 A. M., and 4 P. M. Daily milk records were kept on the regular barn milk sheets. At the end of the first week composite milk samples were taken of each individual cow for the three milkings and tested for butterfat by the members of the Dairy Industry Department. The cows were tested at the end of every two weeks thereafter, one test sufficing for the week preceding and the week following the test.

Housing and Equipment: No change was made in the handling of the experimental cows from the usual herd practice. The cows had access to water at all times. Except in exceptionally bad weather they were turned into a dry lot during the afternoon for exercise..

The mangers were very deep and did not allow the loss of any considerable amount of hay, having been planned especially for experimental purposes. A tight box was fitted to a movable scale for the weighing of the hay. A grain cart, to which was attached a spring scale, was used for grain feeding. Milking machines were used throughout the experiment on all experimental cows and were handled by the same man throughout the experiment.

Ration Fed and Methods of Feeding: The alfalfa hay was graded by A. H. Post, Associate Professor of Agronomy and L. P. Reitz, Assistant in Agronomy. During the first period the alfalfa was graded as No. 3 green-light timothy-mixed. During the second period the alfalfa was graded as No. 3 green.

The concentrate mixture consisted of 400 pounds of mill run*, 300 pounds of wheat, 200 pounds of barley, 50 pounds of oats, 25 pounds of cottonseed meal, 10 pounds of salt and 5 pounds of bonemeal.

The two groups were fed as follows:

Group I. This group was fed according to the Usual Method. The cows in this group received all the alfalfa hay they would eat and in addition the Holsteins received 1 pound of grain for every 4 pounds of milk, and the Jerseys received 1 pound of grain for every 3 pounds of milk. The amount of grain fed was corrected at the end of each week according to the average milk production for that week. This method is called the Usual Method by the author because the majority of dairy husbandmen advocate the feeding of grain according to this general method. The proportion of grain to milk varies in different feeding rules from 1 pound of grain to 2 1/2 pounds of milk to 1 pound of grain to 5 or 6 pounds of milk. The principle is the same, however, inasmuch as a certain amount of grain is fed for every pound of milk produced regardless as to whether or not the roughage alone provides sufficient nutrients for maintenance as well as a certain amount of milk.

Group II. Group II was fed according to Woodward's Method. This group received all the alfalfa hay they would eat. At the end of each week the average daily consumption of alfalfa hay was determined for each individual. By deducting the maintenance requirement of that individual, as given in the Meigs and Converse standard, from the total nutrients consumed in the form of alfalfa hay, the amount of milk that could be

*The mill run consisted of a mixture of bran and shorts.

produced from this excess of nutrients was determined. For every pound of milk produced above this amount the Holsteins received 0.4 pound of grain and the Jerseys received 0.6 of a pound of grain. For example, a 1,000 pound Jersey cow consuming 25 pounds of alfalfa hay per day would be receiving 4.98 pounds of total digestible nutrients in excess of her maintenance requirements as shown by the Meigs and Converse standard. This 4.98 pounds of total digestible nutrients is sufficient for the production of 11 pounds of 5.35 per cent milk according to this same standard. For every pound of milk produced in excess of 11 pounds this Jersey cow would receive 0.6 of a pound of grain. If she did not produce more than 11 pounds of milk, no grain would be fed. For this group the change in the amount of grain fed was made at the end of each week according to the average daily consumption of alfalfa hay as well as the average daily production of milk. In determining the requirements of total digestible nutrients for milk production the generally accepted average butterfat test of 5.35 per cent for Jerseys and 3.5 per cent for Holsteins was used.

At the end of the first period of 42 days, the two groups were reversed with respect to the method of feeding and continued for another period of 42 days.

A trial period of 7 days preceded each experimental period. During this time both groups received all the alfalfa hay they would eat and grain at the rate of 1 pound to each 3 and 4 pounds of milk produced.

The requirements of total digestible nutrients for maintenance and milk production was determined from the Meigs and Converse tables.

Alfalfa hay was fed at 5:30 A. M., 11 A. M., and at 5:30 P. M. The left over alfalfa hay was weighed back at 5 A. M., and at 3 P. M.

Feeds Used: The grains and alfalfa hay were secured from several different growers in the Gallatin Valley. The mill run and cottonseed meal was purchased from local dealers. Table V shows the actual analysis of the feeds as reported by Cy D. Evans of the Chemistry Department of the Montana Agricultural Experiment Station.

Table V Analysis of Feeds Used

Feed	Moisture	Ash	Crude Protein	Fiber	N-Free Extract	Fat
	%	%	%	%	%	%
Wheat	10.4	2.06	13.23	2.99	69.47	1.85
Mill Run	8.85	5.39	18.65	10.61	48.35	5.52
Oats	8.73	3.62	12.80	9.08	62.65	3.12
Barley	9.64	2.58	12.87	7.87	65.59	1.45
Alfalfa Hay	5.32	5.96	8.44	44.12	35.09	1.07
Cottonseed Meal*	-	-	43.00	12.00	23.00	6.00

These figures were converted into digestible nutrients by the use of Henry and Morrison's table (32) on the average digestibility of American feeding stuffs.

According to the actual analysis of the feeds by the members of the Chemistry Department and the average per cent of digestibility of these feeding stuffs as given by Henry and Morrison, the concentrate ration contained 12.2 per cent digestible crude protein and 72.3 per cent total digestible nutrients, and the alfalfa hay contained 5.99 per cent digestible crude protein and 47.14 per cent total digestible nutrients.

Results of the Experiment. For comparison of Woodwards Method of feeding grain to dairy cows with the usual method of feeding 1 pound of grain to each 3 or 4 pounds of milk produced, records were kept of the total

*Analysis given on commercial feed tag.

feed consumed by each group during both periods, the consumption of digestible nutrients as compared with the requirements given in the Meigs and Converse standard, the average decline in milk production and the gain or loss in body weight.

Production. One Jersey cow and two Holstein cows began the second period as dry cows so they were not included in determining the average of the two groups. The five Jersey cows in milk, in the group fed according to Woodward's Method, averaged 21.1 pounds of 5.8 per cent milk per day. The four Holstein cows in milk averaged 38.2 pounds of 3.2 per cent milk per day.

The same five Jersey cows fed according to the Usual Method averaged 18.9 pounds of 6.03 per cent milk per day and the same four Holstein cows averaged 33.6 pounds of 3.24 per cent milk per day.

Comparison of Nutrients Consumed with the Nutrients Required. With both methods of feeding a comparison was made of the nutrients provided and the nutrients required according to the Meigs and Converse standard.

Protein was apparently supplied in sufficient amounts to both groups. The group fed according to Woodward's method lacked only .2 per cent of receiving enough digestible crude protein and the other group received an excess of 7 per cent. According to Henry and Morrison's tables, the average per cent of digestible crude protein in alfalfa hay is 10.6, whereas the average per cent of digestible crude protein in the alfalfa hay fed was 5.99 according to the actual analysis and the digestibility of crude protein as given by Henry and Morrison. If the alfalfa hay eaten had been of average quality, as shown by Henry and Morrison's tables, the former group would have eaten an amount of digestible crude protein, 47 per cent in excess of their requirements and the latter group would have eaten an excess of 61 per cent digestible crude protein.

Tables VI and VII show that when the actual analysis of alfalfa hay was used in determining the amount of nutrients consumed there appeared to be very little difference in the total averages of the two groups in the amount of total digestible nutrients eaten above or below the requirements given in the Meigs and Converse standard. The cows fed according to Woodward's Method lacked 4.7 per cent of consuming enough total digestible nutrients and the group fed according to the Usual Method consumed 3.75 per cent more total digestible nutrients than were required. The three dry cows in table VI were not included in the totals.

When the individual cows were compared within their respective groups there was a marked difference, however. Table VII shows that three high producing cows, Beauty, Queen and Idabelle, fed according to the Usual Method, did not receive enough total digestible nutrients according to the Meigs and Converse standard. Beauty and Queen lacked 9.6 per cent and 12.6 per cent respectively of consuming enough total digestible nutrients. In this same group 5 cows of comparatively low production consumed a considerable excess of total digestible nutrients. The three lowest producing cows, Stephanna, Alberta, and Amy, consumed an excess of total digestible nutrients above requirements amounting to 21.7 per cent, 20.4 per cent and 17.7 per cent respectively.

From the data in Table VI, it was found that according to the actual analysis of the feeds received by the cows fed according to Woodward's Method, there were no large variations in the percentage of total digestible nutrients consumed, the greatest excess above the Meigs and Converse requirements being 1.9 per cent and the greatest deficiency below requirements being 11.8 per cent. It will be noted that with one exception all of the Holsteins were fed slightly above requirements and all of the Jerseys were fed somewhat below requirements. This was undoubtedly due in part to the fact that the Jerseys produced milk considerably higher in per cent of butterfat than the average Jersey and the Holsteins produced milk containing a lower per cent of butterfat than the average Holstein. The average test for Jerseys, used in determining the apportionment of grain, was 5.35 per cent, whereas the Jerseys on the experiment averaged above 5.8 per cent in test. The average test for Holsteins used in apportioning grain was 3.5 per cent, whereas the Holsteins in the experiment averaged less than 3.3 per cent in test. The result was that the high testing Jerseys in this experiment required more nutrients per pound of milk produced than the average Jersey and the low testing Holsteins required less nutrients per pound of milk produced than the average Holstein, due to the fact that the requirement for nutrients increases with the increase in the per cent of butterfat in the Milk (21). Amelia was the only Holstein cow that did not receive enough nutrients. This was due probably to her high average test of 3.8 per cent.

After deducting the maintenance requirements determined from the

Table VI PRODUCTION AND FEED CONSUMPTION OF TWELVE COWS FED ACCORDING TO WOODWARD'S METHOD*

Cow	Production		Grain Mixture	Alfalfa Hay	Average Weight	Gain or Loss in Weight	Total Digestible Nutrients**				
							Consumed			Excess or Deficiency	
	Milk	Butterfat					Actual	H&M	Required***	Actual	H&M
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	%	%
Jerseys											
Beauty	1441	79.8	588	974	1121	-12	884	928	983	-10.0	-5.6
Stephanna	644	31.8	245	908	997	+12	605	646	617	-2.0	+4.6
Latona	786	51.2	224	999	848	-5	633	677	680	-6.9	-.31
Queen	869	53.8	315	948	949	+27	675	718	731	-7.8	-1.9
Idowell	Dry			844	1037	+15	398	436	355	+17.3	+22.8
Ona	698	42.4	119	1102	948	-28	606	655	644	-5.9	+1.7
Holsteins											
Amy	853	27.4	147	1263	1535	+19	702	758	700	+0.3	+8.3
Amelia	1501	57.4	350	1295	1325	+21	864	921	979	-11.8	-5.6
Fobes	2218	66.4	595	1347	1439	+36	1065	1125	1061	+.37	+6.0
Alberta	Dry			1228	1586	+3	579	634	452	+28.0	+40.1
Adeline	Dry			1263	1588	+3	595	652	452	+31.6	+44.0
Idabella	1839	52.9	483	1210	1258	-2	920	972	902	+1.9	+7.9
Average	1205	51.4	341	1116	1158	+7.5	773	822	811	-4.7	+1.4

*Dry cows not included in totals.

** The actual analysis of concentrates was used in both columns. Actual refers to the actual analysis of the alfalfa fed and H&M refers to average analysis of alfalfa hay given by Henry and Morrison.

*** Requirements determined by means of the Meigs and Converse standard.

Table VII PRODUCTION AND FEED CONSUMPTION OF 12 COWS FED GRAIN ACCORDING TO THE USUAL METHOD OF 1 POUND TO EACH 3 AND 4 POUNDS OF MILK PRODUCED.

Cow	Production		Grain Mixture	Alfalfa Hay	Average Weight	Gain or Loss in Weight	Total Digestible Nutrients*				
	Milk	Butterfat					Consumed			Excess or Deficiency	
							Actual	H&M	Required**	Actual	H&M
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	%	%
Jerseys											
Beauty	1204	76.1	434	1114	1113	+4	839	889	928	-9.6	-4.2
Stephana	204	14.1	91	985	1002	+3	530	574	435	+21.7	+31.8
Latona	691	39.7	245	1033	843	+4	664	710	603	+17.8	+17.8
Queen	998	59.5	343	912	949	-42	678	719	775	-12.6	-7.3
Idowell	482	25.7	189	823	1053	-17	525	561	547	-4.2	+2.5
Ona	875	49.5	301	1059	970	-6	717	764	711	+ .8	+7.5
Holsteins											
Amy	496	16.8	140	1282	1549	-10	706	763	599	+17.7	+27.3
Amelia	1168	45.3	308	1331	1327	+16	850	909	803	+5.9	+13.3
Fobes	1918	62.1	497	1419	1448	+18	1028	1091	1004	+2.4	+8.7
Alberta	334	14.2	119	1248	1508	-36	674	730	560	+20.4	+30.3
Adeline	752	24.0	231	1285	1571	+36	773	830	674	+14.7	+23.2
Idabelle	2068	59.2	539	1173	1264	-14	943	995	965	-2.3	+3.1
Average	933	40.5	286	1138	1216	-3.6	744	795	717	+3.75	+10.8

* The actual analysis of concentrates was used in both columns. Actual refers to the actual analysis of the alfalfa fed and H&M refers to average analysis of alfalfa hay given by Henry and Morrison.

** Requirements determined by means of the Meigs and Converse standard.

Meigs and Converse standard, the group fed according to Woodward's Method consumed only 7.75 pounds of total digestible nutrients per pound of butterfat, whereas the group fed according to the usual method consumed 9.05 pounds of total digestible nutrients per pound of butterfat. The figures on the actual analysis of the feeds were used in making this comparison.

If the alfalfa hay had been of average composition as shown by Henry and Morrison's tables or if the actual percentage of total digestible nutrients in the alfalfa hay had been known at the beginning of the experiment, the cows in milk fed according to Woodward's Method would have been fed considerably closer to the Meigs and Converse standard. Table V shows that by using Henry and Morrisons figures of 51.6 per cent total digestible nutrients for the alfalfa hay, this group would have received an average of only 1.4 per cent total digestible nutrients above requirements. The greatest excess of total digestible nutrients would have been 8.3 per cent in the case of the Holstein cow, Amy, and the greatest deficiency would have been 5.6 per cent in the case of the Holstein cow, Amelia.

However the group fed according to the Usual Method might not have fared so well if the alfalfa hay had been of average quality since the average excess of total digestible nutrients would have been 10.8 per cent above requirements as shown by Table VII. Two cows, Beauty and Queen, would still have failed to receive enough nutrients and six cows, Stephanna, Latona, Amy, Amelia, Alberta, and Adeline, would have consumed total digestible nutrients considerably in excess of requirements, ranging from 13.3 per cent to 31.8 per cent in excess of the Meigs and Converse requirements.

Gain or Loss in Weight. Tables VI and VII show that there was little difference in the change in body weight in the two groups. Table VI shows that the cows fed according to Woodward's Method gained an average of 7.5 pounds during the 42 days, Table VII shows that the group fed according to the Usual Method lost an average of 3.5 pounds during the 42 days.

Although the data in Table VI shows that the three dry cows, fed an exclusive alfalfa ration, consumed total digestible nutrients considerably in excess of their maintenance requirements, they did not make as much gain in weight as some of the cows in milk that were receiving grain but were not receiving an excess of total digestible nutrients above their requirements. The Jersey cow, Idowell, gained 15 pounds during this 42 day period and the two Holstein cows, Alberta and Adeline, gained only 3 pounds each during this period. The two Holsteins did not make the gain in weight that was expected of them considering the work of Vinke (56) and of the other experimental work reviewed in this thesis. Alberta and Adeline consumed an excess of 28 and 31 per cent total digestible nutrients respectively, above their requirements, according to the Meigs and Converse standard, and were expected to make a more substantial gain in weight.

Decline in Milk Yield. Since three of the cows were turned dry at the end of their first period, neither they nor the three cows in the other group, used as check cows, were used in comparing the two methods of feeding, with respect to the effect of each upon the rate of decline in milk yield. Figure 1 shows the decline in milk production of six cows, two Holsteins and four Jerseys, that were fed according to both methods during two different periods of 42 days each. Beauty, Latona and Fobes were fed according to Woodward's Method the first period and according to the Usual Method the second period. Queen, Ona, and Idabelle were fed according to the Usual Method during the first period and according to Woodward's Method during the second period.

It will be noted from Figure 1 that there was very little difference in the rate of decline of the milk yield of these six cows when fed according to one or the other of the two methods. When fed according to the Usual Method, these six cows declined in milk at a slightly more rapid rate during the first period, but declined at about the same rate during the second period.

It is interesting to note that although the cows fed according to the Usual Method received total digestible nutrients in excess of requirements, they did not hold up in milk yield any better than when they were fed according to Woodward's Method. When fed by the latter method they failed to receive enough feed to meet their requirements of total digestible nutrients by a slight margin, according to the Meigs and Converse standard.

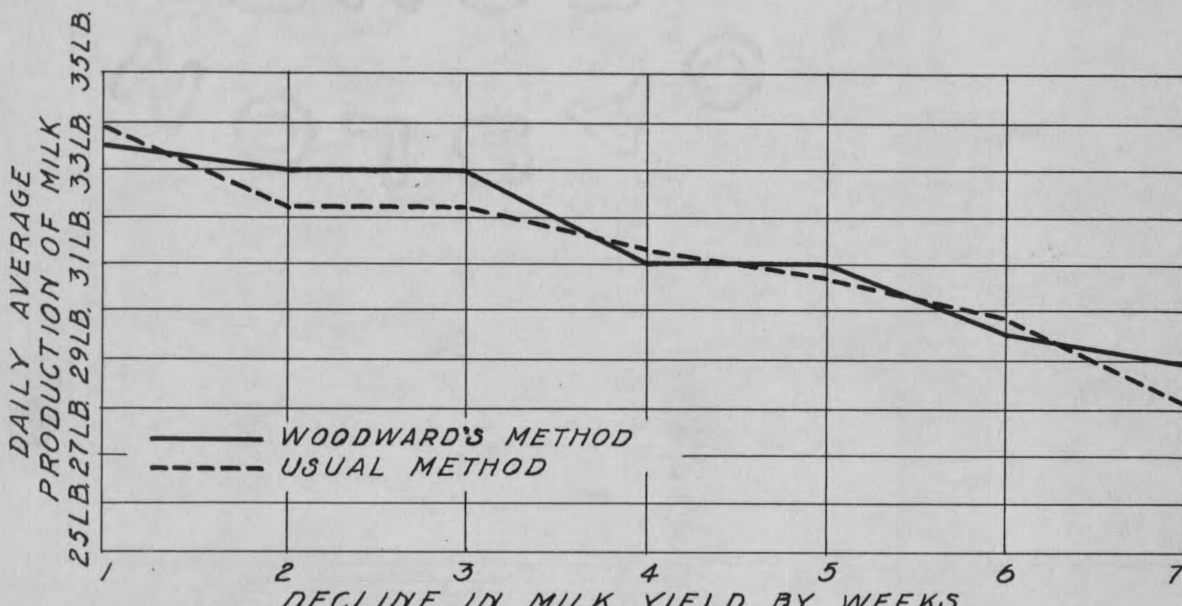

Figure 1. Average decline in milk production of six cows fed according to Woodward's Method compared to the average decline in milk production of the same six cows when fed according to the Usual Method.

<u>Average Consumption of Alfalfa.</u> The amount of alfalfa hay eaten per day did not vary within very wide limits from day to day. The six Jersey cows consumed an average of 23.2 pounds of alfalfa hay per day and the Holsteins consumed an average of 30.4 pounds per day as shown in Table VIII.

Table VIII. Average Daily Consumption of Alfalfa by 6 Jerseys and 6 Holsteins and average daily milk production provided for by the nutrients consumed in excess of maintenance

Alfalfa Eaten Lbs. per day	Average Body Weight Lbs.	Total Digestible Nutrients In alfalfa Eaten* Lbs. per Day	Required for Maintenance** Lbs. per Day	Consumed in Excess of Maintenance Lbs. per Day	Milk Production Provided for by Excess of Nutrients in Alfalfa Lbs. per Day
			Jerseys		
23.2	986	10.94	7.87	3.07	7.3
			Holsteins		
30.4	1450	14.33	10.16	4.17	13.

The Jerseys consumed only enough total digestible nutrients above maintenance, in the form of alfalfa hay, to provide the nutrients for 7.3 pounds of milk testing 5.35 per cent butterfat, and the Holsteins consumed only enough to provide the nutrients for 13 pounds of milk testing 3.5 per cent.

The alfalfa hay would undoubtedly have been eaten in much larger quantities if it had been of better quality. The day following the close of the experiment a few loads of fine, bright, leafy alfalfa hay were delivered to the dairy barn. The cows ate such large quantities of this hay that at the end of the third day one day trial weights were taken of the amount of alfalfa hay eaten by the cows which had been in the experiment. During that one day the Jerseys ate an average of 28 pounds of alfalfa hay and the Holsteins ate an average of 40.5 pounds of alfalfa hay.

* Actual Analysis. ** Determined from the Meigs and Converse Standard.

CONCLUSIONS

1. Grain apportioned to dairy cows according to Woodward's Method supplies the total digestible nutrients to each individual cow in more nearly the correct amounts, as given in the Meigs and Converse Standard, than does grain apportioned to dairy cows according to the Usual Method of 1 pound of grain for each 3 and 4 pounds of milk produced, depending upon the richness of the milk. Woodward's Method is to apportion grain at the rate of 0.4 and 0.6 pound, to low and high testing cows respectively for each pound of milk produced above the amount provided for by the roughage alone.

2. Grain apportioned to dairy cows according to the Usual Method of 1 pound of grain to each 3 or 4 pounds of milk produced, resulted in the overfeeding of low producers by as much as 21.7 per cent and the underfeeding of high producers by as much as 12.6 per cent. There was a greater tendency to overfeed low producers than there was to underfeed high producers.

3. More efficient production was realized by feeding according to Woodward's Method than was realized by feeding according to the Usual Method. Above maintenance requirements the cows fed according to Woodward's Method averaged a pound of butterfat from 7.75 pounds of total digestible nutrients, whereas the cows fed according to the Usual Method consumed an average of 9.05 pounds of total digestible nutrients for each pound of butterfat produced.

4. There was little difference in the rate of decline of milk production of the cows fed by either one or the other of the two methods.

5. Good quality alfalfa hay was eaten in much larger quantities than was poor quality alfalfa hay.

6. Sufficient protein was apparently provided by the poor quality alfalfa hay and a grain mixture containing 12.2 per cent digestible crude protein.

PART V

GENERAL CONCLUSIONS

1. When cows are fed all the alfalfa hay they will eat and grain at the rate of 1 pound to every 3, 4, or 5 pounds of milk produced, the low producers are overfed because cows will get enough nutrients from good alfalfa hay alone for the maintenance of their bodies as well as for the production of a certain amount of milk.

2. There is a general tendency for high producers to be underfed when apportioned grain at the rate of 1 pound to each 3 or 4 pounds of milk produced when alfalfa is fed ad libitum because 1 pound of grain will not furnish the nutrients for as much as 3 pounds of milk.

3. A satisfactory method of feeding dairy cows under Western conditions that can be worked out by Experiment Stations, is to determine the amount of milk that can be produced on alfalfa hay alone, for high testing and low testing breeds, and then feed cows of the high testing breeds 0.6 of a pound of grain for every pound of milk produced in ex cess of that amount and to cows of the low testing breeds feed 0.4 of a pound of grain for every pound of milk produced in excess of that amount.

4. In order to formulate a satisfactory method of feeding dairy cows as described above, data must be secured on the consumption of alfalfa hay of both good and poor quality.

5. Jersey cows cannot eat enough poor quality alfalfa hay to provide the nutrients for maintenance and more than 8 pounds of milk.

6. Holstein cows cannot eat enough poor quality alfalfa hay to provide the nutrients for maintenance and more than 13 pounds of milk.

7. Good quality alfalfa hay, because of its greater palatability, is eaten in much larger quantities than is poor quality alfalfa hay.

8. Good quality alfalfa hay is more effective in maintaining the milk flow than is poor quality alfalfa hay.

9. The accepted feeding standards for dairy cattle are probably too high in protein requirements for both maintenance and milk production.

10. When good quality alfalfa hay is fed ad libitum the value of adding high protein concentrates to the ration is questionable.

11. Feeding standards for dairy cows agree more closely in total digestible nutrients than they do in protein requirements.

12. Total digestible nutrients are more satisfactory for formulating feeding standards at the present time than is net energy.

13. Feeding at a plane of nutrition higher than is called for in the accepted feeding standards results in an increase in production but not in proportion to the amounts of nutrients fed.

14. Except in mineral deficient areas, the only mineral that is apt to be lacking in dairy cattle rations is common salt.

15. When alfalfa hay is fed to dairy cattle, none of the known vitamins of importance in dairy cattle feeding will be lacking.

ACKNOWLEDGEMENTS

Acknowledgements are made to Professor Louis Vinke, head of the Department of Animal Husbandry, Montana State College, for his valuable assistance in conducting the experimental work and his aid in the preparation of this manuscript; also to W. F. Dickson, Assistant Animal Husbandryman, for his aid in the interpretation of the experimental work.

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